

letter and word
Early processes in ~~the~~ recognition ,
^
~~of letters and words~~

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Thesis submitted to the
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Abstract

Recent work in psychophysics and neurophysiology suggests that vision is divided into two channels magno (transient) and parvo (sustained). What relationship do the two vision channels have to the recognition of written words? Two theories have been suggested: first, that the magno (transient) channel inhibits the visual persistence of words seen in the parvo (sustained) channel; and second, that dyslexics have a defective magno (transient) channel which disrupts this persistent inhibition and causes a low level visual problem seeing words. None of these theories is supported by direct research upon the two channels and reading.

Neurophysiologists have developed techniques for selectively blocking the two channels. They are noninvasive and enable the direct investigation of the role of each channel in stimulus processing. These depend upon manipulating the visual characteristics of the stimuli. These techniques were adapted for use in reaction time experiments displayed on a PC fitted with a VGA graphics card.

Preliminary research uncovered a previously unreported luminosity artifact which affects the boundaries of images presented on, at least some, PC monitors. A correction was devised to minimise this artifact.

The technique for blocking parvo channel stimulus perception while permitting magno channel stimulus perception involves presenting images in counterphase: the magno channel unlike the parvo one can resolve fast alternating images. It was found that counterphase stimuli can be recognised through a process which side steps temporal resolution. Experiments in this thesis show that this process can be blocked by preceding counterphase stimuli by pre-masks.

Lexical decision and letter matching were investigated using magno and parvo blocking techniques. There were indications that word vs nonword classifications and letter length were affected. However other variables such as word frequency and imageability were not. There is evidence in letter matching that positive identity matches between letters were affected by magno channel blocking while negative ones were not.

Acknowledgements

When I started this thesis I had two ideas, one good and one bad. One was published in Nature, and solicited as the basis of a book. This thesis is not that idea. I thank...

Chris McManus, Alan Johnson, Semir Zeki, Dr. Kenneth Knoblauch, V. S. Ramachandran, Frank Vellutino and Jackie Masterson for various kinds of technical help and advice; for those friends and fellow humans who supported and tolerated me in their own ways during the preparation of this thesis; to those that suffered my experiments particularly to Caroline Christie and Mary Ward whose work while not included in this thesis did much to inspire it.

And finally completing a thesis is a difficult task -- I thank Brian Butterworth for his uncanny and unique talent to saying the right thing at the right time in the right manner. Lastly to my extraordinary father who never doubted my capacity to complete this thesis and more importantly made its writing up possible.

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What is a thesis?

'A thesis should be ... an original contribution to knowledge'. Instructions to PhD candidates.

But what is an original contribution? A supervisor's pet idea they have not time for? Original in idea but not in method or in execution? Even where the candidate contributes ideas the means and methods used to explore them are frequently well worn from the experience of others.

There is a place for the thesis which attempts serious originality -- that which asks novel questions and explores novel techniques for answering them. Such work may frequently fail -- untrodden paths are liable to be difficult though they may turn out to be passable.

This thesis reports an attempt to answer new questions in new ways using (for reading research) new techniques with previously unused hardware.

I have tried to develop new ways of exploring the reading process by borrowing ideas from neurophysiology (Livingstone & Hubel, 1987; Ramachandran & Ramachandran, 1991) for use upon written stimuli.

As Peter Medawar notes, scientific papers (and surely it is true of theses) are fictions. Part of the real story unwritten in the main part of this thesis is the extensive development and debugging of programmes and techniques.

'The biggest cost of computerized research is software development. In an informal survey of some of colleagues who conduct extensive computerized research it is estimated that software development runs around 80% of the total data-acquisition cost in funds and time' (Schneider, 1991, page 114).

Moreover discoveries were made not relevant to the purpose of the thesis though pertinent to its execution. As chapter 3 narrates, the commercial monitor used (one which will be increasingly used by psychologists) is subject to a previously undocumented artifact. An artifact that seems to have been responsible for the intriguing results of one paper that contradicted previous research (Knoblauch, Arditi & Szlyk, 1991; Kenneth Knoblauch, personal correspondence). In chapter 4, I narrate the discovery and overcoming of problems of presenting stimuli in counterphase (flicker). Like the above mentioned artifact, the difficulties and wrong turns they represent is left out of their description. The experimental content of this thesis may disappoint but it is the product of a long arduous trek.

Why the trek? In chapter 1, I show that visual science has not contributed as much as it could do to the investigation of reading processes¹. The visual sciences

have shown the existence of two visual pathways or channels. It is not implausible that these two channels may have some connection with reading both normal and disabled. Bruno Breitmeyer and William Lovegrove from a psychophysical perspective have tried to link them to reading and dyslexia. I argue their approach is severely flawed. This is partially because they did not know enough about reading or dyslexia and partially because their evidence is indirect. But there are good questions (ignored by Breitmeyer and Lovegrove) to be asked about the linkage between the two visual channels and reading and the two visual channels and dyslexia. In chapter 2, I argue the techniques used by neuroanatomists and neurophysiologists to study these channels² may be used to directly investigate their role in reading (and dyslexia but the present work regrettably did not get so far). The rest of thesis is the story of the attempt to use these techniques upon this untrodden path.

Notes.

1. This is a generalisation. I consider the work of Legge and colleagues very highly. Unfortunately it not widely cited by reading psychologists.

2. I discuss their work separately from that of psychophysicists because while it is logically connected to their work it has developed in isolation to it. I have not found one reference to the psychophysical work reviewed in chapter 1, in the publications of the neuroanatomists and neurophysiologists reviewed in chapter 2 (the converse is not true: psychophysicists frequently cite the work where relevant of neuroanatomists and neurophysiologists).

1.1 Introduction

Except for braille we read through our eyes. How does the channel of vision affect reading. Is it a neutral conduit which can be ignored by those trying understand the processes of reading (much as they ignore the effect of wearing or not wearing glasses). Or, are visual processes (those carried out between and within the eye and the visual cortex) integral to reading?

Evidence exists for a possible linkage between reading and visual processes. Positron emission tomography (PET) research (Petersen, Fox, Posner, Minton & Raichle, 1988; Posner, Petersen, Fox & Raichle, 1988) suggests that the occipital (visual) cortex is activated during written word recognition. This activation has been claimed (Petersen, Fox, Posner, Minton & Raichle, 1988; Posner, Petersen, Fox & Raichle, 1988) to relate to the recognition of words not just to their perception. Saccade-related brain potentials associated with reading confirmed this finding: the lexical responses following word recognition occur simultaneous with visual ones (Marton & Szirtes, 1988).

The nature of this connection is unknown. However, in recent years, our understanding of vision has increased

giving rise to new possibilities by which vision may interact with reading. One discovery is that vision has become recognised as being divided into two visual 'channels' (Breitmeyer, 1984; DeYoe & Van Essen, 1988; Livingstone, 1988; Livingstone & Hubel, 1987; 1988; Schiller & Logothetis, 1990; and Zeki & Shipp, 1988). Loosely, one of them is concerned with perceiving things, the other with seeing motion.

This situation suggests a need for a:

- Theoretical linkage between present models of the visual system and present models of reading processes. Such theoretical models need not specify linkages, given present limitations upon our knowledge of the processes involved it may be limited to mapping terra incognita for future research.
- Experimental research linking reading processes and visual processes, particularly in regard to the contribution to reading of the two visual channels.

Such a theoretical and empirical linkage has been made by two visual psychophysicists, Bruno Breitmeyer (1980; 1982; 1983; 1984; in press; Breitmeyer & Ganz, 1976) and William Lovegrove. Their work is reviewed later in this chapter.

Dyslexia makes the linkage between vision and reading important. Until recently, dyslexia was attributed to visual problems. But starting in the seventies, this view was revised in view of studies which demonstrated a strong contribution of phonological deficits to the reading difficulties in the majority of dyslexics with only a minority of dyslexics suffering visually related problems, rather than phonological ones (Boder, 1973; Mattis, French & Rapin, 1975). However, in spite of evidence to the contrary many non-scientists particularly teachers (Allington, 1982) maintain visual problems underlie the reading problems of the majority of dyslexics.

The idea that visual problems underlie the problems of the majority of dyslexics could be ignored if it was not also that the same vision scientists linking the above mentioned visual channels to reading also explain dyslexia in terms of low level visual problems (Breitmeyer 1989; 1991; Lovegrove, Martin & Slaghuis, 1986; Lovegrove, Garzia, & Nicholson, 1990).

Their work it should be emphasised does not link the two visual channels with reading problems of the minority of dyslexics thought by other reading researchers to have visual problems (they specifically exclude this possibility), but the reading problems of the majority thought by reading researchers to be phonological in origin.

This is unfortunate since theoretical and empirical studies linking vision and reading would seem to be required to further understand the problems of the minority of dyslexics with visual related difficulties rather than the problems of the majority whose problems are well accounted for by phonologically related ones.

Of potential relevance is that their work lacks strong connections with non-psychophysical reading research. It might be that their psychophysical methods have enabled them to probe aspects of dyslexia overlooked by reading researchers. Alternatively, their lack of familiarity with reading research may have caused them to underestimate or ignore aspects of reading and dyslexia which could negate their model.

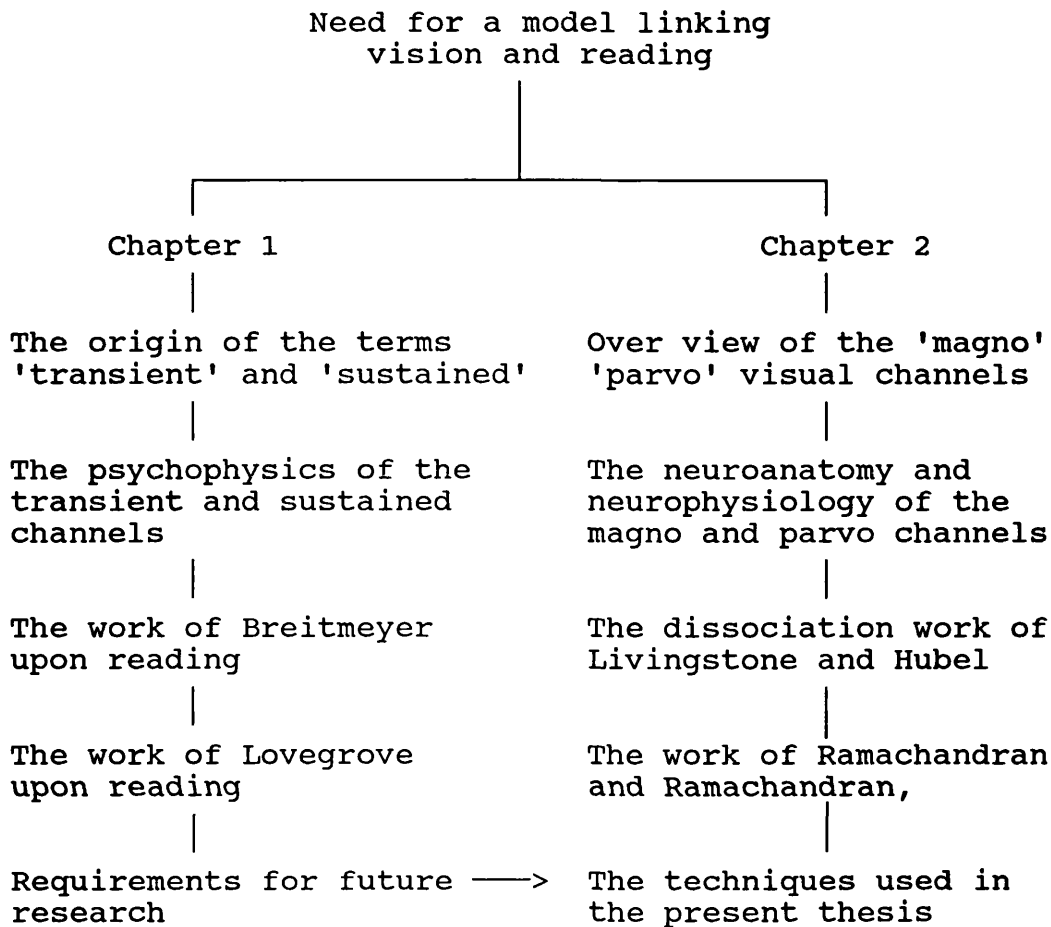
Their work therefore presents for reading researchers an interesting challenge. If their account linking vision with reading and dyslexia is correct then the phonological account of dyslexia needs reexamining and perhaps replacing. However if their theoretical and empirical explanation of reading is flawed then a new attempt, (learning from their mistakes), might be required to begin to link vision and reading. This chapter will review both their contribution to the understanding of reading both in normals and dyslexics. I shall draw from their work conclusions about the requirements for guiding future theoretical and experimental

research linking visual channels and reading carried out later in this thesis.

Bruno Breitmeyer and William Lovegrove have had their ideas and research about reading and dyslexia concerning the two visual channels widely published: Science, Neuropsychologia, Cognitive Neuropsychology and the Journal of Experimental Psychology. Bruno Breitmeyer is chiefly concerned with linking the two visual channels to reading and William Lovegrove is concerned with making the further link with dyslexia (though in recent years Breitmeyer has also contributed to this area).

My review of their work first discusses the psychophysics of the two visual channels in sufficient detail to enable their ideas to be understood (a much fuller account of them is given in the next chapter). Second, I outline and discuss the work of Breitmeyer followed by Lovegrove's work upon dyslexia. Third, as part of my comment upon Lovegrove's theory of dyslexia, I discuss whether alternative non-visual explanations of dyslexia, theoretically and experimentally provide a better account. Fourth, I propose requirements for future research upon vision and reading. This leads on to my own approach in the next chapter (for synoptic view of the organisation of this and the following chapter see figure 1.1).

Figure 1.1. Outline of organisation of this and the following chapter.



A terminological warning is needed. Reasons (discussed in chapter 2) exist for believing that the 'transient' and 'sustained' channels of the visual psychophysicists are equivalent to the magno and parvo visual channels discussed by neuroanatomists and neurophysiologists. After this chapter, I will use the terms 'magno' and 'parvo'. However, for this chapter, since these are the terms used by those

whose work I review, I will use the terms 'transient' and 'sustained'.

1.2. Transient and sustained channels

Visual psychophysics has identified two component channels in vision: (Breitmeyer, 1984, chapter 6; Cleland, Dubin, & Luvick, 1971; Enroth-Cugell & Robson, 1966; Kulikowski & Tolhurst, 1973; Legge, 1978; Lennie, 1980). Within psychophysics they are known as the 'transient' and 'sustained' channels. The origin of this work and these terms lies with research upon the response characteristics of cat retinal ganglion cells (Cleland, Dubin & Luvick, 1971). These response characteristics have also been found for the cells they project to in the lateral geniculate nucleus. Two types of cells were found characterised by different responses to prolonged stimulus exposure (a review of this neuroanatomical and neurophysiological work is left to the next chapter -- the present reference is to explain the origin of psychophysical terminology). The cells differed in two distinct ways. Some of the cells Y recorded responded throughout the stimulus' presentation in a manner that was sustained. Others, X cells, responded to the onset or offset of stimulus presentation in a manner that was transient. These characteristics led to the terms 'transient' and 'sustained' (though cat vision researchers now use another pair of terms, X and Y cells -- a fortunate

situation since human and cat ganglion cells have different properties¹).

Psychophysicists following on from this work have inferred the existence of two similar cell types underlying human vision (Kulikowski & Tolhurst, 1973). These investigations do not involve recoding directly from ganglion or geniculate cells (which would be unethical) but examining their effects on vision using appropriate psychophysical techniques. Some of these techniques and characteristics of the two visual channels will be described below with the ideas of Breitmeyer.

1.3. Breitmeyer's theory of reading

Breitmeyer (1980; 1982; 1983; 1984; in press; Breitmeyer & Ganz, 1976) brought together several properties of the transient and sustained channels in a low level visual theory of written word perception.

Breitmeyer observed that psychophysical research had found that brief stimuli produced a short transient channel response but a long sustained channel response. The long duration of the sustained channel response had moreover the effect of causing the image in the sustained channel to outlast its physical presence. Breitmeyer identifies this persistence (1984, pp 67 - 76) with neural persistence (Coltheart, 1980). Other characteristics of the visual

system led Breitmeyer to assume that no direct role exists for the transient channel in word recognition with word recognition happening exclusively in the sustained channel.

Figure 1.2. The perceptual blurring of sustained images across fixations; taken with slight adaptations from Breitmeyer (1980) who modelled the illustration after Hochberg, 1978.

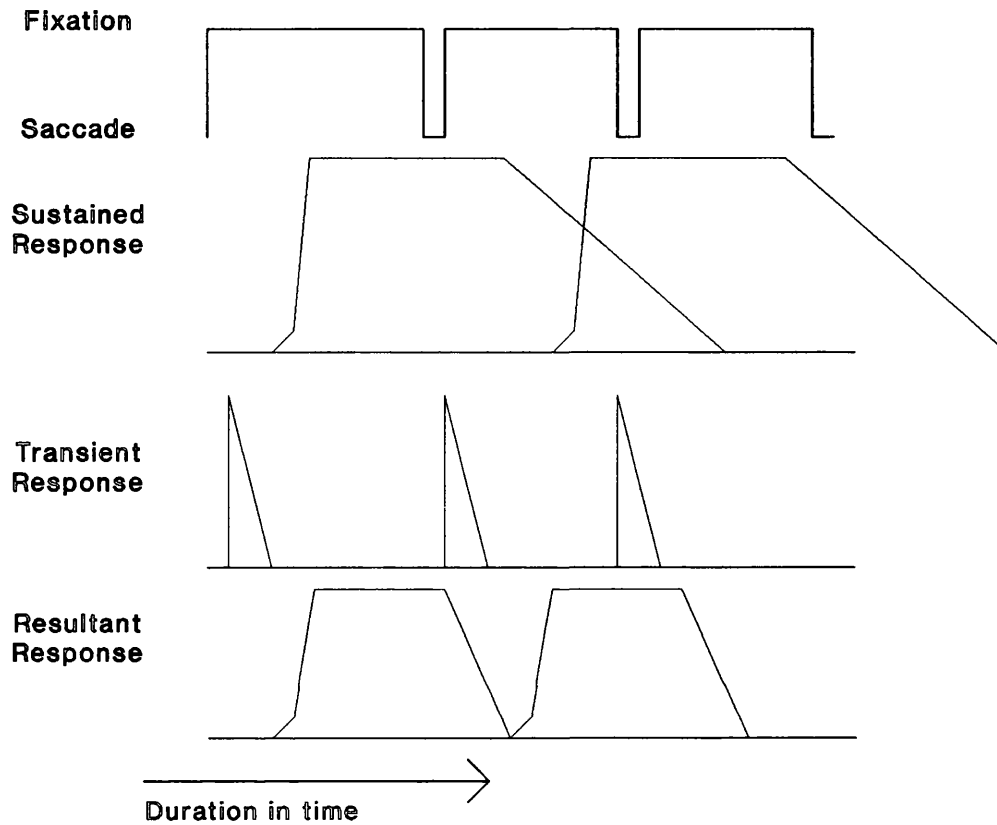
VISION IS ICONOCLASTIC (Three fixations)

VISION IS ICONOCLASTIC (Two fixations)

VISION IS ICONOCLASTIC (One fixation)

The persistence of word images in the sustained channel, Breitmeyer suggested, might cause problems for readers when reading text. In reading, a reader constantly brings new word images with each fixation on to their retina. The visual system up to the primary visual cortex is organised retinocentrically (Fox, Miezin, Allman, Van Essen & Raichle, 1987). Thus there is a risk that visual persistence in the sustained channel may impair the processing of word images as the eye repeatedly moves to new words. Breitmeyer suggests that the effect of persistence would be to superimpose words from different fixations upon each other causing impaired reading (see figure 1.2).

Figure 1.3. Hypothetical channel interaction during reading fixations. Sequence of fixations, top panel, Sustained responses, second down, Transient responses, third down, resultant interaction, bottom. Taken from Breitmeyer (1980).

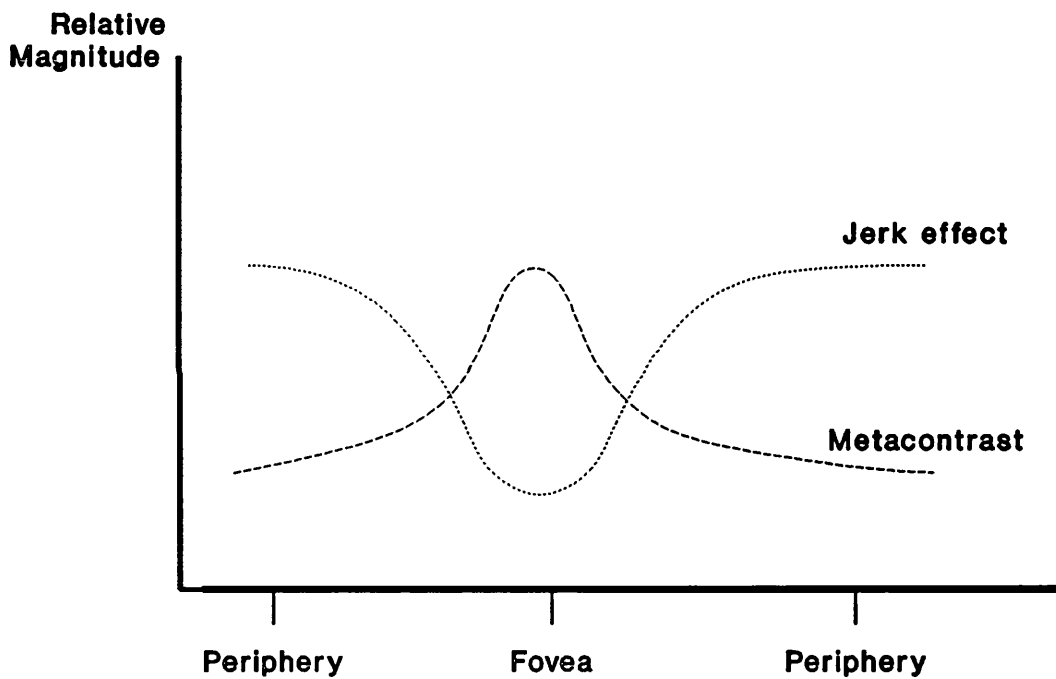


This does not happen. We see words in a text without superimpositions. Breitmeyer offers a reason. He suggests that the channels interact to inhibit each other. The transient channel is activated by the eye scan to mask and so remove the image in the sustained channel (see figure 1.3). This transient-upon-sustained inhibition if true would be an example of the phenomena of metacontrast contributing

to functional vision (Breitmeyer, Rudd & Dunn, 1981).

(Metacontrast is the reduction in the visibility of one briefly presented image by another image presently next to it shortly and briefly afterwards.)

Figure 1.4. Contrasts between the disruption of sustained channel activation (metacontrast in the fovea) and that of the transient channel (the jerk effect in the periphery). From Breitmeyer (1984).



Breitmeyer offers two accounts how this happens. First, the transient channel in the fovea has a non-recognition role in reading. When new words fall on the retina during reading fixations the transient channel is temporarily activated. This transient channel activation causes it to

block for a moment visual persistence in the sustained channel wiping out its residual image². In effect, the scan of the eye to a new word triggers the transitory channel to clear the sustained channel of its old word image so preparing it for perceiving the new one. (See figure 1.3).

This theory is elegant. Unfortunately, as Breitmeyer emphasises the transitory-upon-sustained effect and persistence vary in the eye. Persistence is strongest in the fovea and weaker in the periphery while the transitory-upon-sustained effect is strongest in the periphery but weakest in the fovea (see figure 1.4.). Therefore he has to acknowledge that the transient-upon-sustained effect following an eye scan is insufficient to clear the sustained channel. As Breitmeyer (1980, page 63) notes:

'Visual persistence is particularly long and strong in the fovea, therefore, it is in the fovea that saccadic suppression ought to be the most potent. However several studies clearly show that metacontrast is weaker [the references to four studies follow] and of shorter duration [another reference] in the fovea than in the parafovea or periphery. [He concludes, after a sentence why this is the case that] .. the problem for visual processing can be stated in the following manner: Metacontrast, as a short-range mechanism of saccadic suppression, is too weak in the fovea.'

And again, Breitmeyer (1983, page 11): 'In view of the stronger and longer response persistence of foveal sustained channels noted earlier, foveal metacontrast, as a short-range mechanism of saccade suppression is too weak'.

Breitmeyer's theory to be credible has to find a way in which the reading process increases foveal transient-upon-sustained inhibition. Therefore he proposes another account of reading. He notes that in reading a text, a reader moves his or her eyes. This leads him to postulate that saccadic eye movements in addition to changing the foveal image enhance through another mechanism, the jerk effect, the transient channel suppression in the fovea. (The jerk effect occurs when the transient channel is stimulated by the images in the visual periphery jerking as the eye changes its place on a page with new fixations). In Breitmeyer (1984, pp 331-335) he expands upon this suggestion by adding that saccades also 'activate central corollary discharges which reinforce this suppression [transient-upon-sustained inhibition]'. These conclusions it should be emphasised are based upon simple psychophysical stimuli and situations, Breitmeyer has never worked as far as I am aware with real words or reading eye movements.

This second mechanism for clear reading vision requires that readers make (1) eye saccades, and (2) (for the jerk effect to work) these eye movements occur when reading texts (since the jerk effect requires there to be visual stimulus

in the visual periphery which will visually change position and so jerk with eye movements). Thus it directly predicts that people will have problems reading words in circumstances which do not require them to move their eyes particularly in the absence of text surrounding their fixation point. A form of reading which does not need eye movements exists, RSVP (rapid, serial, visual presentation) (Foster, 1970; Potter, 1983). In RSVP, written words rapidly appear in succession at a location where the reader keeps a constant fixation. Normally, this location is the centre of a visually blank screen or tachistoscopic field. People have no problems reading words and texts presented in these circumstances. Further, not only do they lack problems reading such texts they can achieve higher rates of reading -- 12 words per second -- compared to the scanning of normal text of about 6 words per second (Potter, 1983 page 432, 1984).

If RSVP reading had been developed as a test of Breitmeyer's theory his theory would have been considered refuted. A corollary of this is that it should be considered refuted even though RSVP was well studied in the reading literature some years before Breitmeyer proposed his theory. It is a curiosity of science why Breitmeyer's work has never been criticised (at least publicly in the published literature) on this point. Both Breitmeyer's theory and RSVP are not only logically connected but have been described in successive years in the same journal, Psychological Review.

Moreover, chapters by both Bruno Breitmeyer (1983) and Mary Potter (1983) are in the same volume edited by Keith Rayner. Why did not its editor, Breitmeyer or Potter or its other contributors; its book reviewers and its many readers (chapters in it are well cited; the copy in the University of London library in the Senate House is worn heavily with use) spot the incongruity? It seems unlikely that Breitmeyer is aware of RSVP since he has never even tangentially mentioned the problems RSVP might pose for his theory.

Though Breitmeyer does not mention research directly concerned with the persistence of images between eye movements some relevant research has been carried out. Though some early research (Davidson, Fox & Dick, 1973) was thought to show the existence of visual masking by the persistence of previously seen images this work has not been replicated and is now questioned by more recent and careful work (Irwin, Brown & Sun, 1988). Irwin has carried out research (though not with reading material) aimed at discovering the role of transsaccadic persistence during reading and has found no evidence for it (Irwin, Brown & Sun, 1988; Irwin & Yeomans 1986; Sun & Irwin, 1987).

Clearly, Breitmeyer's theory is in some respect deficient: either word images in the sustained channel are cleared by some non-saccade dependent process or visual persistence does not affect the perception of images seen during reading.

1.4. Lovegrove's theory of dyslexia

1.4.1. Introduction

Breitmeyer's theory has been expanded by himself (1989; 1991) and Lovegrove (Lovegrove, Martin & Slaghuis, 1986; Lovegrove, Garzia, & Nicholson, 1990) into a theory of dyslexia. Their line of argument has been this: if psychophysical research has shown that the clear perception of successive images in the sustained channel requires transient channel inhibition what happens if the transient channel is defective? This line of reasoning has led to a theory of dyslexia as a transient channel defect. I shall now review evidence for it.

William Lovegrove and colleagues published a series of papers (Lovegrove & Brown, 1978; Lovegrove, Slaghuis Bowling, Nelson & Geeves, 1986; Martin & Lovegrove, 1987; Martin & Lovegrove, 1988; May, Lovegrove, Martin & Nelson, 1991; Slaghuis & Lovegrove, 1986a; 1986b; 1987) claiming to show dyslexics suffer a transient channel defect. Other groups have confirmed some of their findings (Brannan & Williams, 1988a; 1988b; Williams, LeCluyse & Bologna, 1990; Williams, Molinet & LeCluyse, 1989; Winters, Patterson & Shontz, 1989) though not all, (Howell, Smith & Stanley, 1981; Smith, Early & Grogan, 1986).

Lovegrove and his colleagues summarised their theoretical and empirical arguments in a paper in Cognitive Neuropsychology (1986). There have been further reviews by Lovegrove (Lovegrove, Garzia, & Nicholson, 1990) and Breitmeyer (1989, 1991). Charles Hulme gave a critical response to Lovegrove's Cognitive Neuropsychology paper in the same journal (1988). Lovegrove has a reply (in press). Like Hulme, my review of Lovegrove's ideas is critical. However, and surprisingly given the apparent rigour of Hulme's attack, I find many weaknesses Hulme overlooked. Nonetheless I am indebted to Charles Hulme's paper for some of the following comments and observations. However, most of them are my own: where not, this is indicated.

Breitmeyer's theory suggests that the clear perception of print depends upon the transient channel suppressing visual persistence in the sustained channel. Since the late seventies, William Lovegrove and colleagues (Lovegrove & Brown, 1978; Lovegrove, Slaghuis, Bowling, Nelson & Geeves, 1986; Martin & Lovegrove, 1987; Martin & Lovegrove, 1988; Slaghuis & Lovegrove, 1986a; 1986b; 1987; May, Lovegrove, Martin & Nelson, 1991) have been publishing work claiming to show that specific-reading-disabled readers (whom I shall call dyslexics) have a defective transient channel. They observe that a defective transient channel according to Breitmeyer's theory would cause dyslexics to suffer problems seeing words and this could be the cause of their reading difficulties. Breitmeyer concurs with them "reading

disability without perceptual deficit" by and large may be an empty diagnostic category (Breitmeyer, 1983 page 23 citing with approval Badcock and Lovegrove, 1981).

The transient channel theory of dyslexia is a low level visual account of the problems of dyslexics. It claims that dyslexics cannot read because a defective transient channel makes it difficult to see written words. The transient channel theory of dyslexia unlike other visual theories of reading difficulties it has the merit that it is supported by well designed psychophysical research. Further, their specific-reading-disabled group seem a proper dyslexic group (defined as 2.5 years [a difference sufficient to suggest reading problems rather than general delay] below expected grade level reading with average or above average non-verbal IQ and performance in other subjects) with their performance compared to a properly matched control group. Lovegrove and colleagues have carried out many studies which show that the majority of dyslexics have what they claim to be defective transient visual channels. Whether they have found evidence for a defective channel or merely a slightly differently performing one to normals, I shall question below.

It needs to be emphasised that Lovegrove's theory concerns the vast majority of dyslexics. Lovegrove is not suggesting that a transient defect is responsible for the problems of the minority of dyslexics thought by dyslexia researchers to have visually related difficulties. '..the

majority of our subjects would not be considered as visual-spatial by Mattos et al (1975) or by Pirozzolo (1979)' Lovegrove et al (1986) page 255. Instead, they identify their dyslexic group clearly with those with recognised phonological defects. Towards this end they carried out a nonword naming task to show their dyslexics had impaired phonological reading. On this nonword naming task, their control subjects obtained over 90% correct, while none of their dyslexic subjects got more than 50% right. As they conclude 'This failure shows an inability in phonology. Consequently it is likely that many SRDs (Specific Retarded Dyslexics) tested here have some form of both language and visual deficits' Lovegrove et al (1986) page 255. Whether their dyslexic subjects in fact had any visual deficits which contribute to their reading difficulties I shall question.

1.4.2. Preliminary observations upon implausibility

Before discussing Lovegrove and colleagues' case (and the relevant papers they cite) several comments upon the intrinsic implausibility of their hypothesis need to be noted.

First, dyslexics have been found to perform no differently from controls on a wide range of visual tasks (Ellis & Large, 1987 page 14; Vellutino, 1979). It is surprising but not, that these tasks did not tap all the

visual skills which contribute to unimpaired reading. Because it is not totally implausible, Lovegrove and his colleagues are correct in suggesting that they may have found a defect in a visual skill unrelated to previously tested visual skills. However, their argument against the ease with which people read in spite of visual handicaps is not valid. People have a remarkable ability to read in spite of severe ophthalmological handicap, (for comments by ophthalmologists on this point see Critchley, 1970, and Linz, 1973). Moreover, several studies have failed to find an association between static ocular problems (such as myopia and astigmatism) and reading handicap (Bedwell, Grant & McKeown, 1980; Bishop, Jancey & Steel, 1979; Evans & Drasdo, 1990, note the latter is a review). Lovegrove fails to grasp the importance of the absence of an effect of visual impairment upon reading for their theory implausible. He attributes it to the wrong problem. It is not, as they imply, that 'because some visual deficits do not correlate with reading disabilities, no visual deficits do' page 228. It is because their theory requires that distorted and blurred words disturb the process of reading. People with static ophthalmic problems can have blurred and distorted vision. Nonetheless these problems do not make them dyslexic. If optical blur does not prevent people learning to read why should one caused more centrally have this effect?


Second, the majority of dyslexics suffer one or several of a range of language problems: rapid automatized naming (Denckla & Rudel, 1976; Wolff, Michel & Ovrut, 1990); naming unfamiliar words (Kamhi, Catts & Mauer, 1990); syntactic competence (Bentin, Deutsch & Liberman, 1990); hearing words masked by white noise (Snowling, Goulandris, Bowley & Howell, 1986); short term memory for spoken letter names (Shankweiler, Liberman, Mark, Fowler & Fischer, 1979); word strings and sentences (Mann, Liberman & Shankweiler, 1980) and digits (Campbell & Butterworth, 1985); language development and narrative speech defects (Davenport, 1986). Lovegrove completely ignores these deficits even though on his own data the dyslexics he studied suffered a phonological decoding problem while this was not the case with his normal readers. (Interestingly, the relationship between 'transient' deficits and reading was much weaker: a quarter of the dyslexics lacked a 'transient' deficit while it afflicted eight percent of normal readers. This point is discussed in greater detail later). Not only are dyslexics poor at language tasks but training children to enhance their phonological abilities enhances their reading acquisition (Bradley & Bryant, 1985). This suggests a causal relationship between phonological skills and reading development. Lovegrove has to offer some explanation for the strong association of dyslexia with language related deficits.

Third, as Charles Hulme (1988) notes, dyslexics have more problems reading single words than reading text (presumably because their problems are confined to recognising individual words and this is to some extent avoided when reading text through the use of context for word identification). Lovegrove's theory predicts the opposite pattern: problems reading texts where images can superimpose upon each other and none for single word reading for which no residual images exist to affect reading.

Fourth, as noted, the theory of Breitmeyer it develops is questionable in view of RSVP reading. Thus doubts must be raised on logical grounds about any theory deriving from it. Breitmeyer's theory would predict RSVP reading would be particularly difficult for dyslexics. No published studies on dyslexia and RSVP reading exist: however one unpublished technical report (Chen, 1983) has been described by Potter (1984, page 104). According to Potter this study found that RSVP compared to conventional text aided poorer readers while having no effect for normal readers. If these poorer readers were dyslexic then this would suggest that a technique that should make word recognition harder for dyslexics, in fact, makes their reading easier.

1.4.3. Lovegrove's research

Lovegrove and colleagues find that compared to normal controls dyslexics perform differently on three tasks sensitive to the integrity of the transient channel. There is some limited support for their work from other researchers (Brannan & Williams, 1988; Winters, Patterson & Shontz, 1989).

The transient and sustained channels differ in three measurable characteristics: (1) visible persistence, and sensitivity across spatial frequencies for (2) luminosity contrast and (3) flicker. The transient and sustained channel have different specialisations in processing different spatial frequencies: the transient channel processes low spatial frequencies and the sustained channel high ones (Breitmeyer, 1984). In brief, the large visual components of an image are made up of low spatial frequencies e.g. ■ ■ ■ ■. While the fine details are made up of high spatial frequencies e.g, , (a more exact definition is given in the methods chapter).

First, visual persistence, as noted above, is a sustained not a transient channel characteristic. Therefore visual persistence should be greater for high spatial frequencies (processed by the sustained channel) than for low spatial frequencies (processed by the transient channel). This indeed is the case for normal readers:

Badcock and Lovegrove (1981) found dyslexics compared to their controls had longer persistence for low spatial frequencies. They interpret this deficiency in terms of the dyslexics possessing a compromised transient channel. One group (Howell, Smith & Stanley, 1981) failed to replicate their finding. The difference between them was later attributed by Slaghuis and Lovegrove (1986) to the use by Lovegrove and Badcock of a flickering stimuli. It appears this greatly magnified the difference they originally found. Of two other groups one has replicated (Winters, Patterson & Shontz, 1989) and another failed to replicated these findings (Smith, Early & Grogen, 1986).

Second, the two channels differ in the luminosity contrast needed to recognise the presence of different spatial frequency sine wave gratings. A limitation in transient channel processing should increase the luminosity contrast needed for perceiving gratings of low spatial frequencies. This indeed was found to be the case for dyslexics (Martin & Lovegrove, 1984). A similar difference between controls and dyslexics has been found for contrast judgments made upon flickering stimuli (Martin & Lovegrove, 1987). The interpretation of this latter finding is made somewhat difficult because, as Badcock and Sevdalis (1987) note, their experimental technique contained an artifact: the contrast of the sine-wave grating was modulated in synchrony with the flicking uniform field; this affects the contrast. Removing this artifact they found a much reduced

effect of flicker upon the contrast needed to see low spatial frequency gratings. As Badcock and Sevdalis (page 646), note, while this does not remove the differences Lovegrove found it does suggest that they 'may need to be reinterpreted'.

Third, the flicker rate (the rate before two alternating images fuse) varies with spatial frequency and luminosity contrast. As will be discussed later, flicker is confined to the transient channel. Martin and Lovegrove (1987, 1988) found dyslexics had lower contrast sensitivity than controls to low spatial frequencies particularly at higher rates of flicker. This finding has been replicated (Brannan & Williams, 1988).

1.4.4. Problems with Lovegrove's research

Three things should be noted before further comment. First, Lovegrove has failed to show that the transient channel is defective in dyslexics in a way that would predictably impair reading according to Breitmeyer's model. Nothing about the performance of dyslexics on these tasks indicates transient channel deficit -- the performance only looks deficient in comparison with normals. But this comparison is irrelevant -- it might be that both dyslexic and normal performance are different but yet both are at a functional ceiling level. The evidence only permits the conclusion that the performance of dyslexics is different

from that of normals. To show they were defective Lovegrove would have to show that a certain degree of transient channel performance is needed for clear word perception and that dyslexics fall below this level. This is something they do not show or even attempt to show.

Second, it can be argued that he has found evidence that dyslexics have a healthy working transient channel. Studies on monkeys with transient channel lesions (in these studies the transient channel is referred to as the magno channel) are unable to process stimuli flickering over 6 Hertz (Schiller, Logothetis & Charles, 1900). Lovegrove presents evidence for competent flicker processing in dyslexics up to 25 Hertz. This can be interpreted as evidence that the transient channels of dyslexics are unimpaired.

Third, the evidence that Lovegrove presents for a transient channel defect in dyslexia depends mostly upon subjective rather objective threshold criteria for detection of flicker. As Breitmeyer (in press) notes "when putative 'criteria-free' or forced-choice methods are used, differences between form/pattern and flicker/motion thresholds can be either eliminated (Derrington & Henning, 1981; Lennie, 1980) or, as shown by Burbeck (1981), reversed at all but the lowest spatial frequencies". Thus it is possible that the differences in thresholds between dyslexics and normals which Lovegrove attribute to a

transient channel deficit may reflect differences between the two groups in subjective criteria, rather than channel deficits.

Lovegrove argues that his findings for dyslexics' transient channels are not an effect of failure to learn to read. Charles Hulme accepts Lovegrove's argument here. However, while transient channel performance may well not be affected by reading experience, Lovegrove does not provide the required evidence.

Lovegrove makes two observations, one of which is seriously flawed. First, he notes that the slope between visual persistence and spatial frequency is constant between the ages of 7 and 13. He acknowledges that the persistence duration changes over this period (the slope is constant because persistence decreases uniformly across spatial frequencies). As Lovegrove acknowledges this provides only indirect evidence that the relative relationship between the two channels does not change with reading experience.

This led to his second observation. In an attempt to remedy the limitation of the first point, he and his colleagues measured the transient channel function in pre-readers and reading performance two years later (Lovegrove, Slaghuis, Bowling, Nelson & Geeves, 1986). They claim to have found a $+0.27$ $p = .01$ (with intelligence partitioned out, $+0.34$, $p < .01$) correlation coefficient between their

transient channel measure at 6 years of age and reading ability at 8 years old. They argue that this study provides evidence that 'visual deficits reported here do not result from children failing to learn to read but exist before children commence reading instruction' (page 254). This conclusion is invalid. There is no reason to assume as Lovegrove does that his pre-reader group did not include children who could read. In a straw poll of Australians, I found most recall learning to read before the age of five. This was an exceptional group consisting of university educated people. However, one study provides data from ordinary Australian children (Jorm, Share, MacLean & Matthews, 1986). As part of a longitudinal study of reading, 543 kindergarten children (mean age 5 years 4 months) were given two reading related tasks predictive of later reading success: letter naming and personal name writing. They reported data upon children who two years later developed normally (n = 414) and those who showed dyslexia (n = 25). Normal kindergarten children could read 3.42 (SD 3.14) of nine letters. Children who however turned out to be dyslexic could read only 0.72 (SD 1.1) letters. Thus by 5 years 4 months these children had sufficient familiarity with written material to enable differentiation between future dyslexic children and their normal peers. The children in Lovegrove's study were seven months older and so differences in this group between future dyslexics and normals would probably have been even larger. It is therefore likely that when he first tested transient channel

functioning the normal and dyslexic children had already different exposure to reading materials. Thus the transient channel performance of pre-readers would have been contaminated by the performance of children whose transient channel performance had already been affected by reading experience. Further, these children would be the better readers two years later thus creating a spurious correlation between transient channel function and reading ability.

Another objection is that the theory predicts reading defects for clinical groups with impaired transient channel function. One of the effects of glaucoma is selective destruction of large over small fibres in the optic nerve. Large fibres carry the transient channel (larger sized fibres have quicker transmission so this connection fits functionally with the fast response needs of the transient channel). Several studies have shown loss of transient channel function in glaucoma patients (Atkin, Wolkstein, Bodis-Wollner, Kels & Podos, 1980; Fitze, Poinosawmy, Nagasubramanian, & Hitchings, 1990; Quigley, Dunkelberger & Green, 1988; Silverman, Trick, & Hart, 1990; Tyler, 1981). Specific loss of reading skills is not one of the characteristics of glaucoma (though obviously reading difficulties might follow general loss of vision). Given its direct relevance to their work it is surprising that Lovegrove and colleagues do not mention glaucoma³.

I will assume to question even more basic aspects of Lovegrove's attribution of dyslexia to the defective transient functioning that these points are not valid -- that the transient channel differences between normals and dyslexics is large enough to affect reading and that transient deficits do not follow from reading.

1.4.5. Lovegrove's data for normal readers and low level visual transient problems

The rationale behind Lovegrove's theory of dyslexia would seem to allow little room for low level visual problems caused by transient channel defects to selectively affect reading. Either low level visual problems cause reading problems through making words hard to see or they do not. Thus there must be some disquiet at the way Lovegrove underplays two problems with his findings: first, a small minority of normal readers also show transient channel deficits; second, a considerable number of dyslexics -- a quarter -- did not. The first figure is the most important. The dyslexics without transient channel problems might have other explanations for their reading difficulties. But normal readers with transient channel problems raise questions as to why transient channel problems have affected the reading of some children but not all.

The number of children with transient channel deficits is calculable from Lovegrove's figures. Lovegrove reports

that eight percent of the control group showed transient defects. That may not sound a large number and perhaps for this reason it might have been ignored but it must be borne in mind that most readers are normal ones -- thus this represents a small percentage of a potentially very large one. Lovegrove provides figures which make it possible to calculate its limits. According to Lovegrove and colleagues, between 4% to 15% of children by their definition are dyslexic. Simple arithmetic shows that normal readers make up between 38% and 72 % of those with transient deficits⁴. (This is a nice illustration that a small number of a large percentage can often be numerically larger than a large number of a small one). These figures are not published in their paper. Lovegrove and colleagues (1986), however do comment upon the 8% of normal readers with transient channel defects:

'some children who are potentially reading disabled are able to keep up to their reading age level until they reach a more advanced stage requiring more skills. They may register as SRD [dyslexic] at a later age. It is possible that some subjects chosen as controls may simply not have been normal readers despite their reading age scores. This is especially likely in terms of the criterion that SRDs have a reading lag of 2.5 years' (pp 252 - 253).

What does this mean? How can a low level visual defect not affect early reading only to affect it at 'a more advanced stage requiring more skills'? Surely the opposite would be the case -- the better a reader's reading skills the more able they are to compensate for perceptual problems. What does it mean to suggest that 'some subjects chosen as controls may simply not have been normal readers despite their reading age scores'? It is difficult to avoid the suspicion that Lovegrove is trying to cover up a fact which renders their hypothesis meaningless. For if 38% to 72% of readers can read in spite of a transient channel deficit then a lack of an intact transient channel cannot be that critical for normal reading.

In conclusion, the theory they propose is not supported by their evidence: it does not offer an explanation for the problems of the 25% of those dyslexics without transient disfunction, nor does it explain the reading abilities of the 38% to 72% of readers with transient defect but intact reading abilities.

1.4.6. Lovegrove's mistake

Then what did Lovegrove and colleagues find? I suggest like Charles Hulme that they found a minor variation in the transient channel function unassociated with reading but incidentally associated with dyslexia. As Hulme notes, such an association would not be surprising: dyslexic children

are different from matched controls in a number of ways. Dyslexics have been reported to have a greater incidence than controls, in addition to the above mentioned language problems, of one or more of the following: immune-diseases (Hugdahl, Synnevåg & Satz, 1990); mothers who have experienced major stressful life-events and diseases during their pregnancy (Hugdahl, Synnevåg & Satz, 1990); weak left hand skills (Annett & Manning, 1990); failure to suppress attention to input in the right ear (Smith & Griffiths, 1987); inability to shift attention between ears (Kershner & Morton, 1990); and difficulties automatising skills (Nicolson & Fawcett, 1990). The factor which compromises language skills may also compromise other skills (see also the postscript to this chapter).

1.5. Alternative theories of dyslexia

The transient channel dyslexia hypothesis provides a causal explanation of dyslexia. Indeed, it shares this advantage with other visual theories of dyslexia (together with their lack of convincing evidence). It is a striking phenomenon that the considerable evidence for dyslexics suffering phonological problems has produced few if any successful causal explanations (except perhaps myself, Skoyles 1988 and 1991a which I shall review and expand below the only one I am aware of is Jorm and Share, 1983), a point made by Hulme 1988 and more recently by Goswami and Bryant (1991).

If the continued popularity of visual theories of dyslexia is going to be changed then a causal explanation linking phonological defects and dyslexia is needed. In 1988, I published such a theory in Nature (also presented at the Experimental Psychology Society 1989 London meeting and discussed briefly in Skoyles, 1988; and more fully 1991a with commentaries Cassidy, in press, Coltheart 1991, and Reilly, 1991; and replies, 1991b, 1991c, and in press). Its original motivation was to offer an explanation linking two problems in reading research rather than to provide a causal theory of dyslexia. However it offers such and that aspect of it will be emphasised. The theory suggests that phonology related word identification skills provide a cognitive scaffolding for the development of non-phonological reading abilities.

The first point of theoretical departure concerns adult reading. At the beginning of the eighties a consensus emerged that adult reading is non-phonological (Humphreys and Evett, 1985)⁵. Except for rare regular words, phonological skills have a minimal role in skilled reading their place being taken by non-phonological processes of an incompletely understood kind: they are visual but without being logographic. Separate to this consensus, another has emerged: that phonological and rhyme skills are critical for the development of adult reading (Goswami & Bryant, 1990; Wagner, 1988). A pre-school child's phonological skills (Stuart & Coltheart, 1988) and rhyme skills (Bryant &

Bradley, 1985) predict later reading success, as does rhyme skill training (Bryant & Bradley, 1985) (for a general reviews, Goswami and Bryant, 1990; Wagner & Torgeson, 1987). Children with impaired reading skills are most likely to suffer impairments in phonological skills (Snowling, 1987; Jorm, Share, McClean, Matthews, 1986), as are adults who were classified as dyslexic as children (Felton, Naylor & Wood, 1990).

Further, support for a linkage between phonology and non-phonological skilled reading comes from non-alphabetic scripts. Many phonologically opaque scripts are modified to make them phonologically transparent or phonologically readable for learner readers. There are two sources to phonological opacity: vowel omission and logography. For the vowel omitting Hebrew, Arabic and Persian scripts, vowel diacritics are added in children's texts. This enables children to read them through phonological decoding -- something not possible with the adult form of the script. Where a script is logographic, an additional phonological script (pinyin in mainland China, kana in Japan) is often used in children's text to indicate the pronunciation of logographs likely to be unfamiliar to beginner readers. Thus though a logograph may not provide information as to its pronunciation children can use his or her phonological skills to aid reading it. It should be noted that a considerable number of logographs are not devoid of phonological information which might be used in their

identification (Yin, 1991). However, it is rarely sufficient to identify them without other, usually contextual, information sources (these skills being the most predictive skills for Hong Kong logographic Chinese readers, Chen & Wong, 1991). This is because the importance of word phonology in a language like Chinese (dominated by homophonous words) is different to those like English which have relatively few homophonous words: in English the phonology usually gives the identity of a word while in Chinese it does not.

The importance of phonology for beginner readers is problematic. Why should an ability be critical for the development of a skill (mature adult reading) in which it plays no active part? (See also the comments in footnote 5).

The second theoretical problem concerns PDP (parallel distributed processing) or connectionist (the terms are inter-substitutable) network models of reading. These are simulations on computers of the neural networks presumed to exist in the brain that recognise written words. Though there are some problems and many critics, PDP networks have been able to successfully mimic many experimental findings concerning adult reading (Seidenberg & McClelland, 1989)⁶.

The simulation of reading by networks depends upon the networks first being trained. Training involves two processes one of which gets extensive discussion, the other

is virtually ignored. A network learning to read gets trained through making mistakes or correct responses to training input⁷. After a mistake or correct response the nodes of the network are adjusted to improve its future performance. Much discussion has focused upon the rules used to adjust the network's nodes following a correct or incorrect learning response. However little attention is paid to how the processes in the brain tutoring a network know that any given output is correct or not to any given input. The reason for this omission may be partly conceptual -- the issue is not seen as a problem. But this probably relates to the fact that the first process involves PDP theorists and their computer programmers in complex decisions as to programming various training rules while no problems attain to programming a computer to know the correctness or otherwise the networks response, since the stimulus inputted into the network can automatically be matched against the network's output by the computer implementing the network.

PDP or connectionist models are mainly interesting because they model real processes. If PDP simulations of the reading process are correct, and their success suggests that though they have problems they can contribute to our understanding of reading, they must simulate all aspects of learning to recognise written words. This means they must be able to model not only the rules used to train the brain's networks but also the means by which the brain obtains

information to know whether a learning response is correct or not. Without this information, networks cannot be trained. This information is easy to program on a computer since the correct input to network can be temporarily stored for later matching against the networks output. However, the brain is not privileged to know the correct output for any given orthographic input so the brain will find this problem non-trivial. When presented with an unknown word unless it has some word recognition process other than that provided by its network undergoing training, the brain will not know whether its response to it is correct or not. PDP theorists thus leave us with the open question of how training happens in the natural networks in the brain (Skoyles, 1988, 1991).

In an attempt to provide an answer to the question just posed I have suggested linking the two problems. Two processes coexist, I suggest in beginner readers. First, a developing non-phonological word recognition process based around neural networks which needs tuition information. And second, a phonological process recognising unfamiliar words through the learner reader's oral vocabulary of word pronunciations. In effect, phonological decoding takes the place of the correction information automatically provided by the PDP theorists when training their networks.

This phonological decoding may be of several kinds. It could involve the full sounding out of a word. However, it could involve word analogy processes -- a word similar to

the target unfamiliar word is accessed in the oral vocabulary store and then the sounds of any different letters deleted and those of the unfamiliar word added. This analogy and phonological changing of sounds seems most likely given learner readers can use analogy processes (Goswami, 1988) and that a better predictor for nonword reading than phoneme segmentation skills is phoneme deletion and insertion (Lenchner, Gerber & Routh, 1990) -- skills needed for generating new pronunciations from closely matching words.

The proposed role given to phonological decoding skills makes them both unique and non-unique. They are unique in that a beginner reader has few other reliable and convenient sources as to a written word's identity. They are not unique in that alternatives exist: the identity of a word may be obtained using context. Alternatively, beginner reader may prepare themselves before text reading with the help of a teacher by learning a large set of paired-association between the visual image of a written word and its identity. These provide alternative but much more restricted sources of information with which to train reading networks. Their existence to some degree explains why people lacking phonological skills sufficient to identify unfamiliar words, can after a much longer development period than normal, still learn to read (Campbell & Butterworth, 1987; Snowling, Hulme, & Goulandris, submitted). In the absence of phonological skills network training can proceed using

correction information from other sources, but since this information is not always available training proceeds at a much slower rate.

This theory makes the interesting prediction that the reading processes in most dyslexics are relatively unimpaired: their problems originate in training. Thus the theory makes the prediction that dyslexics are potentially normal readers (though handicapped unlike normal readers in their ability to learn new words). This suggests that the problem in helping dyslexics is to either make their limited phonological abilities more efficient or provide them with alternative new training processes. This suggests much stronger attention should be given to how a phonologically disabled reader might be helped to use their remaining phonological and non-phonological abilities to identify written words.

In summary, there is no need for a visual deficit to explain dyslexia. It fails to account for the problems experienced by the majority of dyslexics. Its theoretical rationale is questionable. The data used to support it is at best demonstrative of slightly differing transient channels to be found in most dyslexics -- a characteristic also to be found in many normal readers; and there are good causal reasons to connect the phonological deficits found in dyslexics to their reading difficulties.

Visual psychophysicists have proposed two implausible theories connecting the two visual channels with reading. Two questions arise of which only one can be answered here.

First, how could Breitmeyer successfully advocate a theory for so long (and at the present time of writing is still continuing to do so) which is implausible given known forms of reading such as RSVP? A similar question also needs to be asked about Lovegrove. Though his work is not so flawed (though obviously flawed by its dependence upon Breitmeyer), he nonetheless advocates (and continues to do so along with Breitmeyer) a relationship between dyslexia and transient channel deficits while ignoring the consequences for his theory of the high percentage of normal readers with these deficits.

Second, the more general flaws in Breitmeyer and Lovegrove's approach need to be discussed. Are there aspects of how they theorised and investigated the relationship between vision and reading which made it likely their work would turn out flawed? I suggest they made three mistakes.

(1). They ignored the limited knowledge we have about the visual-cognitive processes used in reading which plausibly could be connected to the two visual channels. Instead of trying to link visual processes with known reading ones they focused upon low level perception. As I

note degradation of perception except in extremes has little effect upon reading.

(2). They ignored the small group of dyslexics with problems not accounted for by phonological impairment but who show visual ones. It is plausible that their problems might relate to compromises in one or other (or both) of the visual channels. Instead of this they focused upon the majority of dyslexics whose problems are well understood in terms of problems in phonological decoding. If they had known more about dyslexia they would have been aware that the reading problems of dyslexics do not occur so much with connected prose but single words (their theory predicts the opposite, see Hulme, 1988), and that commonly associated with dyslexia are non-IQ deficits (this would have warned them that many dyslexics could perform differently on tasks unrelated to reading without these being causally related to their reading problems).

(3). Their theory was based upon indirect and correlational evidence. It is striking that neither of the two theories of this approach was supported by any actual research on the role of these two channels in reading. Breitmeyer speculated eye movements cleared the sustained channels without carrying out (or citing the work of others who had) research upon eye movements or the role of eye movements and reading. Further, Lovegrove argued for a visual origin for dyslexia entirely upon indirect

correlational evidence. He has not carried out any research upon the functioning of the visual system during reading related tasks in dyslexics.

1.6. Lessons from Breitmeyer and Lovegrove

Learning from Breitmeyer and Lovegrove I suggest three pre-requisites for research which relates reading and dyslexia and the two visual channels. Such research must be based upon:

- known facts about reading,
- known facts about dyslexia,
- and must be based upon research using actual reading stimuli.

A program to do this will involve two steps. First, a stage to develop techniques to find the nature of the performance of normal readers upon stimuli that block the two channels. Second, following this, a stage of using this techniques upon dyslexics to see how their performance upon them differs from normal readers.

This thesis is an attempt to create an approach to link vision and reading which began the first step.

Postscript -- to Chapter 1.

After finishing this thesis a paper (Livingstone, Rosen, Drislane & Galaburda, 1991) appeared that might cast doubt upon this chapter's criticisms of the transient deficit theory of dyslexia. I briefly review this paper since it is likely to be widely cited as giving this theory strong empirical support -- something which does not necessary follow from it (and is not a conclusion of its authors). The paper in my view is important since, unlike previous work, it uses neurophysiological techniques (histological findings in control and dyslexic autopsy brains; and visual evoked potential studies) to link transient (which the authors call magnocellular) defects to dyslexia.

In essence the authors show (1) that of five dyslexic brains all showed histological abnormalities (disorganised cell layers and smaller cell bodies in the lateral geniculate nucleus) in the transient (magnocellular) but not the sustained (parvocellular) cell layers. None of their five matched control brains showed abnormalities in either channel. (2) Visual evoked potential responses to high and low frequency spatial and temporal frequency presented pattern reversed checker boards showed deficits in an early negative wave in five dyslexics but not in seven matched controls. The spatial and temporal frequencies at which this deficit occurred are associated with transient channel

processing. A further connection between this defect and this channel is that this defect occurs in the first negative wave in visual evoked potentials: they attribute this visual evoked potential component to visual processing in the primary visual cortex in a layer (4C) associated with the transient (magno) channel (for details of the association between the transient channel and the 4C layer of primary visual cortex see the next chapter).

However, the authors of this paper suggest that these deficits relate not primarily to a transient channel deficit but a general deficit within the general perceptual discrimination of rapid transitions in sensory input. They note that phoneme discrimination is dependent upon rapid auditory discriminations. They argue that the deficits they have found in the visual system might also be found in the auditory one. (Though they do not cite it, some work has shown that 40% of the input of the visual cortex is auditory see endnote 6 to the next chapter). In this case the phonological problems of dyslexics could originate in difficulties in processing the rapid auditory changes needed to discriminate phonemes. Thus their neurophysiological findings linking dyslexia with transient channel defects also support a possible neurological origin for the phonological difficulties found in dyslexics.

In this case, the theory I propose above linking dyslexia and phonology holds -- dyslexics are poor readers

because they cannot use phonology to aid the identification of written words using their oral knowledge of their pronunciation and so train their nonphonological reading networks. The work of Livingstone et al (1991) changes this account only by postulating an neurological origin for the phonological deficit. In this new account, the deficits found in the transient channel are neurological problems which associate with this neurological impairment -- they are not however responsible for it (a possibility I have suggested following Charles Hulme already in section 1.4.6).

Notes.

1. Human ganglion cells are segregated in the lateral geniculate nucleus but those of the cat are not. The two visual channels in humans have different colour properties while those in the cat do not. The cat's eye is not primate and hence lacks a developed fovea and capacity for seeing colour: it would be surprising if its visual system was like ours.

2. It has been suggested that the work of Campbell (and Wurtz, 1978) showed that visual blur during the eye saccade had this effect. What they showed was something slightly different: the non-perceivability of short intervals of blur and blank uniform fields (such as found during saccades). There is no reason to believe from their work that non-perceived blurs removed visual persistent images between eye saccades.

3. It cannot be that they were not interested in the possible support their theory might gain from patients with problems related to difficulties in visual processing: Lovegrove and colleagues readily cite as directly relevant two cases (Bodis-Wollner, 1972) where lesions produced reading problems and changes in spatial frequency sensitivity (their citation is slightly less than honest -- at a quick glance they seem to suggest that the patient had spatial frequencies losses for those low frequencies

associated with the transient channel thus confirming their theory [in fact the individuals had losses for high and medium spatial frequencies], rereading it I notice some careful phrasing 'altered sensitivity in only some spatial frequency channels').

4. Taking the lower percentage that 4% of readers are dyslexic (and 96% unimpaired), then 3% of readers are dyslexic and visually impaired (75% of 4% = 3%) and 7.7% of readers are not dyslexic and visually impaired (8% of 96% = 7.7%). By adding these two figures, 3% and 7.7 % we get the total percentage of all readers with visual impairment: 10.7%. The percentage of non-dyslexic readers in this is 100 X (7.7 divided by 10.7) ie 72%.

Taking the higher percentage that 15% of readers are dyslexic we find 11.25% of readers are dyslexic and visually impaired and 6.8% of readers are non-dyslexic and visually impaired. In total, 18.05% of readers are visually impaired thus of the total number of visually impaired readers 38% are not dyslexic ie 100 X (6.8% divided by 18.05%) = 38%.

5. Van Orden (1987) and colleagues (Van Orden, Pennington & Stone, 1990) and Perfetti and colleagues (Perfetti, Bell & Delaney, 1988) have suggested that phonological processes play an important role in word recognition. However there is a sharp distinction between my notion of phonology and theirs. By non-phonology I mean the identification of words

that does not access oral knowledge of their pronunciation through the use of spelling information. This is not Van Orden's understanding of phonology. In his interpretation of reading, a set of mapping has been set-up through experience between the orthographic subsymbolic letter string inputs and the phonological subsymbolic pronunciation outputs. These mappings extract covariances of a phonological kind between the subsymbolic units representing spelling and pronunciation. Thus when he refers to phonologically mediated recognition of words he is referring to covariances generated in a network which has the characteristic of making phonological mappings between input and outputs -- not recognition based upon the access to oral knowledge using its pronunciation. Indeed, he specifically excludes such processes which he recognises as depending upon phonological awareness and he acknowledges facilitates reading acquisition (Van Orden, Pennington & Stone, 1990, page 510, first paragraph). Thus his account of reading is compatible the model I propose for dyslexia.

6. Seidenberg and McClelland's paper describes not only the mimicking of adult performance (some characteristics of which have been questioned by Besner, Twiley, McCann & Seergobin, 1990, see also Seidenberg and McClelland's reply) but also developmental dyslexia. Two comments upon their theory would seem warranted.

First, their theory in no way answers the problem I raise concerning training.

Second, they create a dyslexic performance by lesioning some of its hidden units. They note that such a lesioned network like actual dyslexics shows a strong regularity effect with poor performance upon high frequency exception words. On a fully trained network high frequency exception words are processed equally as well as high frequency regular ones (see pp 547 - 8). However, hidden unit lesioning is not the only means to make a network perform like a dyslexic on this task. A partially trained network also shows a regularity effect. My theory suggests dyslexics have intact but incompletely trained networks thus Seidenberg and McClelland's work provides support, not refutation, for my suggestion. Though I cannot prove it, I suspect a major effect of their lesioning is to make the network harder to train and this is what has affected the performance of their lesioned network.

7. Not all networks have to be trained by error correction but they all require knowledge independent of them of their desired output. For instance, in Boltzmann training, an desired output is given to a network which then settles upon the best internal threshold values for producing it from the given input. The problem is that the system supervising this training has to know what the desired output should be for any given input.

CHAPTER 2: THE TWO VISUAL CHANNELS: THE NEUROANATOMICAL AND NEUROPHYSIOLOGICAL DIMENSION.

2.1. Introduction: the importance of the two channels' neuroanatomy and neurophysiology.

The central problem of this thesis was presented in the previous chapter: what is the relationship between vision and reading. That chapter introduced the idea of a division of vision into two channels (Breitmeyer, 1984, chapter 6; Cleland, Dubin, & Luvick, 1971; Enroth-Cugell & Robson, 1966; Kulikowski & Tolhurst, 1973; Legge, 1978; Lennie, 1980). Further, it introduced work and ideas which related this division to the process of reading and dyslexia (Breitmeyer, 1980; 1982; 1983; 1984; in press; Breitmeyer & Ganz, 1976; Lovegrove & Brown, 1978; Lovegrove, Slaghuis, Bowling, Nelson & Geeves, 1986; Martin & Lovegrove, 1987; Martin & Lovegrove, 1988; May, Lovegrove, Martin & Nelson, 1991; Slaghuis & Lovegrove, 1986a; 1986b; 1987). This division and its applications however was discussed purely in terms of the ideas and work of visual psychophysics.

Psychophysics however is not the only scientific investigation of vision: most of the work on visual perception occurs outside psychophysics in neurophysiology and neuroanatomy. Like psychophysicists, neuroanatomists and neurophysiologists have come to the conclusion that vision is made up of two channels: magno and parvo (alternatively,

referred to as M and P; Magnocellular and Parvocellular; phasic and tonic; or broadband and colour-opponent) (DeYoe & Van Essen, 1988; Livingstone, 1988; Livingstone & Hubel, 1987; 1988; Schiller & Logothetis, 1990; and Zeki & Shipp, 1988).

Psychophysicists (Badcock & Smith, 1989; Breitmeyer & Williams, 1990; Williams, Breitmeyer, Lovegrove & Gutierrez, 1991) have identified these channels neuroanatomically and neurophysiologically respectively, with, the transient and sustained channels of psychophysics. 'The magnocellular and parvocellular systems are closely analogous to the previously proposed transient and sustained systems.' (Williams, Breitmeyer, Lovegrove & Gutierrez, 1991, page 2017).

(Interestingly none of the above neuroanatomical and neurophysiological reviews concern themselves with the parallel identification between magno and parvo and transient and sustained channels [they do not even cite any of the work done by psychophysicists upon them]).

I proposed at the end of the last chapter that psychophysical methods of investigating the possible linkage between reading and the visual channels had failed because they were indirect. In consequence, I argued that there was a need for direct techniques to investigate their role in the reading process. Neurophysiology has produced techniques

for the direct blocking and isolation of the two visual channels (Livingstone & Hubel, 1987; Ramachandran & Ramachandran, 1991a; 1991b). These techniques are the outcome of the discovery of visual channel characteristics that enable researchers to selectively block the perception of stimuli by one or other of the visual channels. Using these techniques, neurophysiologists particularly, but not only, Margaret Livingstone and David Hubel (1987; 1988) have investigated the role of the visual channels in various perception functions.

This thesis seeks to extend the use of these techniques to the processing of written materials. In this chapter, I first discuss the channel characteristics which enable them to be blocked and then proceed to discuss the techniques themselves. The first task takes the form of a review of neurophysiological and neuroanatomical research upon the two visual channels. This review summarises the main reviews in the literature DeYoe and Van Essen (1988); Livingstone (1988); Livingstone and Hubel (1987; 1988); Schiller and Logothetis (1990) and Zeki and Shipp (1988). I have however added where appropriate details from the primary literature. In this review consideration is given not only to the evidence supporting the separation of the two visual channels but also to evidence which suggests the existence of connections and interactions between them and thus the possible presence of difficulties for attempting to

selectively block the two channels. The review starts with an overview before proceeding to a more detailed discussion.

2.2. Overview: division in the visual system

In looking at these words our vision senses them as a visual unity. But vision is divided: at a physical level, we have two eyes; and each eye's retina has two kinds of receptor: rods and cones. Psychologists have suggested deeper divisions at the processing level: for instance, between figure and ground and the perception of what (object recognition and identification) and the perception of where (position, depth and motion) (Mishkin, Ungerleider, Macko, 1983). In the eighties, neuroanatomists and neurophysiologists proposed another division: that the visual system is divided anatomically, neurophysiologically, functionally and evolutionary, into two different visual channels, magno and parvo (Livingstone, 1988; Livingstone and Hubel, 1987; 1988; and Schiller and Logothetis, 1990; Zeki & Shipp, 1988).

- Anatomically, the magno and parvo channels, segregate visual information processing from the retina to lateral geniculate nucleus and visual cortex to the higher association areas of the cerebral cortex (Livingstone, 1988; Livingstone and Hubel, 1987, 1988; and Schiller and Logothetis, 1990).

- Functionally, the two channels have different roles (DeYoe & Van Essen, 1988). In simplified terms, the magno channel appears to enable us to see motion and depth while the parvo channel enables us to see detail.

- Evolutionarily, the magno channel seems to have evolved first and has been suggested (Livingstone & Hubel, 1988) to be homologous to the non-primate visual system.

These are preliminary generalisations; like all generalisations they need qualification. The term channel implies that the two channels are separate, however most reviewers of the literature acknowledge that some interaction occurs between them particularly after the lateral geniculate nucleus; further the magno and parvo channels in some circumstances can carry out the tasks attributed to the other (see note 7, for an example). Moreover, though the word channel could be understood to imply that information flows up from the retina → lateral geniculate → visual cortex → higher association cortex, latter stages are acknowledged to have considerable affects upon early processing stages -- there is information flowing in both directions (Murphy & Sillito, 1987; Zeki & Shipp, 1988).

2.3. The two visual channels

2.3.1. Retinal P α and P β ganglions.

The retina has three layers (Dowling & Bubin, 1986):

- (i) rods and cones,
- (ii) the horizontal and bipolar cells and
- (iii) the retinal ganglion cells.

The magno and parvo channels originate in the third layer of ganglion cells. The majority of these cells divide into two types: P α and P β (known also as A and B ganglion cells) (Leventhal, Rodieck & Dreher, 1981; Perry, Oehler & Cowey, 1984). The P α ganglion cells give rise to the magno channel while the P β ones give rise to the parvo channel. The inputs to the receptive fields (the area in which visual stimuli effect their responses) of both ganglion types come from the same rods and cones so the division between magno and parvo channel goes no higher than the two ganglion cell types (Leventhal, Rodieck & Dreher, 1981).

The two ganglion cell types differ in colour sensitivity with the centre and the surrounding area of the magno ganglion cells being colour insensitive while the majority, 90%, of parvo ones are colour opponent (Schiller & Logothetis, 1990). In contrast, magno cells are sensitive to

particularly low luminosity contrast which the parvo cells are not.

The ganglion cell types vary in their response characteristics to static visual stimuli: those of the magno ganglion cells are transient -- a quick initial response which quickly dies out, while the parvo cells have sustained responses with a slower initial response which maintains itself until the cessation of the stimuli (Schiller & Logothetis, 1990). These findings were the basis (as reported in other papers) for labelling the two visual channels transient and sustained (Breitmeyer, 1984; Cleland, Dubin & Luvick, 1971). Fitting in with these response characteristics, the diameters of magno ganglion cells (Perry, Oehler & Cowey, 1984) and their optic tract axons (Leventhal, Rodieck & Dreher, 1981) are larger and faster conducting than those of the parvo channel (Schiller & Malpeli, 1981).

These response characteristics produce different temporal, and spatial sensitivities. Temporally, magno ganglions have fast responses compared to the parvo ganglions (this applies not only to fibres connecting ganglion and lateral geniculate nucleus but also the lateral geniculate nucleus and the cortex, [Schiller & Malpeli, 1978]). Spatially, it has been claimed (Schiller & Malpeli, 1987; Schiller & Logothetis, 1990) (though note comments below) that the magno cells have wide receptive fields (and

so can detect only low spatial frequencies) and the parvo cells narrower ones (and so can detect higher spatial frequencies).

2.3.2. Lateral geniculate nucleus.

By far the majority of the ganglion's visual input goes to the (dorsal) lateral geniculate nuclei (over a million fibres per eye) (Perry, Oehler & Cowey, 1984). However, other ganglia exist supplying information to other brain areas in particular the superior colliculi (approximately 100,000 - 150,000 fibres). These nongeniculate fibres though of limited importance in normal vision might be responsible for the limited visual abilities shown by those with blind sight (Cowey & Stoerig, 1991).

The majority of the optic nerve fibres go to the lateral geniculate body. This is a layered structure with different layers for magno and parvo inputs (Leventhal, Rodieck, & Dreher, 1981; Schiller & Malpeli, 1978). Its neurons in a ratio of 10 to 1 are parvocellular (Perry, Oehler & Cowey, 1984). The characteristics of the lateral geniculate cells are similar to the retinal ganglion cells from which they derive their input (Schiller & Malpeli, 1978; Zeki & Shipp, 1988). Magnocellular cells like retinal ganglion P α from which they receive their input are contrast sensitive but colour insensitive¹, have transient responses² and are sensitive to low contrast and low

spatial frequencies while the parvocellular cells like the retinal ganglion P β cells from which they receive their input are colour opponent, have sustained responses³ and are sensitive to high contrast and high spatial frequencies (Hubel & Livingstone, 1990; Schiller, Logothetis & Charles, 1990; Schiller & Malpeli, 1978; Merigen, Katz & Maunsell, 1991; Merigen & Maunsell, 1990).

2.3.3. Primary and secondary visual cortex

The segregation of the two pathways continues into the primary (alternatively known as the striatal, or V1) visual cortex. However, this segregation becomes more complex since the parvo channel divides.

As a general pattern, the magno and parvo cells project to different layers (ie vertical segregation) in the primary cortex. The magno channel projects to layer 4C α (which further projects to layer 4B) of the primary visual cortex and then to thick strips in the secondary (or alternatively, pre-striatal or V2) visual cortex. The parvo channel projects into layer 4C β (which in turn projects to layers 2 and 3) in the primary visual cortex. This parvo channel projection splits in layers 2 and 3 into two. There are some areas darkened by the stain cytochrome oxide known as blobs and unstained areas in between these blobs known as interblobs. The parvo blobs and parvo interblobs project to different areas of the secondary visual cortex: the parvo

blobs project to thin strips in the secondary visual cortex while the parvo interblobs project to the interstrips (DeYoe & Van Essen, 1988, Zeki & Shipp, 1987). Figure 2.1. outlines these together with the post visual cortex projections of the magno and parvo (blob and interblob) channels.

2.3.4. Beyond the primary and secondary visual cortex.

Livingstone and Hubel (1988) note that 'The response properties of cells at levels beyond visual area 2 [prestriatal or V2] suggest that the segregation of functions begun at the earliest levels is perpetuated at the highest levels so far studied. Indeed, the segregation seem to become more and more pronounced at each successive level'. The magno channel continues by projecting to the secondary visual cortex projects to an area called MT which further projects to the parietal cortex (projections to the MT also derive from the magno projection to the primary cortex). The parvo channel (both blob and interblob) project to the extrastriatal visual cortex V4 which projects to the inferotemporal cortex (DeYoe & Van Essen, 1988). Mishkin, Ungerleider and Macko (1983) identify on the basis of lesion work upon monkeys the temporal-occipital and the parieto-occipital regions as having different visual functions with the former recognising objects by their appearance and the latter recognising their position - what versus where. Livingstone and Hubel (1988) suggest the magno/ parvo division continues into Miskin's parietal/ temporal one.

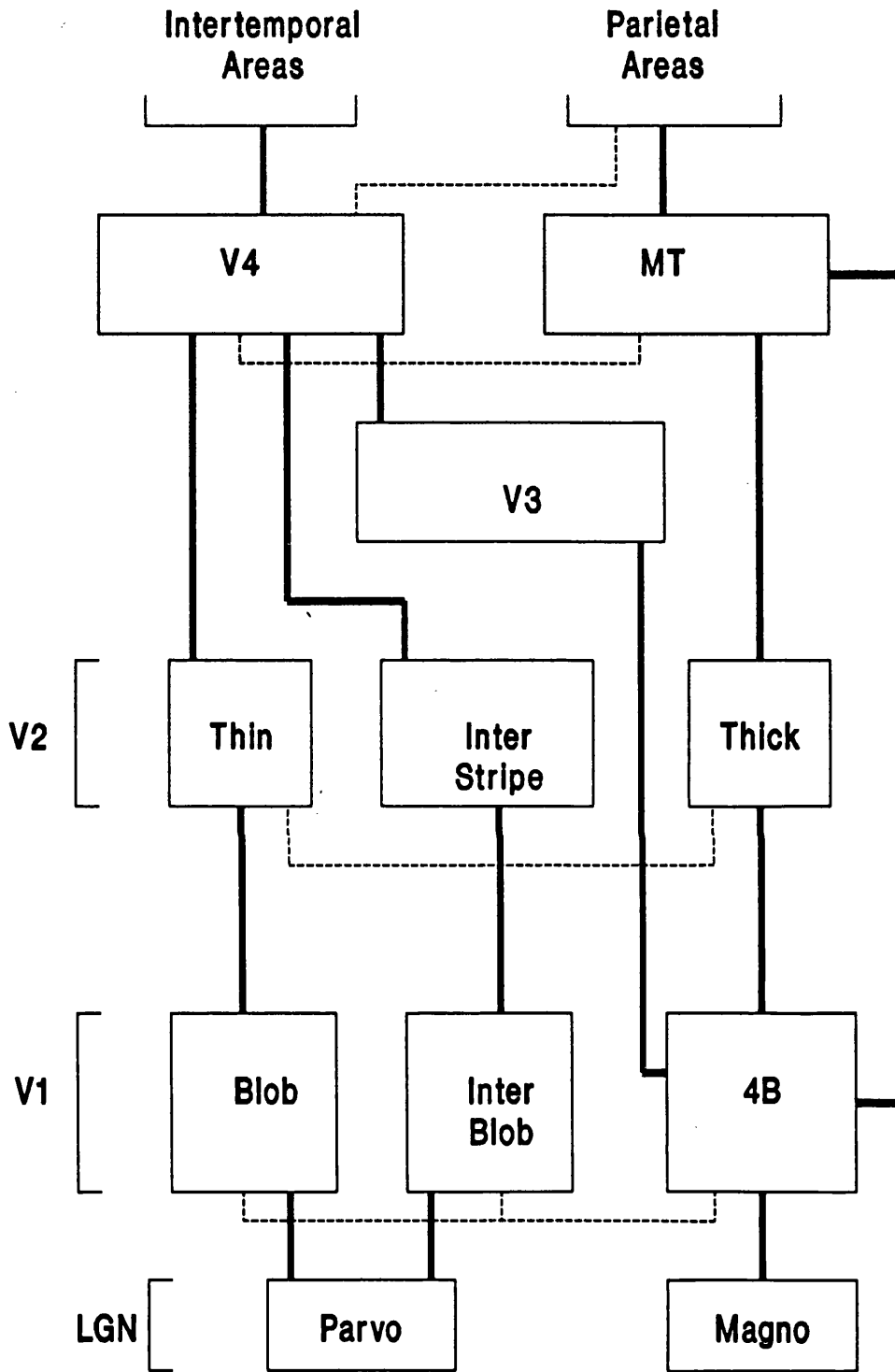


Figure 2.1. Magno and parvo channels' cortical connections and interactions. Copied from DeYoe & Van Essen (1988). Some connections mentioned in text not included. Pathway lines: thick = strong; dashed = weak or unverified.

There is support for the continued separation of the two visual channels: injections of different coloured retrograde tracers in inferior parietal and inferior temporal cortex show their visual input comes from segregated magno and parvo paths (though see comments below) (Morel & Bullier, 1990) and conversely blocking the magno cells in the lateral geniculate nucleus disrupts the responses of cortical cells in the middle temporal visual area (MT) but blocking parvo cells does not affect this areas cortical responses (Maunsell, Nealey & DePriest, 1990).

However, it is important to emphasise that channel mixing and interaction occur after the lateral geniculus nucleus. Vision acts as a whole and this is partially because the two channels are interconnected⁴ and interact upon each other⁵ in complex and only partially understood ways (DeYoe & Van Essen, 1988). Further, connections between cortical areas are more complex in that connections can be two directional. It has been suggested that cortical areas can fine tune the input they receive from earlier ones (Murphy & Sillito, 1987).

For example, a massive projection exists not only from the lateral geniculate nucleus to the primary visual cortex but also from the primary visual cortex to the lateral geniculate nucleus. Indeed, the number of axons in the

projection from the cortex to the thalamus (at least in the cat -- comparable figures are not available for primates) has been claimed to be an order of magnitude larger than those projecting from the thalamus to the cortex with more axons existing in the projection to the lateral geniculus nuclei from the cortex than in the optic nerve (Wilson, Friedlander & Sherman, 1984; see also the discussion of the thalamocortical loop, Llinás & Paré, 1991 page 525). This cortical feedback loop has been shown to fine tune the spatial characteristics of its cells (Murphy & Sillito, 1987). As the authors of this paper comment 'the response property [of output from the lateral geniculate nucleus] emerges from the operation of a neural circuit, not from a hierarchical sequence'.

The evidence that the two channels interact after the lateral geniculate nucleus casts some doubts upon their segregability. Further, the back projection of the visual cortex upon the lateral geniculate nucleus has never been taken account of in any present models of the functioning of the visual system and the two visual channels. It is likely to be important though in ways which are not known. The eventual account of visual processing and the two visual channels is likely to be more complex than the account given here based upon present knowledge.

2.3.5. Conclusion.

The term channel is misleading if read solely to imply a complete segregation of visual processing between the two visual channels. The two visual channels are not two parallel and separate vision systems⁶. However, to a strong degree they are separate: whether this separation is sufficient for a significant part of the visual system to be blocked is an interesting possibility requiring experimental investigation. The experimentation using channel blocking (Livingstone & Hubel, 1987) suggests that sufficient segregation exists between the two visual channels for the blocking of tasks known to be isolated to a channel to be affected by it. However, research in this area is still preliminary and as noted the interaction between the two channels is complex and not understood so this view might change and the effects of such manipulation may be seen to be more complex.

This thesis takes the view that though there might be some doubts about the use of perceptual blocking of the visual channels, sufficient evidence exists to justify, at least at an explorative stage, experimentation using this technique.

2.4. Experimental blocking of the two channels

In the experimental chapters of this thesis I describe work which exploits the different characteristics of the two visual channels to putatively block their involvement in reading related tasks. The characteristics used have been already discussed: the magno channel processes low spatial frequencies and high temporal ones and is colour blind. The parvo channel in contrast processes high spatial frequencies, low temporal ones and is colour sensitive. Within the framework of these characteristics, several techniques avail themselves. Two were used in this thesis.

2.4.1. The heterochromatic and monochromatic approach to blocking.

Livingstone and Hubel (1987) attempted to block the participation of the magno channel in various perception and cognitive tasks. Their work was the starting point for the work reported in this thesis. They used several techniques⁷: I shall focus on the monochromatic /heterochromatic flicker technique⁸. To understand the use of this technique a few brief comments are needed concerning the heterochromatic determination of isoluminosity.

2.4.1.1 Heterochromatic photometry.

If two different coloured patches are alternated then two flickers exist: one due to their different luminosities and a second one due to their different colours. This flicker ceases if the rate of alternation increases, the point at which this happens is known as the critical flicker fusion frequency. The critical flicker fusion frequency for luminosity flicker is higher than that for colour. Luminosity flicker can be removed if the two colours' shades are adjusted so that they are of equal luminosity. Since the flicker of colour alternation is less visibly 'harsh' than luminosity flicker, the removal of luminosity difference between two colour patches is readily noticeable (Boynton & Wagner, 1968; Heath, 1958; Kelly & van Norren, 1977; Wagner & Boynton, 1972). This technique, however, can be made simpler: the rate for critical flicker fusion of colour alternation is below that for luminosity (Kelly & van Norren, 1977) therefore colour flicker can be removed entirely by flicking two colour patches above the frequency needed for colour flicker fusion but below that for luminosity. Therefore by using an alternating rate above the rate for colour flicker fusion isoluminosity can to be found between any two colours without the problem of colour flicker by adjusting the luminosity of one them until luminosity flicker ceases.

Why is the rate of critical fusion of luminosity higher than that for colour? Livingstone and Hubel (1987) have explained this in terms of the different processing of the magno and parvo channels. 'The fact that colour-contrast flicker fusion occurs at much lower frequencies than luminance-contrast flicker fusion suggests that the colour system is slower than the luminance system, and could reflect the higher temporal resolution of the magnocellular system [magno channel], compared with the parvocellular system [parvo channel]'. (1987, page 3422).

This idea is supported by neurophysiological work upon retinal ganglion and geniculate cells (Lee, Martin & Valberg, 1988; 1989a; 1989b; Lee, Pokorny, Smith, Martin & Valberg, 1990). Further, detailed work upon heterochromatic flicker supports the existence of two processes (Kelly & van Norren, 1977) underlying flicker perception which could be identified with the two visual channels.

Heterochromatic flicker applied to images offers a means to selectively block the magno and parvo channels for the perception of letters. The two kinds of flicker (counterphase) are generated not out of coloured patches but monochromatic and heterochromatic pairs of letter images identical with each other except for having the reversed polarity of the other. The heterochromatic pair being made up of isoluminous green and red letter images and backgrounds, one of the images being red upon a green

background, the other, its reverse (or alternative colour polarity) a green image upon a red background⁹. The monochromatic pair needs to consist of two luminosity contrastive letter images, one a dark image upon a light background, the other a light image upon a dark background (its alternative luminosity polarity).

If the first set is alternated then their flicker percept should be confined to the parvo channel due to the magno channel's insensitivity to the colour borders used to define the letters. If the second set is alternated faster than the fusion rate for colour-contrasted images but below that for luminosity contrasted ones then the perception of images should be confined to the magno channel since only this channel should be able to detect its alternating borders. However, as chapter 4 will show the situation is more complex: processes exist which enable alternating images to be seen by processes other than those involving their temporal resolution.

A further manipulation could enhance the blocking effects of these stimuli. Since the magno and parvo channels differ in their processing of spatial frequencies (Kulikowski & Tolhurst, 1973; for review see Breitmeyer, 1984, pp 191 - 199; Livingstone & Hubel, 1987, pp 3436 - 3437) the processing of letter stimuli in one or other channels should be manipulable by varying the spatial frequencies used to construct the alternating images. The

creation of letters with low spatial frequencies components requires in effect making them large with diffuse boundaries (sharp boundaries contain high spatial frequency components) and conversely making letters with high spatial frequency components making them small with sharply defined ones.

An important factor for using heterochromatic and monochromatic stimuli in the above way is the right level of mean luminosity for the stimuli. Flicker perception varies with luminosity -- the brighter the stimuli the higher the rate of flicker which can be seen. The rate of critical flicker perception (the rate above which flicker cannot be seen) is directly proportional to the logarithm of stimulus luminosity -- a finding known as the Ferry-Porter law (Renien, Franssila & Rovanamo, 1991)¹⁰. Since the frequency steps with which stimuli can be presented are fixed while the level of luminosity can be readily changed - luminosity levels are selected in regard to available flicker rates.

In principle, heterochromatic based blocking should enable the involvement of the two visual channels to be investigated by using letters as the counterphase images in reading related tasks. However some cautions are needed.

First, there is no reason why one channel may not communicate what it sees to the other blocked channel. Thus the perception of letters and words presented in these two ways does not guarantee that they have been seen through one

or other of the visual channels. They may enable the blocking of a visual channel but confirming evidence is needed that this has happened before strong conclusions about channel participation can be made.

Second, research (Schiller, Logothetis & Charles, 1991; Shapley, 1990) questions whether activity in the magno channel is blocked and activity in the parvo channel unaffected during isoluminance. Research upon the lateral geniculate nucleus has found (Schiller, Logothetis & Charles, 1991) that the activity of the magno cells are reduced but not eliminated during isoluminance while the activity of the parvo cells becomes similarly less responsive.

Third, there is always the possibility that extraneous visual clues may persist which might enable a blocked channel to detect letters. As I shall narrate in the next chapter on the technical details of this thesis' research, it is difficult to produce completely clean colour boundaries uncontaminated by luminosity artifacts.

Fourth, some research has questioned the division between monochromatic and heterochromatic flicker and the two visual channels. Gouras and Zrenner (1979) suggest that at high flicker rates parvo retinal ganglion cells lose their colour opponency and respond like magno ones to luminosity contrasts. Further, the evidence from lesion work

upon monkeys suggests that the parvo channel cannot process flicker rates much higher than 6 Hz (Schiller, Logothetis & Charles, 1990) which questions its role in processing heterochromatic flicker (this point is developed below when I discuss the second blocking technique).

Fifth, there are some questions (Gouras and Zrenner, 1979; Merigen & Maunsell, 1990) whether the parvo channel might not be able to process high luminosity contrast flicker. It is known that the magno channel has an advantage over the parvo processing low luminosity contrast static stimuli (Livingstone & Hubel, 1987; Schiller, Logothetis & Charles, 1990; Merigen, Katz & Maunsell, 1990). It has been recently claimed that the flicker advantage of this channel over the parvo one is restricted only to the low contrast stimuli and not to high contrast ones (Merigen & Maunsell, 1990). This goes against the claims of Livingstone and Hubel (1987, 1988) and Ramachrandran and Ramachrandran (1991a, 1991b) who have used high contrastive flicker stimuli. The work which follows used high luminosity contrast flicker in imitation of Livingstone and Hubel's earlier work. Future work in view of Merigen and Maunsell's work should however use low contrast stimuli -- they are not much more difficult to create nor necessarily more difficult to see.

The technique reported by Livingstone and Hubel (1987) was used in the experiments reported in chapters 4 and 5. However, (as detailed in the discussion of chapter 5), there

are doubts as to its effectiveness. Consequently, a different technique (though related to the one described above) was used for the last experiment reported in this thesis (chapter 6).

2.4.2. Counterphase blocking

One objection against Livingstone and Hubel's approach is that the parvo channel has been found to find the processing of fast counterphase stimuli difficult (Schiller, Logothetis & Charles, 1990). While this casts doubt upon heterochromatic/monochromatic attempts to isolate the two channels, it also suggests an alternative means of blocking the visual channels. This idea has been taken up by Ramachandran and Ramachandran (1991a, 1991b) who have used it to further evolve Livingstone and Hubel's (1987) ideas.

Ramachandran and Ramachandran's approach involves creating counterphase images using patterns defined by white and black dots upon a grey background. They alternated the polarity of the dots. At high alternation rates -- 20 Hz, the patterns defined by the dots define are observable but not the colours -- black or white of the dots themselves. They refer to these patterns as phantom contours. The dot colours however can become perceptible if the frequency of alternation is reduced to below 8 Hz. If the dots were isoluminous red and green rather than black and white no phantom contours could be seen -- the colour of the dots and

the borders they define both became visible below 8 Hz. Their explanation is that only at the high frequencies can the magno channel detect the dots. They suggest that since the magno channel is insensitive to the sign of the dots, the magno channel should be able to perceive them but not perceive their colour. This perception can only happen at the much lower frequencies where the parvo channel can see the dots and so enable the visual system to register their colour.

The notion that alternations faster than 8 Hz cannot be detected by the parvo channel is supported by lesion work done upon monkeys which suggests the parvo channel cannot process alternations much faster than 6 Hz (Schiller, Logothetis & Charles, 1990). They described their technique as offering 'a psychophysical scalpel for temporary lesioning [blocking] the parvocellular pathway of intact human subjects' (Ramachandran & Ramachandran, 1991, page 1034).

Unfortunately, their use of dots was not a possible option using the available equipment so a slightly different technique not using them was used. Instead of dots, blurred boundaries were used. The Ramachandrans used dots since sharp luminosity boundaries produce perception artifacts known as Mach Bands or rings (colours near a sharp boundary appear more contrasted -- darker or lighter than they are). Blurred boundaries are an alternative means to avoid this

problem. Further, due to luminosity artifacts originating in the monitor sharp boundaries are difficult to create (a problem discussed in the next chapter). These artifacts are minimal or masked by blurred boundaries.

Notes

1. However, the magno channel is not entirely colour blind since about half the magno cells (type IV) in the lateral geniculate nucleus have inhibitory surrounds sensitive to long wave red light (Wiesel & Hubel, 1966; Breitmeyer & Williams, 1990).

2. Further, some cells in the magnocellular layers of the lateral geniculate nucleus (magno channel) show sustained responses: 'we have seen many examples of histologically verified magnocellular cells whose responses show a strong component that is highly sustained' (Hubel & Livingstone, 1991, page 1655).

3. The temporal response characteristics of the parvo cells however are more complex. The stimulus discussed above concern the channel reaction to slow stimuli presentation: Schiller and Malpeli (1978) used three second off-on cycles. At much higher rates there is a different performance. Parvo cells in the ganglion (Lee, Martin & Valberg, 1988) and lateral geniculate cells (Lee, Martin & Valberg, 1989) (Macaque monkey) respond to 40 Hz flicker. These cells show high sensitivity to heterochromatic flicker between 1 and 20 Hz (at higher rates their sensitivity drops off slightly). In contrast Lee et al using the same flicker stimuli found that the subjective perception of human subjects drops off

with increasing flicker rate. This is unlikely to be due to a difference between the visual systems of the Macaque Monkey and the human species as Lee et al cite behavioural tests which suggest similar visual performance in other areas between the Macaque monkey and our species. As Lee and colleagues (1989) note, it is remarkable that the parvo cell 'sensitivity increases slightly up to 10 or 20 Hz, whereas human sensitivity decreases dramatically'. Lee, Pokorny, Smith, Martin and Valberg (1980) found a similar paradoxical response sensitivity for magno cells for flicker which was higher (80 Hz) than experienced by human observers. This suggests that the differences between the temporal sensitivity of the two visual channels may be due not only to the intrinsic neurophysiological and neuroanatomical characteristics of the visual channels but partially determined top-down from the cerebral cortex. One question raised in the text was the function of the back projections from the visual cortex to the lateral geniculate nucleus -- this top-down filtering of flicker could be a possible function.

4. There is some evidence that the magno channel projects in addition to layer 4B of the primary visual cortex also to the parvo blobs (Edwards & Kaplan, 1991) and the parvo interblobs (Nealey & Maunsell, 1991). In the primary visual cortex there are connections between the layer, 4B, to which the magno channel projects and the layers 2 and 3 to which the parvo channel projects (Hubel & Livingstone, 1990). (It

should be noted that there have been no reports for parvo channels inputs projecting in the primary visual cortex into the magno channel -- indeed Hubel and Livingstone [1990] provide evidence against this). In the secondary visual cortex there are interconnections between the thin strips (to which the parvo blobs projects) and the thick ones (to which the magno projects). Further, the areas to which the magno and parvo project from the primary and secondary visual cortex receive inputs from the other channels. Moreover, work has shown areas such as the middle temporal visual area MT (Krubitzer & Kaas, 1990) and various areas in the anterior STS (Ipa, Pga and FST) (Morel & Bullier, 1990) exist which bring visual inputs together.

5. The nature of this interaction must be controversial. However, Shapley (1990) has argued that the magno channel can inhibit and facilitate the sustained one. He intriguingly suggests 'one of the functions of the magnocellular pathway might be to gate parvocellular signals into the cortex'. This indeed is also the suggestion of Breitmeyer reviewed in chapter 1 (but in the context of the transient (magno) channel inhibiting the sustained (parvo) one). In other work, Breitmeyer has claimed to show that the sustained (parvo) channel can inhibit the transient (magno) one (Breitmeyer, Rudd & Dunn, 1981).

6. However it should be noted that no system in the brain is segregated from any other and it may be that the

connections and interactions between the two visual channels are no greater than that between any two other systems in the brain. Consider, the interactions of the visual cortex with inputs from other modalities -- I have noted that the magno channel provides inputs into the parvo channel layers in the primary visual cortex. But so do several other sensory systems: 40% of neurons in the visual cortex of cats have been shown to respond to sound (Murata, Cramer & Bach-Y-Rita, 1965). While no comparable studies have been made of humans it is interesting to note that the visual cortex (striate and extra-striate) of people blind from birth has found to be metabolically active (at much higher levels than blindfolded sighted people) (Wanet-Defalque, Veraart, De Volder, Metz, Michel, Doods & Goffinet, 1988). This suggests that not only in the cat are other modalities projecting to the visual cortex separate from those providing by the visual system. If the visual channels are not separate it could be simply because no system is entirely separate in the brain from any other one.

7. Another technique not discussed here is the use of isoluminosity without flickering the stimuli. This has been used previously by Cavanagh, Tyler and Favreau (1984) who found isoluminosity slowed the perceived motion of coloured gratings. They note that, 'The gratings often appear to stop even though their bars are clearly resolved. In these instances, the motion is appreciated only because it is occasionally noticed that the bars are at some new

position'. Livingstone and Hubel (1987) tested a range of tasks thought to be mediated by the magno channel. If they were performance on them, they should be impaired by isoluminous stimuli. There was a wide variety of tasks among them, motion perception, stereopsis with random-dot stereograms, various classical illusion such as Müller-lyer, Herring, and Zöllner illusions, depth perception from dot shading, parallax, and illusory borders. They found these were either minimised or their effects ceased at a certain red/ green luminosity ratio. Some of this work has been not been replicated (for a review see Davidoff, 1991, pp 41-50; Schiller & Logothetis, 1990). One possible explanation for the conflicting findings might be the failure to control for luminosity artifacts which are discussed in the next chapter. Another is that the poor resolution for colour boundaries affects their perception (Troscianko & Harris, 1988).

Though isoluminance possibly affects motion perception it does not affect all kinds of motion perception (Cavanagh, 1991). Cavanagh provides the interesting suggestion that motion perception that is blocked by isoluminosity is non-attentive while that which is not requires active attention (Cavanagh, 1991). Given that the isoluminous blocking of the magno channel may be responsible for this impaired motion perception, this suggest the complexity with which cognitive tasks are allocated between the two visual channels. In this case motion perception is confined to the magno channel

except where it involves active attention in which circumstance it appears the parvo channel becomes involved. Further, Cavanagh and Anstis (1991) have reported work upon the 'equivalent luminance contrast' between moving luminosity and colour contrasted drifting gratings. These have enabled them to calculate the comparative contribution of luminosity and colour processes to motion perception -- the maximum contribution of colour to luminance contrast for the perception of drifting gratings is about 10% (Cavanagh and Anstis, 1991).

8. Monochromatic stimuli are those with boundaries defined by luminosity not colour. Heterochromatic stimuli are those defined by colour (wave length) and not luminosity. Two colours of the same luminosity are referred to as isoluminant.

Monochromatic stimuli may be any colour providing boundaries are defined by luminosity differences -- by shades of the colour. They need not be shades of white, grey or black. The monochromatic stimuli (for reasons related for controlling for the effects of the colours used in the heterochromatic stimuli) of this thesis were yellow and black. These reasons are discussed in the next, technical chapter.

9. Most work upon flicker photometry uses green and red. Blue cones do not appear to contribute to the perception of

luminosity as defined by flicker photometry (Eisener & MacLeod, 1980).

10. This has been challenged: Rennien, Franssila and Rovamo (1991) found the relationship between critical flicker frequency and luminosity to be best described by an exponential function between 0 and 0.3.

3.1. Experimental set-up.

This thesis describes research using an experimental set-up built around a Dell system 200 IBM PC compatible. The equipment consisted of several components each with different functions. A Dell computer executed the experimental programmes. A NEC Multisync 3D monitor presented the visual stimuli used in the experiments: the monitor was controlled by a Video 7 super VGA card installed in the PC. The experimental programmes were programmed by the author in Turbo Pascal version 5.

Several dependent and independent variables were created and measured. The main dependent variables were reaction time and point of isoluminance (isoluminance varies between subjects). The main independent variables were the stimuli. This chapter describes the various problems involved in the measurement and creation of these variables using the above described equipment.

3.2. Reaction time measurement

3.2.1. Accuracy.

Ideally, response reaction times should be measured as accurately as possible. In the psychological reaction time

literature, time is normally measured to the nearest millisecond. To achieve this accuracy on the PC requires recognising and overcoming several problems. These problems originate in the operating system clock; the synchronisation of the screen and the timer, and the registering of responses.

3.3.2. Timers.

The PC's operating system, DOS (digital operating system), contains a clock function which can potentially be used to time responses. It would be tempting to use this to time responses since it apparently provides timings accurate to within a ten millisecond precision (an acceptable level of accuracy for many purposes). Unfortunately, the clock's actual time resolution is much less than this -- about 55 milliseconds (Dlhopolsky, 1988; Graves & Bradley, 1991). While concern for millisecond timing accuracy in reaction time experiments is often statistically unjustified -- Ulrich and Giray (1989) argue that clocks with resolutions as low as 30 milliseconds have almost no effect on the ANOVA detection of mean reaction time differences -- greater accuracy is desirable (there is no reason to assume more complex ANOVA interactions will be so insensitive to time inaccuracies).

Several programmes are available which use machine code routines to provide for PCs and PC compatibles millisecond

timers (Bovens, & Brysbaert, 1988; Brysbaert, Bovens, d'Ydewalle & Calster, 1989; Buhrer, Sparrer & Weitkunat, 1987; Crosbie, 1989; Dlhopsky, 1988, 1989; Graves & Bradley, 1987; 1991). Brysbaert's was chosen because it was written in Turbo Pascal, the language used to write the experimental programmes. This enabled it to be incorporated easily into the experimental programmes. Brysbaert generously supplied a copy of it.

3.2.3. Synchronisation.

Response times require the synchronisation between the presentation onset of an image on the monitor and the timer's start. In a computer program this is easily arranged: two instructions are given, one to start the timer and the other to present the image on the monitor. These instructions effectively, (that is within microseconds of each other), can be sent at the same time. There is no problem with the timer which effectively starts immediately following instruction. But this is not the case with the monitor which creates the image where there may be a delay of uncertain duration between its instruction to present an image and the images actual presentation. The problem originates in the process by which images are created on a monitor.

Images on a video display monitor are created by a raster beam (electrons) which scans left to right in rows

down the screen writing the image on the screen's phosphors. This writing takes time: depending upon mode (the VGA graphics card supplies three) the image writing can vary between 14.3 and 16.7 milliseconds, (Video Seven V-Ram VGA hardware manual, Anonymous, 1989). This creates a problem for timing stimulus presentation since the instruction to create an image may arrive at the monitor when the raster is at an inappropriate place to write it. In consequence the instruction to present an image will have to wait for its realisation until the raster has progressed its scanning until in the correct position. This wait can produce an uncertainty of up to 14.3 milliseconds as to when the image was actually presented (Brybaert et al, 1989).

Fortunately, other instructions can be used to synchronise the presentation of an image with the timer. These instructions work by delaying the onset of the timer and the instructions to write the image until the raster is in a fixed place on the screen. This synchronisation involves instructions in the program reading the position of the raster beam from a register in the graphics card and waiting until the raster beam is in a particular place -- the most convenient one is the upper-left hand corner of the screen, where it initiates its writing and rewriting of the screen¹.

3.2.4. Registering responses.

Several means exist for registering responses on the PC. Two were available on the Dell system 200: buttons connected to the joystick-port and the keyboard. The keyboard would have been the most convenient. However, keyboards are not designed as input devices -- which makes them unsuitable for timing responses. The keyboards of PCs use complex scanning and buffering techniques to read key presses (Graves and Bradley, 1987). The consequence of this is that their key response reading suffers variable delays: two PC keyboards measured by Graves and Bradley (1987) had delays of 18 and 37 milliseconds and SDs of 4.3 and 2.9 milliseconds. These problems however do not apply to buttons connected to the joystick-port: Graves and Bradley (1987) report response delays using buttons of .55 millisecond (SD = .51 millisecond). Given that the response characteristics of the Dell keyboard were unknown and would be difficult to discover combined with the ready availability of buttons as an accurate alternative, keyboard responses were not used for timing.

The button/ joystick-port set up consisted of two buttons provided by the department (of unknown origin but would appear standard for use in psychological experiments), and a Konix twin port interface card standard. Depending which button (or both) was pressed a different number was

internally registered within a memory store which was read by a line in the program².

3.3. Screen and luminosity control

The VGA card was designed for CAD (Computer Aided Design) and other commercial applications -- not research. In consequence, the VGA card has limited control over luminosity (though it is far greater than provided by any other available PC graphics card). This control over the three primary phosphor is limited to 64 luminosity steps or shades (control units).

3.3.1. Monitor Calibration

The luminosity of the various shade steps was measured with a United Detector Technology, Optometer Model 248 (UDT Instruments, 1988). The luminosity was measured in the central area where the stimuli were presented: this is important since luminosity varies with screen position (Livingstone and Hubel, 1987). To create the desired luminosity range the monitor was set with the contrast control adjusted at half maximum and brightness at minimum (these were the setting used in the experiments). With these settings the luminosity curves (illustrated in figure 3.1.) were found.

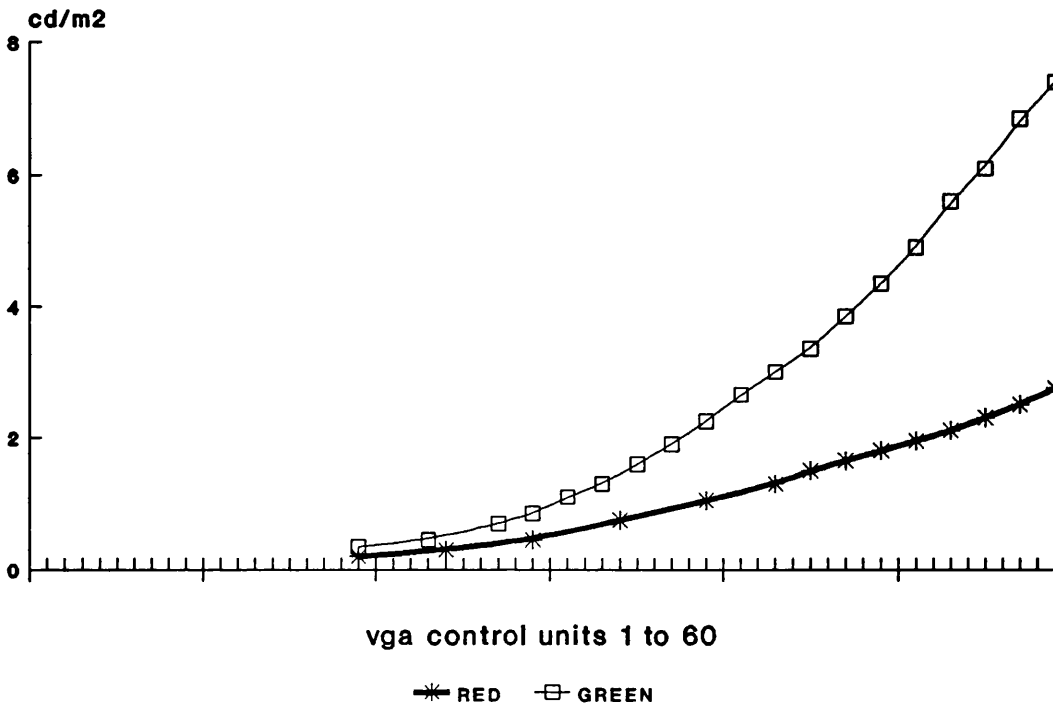
The luminosity curves for the red and the green phosphors are slightly offset reflecting the fact that per control unit the green is brighter than the red. This is a common phenomenon for all monitors designed to produce pure whites and greys. A subjectively judged pure white on a monitor requires a light mixture stronger in green and weaker in red wavelengths (as at least produced by the phosphors available on standard monitors). Thus monitors are designed with phosphors of unequal luminosity. This is reflected in the luminosity units available to control them.

3.3.2. Gamma function

The relationship between the number of shade steps over which luminosity can be controlled and the luminosity they produce is non-linear and known as the gamma function (Rodieck, 1983; Watson, Nielson, Poirson, Fitzhugh, Bilson, Nguyen & Ahumada, 1986).

Figure 3.1 contains the curve relating luminosity of the red and green phosphors in cd/m^2 (candela per square meter) to these 64 units at the settings used in the experiment (the contrast set at half and the brightness set at minimum) on the NEC Multisync monitor. From the curves it can be seen that per unit of control, the green phosphor is brighter than the red one³. As noted above, a pure white or grey requires a colour mixture stronger in green than red and this is reflected in the luminosity given by the control units which are designed to produce pure colours.

Figure 3.1. Gamma function curves (luminosity in candela per meter squared against control units) for the red (bottom) and green (top) phosphors on the NEC Multisync 3D a monitor measured with an optometer.



3.3.3. Contrast

According to Cowan (1983) the contrast control required for vision research ideally requires 128 or 252 shades. However, Cowan's main concern is specialised psychophysical work upon vision receptors. Zeki (personal communication) has performed experiments involving isoluminance with monitors using only 16 shades. Livingstone and Hubel (1987, page 3423) found that the effects of isoluminance upon motion perception (Carvanagh et al, 1984) occurred for a range of around 5% around the point of isoluminosity defined by heterochromatic photometry. Moreover, Cowan does admit that the range varies with "application to application"

(page 152). The experiments within this thesis can be argued to fall into this category since the function of isoluminosity was used to force the processes recognising letters to use colour rather than contrast information. Thus a limited degree of luminosity contrast is acceptable provided it is insufficient to aid letter recognition.

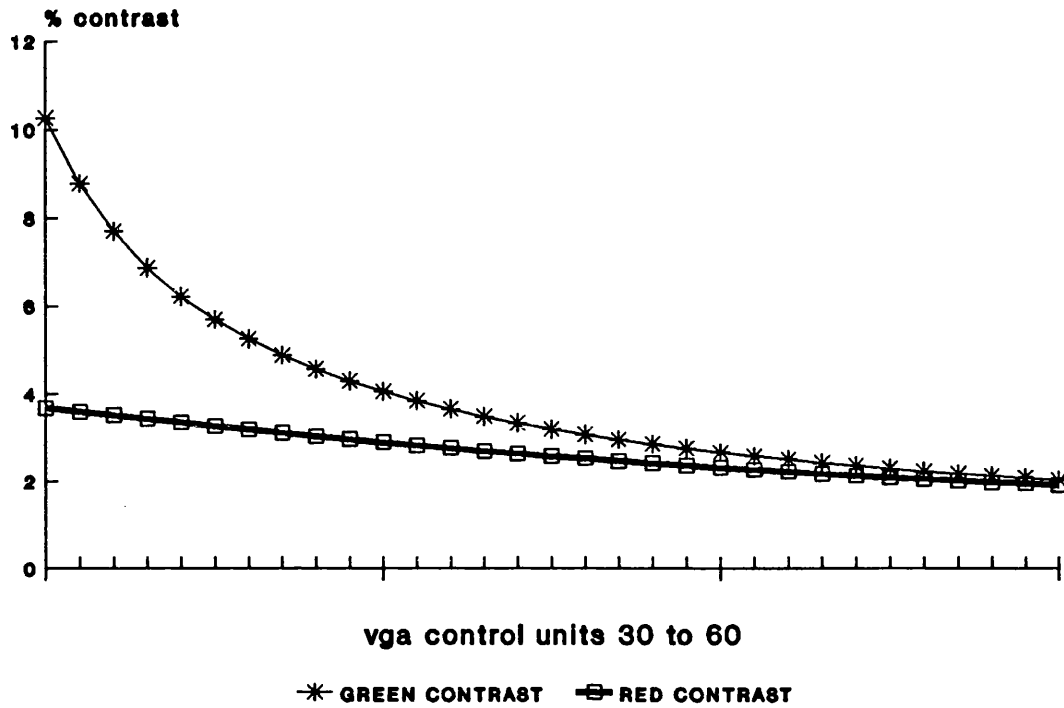
Contrast in vision research normally uses the Michelson definition:

$$C = \frac{(L_{\max} - L_{\min})}{(L_{\max} + L_{\min})}$$

Where L_{\max} and L_{\min} are respectively the maximum and minimum luminosities. The variation of contrast with control units for the green and red phosphors is given in figure 3.2.

From the work of Legge (Legge, Rubin & Luebker, 1987; Legge, Parish, Luebker & Wurm, 1990; Rubin & Legge, 1989) and others (Knoblauch, Arditi & Szlyk, 1991) it is known that the usefulness of contrast rapidly declines within 10% contrast. The contrast between two adjacent shades was kept in the high region of luminosity not less 3% (see figure 3.2). Words darker or lighter by this amount than their backgrounds are barely visible. In contrast, coloured words can readily be recognised if against a isoluminous or near isoluminous coloured background suggesting colour not luminosity provides the contrast used to identify them.

Figure 3.2. Contrast between adjacent vga control units for the red (bottom) and green (top) phosphors. Note, that since the original luminosities were sampled every two units the graph has been calculated from the formula given in the text.



3.3.4. Phosphor persistence

One problem attendant upon research using timed reaction to events presented on monitors is phosphor persistence. This can cause problems if stimuli are presented white against a black background for a fixed period since phosphor persistence will leave in these circumstances a trace stimulus image upon a screen providing the subject with extra time to detect it. (Normally, the way to avoid these problems is to use black stimuli upon white background in which circumstances image persistence does not occur). Experiments described in this thesis were not of this kind: first, most of them did not involve white stimuli against backgrounds; second, stimuli were left on the screen until the subject responded⁴.

3.3.5. Mean luminosity

The purpose of presenting alternating stimuli was to dissociate the two channels by flicker rate -- the magno channel being able to temporally resolve images at a faster alternation rate than the parvo channel. The critical flicker rate for temporally resolving flicker varies, as noted in the previous chapter, with luminosity -- the brighter the image the higher that rate. Normally the critical flicker rate is in excess of the two highest which can be presented on a monitor. Since there were limited rates of presenting alternating flicker the mean luminosity

of the stimuli was reduced using the luminosity and contrast controls to 2 cd/m². At this rate, monochromatic flicker could not be seen at the highest available alternation - 35 Hz, while it could at the next lower one of 17.5 Hz. Heterochromatic flicker could not be seen at this flicker rate but was detectable at the next lower rate of 12.5 Hz. Thus the monochromatic and heterochromatic stimuli could be separated by flicker rates. Since this luminosity is far below that of normal lighting the experiments were run in the semi-dark with illumination provided by a low power 25 Watt lamp adjacent but not directly illuminating the screen or the subject.

3.4. Luminosity artifacts

Monitors are subject to a number of luminosity artifacts. The screen as noted is not of uniform luminosity -- it is lighter by about 30% in the centre compared to its edges (Livingstone & Hubel, 1987). Electrical interference, (created by the computer), can induce nonuniformities leading some experimenters (Kennith Knoblauch, personal communication 1991) to shield the cables connecting the monitor to the computer. These were not detected in the present experimental set up. However, one was found that, apart from one brief mention, has not been reported.

3.4.1. The cold pixel effect.

35 Hz blending of counterphase images makes visible luminosity artifacts not normally seen around the boundaries images. They take the appearance of image ghosts. I have found only one small prior reference to it (Legge et al, 1987), 'The nonlinearity [of input voltage to the raster beam] introduced small, contrast-dependent changes in the luminance profiles of the edges of the letters.' (page 1170).

The origin of these ghosts is the raster beam. Images are created on a monitor by beams of electrons. The luminosity of a phosphor is related to this beam's current. If this current is not uniform then the luminosity of the phosphor and the image it creates upon the screen will likewise not be uniform. The beam scans the screen left to right in vertically descending lines. For some unknown reason when the beam begins or stops illuminating a sequence of pixels, the first and last pixels receive a lower current than those in between. The voltage changes directing the beam are fast, with individual pixels being illuminated for around one 16 millionth of a second each. Since adjacent pixels might need full or no current any lag in the raster gun changing between full and no illumination might effect its creation of boundaries of a colour or illumination by causing boundary pixels to be darker than interior pixels. This cold pixel effect applies only to vertical boundaries:

horizontal ones are made up of raster beams in different lines and so do not involve the raster in a current change.

The cold pixel effect is not noticeable (unless specifically looked for) for static colour or illumination boundaries because the luminosity or colour boundary is far more noticeable. But when two perfect reversed images are alternated at 35 Hz, colour and luminosity boundaries disappear, making luminosity nonuniformities at the images edges readily visible⁵.

The solution to cold pixels was to artificially raise the values of terminal pixels to counter-balance their darkness. The appropriate values for this were found by adjusting video reverse images alternating at 35 Hz until the cold pixel effect was nullified. The cold raster effect appears only to be a problem for strongly contrasting boundaries (perhaps because it relates to large changes in the raster beam's current). Ones involving minor contrasts undergo a small change in the raster's current, which appears to reduce the size of the cold pixel effect. Thus the correction was only needed for sharp boundaries.

3.5. Isoluminosity point

The greater luminosity of green compared to red phosphors means that the brightest shade of red (control unit value 64) did not match with the brightest green shade (ie control unit value 64) but a green shade with a lower control unit value (in fact control unit value around 44). Because of the need to adjust image edge pixels, (described above), and the need to adjust luminosity values through a range for determining isoluminosity the highest available control value could not be used. Instead one several units lower was used (control unit value 56). Since a lower contrast (a desirable property) occurs between the adjacent control units with the highest values it was preferable to vary the red phosphor (which had higher control unit values) and keep constant the green ones (varying the green one would have involved larger contrast steps and so less sensitive isoluminous matching).

3.5.1. Isoluminosity values.

Isoluminosity varies between people (Anstis & Cavanagh, 1983): some experimenters ignore this variability and refer to the isoluminance of a standard observer (Knoblauch, Arditi & Szlyk, 1991). In this set of experiments an attempt was made to obtain an individual isoluminous value for each subject.

3.5.2. Evaluation

Isoluminosity between any two colours varies with spatial frequency (Anstis & Cavanagh, 1983). This variation with spatial frequency suggests methods of evaluating isoluminosity which use large areas of colour, (low spatial frequency), are inappropriate given that the stimuli used in the experiment were composed of high spatial frequencies.

Three methods are used regularly in vision research: minimum motion judgement (Anstis & Cavanagh, 1983, flicker or heterochromatic photometry (Boynton & Wagner, 1968; Heath, 1958; Wagner & Boynton, 1972; Lee, Martin & Valberg, 1988) and minimally distinct borders method (Wagner & Boynton, 1972; Kaiser, Lee, Martin & Valberg, 1990). A modified form of flicker photometry was used (see also the brief description of heterochromatic photometry in section 2.4.1.1. in the previous chapter).

Flicker or heterochromatic photometry depends upon the non-existence of luminosity flicker at isoluminance since two colours with the same brightness (the definition of isoluminosity) lack luminosity contrast and so cannot produce a luminosity flicker. Since the perception of colour flicker ceases at a lower rate of counterphase than luminosity flicker it is possible to set alternation rate between two colours such that only luminosity flicker is perceived. If colours are adjusted at this flicker rate then

perceived flicker will disappear when they are adjusted to isoluminance since the flicker rate has been set too high to perceive their colour flicker. In practice, sometimes it is easier to set the flicker rate so that some colour flicker is observable and the subject judges the absence of luminosity flicker.

Flicker photometry was modified to include the stimuli used in the experiments. This was done by using two fields of letters of opposite polarities (red letters upon green and green letters upon red). In this way any subtle effects of the high spatial frequencies of the letters and their shape (Kelly, 1975) would be taken into account by the subject when judging isoluminosity⁶. With this experimental set-up the best method to judge isoluminosity was found to involve counterphasing field of letters at 17.5 Hz with the experimenter adjusting the red phosphor until the flicker was judged by the subject to be minimal. The subjects were instructed through the use of examples of luminosity contrasting colour pairs either side of the isoluminous point as to the appearance of luminosity flicker. This was described to them as harsh and unpleasant. The values were varied in between these two points to illustrate the change in the harshness of the flicker. The subject was asked the relative harshness of colour pairs until they arrived at a stable minimally harsh value⁷.

3.6. The flicker and static stimuli.

Four types of flicker stimuli were used in the main experiments factored by contrast/colour and low/high spatial frequency.

The flicker stimuli consisted of two images in rapid alternation with the following characteristics:

- (1). They were of the opposite polarity (polarity refers to an image's contrast: black letters on white is the opposite polarity of white letters upon black). Polarity can refer to colour as well as luminosity contrast.

- (2). They were perfect negative reverses of each other. This entails them with the property that if the two images are flickered at rates above luminosity resolution they blended to form a uniform imageless blank. Like with polarity this was also true for colour reverses which blended to form a colour uniform field. Perfect negative reverse was desired because this prevented any process unable to temporally resolve the two images to perceive the image through non-temporal non-uniformities. Perfect negative reverse was judged by the images producing a uniform blur at 35 Hz.

A static image presentations were created out of flickering presentations by presenting separately the two flicker images an equal number of times.

The monochromatic stimuli controlled for the heterochromatic stimuli in two ways. First, by using the same the wave lengths (colours) used to create the heterochromatic stimuli. This was due to the need to control for any effects of wave length -- there is some evidence for these, (Williams, Breitmeyer, Lovegrove & Gutierrez, 1991). Since the heterochromatic stimuli were green and red, the monochromatic ones were yellow. Second, they were of the mean luminosity, 2 cd/m². In consequence, when alternated at the fastest rate where luminosity and colour contrast blurred they produced a colour patch of the same luminosity and colour.

The flicker stimuli were bounded by a surround the mean uniform luminosity and colour as the two flicker stimuli.

3.7. The stimuli

Three sets of letters were used in experiments reported in this thesis.

For the preliminary experiments (chapter 4).

(1). Large green and red letters 14 mm wide by 18 mm high. The letters were created out of the 8X8 bit mapped font enlarged sixfold.

(2). Large black and yellow letters of the same size and font as the above coloured letters. The luminosity of the yellow was matched to be twice the mean luminosity of the green and red letters and background. (This ensured they flickering stimuli were of the same mean luminosity).

The letters had quasi-sharp boundaries - they were jagged by alternatively displaying pixels sideways. At the distance seen by the subject the jagging $.014^\circ$ was below the normal visual resolution, $.017^\circ$. The jagging was judged to reduce luminosity artifacts.

For the lexical decision experiments (Chapter 5).

(3). Small green and red coloured letters/backgrounds. They were 3.4 mm by 5 mm.

(4). Large blurred edge letters. They were 9 mm by 14 mm

For the Posner experiment (Chapter 6). Letters similar to the large blurred ones used in the lexical decision experiment.

Notes.

1. It should be noted that reading this register makes programmes written for one graphics card inoperative without adjustment (the registers differ) on machines using other cards (like Heracles or CGA).

2. The program read this information at the internal software address port[201].

3. The curve of the red phosphor is described between control units 20 and 60 (expressed in the formula by vga) by the quadratic equations $vga^2 \times 0.001 - vga \times 0.02 + 0.25$; and that of the green one by $vga^2 \times .0024 - vga \times 0.002 - 1.35$. Their fitting by a quadratic equations is slightly surprising given the formula usually described for luminosity unit control involves a cubic function Cowan (1983). This could reflect attempts by the designers of the VGA card to provide given its commercial use a more useful spread of luminosity values.

4. A short test was carried out to confirm this. Two checker boards created out of alternate dark and white pixels. In one the checker board was static; in the other the luminosity values of the pixels reversed. A photometer measured their luminosity. It was hypothesised that if a strong persistence existed then the second reversing checker board would be brighter since its black pixels would contain

a residual illuminance from their previous illuminance in the last checker board as white pixels. No measurable luminosity differences were found. This suggests if persistence was present it was negligible.

5. Some preliminary measurements were made of the cold pixel effect. Two techniques were used.

First, two images were generated consisting of alternating vertical and horizontal lines of single pixel width. Each image was counterphase with its video reverse so that white lines changed into black ones and vice versa, black lines changed into white. As observed in the text, horizontal changes in luminosity do not produce boundary artifacts with this being confined to boundaries defined by vertical edges. In theory both horizontal and vertical line counterphase images should have equal luminosity since they are made of the same number of light and dark pixels. However the image made up of vertical lines consists of vertical edges and so its light pixels should be darker than those in the image made up of horizontal lines due to the cold pixel effect. The monitor was set with contrast and luminosity controls at full (hence the luminosity values are greater than those reported for the experimental stimuli which were presented at half contrast to reduce luminosity). The two counterphase images differed by 5.1 cd/m² (22.9 cd/m² and 17.8 cd/m²). This suggests the cold pixel effect reduces luminosity at images by around 14.9%. However, this

is probably an over estimate since there may have been an interaction between edges with a vertical edge immediately following another vertical edge inducing a greater effect upon the second one.

An attempt was made to measure the effect of single edge by using compensation. In this method the pixel at the edge of a boundary was increased in brightness until the cold pixel effect disappeared. The degree its luminosity needed to be increased gives a measure of the luminosity drop at the boundary edge which needs to be compensated. Since the luminosity values of the various control units are known this can give an estimate of the cold pixel effect for a single boundary. This procedure was carried out: the compensation needed was 21.4 cd/m² (nonboundary pixels at 17.0 cd/m²). This gives an estimate of the cold pixel effect of 11.5%.

Thus these two procedures suggest the cold pixel effect reduces luminosity at boundary edges in the region of 11.5% to 14.9%.

6. It should be acknowledged that perfect isoluminosity cannot be achieved with images containing different spatial frequencies due to the slight differences of isoluminosity with different spatial frequency. However, as noted above a certain degree of luminosity contrast (which be present in nearly but not perfect isoluminous colour boundaries) is

acceptable since letters defined by low contrast luminosity boundaries (less than 10%) are difficult to see.

7. For some subjects several values seemed equally isoluminous by this method. For them the two values at which the harshness appeared either side of these isoluminous values was noted and the value in between them was taken as their isoluminous value.

CHAPTER 4: EXPERIMENTS ON THE PERCEPTIBILITY OF COUNTERPHASE LETTERS.

4.1. Introduction

Chapter 2 discussed how the processing of a stimuli by the two visual channels could be blocked by changing its visual presentation (Livingstone & Hubel, 1987; Ramachandran & Ramachandran, 1991a; 1991b). Certain visual characteristics of an image such as its spatial frequency, contrast (colour and luminosity) and temporal frequency (static or counterphase) make this blocking possible by selectively impairing the processing of images by the magno and parvo channels.

Two methods of blocking were discussed in chapter 2. This chapter is concerned mainly with the first one. Its method of blocking takes advantage of the different characteristics of the two channels in regard to the temporal resolution of counterphase and their perception of colour contrast. The magno channel preferentially processes images made up of luminosity contrasted and rapidly alternating boundaries (counterphase) while it is colour blind to images made up of coloured and rapidly alternating boundaries. In contrast, the parvo channel processes images made up of colour boundaries but is poor compared to the magno channel at processing very fast alternating counterphase boundaries. Selective blocking of the two

channels therefore uses two kinds of stimuli: to block the parvo channel's perception of images while leaving the magno channel's perception of them intact they are constructed of rapidly alternating contrasted images (the parvo channel cannot see boundaries which are alternating very fast); to block the magno channel while leaving intact the parvo channel stimuli are made up of less fast alternating but colour isoluminous boundaries (the parvo channel can see the less fast alternating boundaries but the magno cannot see their colour boundaries).

These methods have been previously exploited to study the role of the magno or parvo channels in various non-reading perceptual tasks (Livingstone & Hubel, 1987; Ramachandran & Ramachandran, 1991a; 1991b). The work reported in this thesis tried to apply these stimulus blocking techniques to the investigation of the two channels' involvement in the reading process.

The initial technique described in the previous chapter used two counterphase (flicker) stimuli: first 17.5 Hz monochromatic (yellow and black) letters designed to restrict processing to the magno channel by blocking the parvo channel and 12.5 Hz counterphase heterochromatic (same luminosity green and red) letters designed to restrict processing to the parvo channel by blocking the magno channel.

This chapter had two objectives. First, providing a grounding for the work reported later in this thesis; and second, a preliminary investigation into processes identifying images when presented in counterphase. Understanding the processes involved in perceiving counterphase is an important preliminary for their use in isolating the two visual channels (as this chapter will show). However, their study is in itself of independent interest, since, while much is known about the recognition of static letters, hardly any is known about the recognition of counterphase ones.

Two kinds of processes potentially might exist that could identify counterphase images: (a) those that identify image boundaries by temporally resolving them in the counterphase; and (b) those that side-step the counterphase and identify image boundaries by some other method than temporal resolution. Obviously the existence of processes that side-step the temporal resolution of counterphase images is important since they could undermine attempts (used later in this thesis) to manipulate the visual channel processing of images by means of the different abilities of the two channels to resolve counterphase.

4.2. Experiment 1.

4.2.1. Introduction

As far as I am aware no one has previously generated stimuli similar to the counterphase stimuli used in this research (though Livingstone & Hubel [1987] produced similar non-alphanumeric stimuli). Certain questions come to mind. Are counterphase letters easily read? What are the characteristics of their perception? Are images presented in them necessary recognised through temporal resolution of their counterphase, or can this recognition be done by other alternative means?

Phenomenologically, counterphase letters and words are as legible as static ones. In the course of this research a large number of people saw them without difficulty. However there are temporal limits (given the luminosities with which the stimuli were presented) for their resolution: for monochromatic contrastive ones this was roughly 17.5 Hz and for heterochromatic ones 12.5 Hz. These are approximate boundaries since temporal frequency was variable only in fixed steps; thus resolution, for instance, of the monochromatic stimuli might have been higher than 17.5 Hz but not sufficiently high for them to be resolved at the next step of frequency at 35 Hz. The same comment applies for the heterochromatic stimuli but for the 12.5 Hz and 17.5 Hz frequency steps.

An attempt was judged to be necessary to quantify these subjective impressions and provide information about the circumstances in which counterphase letters were visible.

To explore these questions, two experimental paradigms were created, first, a grid¹ of counterphase letters with controllable counterphase rate and luminosity contrast. Subjects were asked to read aloud two rows of letters in various presentation conditions. Second, a vocal reaction task was created involving the naming of tachistoscopically presented single letters. (The counterphase letters were identical in both paradigms since they were generated using the same computer stored images).

4.2.2. The grid paradigm

The counterphase grid was made up of rows and columns of letters. Since the individual letters were separated from each other by horizontal and vertical black lines, the letter rows and columns took on the appearance of a grid. Each letter was presented once, without repetition, in each row.

Using the keyboard,

- (a) the letters could be switched between colour (alternating red and green letters) and luminosity (alternating black and yellow letters) contrasts;

- (b) the luminosity of the red phosphor could be adjusted for isoluminosity matching with the fixed green phosphor.
- (c) the flicker rate could be increased or decreased;
- (d) the flicker rate could be reduced to static [in this state its polarity was changeable see (e)];
- (e) the polarity of the letters and their background when static could be reversed (black letters upon a yellow background into yellow letters upon a black background; and red letters upon green into green letters upon red).
- (f) the order of the letters could be re-randomised.

There were eight rows each containing ten letters. A set of ten letters was used: {C, D, J, K, L, N, X, Z, T and P}. The ten letters were chosen in regard to their ease of registering responses upon a voice key (the letters were to be used in another experiment where voice responses would be required), and visual nonconfusability. None of the letters was repeated in a row. The letters were 14 mm wide by 18 mm high (0.67° by 0.86° from the experimental position of the subjects -- 1.2 meters). A fuller description of them is to be found in chapter 3.

Prior to the letter reading experiments, the display was used to find isoluminance between red and green for each subject. The procedure describing this is described in the previous chapter.

The display was used experimentally in two ways: first, subjects were asked under various conditions (described below) to read the top two rows of letters. The conditions were factored by contrast (monochromatic or heterochromatic) and counterphase rate (35 Hz [high], 17.5 Hz [medium] and 12.5 Hz [low]). In the conditions in which the letters were legible, the letter reading was manually timed.

The grid reading experiment was immediately followed by a tachistoscopic reaction time letter naming task.

4.2.3. Method.

The effects upon contrast (monochromatic and heterochromatic) were explored for three flicker rates: 35, 17.5 and 12.5 Hz (Hertz factor). It was predicted that given the characteristics of monochromatic and heterochromatic flicker perception (discussed in chapters 2 and 3) that the monochromatic contrastive letters would be recognised at the 17.5 Hz and 12.5 Hz flicker rates but not the 35 Hz one. While the isoluminous colour contrastive (heterochromatic) image letters would be recognised only at the 17.5 Hz one.

4.2.4. Procedure.

The subjects were positioned 1.2 meters from the screen with their chins resting upon a stabiliser. Ten undergraduates, postgraduates and research assistants assisted. All subjects had normal or corrected vision. No subject was used if following questioning they reported possible colour blindness, reading disabilities, or histories of epilepsy or migraine.

The experiment started with an evaluation of green/red isoluminosity (as detailed in the previous chapter). The colour value was retained and used in the following two sections of the experiment.

4.2.5. Grid reading

The subject was instructed to read as quickly and accurately as possible the upper two rows of the display. The onset of the subject's reading was initiated by removing a sheet of paper covering freshly generated letters on the screen. A long duration (and so readily legible) counterphase 9.4 Hz not included in the experiment was used for practice. The presentation of monochromatic and heterochromatic reading conditions was alternated. Reading time was measured by a hand held timer manually started with the removal of the paper. It should be acknowledged that the manual initiation and recording of reading time (on a stop

watch) introduced a large degree of variability into the accuracy of recorded times due to (a) variation in coordinating removal of the sheet to reveal the letters on the screen with simultaneous starting of the timer² and (b) determining when the subject had completed reading them³. Attempts were made to record errors, however the position of the experimenter to the screen made the recording of errors difficult⁴. Further, the act of manual timing handicapped the recording of errors and generally added to the difficulties of spotting them. However, in practice, the legibility of letters was such that if subjects were able to read the letters in under 10 seconds, they were able usually to do so without error. For each trial the letters were regenerated in a new random order. A trial was repeated if during letter reading the subject stuttered or stumbled. Two times were taken for each condition.

In general, the importance of this part of the experiment was qualitative: in certain conditions subjects could readily and fluently read letters that in other conditions they could not even register as being present on the screen.

4.2.6. Tachistoscopic reading

When grid reading was completed, the subject was assisted with putting on a voice key (a throat microphone used to determine the onset of vocal responses). The subject was informed minor movements and coughs could accidentally cause the voice key to produce false responses. The second tachistoscopic part of the experiment was initiated by pressing on the keyboard the P key. The screen cleared and a central letter appeared signalling the start of a practice trial. The subjects were told that the aim of the experiment was to name the letter as clearly, quickly and accurately as possible. Since naming non-perceived letters was judged from preliminary testing of the experimental procedure to be distressful the subject was given the option of a do not see response (a further experiment [experiment 3] is reported latter in which this option was not included -- it does not appear to have affected the results). It was explained to the subjects that they might not see some letters and, if they felt they could not guess a letter's identity, that they had the option to respond by saying cannot see⁵ (or something similar). After each subject's response, the experimenter typed the letter pronounced by the subject on a keyboard. If the subject indicated they did not recognise a letter the # key was typed. During the practice session the return was also typed to bring on the next trial. The main factor delaying initiation into the experiment were problems with the subject's voice failing to consistently trigger the

voice key. The subjects continued in the practice session until they were judged proficient. The letters of the practice stimuli were randomly selected. They were presented sequentially through the six presentation conditions. The experiment was initiated by pressing the E key.

The letters used in the tachistoscopic part were visually identical (they used the same bitimages) to those used in the grid reading part. The letters were presented tachistoscopically in the centre of the screen surrounded by a black line box. They remained present on the screen until the subject triggered the voice key. There were 180 trials. The monochromatic and heterochromatic and three frequency conditions were balanced across stimuli with the letters each appearing once in every 60 trials. There was no break. The onset of the subject's vocal response was registered by the voice key and used to calculate the subject's reaction time in milliseconds.

4.2.7. Results

The means of the various conditions were computed using a program written in Turbo pascal. Both the do not know and the wrong responses were collapsed together into the error score (for comments upon this see section 4.5.1.). These were then analyzed using Genstat5 (Payne, Lane et al, 1987). Genstat5 was used because its procedures for analyzing ANOVA enable the use of planned contrasts (Digby, Galway, & Lane,

1989) (these can be done with other statistics packages but with less ease and convenience).

The main finding was that subjects could recognise tachistoscopically presented letters which they could not perceive when presented in a grid of letters.

4.2.7.1. Grid reading

The grid reading explored the variables which affected the legibility of the grid counterphase letters. In the monochromatic stimuli presentation condition for 35 Hz and in the heterochromatic stimuli presentation condition for 35 Hz and 17.5 Hz letters subjects either had great difficulty reading letters or failed to recognise their presence on the screen; however, subjects had little difficulty reading letters at the slower presentation rates. This effect was abrupt: at the highest rate the twenty letters were unreadable or readable only with hesitant guessing; in contrast at the lower rates the twenty letters were read quickly (in about six to seven seconds). Significantly, however, a few subjects could read the stimuli at the high counterphase rates. For monochromatic stimuli, 4 subjects (40%) could read the stimuli though slowly and with difficulty (reasons for this are discussed later). None of the subjects however was able to name any of the colour ones at the very highest 35 Hz counterphase rate. For the 17.5 Hz rate counterphase presentation, as expected, all the

subjects could read the monochromatic letters (in about six or seven seconds) but only three of the subjects (30%) could read the coloured ones. In both the monochromatic and heterochromatic conditions, all the subjects could read the 12.5 Hz letters. Thus there was a pattern confirming the general predictions made above but with some exceptions.

In contrast to the general difficulty subjects had reading grid letters, it was noted that they could read tachistoscopically presented letters irrespective of flicker rate and contrast type. The individual data for reaction times and errors (with SDs) for the six conditions is presented in data table 4.2. and that for the grid reading times in data table 4.1. (these are positioned in section 4.2.7.2.). Since subjects could in addition to responding with a letter give a do not know response, (thus avoiding accidentally guessing letters correctly), the chance level of accuracy potentially could be less than 1 in ten (the number of potential letter choices).

In the following analysis less attention is given to reaction times than errors. This is because high error rates make the interpretation of reaction times to the remaining correct items difficult. The nature of the processes underlying correct responses among numerous errors is unclear. They could be (1) responses to letters which were recognised or (2) responses which happened to have been guessed correctly. But which? Further, error rates are the

main concern of these experiments since they (rather than reaction times) are relevant to the hypothesis under review -- that beyond certain frequencies the letters are nonvisible.

4.2.7.2. Errors.

In the tachistoscopic presentation, subjects readily identified both monochromatic and heterochromatic letters at 35 Hz getting for the monochromatic letters, 75% correct (range 60% - 100%); and for the heterochromatic ones 44% correct (range 17% - 76%). For isoluminous letters flickering at 17.5 Hz the subjects identified 80% of the letters (range 50% - 97%). The striking aspect of these figures is that subjects readily read letters they found difficult or impossible when reading them in a grid. Figure 4.1.a. and 4.1.b. shows the results from reading the letter array and those from the tachistoscopic presentation.

There were two separate predictions for the monochromatic (luminous contrast) and the heterochromatic (isoluminous) stimuli. For the monochromatic letters, it was predicted that they would be nonvisible in the fastest, 35 Hz condition but that they would be equally legible in the two slower ones. For the heterochromatic letters, it was predicted that the two fastest frequencies would be equally above the perception threshold with only letters presented in the slowest frequency being visible. These predictions

Figure 4.1. Counterphase letters experiment 1. Error data for tachistoscopic presentation. Left side: monochromatic letters; right side: heterochromatic letters.

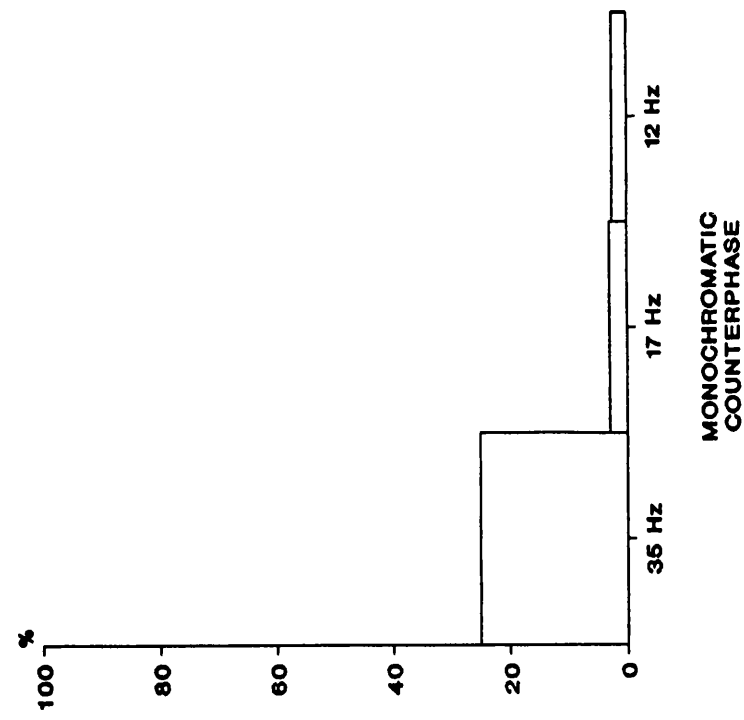
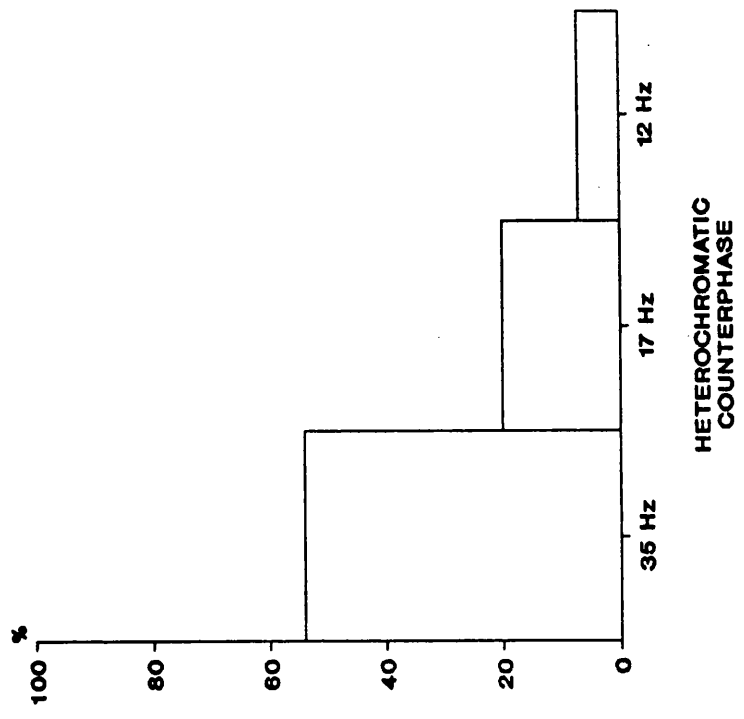


Table 4.1. Counterphase letters experiment 1.
Time to read 20 letters in seconds; dashes -- subject
unable to read letters.

Hz	monochromatic			heterochromatic		
	35	17.5	12.5	35	17.5	12.5
18	6.8	5.9		--	--	6.3
--	7.3	7.1		--	4.9	7.7
24	5.4	5.3		--	--	5.6
--	6.1	5.2		--	--	5.2
--	6.4	5.8		--	9.1	9.3
--	9.4	10.5		--	--	11.9
--	5.6	5.3		--	8.8	5.5
--	8.1	8.4		--	--	11.4
15	4.5	3.3		--	--	3.9
15	5.3	5.3		--	--	4.8
--	6.5	6.2		--	--	7.2

Table 4.2. Counterphase letters experiment 1.
Tachistoscopic presentation: mean reaction times and
errors.

monochromatic contrast					
35 Hz		17.5 Hz		12.5 Hz	
rt	er	rt	er	rt	er
944	31	649	0	704	3
577	13	529	3	573	3
1043	30	743	14	784	3
852	40	749	3	855	3
861	26	611	0	601	0
1103	6	661	0	618	0
884	0	670	0	690	0
962	33	830	6	818	0
990	40	634	0	660	3
1057	34	589	3	612	10
927	25	667	2.9	692	2.5

heterochromatic contrast					
35 Hz		17.5 Hz		12.5 Hz	
rt	er	rt	er	rt	er
1604	83	927	33	717	6
600	24	545	6	570	10
795	66	933	26	771	10
1002	73	901	50	844	20
895	56	706	6	663	3
1531	70	1047	13	733	0
934	23	767	3	733	0
1050	66	978	31	928	6
1377	63	910	10	781	3
667	33	726	23	664	10
1045	56	844	20	740	7

formed the basis of planned contrasts (Digby, Galway & Lane, 1989; Rosenthal & Rosnow, 1985) used to analysis the monochromatic and heterochromatic letters (see ANOVA tables 4.1., 4.2. and 4.3. -- note all ANOVA tables are in appendix Section 1, ANOVA tables).

Two interpretations of these predictions are possible. First, that no stimuli should be seen in the higher frequencies; and second, that letters should be visible at the higher frequencies with a trend that in the 35 Hz condition letters would be more difficult to see than in the 17.5 Hz and 12.5 Hz ones which in turn should be equally easy (or difficult) as each other. The first interpretation would be falsified by the existence of a high proportion of letters that were seen correctly in the fastest 35 Hz (monochromatic) and 35 Hz and 17 Hz (heterochromatic) conditions. However, this might be too strong an empirical requirement if there were processes separate from the one being studied that enabled the detection of some of the high frequency letters and so masked the effect being investigated. In these circumstances, the second interpretation would be more appropriate since this would allow the detection of the effect sought by the experiment but in the form of the weaker requirement of a significant pattern for the letters in the highest condition to be less

visible in the two slower ones. A repeated measures ANOVA with appropriate contrasts was performed on the error data to test the second prediction (see ANOVA tables 4.1., 4.2. and 4.3).

Subjects made more errors upon heterochromatic stimuli than monochromatic ones $F(9, 1) = 34.42, p < .001$. Though all subjects could read letters presented at the highest flicker rate, 35 Hz, there was a pattern in terms of errors for their recognition to be easier at the lower 17.5 and 12.5 Hz frequencies. The Hertz condition was significant over both monochromatic and heterochromatic stimuli $F(1, 18) = 55.83, p < .001$. Two separate ANOVAs with planned contrasts for the monochromatic and heterochromatic stimuli were made over the Hz condition (ANOVA tables 4.2. and 4.3.). The contrast used over the monochromatic stimuli (discussed above) was highly significant $F(1, 18) = 53.36, p < .001$. Further, examination of the ANOVA in table 4.2. shows that this contrast explained most of the sum of squares variance of Hz condition.

This situation was not the case with the contrast used over the heterochromatic stimuli. Though this contrast was significant $F(1, 18) = 46.53, p < .001$, it only explained half the sum of squares. Thus unlike the contrast over the monochromatic stimuli, the contrast over the heterochromatic stimuli failed to fully explain the differences between the means. One explanation could be that many subjects had high

thresholds for detecting heterochromatic flicker (and thus had a letter recognition performance difference to that described by the contrast). This is supported by the fact that the three subjects with the lowest error rates in the middle 17.5 Hz condition were also the three subjects that could read (and read at fairly normal speeds) at this rate (see data table 4.1).

4.2.7.3. Reaction times.

Subjects often performed near ceiling and floor levels in the various conditions. Repeated measures ANOVAs were carried out on the reaction times similar to those carried out upon the error data (see ANOVA tables 4.4., 4.5. and 4.6.). These support the observations found with the error data. Reaction times were slower for heterochromatic stimuli compared to monochromatic ones $F(1, 9) = 7.64, p = .026$ with significant differences between the means: $F(2, 18) = 16.95, p < .001$. The two ANOVA with planned contrasts supported the findings found with errors. The contrast over the monochromatic stimuli was highly significant $F(1, 18) = 51.77, p < .001$. Moreover, examination of the ANOVA table 4.5. shows that it, like that used upon the error data, explained most of the sum of squares in the Hz condition. The contrast over the heterochromatic stimuli was also significant: $F(1, 18) = 8.93, p = .008$ but as with the error data this contrast only explained roughly half the variance between the three means.

4.2.8. Discussion.

The main findings of the experiment was that: (a) some subjects read letters in a grid with difficulty at 35 Hz counterphase (monochromatic) and 17.5 (heterochromatic); and (b) that subjects could name letters when presented tachistoscopically they could not read (or could read only with great difficulty) when presented in a grid. Were these letters recognised by processes which temporally resolved the counterphase or ones which side-stepped it?

4.3. Perception side-stepping counterphase

4.3.1. Grid reading.

Some subjects were able to recognise grid letters that were expected to be difficult or impossible for them to see. What might account for their ability to do this?

Letters recognised in the grid were unlikely to be recognised by temporally resolving the counterphase. First, the counterphase rate was higher as noted in the introduction (and in chapter 3) than that previously found experimentally to be resolvable. Second, they were read non-fluently -- as if subjects were using clues to letter identities that occurred relatively infrequently -- below, processes are proposed that side-step counterphase

resolution by using clues that are produced by irregularly occurring eye movements.

Three circumstances could enable subjects to perceive letters without temporally resolving the counterphase: eye movements, blinking and the detection of luminosity artifacts. Since the inducement and the use of them could vary between subjects they could account for why some subjects could read letters other subjects could not.

To understand how these factors could make counterphase letters visible, a slight digression into the nature of counterphase stimuli is needed. Counterphase stimuli are made from two superimposed opposite polarity images. Since they are physically aligned and compensate exactly for each other's luminosity they blur when alternated faster than the temporal resolution of the visual system (for discussion of this see the previous chapter). They however remain only invisible while they are retinocentrically aligned -- when the two images of the counterphase superimpose themselves exactly on the same part of the retina. If this exact superposition is broken by even small momentary misalignments of the two images upon the retina then the nonaligned parts of the counterphase image create visual ghosts from which the stimuli can be recognised. Physical changes in the shape of the eye ball can be sufficient to induce minor misalignments of the two images sufficient for this to occur. (These misalignment need only happen for a

brief moment to be noticeable - further discussion upon this point follows). Such changes can be induced by frowning, pressing the eye ball or focal accommodation (in which the muscles around the eye change its shape and so alter its focal distance).

Blinking can also momentarily make counterphase images visible. The mechanisms by which this happens are shared with those which made tachistoscopically presented letters visible and so for this reason are discussed later with them.

As noted in the technical chapter the presentation of images upon monitors is troubled by image artifacts. It is difficult to produce completely clean images. This is particularly the case at image boundaries where luminosity nonuniformities occur. These could not be removed entirely. Thus there were some minor ghosts around the counterphase letters. These were sufficiently near threshold that if subjects could detect their presence they were unable to use them to identify the images hidden in the counterphase. However, it is possible that some subjects were able to use the partial information provided by them with other clues to identify letters. For instance, eye movement induced misalignment and the luminosity artifact ghosts by themselves might have been insufficient to identify the letters but they might have together. A further possibility is that due to different innate temporal sensitivities

between subjects some subjects might have been near the threshold for resolving the fastest counterphase. In consequence, their resolution while not by itself sufficient to resolve the letters could when combined with information from eye movements, blinking and luminosity artifacts.

4.3.2. Tachistoscopic reading: the noncounterphase perception of letters.

Grid letters were considerably harder to detect and recognise than tachistoscopic letters. Most subjects could not detect letters in the letter grid at 35 Hz (monochromatic and heterochromatic) and 17.5 (heterochromatic). Thus their reading performance was roughly in accordance, though not completely, with expectations. The detection of letters in the tachistoscopic presentation was different. Some subjects readily and easily detected letters presented at 35 Hz (monochromatic and heterochromatic) and 17.5 Hz (heterochromatic).

Phenomenologically the detection of letters occurred at the onset of their presentation: when observing the fixation point the letter appeared to flick into view before being lost in the subsequent blur of the counterphase. Similarly voluntary and involuntary eye blinks appeared to cause otherwise invisible counterphase images to become visible as a flash. One interpretation of this is that when images making up the counterphase are preceded by other

counterphase images the individual images are not visible, however, the individual images become temporally visible if they are preceded by something other than a counterphase image. For instance, if they are preceded by the blank field prior to the onset of a counterphase, or when the perception of counterphase is temporarily interrupted by a blink.

There are several conjectures as to the processes which might be responsible. First, there may be a visual sampling process with a limited temporal window. If the letters in counterphase are alternating faster than the temporal size of this window then images cannot be sampled through this window and so perceived. In this account, the images of counterphase after a blink or at its onset can be sampled because they occur in a perceptual period longer than window and so can be sampled and visually processed.

Second, together or in addition to the sampling process there may be a buffer in the early stages of visual processing which stores iconic traces (Sperling, 1960) of the onset image of the counterphase stimuli. In this case, image recognition may occur upon the buffered image even though recognition for the latter images contained in the counterphase is not possible.

One problem with these conjectures is the question why the letters in the grid were not detectable through this method. When reading the grid the eye experiences a

counterphase on-start. Why did this not make the letters visible? In the introduction I discussed Breitmeyer's theory that images are visually carried over between eye scans. There is little evidence for this. However there is evidence for the suppression of the initial perception of images after an eye scan. Following eye movements, there exists a short period of about 60 to 100 milliseconds in which visual input is suppressed (Volkman, Riggs, & Moore, 1978). This could be expected to interfere with any visual input into the hypothesised iconic buffer either indirectly through interference with the perceptual input of images into the buffer, or directly by effecting the buffer itself.

An important consequence follows from the perception of letters at 35 Hz. If images are perceivable through mechanisms that side-step the temporal resolution of counterphase at this high frequency then images would be perceived through these processes when presented at the slower counterphase used in the experiments. If this was the case it could not be known whether images seen at slower rates were recognised by processes temporally resolving the counterphase or by the processes side-stepping it. If this occurred it would have undermined the rationale for using counterphase image presentation to manipulate the processing of images to isolate the visual channels. Therefore a technique was needed to interfere with the processes responsible for side-stepping counterphase.

The conjecture that much of this perception occurs in an iconic buffer suggests that a premask might take up the storage of the initial counterphase image thus preventing its buffer storage and so visibility. This suggestion admits of ready testing.

4.4. Experiment 2.

To test the theory that a visual buffer stored the first frame of the counterphase, a second experiment was carried out. It was a replication of the first experiment in that it included a section testing the subjects ability to read counterphase letters in a grid and a section requiring them to identify them when presented tachistoscopically. The tachistoscopic presentation was different however from that in the first experiment in that the stimuli were preceded by a mask.

4.4.1. Method and procedure.

The method and procedure were the same as in the first experiment except for the mask. 10 subjects were run.

4.4.2. The mask

The mask consisted of two successive checker board images. The first consisted of a 3 by 3 array of 6 mm X 4 mm squares; the second consisted of a 4 by 4 array of 3 mm X 4 mm squares. On the basis of pre-trials, these masks were judged to use the visual components that most overlapped with the main visual components of the letters and thus could be expected to most strongly interfere with their iconic buffering. Each mask was counterphased during its presentation i.e. reversed polarity. Each mask was sequentially presented. The duration of presentation was equal to that of the individual counterphase letter images which followed them.

4.4.3. Results.

The results of the subjects are presented in data tables 4.3. and 4.4. The reading times for reading letters in a grid were comparable to those in experiment 1. The reading times from both experiments were combined and analyzed in the form of a split-plot ANOVA. Though the general pattern of results was in line with those found in the tachistoscopic presentation of letters, the fact that three of the six conditions lacked data from the majority of the subjects makes them difficult to interpret.

Figure 4.2. Counterphase letters experiment 2. Error data for tachistoscopic presentation. Left side: monochromatic letters; right side: heterochromatic letters.

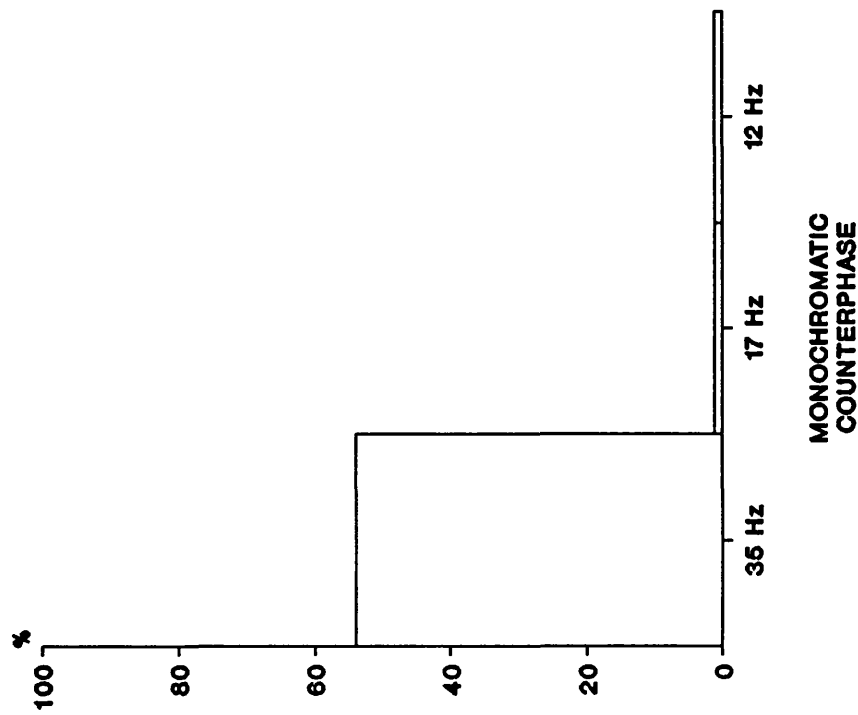
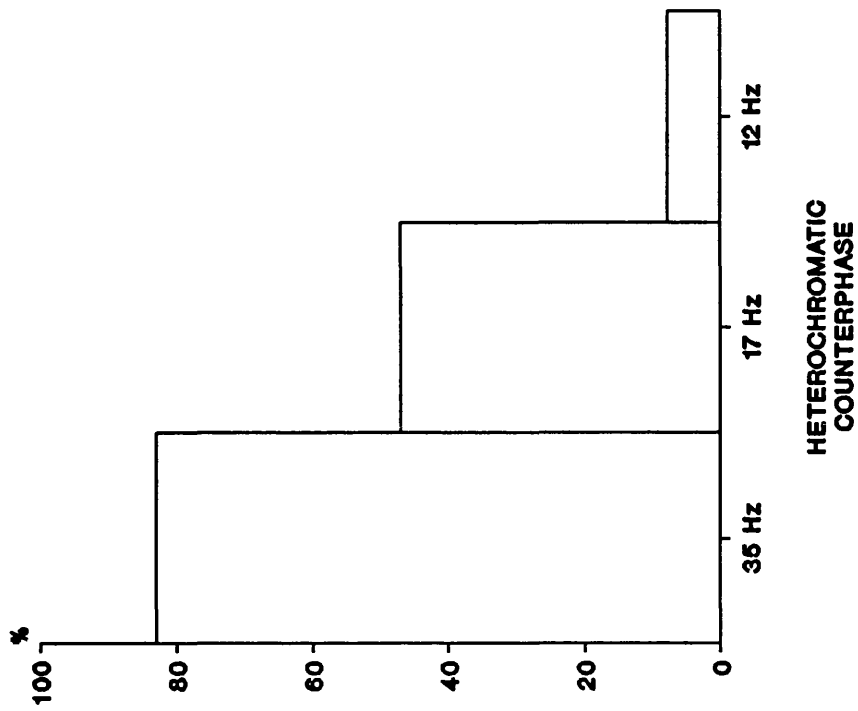


Table 4.3. Counterphase letters experiment 1.
Time to read 20 letters in seconds; dashes -- subjects
unable to read letters at this Hertz.

Hz	<u>monochromatic</u>			<u>heterochromatic</u>		
	35	17.5	12.5	35	17.5	12.5
28	6.0	6.1		--	--	6.2
--	8.3	8.1		--	--	9.3
--	6.5	6.5		--	--	7.7
--	6.4	6.0		--	--	7.5
--	7.5	7.8		--	--	7.8
--	5.5	5.4		--	--	5.8
24	4.2	4.2		--	6.9	5.2
--	4.9	6.9		--	7.8	5.9
--	5.5	5.3		--	6.9	5.6
--	5.6	4.8		--	6.5	4.0
--	6.1	6.1		--	--	6.6

Table 4.4. Counterphase letters experiment 1.
Tachistoscopic presentation: mean reaction times and
errors; dashes -- insufficient data for mean to be
calculated.

monochromatic contrast					
35 Hz		17.5 Hz		12.5 Hz	
rt	er	rt	er	rt	er
1048	46	632	0	610	0
758	53	611	0	635	0
871	62	775	0	756	0
957	68	758	0	707	3
1112	46	712	3	793	6
721	75	699	0	756	0
1112	60	982	6	814	0
1028	44	800	0	692	3
864	46	804	0	698	0
1403	41	662	3	645	3
991	54	744	1.2	711	1.2

heterochromatic contrast					
35 Hz		17.5 Hz		12.5 Hz	
rt	er	rt	er	rt	er
1180	73	1059	70	710	0
922	80	804	33	681	0
808	88	931	26	775	3
----	100	---	96	846	21
860	79	872	37	757	7
713	86	809	33	727	0
1132	90	1263	70	1054	10
1187	83	803	82	927	33
----	96	873	46	827	0
895	83	802	3	645	3
962	86	905	47	795	7.7

The reaction times and errors for the tachistoscopic presentation of letters are noticeably different from the first experiment. They show a significant decrease compared to the first experiment in the ability of subjects to detect letters at 35 Hz (monochromatic and heterochromatic) and at 17.5 Hz (heterochromatic). In experiment 1, subjects recognised 74% of the monochromatic letters correctly. With the presence of a pre-mask, this was reduced to 46% (range 25 - 69%). For the heterochromatic letters, this fell for the 35 Hz condition from 45% to 14% (range 0 - 27%) and for the 17.5 Hz condition from 80% to 53% (4 - 97%). The results for experiment 2 are illustrated in figure 4.2.

As in the last experiment repeated measures ANOVA and contrasts were carried out on the error and reaction time data. Roughly the same results were found for this experiment but with higher significance levels for errors (see ANOVA tables 4.7., 4.8. and 4.9. [in appendix]). Again the monochromatic condition produced significantly fewer errors than the heterochromatic one $F(1, 9) = 37.93, p < .001$. However, only a trend existed for the monochromatic letter presentation being faster $F(1, 9) = 3.62, p = .089$. Planned contrasts were carried out separately on the monochromatic and heterochromatic stimuli. For monochromatic stimuli the contrast was highly significant -- $F(1, 18) = 375.93, p < .001$; likewise for heterochromatic stimuli, $F(1, 18) = 83.29, p < .001$. In the first experiment the sum squares between the three frequency conditions for the

heterochromatic letters was only partially (about half) accounted for by the contrast. In this experiment, the sum squares was divided more in its favour: the planned contrast accounted for two thirds of it. This suggests that processes other than those affected by the mask were still enabling letters in the heterochromatic presentation condition to be visible but at a reduced level.

The reaction times (ANOVA tables 4.10, 4.11. and 4.12.) like those for the first experiment supported the conclusions from the error data. The contrast over the monochromatic stimuli was highly significant: $F(1, 18) = 25.98$, $p < .001$ as was the heterochromatic one: $F(1, 18) = 12.41$, $p = .003$.

Did the premasking of the stimuli work? Were the results of this experiment significantly different from the first unmasked one? A series of split plot ANOVAs were carried out. Like the above results the error ANOVA tables (4.13., 4.14. and 4.15.) are reported before those for reaction times (4.16., 4.17. and 4.18.).

The first split plot shows that the mask had a strong effect: $F(1, 18) = 15.97$, $p < .001$. However the mask did not significantly (though it was present as a trend) have an effect upon the relatively difficulty of the two stimuli conditions (monochromatic or heterochromatic) between the two experiments $F(1, 18) = 3.95$, $p = .062$. The mask however

did effect the three frequency conditions: $F(2, 32) = 14.01$, $p < .001$; and the interaction between them and the monochromatic and heterochromatic presentation $F(2, 32) = 5.81$, $p = .008$.

The separate split plot ANOVAs for the monochromatic and heterochromatic conditions showed that the mask had a strong effect upon errors. The contrast over the monochromatic stimuli was significantly increased $F(1, 32) = 53.96$, $p < .001$. This suggests that premasking the stimuli made, as theorised, the 35 Hz counterphase stimuli more difficult to recognise. For the heterochromatic stimuli, the contrast was also significant: $F(1, 32) = 11.84$, $p = .001$. The sums of squares suggest that the effect of the mask was confined to changing the means accounted by the contrast. This suggests that the mask was removing a factor which had hidden the pattern of expected differences between the means.

The data for reaction times differed from those for error data (see ANOVA tables 4.13., 4.14. and 4.15.). There was no effect of masking upon reaction times between unmasked and masked stimuli: $F(1, 18) = .4$, $p = .536$ nor between the mono and heterochromatic presentation $F(1, 18) = .66$, $p = .426$; likewise there was no effect upon reaction time differences between the three flicker conditions $F(1, 18) = .92$, $p = .407$; nor their interaction with the mono heterochromatic presentation $F(1, 18) = 2.31$, $p = .115$. This

lack of significant effects continues with the split plot ANOVAs that looked specifically at the effects of masking upon the monochromatic (ANOVA table 4.14.) and the heterochromatic stimuli (ANOVA table 4.15.). The contrast over the monochromatic stimuli did not interact with masking: $F(1, 36) = .06$, $p = .886$; likewise the contrast over the heterochromatic stimuli did not either $F(1, 36) = .54$, $p = .468$. This suggests that the duration of reaction times though affected in part by the processes effecting the visibility of stimuli were insufficiently affected by them to be effected by the mask.

4.4.4. Discussion.

Experiment 2 showed that the recognition of letters is not possible when presented in a grid but visible when presented tachistoscopically. This can be explained in terms of some kind of process, perhaps an iconic buffer, that can be blocked by a pre-mask. However, the effect was not eliminated completely -- just under half the monochromatic letters preceded by a pre-mask were identified at 35 Hz. This suggests that either the mask was not completely successful in filling the buffer or that other processes were present.

These experiments suggest the need for modifications to the counterphase stimuli that were to be used in the later experiments of the thesis. Two problems can be identified.

First, it was suspected that eye movements could readily cause letters to become visible through the non-alignment of successive images upon the retina. Second, that letters in a counterphase image could become visible through buffering at its onset. Two modifications were made. (a) To reduce the first problem the boundaries of those letters which were large enough were blurred. This should make the counterphase letters less easy to recognise from retinal misalignments by preventing misalignments crossing a visually sharp and so identifiable boundary. Though no specific experiments were carried out letters with blurred boundaries appeared to be less easily seen than sharp boundary ones by eye movements and distortion of the eye balls. (b) To reduce the problem of the visual buffering of counterphase images, a mask preceded all the stimuli in future experimental presentation of letters. It is interesting to note that one other researcher using counterphase stimuli to investigate the visual channels (Ramachandran & Ramachandran, 1991a, 1991b) has also found that they need to be preceded by a mask (V. S. Ramachandran, personal communication).

4.5. Experiment 3

4.5.1. Introduction

After the experiments reported later in this thesis were run I had doubts that I used the optimal mask. To make the mask continuous with the counterphase stimuli several

masks were used which reversed polarity (as in counterphase). However, it might have been the case that a static one would have filled any hypothetical iconic buffer much more effectively. This question led to a third experiment to find out whether a counterphase or a static premask was more effective.

A further problem was explored in the third experiment. The subjects in the above experiments were given the option of a do not know response. For the above analysis errors and do not know responses were collapsed together as errors. However, the first two experiments differed on the proportion of the two types of error responses. A split plot was carried out to check this possibility (see ANOVA table 4.20.) confirmed this suspicion. There was a significantly greater percentage of missing derived error responses in the masked experiment compared to the unmasked one $F(1, 18) = 11.35, p = .003$. The percentage of missing responses did not vary with mono or heterochromatic presentation $F(1, 18) = 1.06, p = .317$; however they did interact with the three frequency conditions, $F(2, 32) = 9.07, p < .001$ and the interaction between them and mono and heterochromatic presentation $F(2, 36) = 7.72, p = .002$. There are several possibilities. It could be due to the stimuli being harder in the second experiment causing subjects to be more uncertain as to the letter stimuli and so more likely to make a do not know response. Alternatively, the presence of masks could have caused the subjects to adopt in the

second experiment a different guessing strategy. This rather than the effects of the mask could underlie the different accuracy of responses in the second experiment compared to the first. To check for this possibility a further experiment [experiment 3] was carried out to specifically explore the effects of masks and the absence of a do not know response upon the perception of 35 Hz stimuli.

4.5.2. Methods and procedures

The pre-mask used in experiment 3 had two properties. First the duration of its component mask images were tied to the duration of the following image frames which followed it in the ensuing counterphase. Since the image frames of the stimuli in the main experiments were presented at 17.5 Hz (monochromatic) -- 52 ms, and 12.5 Hz (heterochromatic) -- 84 ms, their pre-masks had images that were of longer duration than those preceding the 35 Hz condition -- 38 ms. Because they were longer they might have had different effects to those preceding the 35 Hz in blocking the processes storing the initial counterphase image. Second, the mask was dynamic alternating between the polarities. It could be that a static mask would have been more effective.

To investigate the effects of masking, the experiment paradigm described above was repeated with 35 Hz letters factored by monochromatic or heterochromatic presentation and by three mask conditions. They were:

- (a) no mask,
- (b) a counterphase mask of the type used in the experiments for monochromatic and heterochromatic stimuli and
- (c) a static (polarity unchanging) masks of the same total duration as (b) 52 ms monochromatic; 84 ms, heterochromatic.

Six subjects were run. The same letters used in the first two experiments were presented tachistoscopically at 35 Hertz. There were two factors: monochromatic vs heterochromatic stimuli presentation and masking: no mask; counterphase mask and a static mask. Unlike the tachistoscopic presentation in the two experiments described above the subjects were forced to guess a letter -- they were not given a do not know option.

4.5.3. Results

Though only six subjects were run the experiment provided significant information concerning masking. The reaction times and error scores for the individual subjects are presented in data table 4.5.

An important finding was that subjects reported distress and discomfort at having to guess a letter name to stimuli they claimed they did not perceive. This finding of subject distress was in part why no more than the six subjects were run. Its presence needs comment since subliminal perception experiments involving forced word guessing have not been reported to produce distress. It is possible however that there is something innately unpleasant in generating guesses from a small set of responses (the case with letter names) rather a set with a large set of possible responses (words). It is also possible that words may be more readily seen by preconscious processes than letters. These observations deserve further investigation. The finding suggests that the use of a missing response for the first two experiments was not unreasonable given its absence did not effect performance and would have distressed subjects.

The six subjects were able to recognise the monochromatic letters with great accuracy, 90%, when they were not preceded by a mask (this is a worse performance

Figure 4.3. Experiment 3. Error data. Left side: monochromatic letters; right side heterochromatic letters.

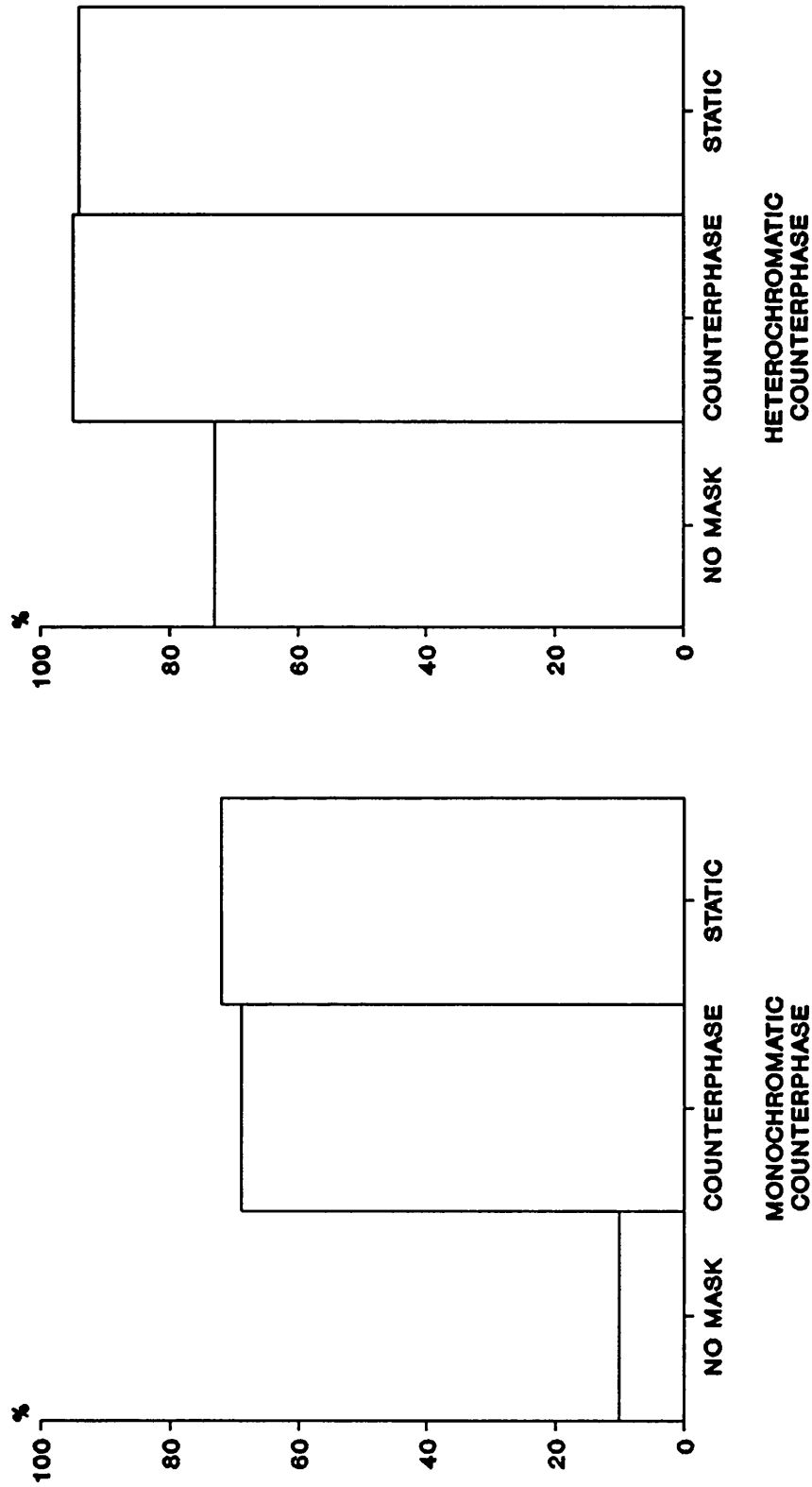


Table 4.5. Counterphase letters experiment 3. Means, SDs, and error percentages; dashes -- insufficient to calculated mean.

<u>monochromatic letters</u>								
no mask			counterphase mask			static mask		
mns	<u>SD</u>	er	mns	<u>SD</u>	er	mns	<u>SD</u>	er
563	81	10	626	145	46	1203	315	93
596	145	23	---	---	96	---	---	96
639	132	0	758	154	66	705	107	83
468	94	3	517	146	68	595	154	30
511	56	6	626	149	80	681	169	66
587	140	20	760	232	60	825	248	63
561		10	657		69	802		72

<u>heterochromatic letters</u>								
no mask			counterphase mask			static mask		
mns	<u>SD</u>	er	mns	<u>SD</u>	er	mns	<u>SD</u>	er
701	173	73	884	239	93	---	---	100
776	33	93	---	---	100	---	---	100
678	10	90	644	251	93	795	215	86
550	111	51	---	---	96	781	134	90
708	222	70	---	---	100	891	116	93
738	119	63	707	350	86	755	176	93
692		73	745		95	806		94

than with the unmasked monochromatic 35 Hz letters -- 25% in the first experiment). However both types of mask (counterphase and static) greatly reduced the ability of subjects to recognise monochromatic letters compared to the unmasked condition with only 30% correct for the counterphase mask and 28% correct for the static one. For the unmasked heterochromatic letters, subjects made more errors, getting 27% right. The addition of premask greatly reduced accuracy: the counterphase mask reduced accuracy to 5% and the static mask to 6% correct. This is near chance: because the subjects responses potentially included responses from the whole 26 letter alphabet (they were never

told there was only ten letters) consequently chance accuracy would have been around 4%. However, their accuracy (90%) in seeing letters in the monochromatic unmasked condition would have enabled them to see many letters which might have biased their other responses to unseen ones to those they had previously seen so making them more likely to guess letters from the ten letter set (therefore by increasing chance response to near 10%). The fact that the accuracy was less than this suggests that the letters the subjects did see only partially affect the letter guesses they made -- something confirmed by the range of letters they guessed including many that were outside the ten letters which was actually used.

A repeated measures ANOVA, (see ANOVA table 4.21) between the unmasked stimuli and the counterphase masked ones showed this reduction was significant: $F(1, 5) = 180.14$, $p < .001$. This interacted with whether stimuli were the monochromatic and heterochromatic: $F(1, 5) = 7.74$, $p = .039$. This interaction could have been an artifact: the unmasked stimuli had very different levels of accuracy -- the monochromatic letters were at near ceiling level with ten percent errors while the unmasked heterochromatic ones were comparably inaccurate with 73% errors. This affected the opportunity for a mask to change the percentage level of their accuracy -- for the monochromatic letters a mask could have potentially reduced it to 90% but for the heterochromatic letters the masks could have only reduced it

to at most 27%. Thus even if the mask effected both types of stimuli equally it might have shown a stronger effect upon the monochromatic stimuli since there was more room with these stimuli to decrease the accuracy of their identification. A stronger reduction for this reason upon monochromatic letters compared to heterochromatic would give rise to an apparent interaction and so could have been responsible for it.

The static mask also reduced accuracy. A repeated measures ANOVA, (see ANOVA table 4.22.) between the unmasked and the static masked stimuli found this reduction significant: $F(1, 5) = 73.63, p < .001$. Like the counterphase mask, this interacted with stimulus type (monochromatic compared to heterochromatic) $F(1, 5) = 13.76, p = .014$. Since the circumstances between its error data and those of the unmasked condition were the same as with the counterphase mask, the same reasoning applies to it, as discussed above, used to account for its interaction. The counterphase and static masks affected accuracy similarly for both monochromatic (70% and 72% respectively) and heterochromatic stimuli (95% and 94% respectively). A repeated measures ANOVA between the two masks shows that these slight differences were not significant $F(1, 5) < 1, n.s.$ This suggests that both types of premask, counterphase vs static, were equally effective in blocking the onset perception of counterphase stimuli.

The reaction time data in the previous two experiments did not support conclusions derived from the error data. As noted, the interpretation for reaction times is difficult in conditions where subjects make many errors: the factors determining the time of the few correct response is not necessarily going to be the same as when response accuracy is high. Further, the subject of interest was not whether the masks affected the processing of letters making it longer (something which reaction times might provide information about) but whether they stopped their perception. Nonetheless in view of the longer reaction times for masked conditions (561 ms and 691 ms for unmasked; 657 ms and 745 ms for counterphase mask; and 801 ms and 805 ms for static mask [monochromatic times followed by heterochromatic ones]) the reaction time data was analyzed.

The effect of the counterphase mask compared to the unmasked condition upon reaction times was a trend $F(1, 4) = 7.11$, $p = .056$. for the repeated measures ANOVA (see ANOVA table 4.24), it should be noted that one subject was excluded (as they were from some calculations which follow) because their high error rate prevented a reaction time being calculated for them. In contrast, the static mask showed a significant effect compared to the unmasked condition $F(1, 4) = 14.01$, $p = .02$ (see ANOVA table 4.25). However, there was no significant difference between the two masks $F(1, 4) = 3.64$, $p = .129$ (see ANOVA table 4.26.) suggesting that they had equal effects upon reaction times.

4.5.4. Discussion

The third experiment showed that the fears expressed concerning the efficacy of the pre-masks was groundless. Letters presented at 35 Hz, a rate at which they are normally nonrecognisable (as shown when subjects tried to read them when presented in the form of a grid in experiments 1 and 2) were shown to be, as in the first second experiments readily visible if presented without a premask. In this condition, the subjects were able to recognise 90% of the monochromatic letters and 27% of the heterochromatic ones. However, the accuracy with which subjects identified tachistoscopically presented letters reduced to chance or near chance if they were preceded by a premask. Two masks, static and counterphase, were used in this experiment. An important finding was that there was no difference between the effects of static compared to counterphase masks.

In the introduction to this experiment, the fears were expressed that the do not know response option of the first two experiments could have effected their results. Indeed it was shown that there were significantly more do not know responses for experiment 2 (which used pre-masks) than in experiment 1 (which did not use pre-masks). Thus the difference between the two experiments might have not been due to the existence of pre-masks blocking the hypothesised buffer but effected how subjects responded to letters they

were not sure they could identify. For instance, the presence of pre-masks before tachistoscopically presented letters might have biased subjects to make more do not know responses to letters they otherwise would have identified correctly thus artificially inflating the error scores to letters preceded by a mask. An alternative possibility is that subjects responded with a do not know response because they genuinely could not identify the letters to which they had been exposed. The do not know response was not available in the third experiment thus the two possibilities could be distinguished. Subjects responded in the third experiment much as they did in the first second experiments suggesting that the second possibility is most likely to be correct: that they responded with a do not know response because they genuinely could not identify the letter -- if forced to guess they would not have guessed it correctly. Thus the presence of a do not know response is unlikely to affect the results of the first two experiments.

4.6. Conclusions

The introduction suggested that counterphase stimuli might be recognisable either through temporal resolution of their counterphase or by processes that could side-step it.

The first experiment showed that the identification of letters was affected by their rate of counterphase. It had been predicted that very high rates of counterphase 35 Hz

would be difficult to see compared to lower ones. Moreover that monochromatic stimuli would be visible at higher rates compared to heterochromatic ones. This in general was confirmed both by the grid and the tachistoscopic presentation of letters.

However, the first experiment also showed that counterphase images can be perceived through mechanisms which by-pass the temporal resolution of their counterphase. Tachistoscopic presentation of single letters suggested that this perception occurred at the onset image of the counterphase.

The second experiment shows that the perceptibility of the initial image of counterphase could to some degree be minimised by the use of a premask. Presumably this works by occupying a buffer which otherwise could be used to store the initial image of the counterphase.

The second experiment also showed that the problem identified in the first experiment concerning the perception, without temporally resolution, of counterphase letter can be ameliorated by using a pre-mask. The existence of this problem and the existence of a means of minimising suggests all work using counterphase images should where appropriate proceed them with suitable pre-masks.

The third experiment ruled out an explanation of the effectiveness of the premask in terms of a difference between the experiments in the use of the nonguessing option. When this option was absent the premask was still as effective, as when present, in inhibiting the visibility of tachistoscopically seen letters.

The third experiment also showed that the nature of the premask -- counterphase or static -- did not matter as each was equally effective as the other. This removes doubts raised earlier in this chapter whether the premask used in the later experiments were not as effective as static ones.

Notes.

1. The presentation of letters in the form of a grid was settled upon after preliminary explorations. One of the problems of presenting letter stimuli in rapid flicker are artifact dark ghosts that form around the letter outlines (this was discussed in the previous chapter). It was found that a black line box tightly fitting around a letter minimised the perception of otherwise detectable visual ghosts. Organising black line boxes in horizontal and vertical rows and columns produces the appearance of letters contained in grids. Letters presented tachistoscopically were also in black line boxes.

2. Unfortunately, electronic alternatives which would have increased accuracy were either not feasible or not available. The reason was limited video buffer memory accessible in the programming language. In computer terminology, there were only two video pages of memory available. One was used for each of the two frame-images: the consequence of this was that there was not a third which could act as a dummy page to hid the two containing the two frame-images. Ironically, the Super Seven vga card allows up to eight video pages. Unfortunately, they are not accessible accept through machine level programming. In the experiments reported in this thesis, a different programming technique was used for which this problem does not arise. However, the technique was limited to images of around 2 cm by 2 cm and

not applicable to the presentation of a large array of letters. The hand timing follows from the lack of an electronic start. Further, there would have been problems in electronically determining the end point of a sequence of 20 named letters. While this could have been overcome, the limited accuracy of the means used in this experiment were adequate since the aims of it were more qualitative than quantitative (quantitative timing was carried out in part B).

3. A further problem was that subjects varied in the pacing of their letter reading particularly whether they paused at the beginning of the second line.

4. There were two further factors: first, writing errors and manually recording time are difficult concurrent tasks. Second, this was compounded by the experimenter's limited short term digit span. In retrospect, use of a tape recorder should have been made.

5. The reasons for this were (a) to ensure a steady rate of subject responding and (b) to minimise subject discomfort. Preferably, subjects should have been forced to guess since the findings of subliminal perception suggest subjects often claim not to be able to see things, which they do if forced to guess. However, preliminary experience with the use of flickering stimuli suggested subjects found them uncomfortable. It was therefore decided to minimise

this as far as possible. Forced guessing is not pleasant and it was felt that its removal while not compromising the central aims of the experiment made the experiment easier on the subject.

5.1. Introduction

In chapter 2, the problems and opportunities for exploring the two visual channels were reviewed. It was concluded two different techniques could functionally dissociate the magno and parvo channels. This chapter experimentally explores whether they had any effects upon the processing of the lexical stage of reading (the next chapter explores their effects upon prelexical reading processes).

The two methods presented stimuli in counterphase (flicker). They differed (as discussed in chapter 3, section 3.7.): (1) in their spatial frequencies (low: 1 to 2 cycles per degree; high: 4 to 8 cycles per degree); (2) whether they were near-isoluminous or luminosity contrastive and (3) counterphase (17.5 Hz and 12.5 Hz). In chapter 2, it was argued that while the magno channel could perceive low spatial frequency luminous contrastive stimuli it had difficulties perceiving high spatial frequency near-isoluminous ones; (and vice versa, the parvo channel could perceive high spatial frequencies and isoluminous stimuli but had difficulties with low spatial frequencies and contrastive ones). Further, it was suggested (chapter 2, section 2.4.1.) following Livingstone and Hubel (1987) that the magno channel could see images presented in 17.5 Hz

counterphase but this would block their perception by the parvo channel which could however see images in the slightly slower 12.5 Hz counterphase.

Discussion of these composite presentation conditions refers to them individually as 'magno' and 'parvo' and collectively as the 'channel' factor. This was done because it provided a short and convenient means of labelling them. It should be emphasised this is a putative labelling based upon their intended characteristics (to emphasise this the names 'magno', 'parvo' and 'channel' are always placed in quotation marks). It does not intend to imply the claim that they actually functioned to isolate these channels -- indeed to show this was one aim of the experimentation.

Figure 5.1. Summary of the two visual presentations 'magno' and 'parvo' and theoretical rationale. (Full details in chapter 2, section 2.3.).

magno	effect	parvo	effect
isoluminosity	-	isoluminosity	+
contrast	+	contrast	-
High Spatial frequency	-	High Spatial frequency	+
Low Spatial frequency	+	Low Spatial frequency	-
17.5 Hz counterphase	+	17.5 Hz counterphase	-
12.5 Hz counterphase	+	12.5 Hz counterphase	+

- + = factor causes no cognitive interference
- = factor causes cognitive block or impairment

note later in this chapter the effects of counterphase are qualified (as already discussed in chapter 2).

5.2. The lexical decision experiments.

5.2.1. Aim.

Three lexical decision experiments investigated the effects of 'magno' and 'parvo' stimulus presentation upon the reading process. In each experiment three variables believed to affect lexical decision reaction times were used: word frequency, imageability and letter length. The rationale was that if 'magno' or 'parvo' stimuli had separate influences upon lexical processing then these influences would interact differently with the effects of these variables upon lexical decision.

5.2.2. Lexical decision and lexical processing.

Lexical decision involves subjects making, as quickly and accurately as possible, a judgement whether a stimulus is a word or a nonword (a sequence of letters that do not spell a proper word). Usually, as in the following research, subjects pressed one of two keys: one for words, the other for nonwords. The dependent variables measured in lexical decision are time taken to make the decision response, and its accuracy.

In lexical decision, response time and accuracy vary with word and nonword characteristics. For instance letter length usually has little effect upon words and nonwordlike

nonwords while it effects wordlike nonwords (the more letters the longer the response time) (Frederiksen & Kroll, 1976; Seymour, 1987a; 1987b). In the case of words, the frequency of written usage (Frederiksen & Kroll, 1976; Seymour, 1987a; 1987b) and their imageability (the ability of people to visualise their referents) affects (Kroll & Merves, 1986) the accuracy and durations of lexical decisions (the more commoner and more imageable a word the quicker and more accurately it is recognised as a word). There are two approaches to explain the effect lexical variables have upon the time and accuracy to judge whether a letter string stimulus is a word or not.

First, the lexical approach suggests that lexical variables affect lexical decisions through their affects upon lexical processes. Second, the familiarity approach, which in contrast suggests that lexical decisions are made without involving lexical processes.

According to the lexical approach, subjects try and make for each stimulus a unique word identification. If after a deadline they fail to make an identification, they treat the stimulus as a nonword. This is only the case for wordlike nonwords; nonwordlike nonwords may be detected by their visual dissimilarity to real words, (for instance, KLXVC could not visually [due its lack of vowels] be a word and so can be quickly identified as a nonword [Seymour, 1987a; 1987b]). The lexical approach tends to assume that

the processes used in lexical decision overlap with those used during reading to identify words. This until recently provided the only explanation for why lexical variables effected lexical decisions.

However, an alternative approach: the familiarity approach (Balota & Chumbley, 1984) has recently been suggested. This approach unlike the lexical one does not assume that the processes used in lexical decision are the same as those for reading. More specifically, it claims that people make lexical decisions without making unique word identifications. Instead this approach suggests subjects use the stimuli's familiarity and meaningfulness. The basic notion is that words and nonwords vary in a continuum of familiarity and meaningfulness. (1). Subjects filter out the extremes of this continuum with stimuli experienced as highly familiar judged to be words and ones experienced as unfamiliar as nonwords. (2). In the middle of the continuum, words and nonwords cannot be easily distinguished hence an extra stage occurs involving a spelling check. In neither case is a unique word identification made so there is no overlap between the processes involved in lexical decisions and the lexical reading processes responsible for identifying words.

Balota and Chumbley's non-lexical approach, if correct, would undermine the use of the lexical decision for investigating lexical reading processes. However, their

arguments have been challenged by Monsell, Doyle and Haggard (1989; Monsell, 1990). Monsell's criticisms are partially explained in the next section concerning frequency effects.

5.2.3. Word frequency

Some words are more commonly found in writing than others. The frequencies with which words appear in print has been calculated from representative samples of commonly read texts (Francis & Kučera, 1982). Word frequency has been shown to effect lexical decision: the time taken to respond to whether a letter string is a word is quicker for high frequency words than low frequency ones. Several types of theory, the main ones being the logogen model (Morton, 1969) and the parallel distributed processes account of reading (McClelland & Rumelhart, 1986) explain this phenomena in terms of lexical processes. Space limits giving full details of these various accounts, though briefly: in Morton's model the frequency effect is produced as a consequence of the different activation levels of word identification units in the logogen; and in connectionist models it lies in the better trained associations by which units recognise words (for connectionist models of reading see also Chapter 1, section 1.5.).

Balota and Chumbley (1984) questioned the idea that the word frequency effect derives from lexical processes. Instead they argue that the frequency effect is the by

product of a nonlexical familiarity/meaningfulness judgement process: as noted above (1) high frequency words are easily distinguished from nonwords by familiarity, while (2) those that are less familiar and might be confused by this criteria with nonwords are recognised by a spelling check.

The positive evidence provided by Balota and Chumbley is slight. Their main argument is negative: that they failed to find frequency effects on several tasks which should have produced them if the frequency effect associated with lexical decision was indeed a product of lexical processing. Since the credibility of the following experiments using lexical decision partially depends upon them potentially tapping lexical processes, a brief review of their arguments and their critique by Monsell needs to be presented.

First, Balota and Chumbley claim that no word frequency effect is found in semantic categorisation tasks (for instance, a subject is given a category like BIRDS and asked whether a trial word like ROBIN is an example). This task requires words to be lexically identified. If lexical identification is frequency sensitive then this should effect reaction times to category judgements. However, Monsell et al (1989) noted several limitations in the category task used by Balota and Chumbly as an index of lexical processing.

- The words used by Balota and Chumbley had a limited frequency range. The narrower the range of frequencies used the less likely an effect of frequency will show.

- There were processes subsequent to lexical identification related to the categorisation task. The extra time needed to carry these out might have masked the effects of frequency of the earlier lexical identification stage.

- Balota and Chumbley's categorisation task was complex: the subject was given a category and then the trial word. Monsell et al (1989) simplified the task by removing the category word by asking subjects to make general category judgement concerning personhood or thingness. This modified task produced a frequency effect.

Second, Balota and Chumbley (1986) criticised the attribution to lexical processes of the frequency effect for pronouncing written words. Balota and Chumbley (1986) claim that most of the frequency effect happens after lexical access at the stage concerned with vocal production. They argued that frequency effects persisted even if subjects were required to delay their pronunciation -- a circumstance which should have eliminated any time effects deriving from lexical processes. Monsell et al found a number of limitations in Balota and Chumbley's delay task.

- They failed to match high and low frequency words for initial letter a factor known to influence pronunciation times.

- The words which the subjects were to respond to remained visible until they responded -- they could have (re)read the display before responding.

- The above possibility of rereading stimuli perhaps explains an oddity in their data: normally prepared delayed responses take 160-300 ms; Balota and Chumbley's subjects averaged about 350 ms. Monsell et al carried out a more carefully designed delay pronunciation tasks and failed to find frequency effects.

In conclusion, there is considerable doubt over Balota and Chumbley's work.

5.2.4. Imageability

There is little evidence that imagery effects lexical access. However, since there could be an interaction between the visual channels and imagery (argued for below) this was thought to be a possibility worth exploring even against doubts (creating the required factoring of the stimuli with imageability was not that difficult and so was judged worth including even though there was a low probability it might yield interesting findings).

Some words make reference to visually identifiable objects or properties like BLUE or HOTEL. They are imageable. Other words, in contrast, do not. They are not readily visualised and are abstract, examples are TRUTH and HOT. The property of imageability is closely related with that of concreteness: the degree to which a word's reference has a concrete referent. The difference between them can be illustrated by the words BLUE and HOTEL both of which are high imageability words though only HOTEL is a highly concrete one. Concreteness and imageability values for words are closely correlated -- $r = .78$ (Gilhooly & Logie, 1980). In some of the following discussion I make the assumption that the high correlation between concreteness and imageability enables research upon one to a limited extent to be generalised to the other.

As noted, imageability is of interest since like word frequency it might tap lexical processes. In addition, it is conceivable that the lexical processes of highly imageable words may have a special relationship with the parvo channel. Though conceivable it is however most likely that imageable and abstract words are processed the same way with any differences between them occurring postlexically. It is however possible that they may be processed differently.

The reason for raising this possibility is that the lexical processes responsible for recognising concrete and abstract words appear from two case studies to be neurologically doubly dissociable with the reported existence of lesions producing deficits in reading low but not high concrete words (Shallice & Warrington, 1975) and conversely lesions producing defects affecting the reading of high concrete words more than low ones (Warrington, 1981). One interpretation of this double dissociation is that the lexicons responsible for representing imageable and abstract words are differently or separately stored or connected with the semantic system. This suggests that there may exist different processes or connections underlying the identification of concrete and abstract words.

There are a number of possibilities for the nature of these processes or connections. One candidate (other interpretations are possible, indeed they are more likely) for the difference between them could derived from the

parallel existence to the reading lexicon of an image lexicon (Paivio, 1971, 1986) used to recognise visual objects and properties. The existence of this extra lexicon could change (one way is described below) the processing of imageable words making their processing different from abstract ones.

Kroll and Merves (1986) suggest one possibility. In suggesting an explanation for the reaction time advantage in lexical decision for high concrete words over frequency and length matched abstract words (Kroll & Merves, 1986; James, 1975), Kroll and Merves (1986) hypothesised that 'concreteness effects might arise as a function of prelexical factors that influence earlier stages of lexical retrieval' page 100. One possible influence upon this prelexical stage might lie in the visual channels. As mentioned in chapter 3, the main function of the parvo channel is the visual recognition of objects, something which involves it with a special relationship to the image lexicon. In contrast, the functions of the magno channel primarily involve aspects of vision other than image recognition and so it would not be expected to have a special relationship with the image lexicon. The existence of a special relationship between the recognition of imageable words and images and special relationship between the parvo channel and image processing could result in a third between between the parvo channel and imageable words.

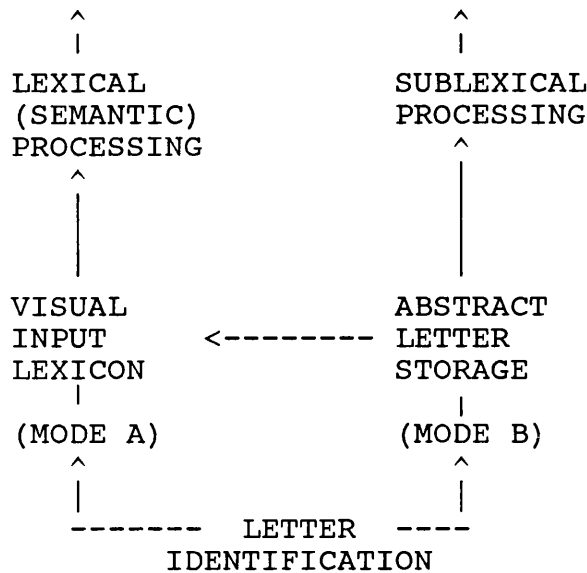
If this was the case then an interaction might appear between the 'channel' technique of presentation and the imageability/ abstractness effect upon lexical decision. For instance, if there was a special relationship between the parvo channel and imageable words then a visual presentation which blocked parvo channel perception might affect imageable words more than abstract ones.

Failure to find this interaction however would not imply 'parvo' stimuli do not affect the reading process. Concreteness/imageability correlates with other variables such as age of acquisition (Gilhooly & Logie, 1980) and ease of predication (Jones, 1985). Moreover, effects attributed to concreteness/imageability have been attributed to age of acquisition (Coltheart, Laxon, and Keating, 1988) and ease of predication (Jones, 1985). Therefore the concrete/imageable word advantage in lexical decision could be the product of processes unrelated to the conjectured special relationship between imageable words and the image lexicon with this advantage instead deriving from the effects of age of acquisition or ease of predication.

5.2.5. Letter length

Letter length affects lexical decision reaction times with no or slight length effects for words but strong ones for wordlike nonwords (Frederiksen, & Kroll, 1976). There

Figure 5.2. Illustration of Ellis, Young and Anderson's (1988) model of processes which give rise to length effects. With alternations from their illustration on page 269.



are several ideas why this might be the case. The letter length effect for wordlike nonwords has been attributed by Seymour (1987a; 1987b) to their being parsed into-sublexical units, a process not required for words. Ellis, Young and Anderson (1988) have suggested, not incompatibly with Seymour, that nonwords are buffered (by a process they refer to as mode B) in an abstract letter storage. Words in this account however do not need storage and thus are directly inputted by a quick and parallel process they call mode A (see illustration). Though there might be length effects for this process they are slight. Why should nonwords be parsed or buffered in abstract letter storage? One possibility is that words and nonwords are processed differently in lexical decision with word responses originating through a process

involving lexical identification (or if Balota and Chumbley are correct some below threshold criteria on a familiarity/meaningfulness continuum) and nonwords through a spelling check process (as suggested by Balota and Chumbley). The need for parsing and abstract letter storage could be a consequence of the need to prepare letters for this spelling check process.

The qualification wordlike for nonwords is important: nonwords which are unwordlike do not show in lexical decision tasks length effects, presumably as noted above because their orthographic illegality provides a quick test for their being nonwords (Seymour, 1987a; 1978b).

Length is a variable of interest since unusual presentation of words and nonwords -- left visual field (Ellis, Young & Anderson, 1988), vertical and zigzag presentation (Seymour, 1987a; 1987b) produces length effects normally absent (as with words) or if already present (as with wordlike nonwords) magnifies them (Seymour, 1987a; 1987b). If the putative magno and parvo stimulus presentations change the processing of letters then they might induce the use of buffering, parsing or other processes that could lead to increased length effects.

5.3. Experimental design

5.3.1. Factoring

The experimental design was factorial with stimuli presentation ('magno' or 'parvo') crossed with word frequency (high or low) and imageability (imageable or abstract). The words and words were blocked into high imageable and abstract groups (four of them). Within each block there were an equivalent number of high and low frequency words.

A strong theoretical reason existed for blocking the stimuli. There was an experimental need to produce as large as experimentally feasible main effects for word frequency and imageability so as to increase the chance of obtaining an interaction between them and the stimulus presentation conditions. Imageability effects are weak compared to frequency ones. However, the effect of imageability can be increased by blocking into high and low imageable (abstract) groups (Kroll & Merves, 1986). (Assuming the findings for concrete words do generalise to imageable ones).

The stimuli were balanced across subjects and blocks such that each stimulus appeared an equal number of times in both stimulus presentations and each block. The order of the visual presentations was alternated between stimuli.

5.3.2. Stimuli

Since the effects of frequency and imageability are greatest at their extremes, the members of the four factorial groups were selected from the extreme members of a large set of words with known frequency and imageability values.

This was done by typing (2599, in total) words in a print out of the MRC psycholinguistic database (Coltheart, 1981) longer than 2 letters and less than eight with a frequency and imageability value into a computer file. The word frequency values in the MRC database are Francis and Kučera, (1967); the imageability values are composite (Wilson, 1987) of Paivio, Yuille & Madigan (1968) expanded, Toggia & Battig, (1978) and Gilhooly and Logie (1980). A program written in Pascal extracted 48 (12 X 4) groups of eight words from this file.

No attempt was made to restrict words to nouns: there is little evidence that grammatical class strongly effects reaction time. That evidence which exists limits it to closed class (articles and prepositions) words (Taft, 1990). No words of this kind were used. Details of the words and their word frequency and imageability are contained in the Appendix Section B: Stimulus tables (Chapter 5) Table B.1.a.

The factorial word groups had the following characteristics: (a) each group had approximately the same mean letter length; (b) each eight word group shared the same mean frequency and imageability value in a factorial pattern. Thus four sets were constructed sharing the same mean letter length of the four permutations of extreme word frequency (high and low) and imageability (imageable and abstract). These were used to create the blocking structure of the stimuli (four blocks of 96 [48 words and 48 nonwords]).

These 192 words were matched for length with 192 wordlike nonwords taken from several sources; (for Experiment 5, an additional 192 nonwordlike nonwords were created from this list of nonwords by substituting randomly selected consonants for their vowels). Their presentation was randomised with the restriction that no sequence longer than two nonwords would appear together. Details of the nonwords are contained in the Appendix Section B: Stimuli tables (Chapter 5) Table B.1.b. Sixteen stimuli sets were generated in which stimuli were balanced across subjects for appearance in the two 'channel' conditions 'magno' and 'parvo' and block position first half or second half.

5.3.3. Subjects

Subjects were recruited from postgraduates, undergraduates and research assistants of the Psychology and

the Geography departments at UCL. All subjects were asked whether they suffered from (a) dyslexia, (b) uncorrected short sightedness, (c) epilepsy or migraine and (d) colour blindness (if there was a query they were tested with the Ishihara (1979) Tests for colour-blindness). Any subject answering yes to these questions was eliminated. No subject whose first language was not English was run and no subject participated in more than one experiment.

5.3.4. General description of Method

Most of the experimental details were shared between the experiments, therefore these are given first and then the specific differences between them are briefly discussed in separate sections before their statistical analysis.

5.3.4.1. Experimental procedure

After recruitment, the subject was sat in front of a table and a monitor. The room was lit with a desk top light containing a 25 Watt bulb placed to the monitor's side shining upon the table such that its light did not directly illuminate the screen or surfaces that might be reflected in it, while providing sufficient light to enable the experimenter to type instructions for the program on the computer's keyboard. The subject was sat 60 cm from the screen. The importance of holding a near constant head distance was emphasised: the experimenter sat in an adjacent

position making observation of head movement easy to see. The subject was first shown the buttons upon which they make their responses and told to hold them in a comfortable position with the red one in their most dominant hand and the black in the other one.

The first part of the experiment involved (as outlined in chapter 3, section 3.5.2.) a determination of near-isoluminance. After this was found it provided the luminosity level for the rest of the experiment.

The subjects were asked to rest their thumbs on the buttons. They were warned that the following experiment would be roughly divided in four by three breaks and would take in total twelve to fourteen minutes. After personal details were taken, it was explained to them that would see flashing words, half of which were words and the other half wordlike nonwords. It was then clarified to them that 'that a real word is one which they could find in an English dictionary, a nonword was one which while it might look like a word was not one they could find in a dictionary'. They were told that if they saw a real word they were to press the red button and the black one for nonwords. A name for their data file was typed in at prompt together with a number (running from 0 to 15) which identified the stimulus balance group to which they were assigned. A group of at least 15 practice words and nonwords started the session. The instructions to press the red button for real words and

the black for nonwords was repeated. They were told to react as fast as they could compatible with accuracy. They were also told it was normal to make errors and while these might be frustrating to continue without unduly worrying about them. They were also told that only a whole word or nonword would appear: preliminary trials found that some subjects experienced a space following the letter I causing them to believe that there existed a word division between it and its adjoining letter. The experimenter continued the practice session until the subject was familiar with the task. Each practice item required a button responses followed by a key press. The experimenter paced the subject by pressing the return key on the keyboard.

When the experimenter was satisfied that the subject had learnt to respond correctly, the subject was told that the experiment would begin and that they were not to talk while it was running. The experimenter initiated the experiment by pressing the E key (for Experiment). After 96 stimuli the program displayed a break sign. The experiment was restarted by the experimenter pressing the return key. At the end of the experiment the subject's reaction times and key responses were written to a file on the computer's disk.

5.3.5. Stimulus presentation

The details of the letters and the two presentation conditions have been discussed, respectively, in chapter 3, section 3.7. and chapter 2, section 2.4.1. They were used to generate the stimuli which were centred at the screen's centre. A small cross initiated a trial and was displayed for a second plus a random number of milliseconds between 0 and 200. It then disappeared to be replaced by the stimulus which remained on the screen until one of the buttons was pressed. This returned the screen to the fixation cross.

Initially, only one experiment was planned to explore the possible effects of channel dissociation upon lexical decision. In the end three were carried out.

5.4. Results

5.4.1. General

Fifteen words had errors in at least one experiment of 50% or more. They were excluded from the following analysis. For details of individual stimuli including where appropriate their frequency and imageability values and their mean experimental reaction times and errors in the three experiments, see Appendix Section 2: Stimuli tables (Chapter 5). Table B.1.a. (words) and Table B.1.b (nonwords). Reaction times less than 300 ms and greater than 1,500 were excluded from the analyses.

Box and Cox (1964) suggested that there were a number of advantages for transforming (for instance, inverse, log and square root) data. However, data transformation has been criticised for making interpretations particularly of interactions, difficult and for being unnecessary given the robustness of ANOVAs (Games, 1983, 1984). Further, in the search for significant results 'transforming to significance' may occur increasing Type I errors (ie finding a nonsignificant result by chance as significant) (Games, 1983, 1984). The data was analyzed untransformed.

The statistical analysis which follows used SPSS PC+ v.3 and Genstat5 (Payne, Lane et al, 1987). The data was preprocessed into appropriate means by programmes written in Pascal. The ANOVAs used the regression method. The analysis of letter length occurs in a separate section following the discussion of the individual experiments.

5.4.2. Experiment 4.

The main question addressed in the fourth experiment was whether the two presentation conditions, 'magno' and 'parvo' affected the two lexical factors, word frequency and imageability. This presumes positive answers to another: did the two presentations actually tap magno and parvo channels. This question receives some kind of a tentative answer from this experiment and the following two.

Method: Experiment 4.

The 192 words and 192 wordlike nonwords were randomly presented and balanced across subjects for presentation in the two 'magno' and 'parvo' 'channel' conditions. The subjects were asked to make lexical decisions upon them. The 'magno' presentation involved the word's letters being presented at 17.5 Hz and the 'parvo' presentation involved them being presented at 12.5 Hz. The 'magno' stimuli were made up of 17.5 Hz alternating black and yellow, 9 mm by 14 mm, blurred edged letters. The 'parvo' ones were made up of smaller 3.4 mm by 5 mm green and red coloured letters/backgrounds alternating at 12.5 Hz. The mean luminosity of the 'magno' stimuli was the same as that of the 'parvo' ones: 2 cd/m² (for more details see sections 3.6 and 3.7).

Statistical analysis

The means and standard deviations for reaction times and the mean error for words and nonwords and the four word conditions for the 16 subjects in the two visual presentation conditions are given in appendix C.1.a (means for words and nonwords in the two conditions) and C.1.b. (means for the lexical factors in the two conditions).

For reaction times, the nonlexical main (presentation condition and word vs nonword) effects were large (see

figure 5.3. [figures for the Experiment 4 are at the end of this section]): decisions in the 'magno' presentation condition was faster by 122 ms to those in the 'parvo' one (666 ms and 788 ms, respectively) (for the appropriate ANOVA see ANOVA table 5.1. [contained in the Appendix]). The main effect is illustrated in the graph contained in figure 5.3. This main effect was significant by repeated measures ANOVA $F(1, 15) = 58.83, p < .001$. Words were responded to 107 ms faster compared to nonwords (673 ms and 780 ms). This was significant $F(1, 15) = 28.8, p < .001$.

However, for errors, the two presentation conditions were only marginally different: 'magno', 3% and 'parvo' 3.8%, respectively. They were not significantly different $F(1, 15) = 2.34, p = .147$. Likewise, 0.5%, the difference, between words (3%) and nonwords (3.5%) was not significant $F(1, 15) = < 1, ns$. (see ANOVA table 5.2.). This suggests that the results were not affected by a time accuracy trade off where an increase in reaction time is associated with a corresponding decrease in the number of errors.

The main effects for reaction times for the lexical factors were large. Imageable words were read 82 ms faster than abstract ones (646 ms and 728 ms) $F(1, 15) = 92.6, p < .001$. The high frequency words were read 107 ms faster than the low frequency ones (634 ms and 741 ms), $F(1, 15) = 64, p < .001$ (see ANOVA table 5.3.). The main effects are illustrated in figure 5.4.

The error data unlike that for nonlexical factors was significant for lexical ones. Imageable words produced fewer errors (2.4%) than abstract ones (5.9%). The relevant ANOVA is contained in ANOVA table 5.4. The difference between abstract and imageable words was significant $F(1, 15) = 10.7$, $p = .005$. Similarly, frequency affected error rate with high frequency words producing less errors (3.8%) than low frequency ones (4.5%). A difference which again was significant $F(1, 15) = 31.1$, $p < .001$. This suggests that low frequency and abstractness not only caused subjects to delay making lexical decisions but made them more inaccurate.

The two lexical factors strongly interacted with each other with low frequency increasing the effect of abstractness both in terms of reaction time responses and error rates. For reaction times frequency was highly significant, respectively, $F(1, 15) = 51.4$, $p < .001$. Likewise for errors rates, $F(1, 15) = 18.8$, $p < .001$. (See ANOVA tables 5.3. and 5.4.).

However, for both reaction times and errors, there was no interaction either between channel and the two lexical factors; for reaction times: imageability, $F(1, 15) < 1$, ns; and word frequency $F(1, 15) < 1$, ns.; and by errors: imageability $F(1, 15) = 2.5$, $p = .136$; frequency $F(1, 15) < 1$, ns. The third order interactions between the two 'channels' and the two lexical variables were not

significant either: RTs, $F(1, 15) = 2.46$, $p = .138$; errors, $F(1, 15) < 1$, ns. See ANOVA tables 5.3. and 5.4.

This lack of interaction between the two lexical factors and the 'channels' suggests that the 'channel' presentation conditions had no effect upon lexical processing -- at least in so far as word frequency and imageability indexed lexical processing (something which noted above may not be the case). This lack of interaction was not due to a general lack of main effects for the two lexical factors: as noted above they both, individually and in interaction, strongly affected reaction times and error rates.

Was this because the two methods of presenting stimuli did not affect the magno and parvo channels? The two presentations were different in that they produced a strong main effect for the channel factor, with 'parvo' stimuli having longer reaction times than 'magno' ones. However, this is not evidence for the channels having a cognitive effect since this could equally (and perhaps more plausibly) have been due the 'parvo' stimuli being perceptually more difficult to see than the 'magno' stimuli.

There is however, evidence from interactions with word/nonwords that could tentatively suggest that the two 'channels' had an effect. For reaction times there was a significant interaction between the word factor and channel

$F(1, 15) = 8.4, p = .011$. However, this interaction was not found with error rates, $F(1, 15) < 1, ns$. See ANOVA tables 5.1. and 5.2.

This interaction could be either due to (1) some non-perceptual difference between the two channel presentations or (2) a non-perceptual effect secondary to perceptual delay upon the lexical decision process. Nonword decisions for the 'parvo' channel presentation were particularly delayed: at 857 ms they took over 130 ms longer than the other nonword and word decision times. This raises the possibility that the general delay effect of the 'parvo' channel effected nonword decisions more than word ones. The results from later experiments somewhat clarify this issue.

The main effect for imageability needs further discussion: it was surprisingly high. Kroll and Merves (1986) carried out several lexical decision experiments with concrete and abstract words (concreteness as noted above strongly correlates with imageability and so can be used as a limited guide to its effects). Their experiment 3 corresponds most to the present experiment in that it used blocked concrete and abstract words and wordlike nonwords. They found that concrete nouns were responded to 33 ms faster than abstract nouns (693 vs 726 ms, respectively). This was much lower than the present experiment's difference of 83 ms. The interaction between word frequency and concreteness in their experiment was not significant. In the

present experiment the interaction between word frequency and imageability was high $F(1, 15) = 51.4, p < .001$. This result was found in the remaining lexical decision experiments. It probably reflects the extreme values for frequency and imageability used in these experiments. However, at the time of carrying out the first lexical decision experiment, two aspects of the stimulus presentation were thought to be possibly responsible for the strong lexical factor effects and interactions: the use of wordlike nonwords and counterphase presentation.

Further it was felt that slight variation in the first lexical decision experiment could potentially create experimental conditions which might produce an interaction (which had not occurred in the first lexical decision experiment) between visual presentation and the lexical factors. Two further experiments were carried out. Experiment 5 used nonwordlike nonwords and Experiment 6, (using the same nonwords as Experiment 4) presented the counter-phase stimuli statically. Otherwise they were like the first experiment.

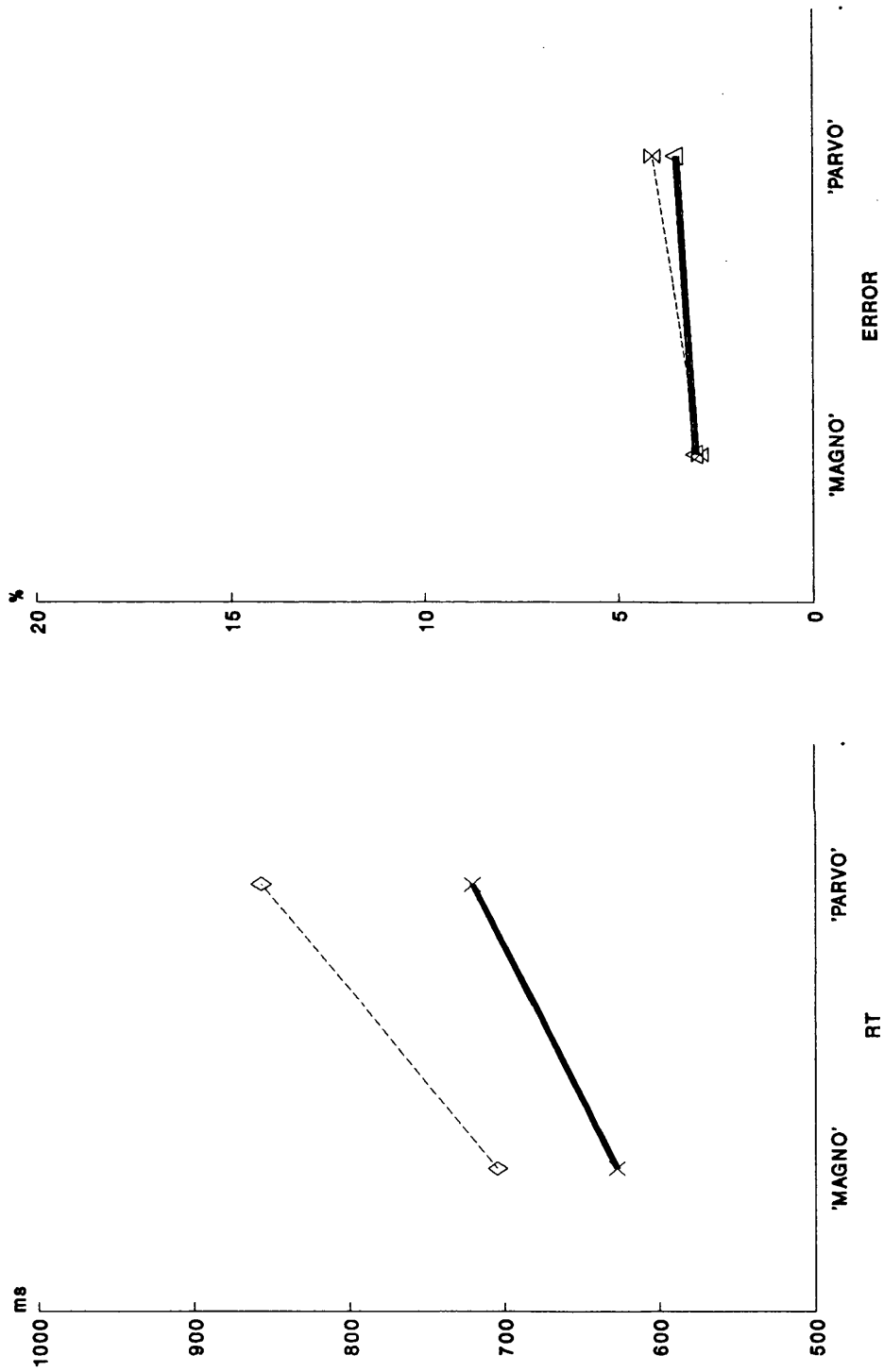


Figure 5.3. Experiment 4. Graph illustrating the main effect of 'channel' upon word (solid line) and nonword (broken line) reaction times and errors.

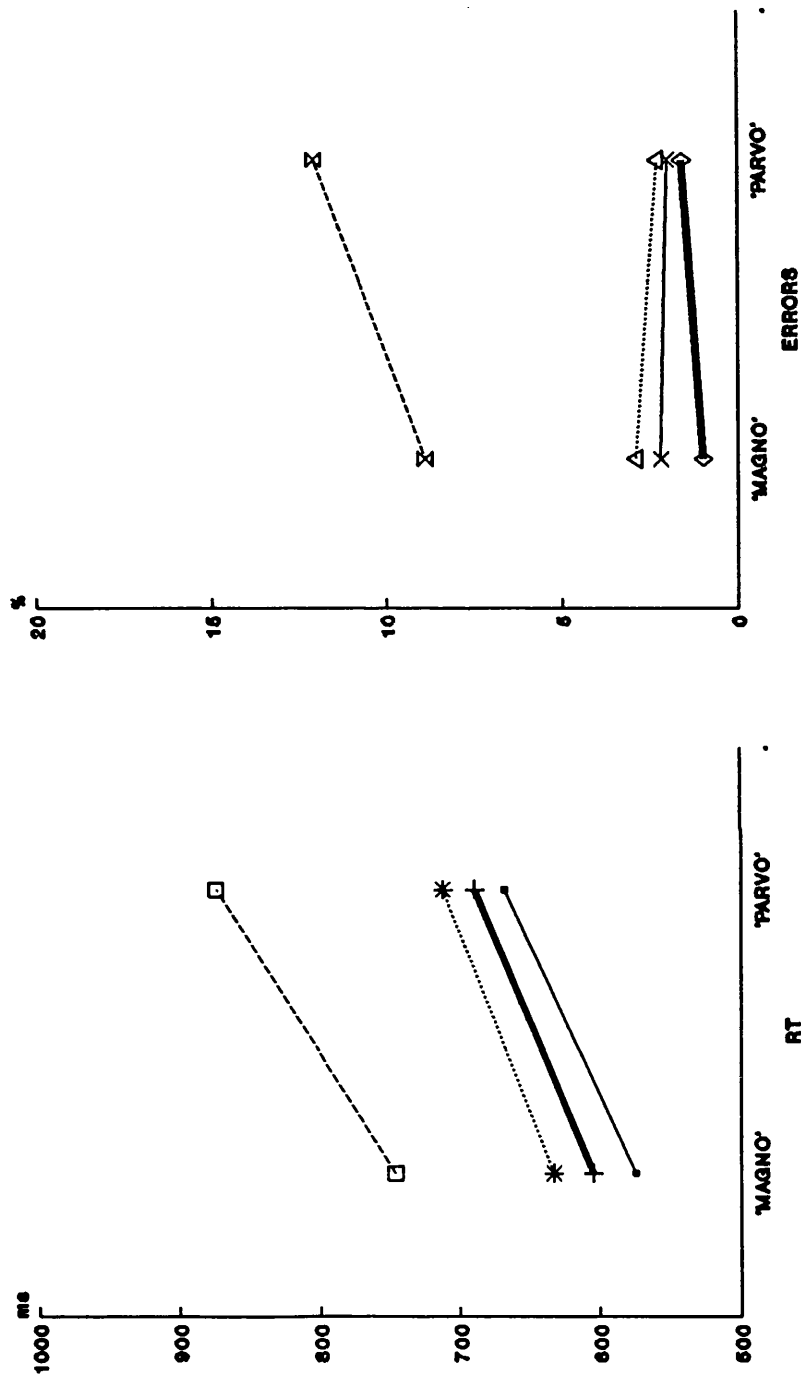


Figure 5.4. Experiment 4. Graph illustrating the main effect of 'channel' upon lexical factors. Solid lines, high frequency (thin = imageable, thick = abstract); broken lines, low frequency (fine broken = imageable, coarse broken = abstract).

5.4.3. Experiment 5.

Method: Experiment 5.

The 192 words and 192 nonwordlike nonwords were randomly presented. The 'magno' and 'parvo' stimuli were presented in the same manner as in Experiment 4. The 192 nonwordlike nonwords were created from the nonwords used in the previous experiment by substituting randomly selected consonants for their vowels

Statistical analysis

The second lexical decision experiment produced a different pattern of word and nonword responses with nonwords being easier to respond to than words. Details of the individual subject's reaction time and error means for the various condition are contained in the data tables in the appendix C.2.a (word vs nonwords) and C.2.b. (lexical factors).

Nonword responses (624 ms) in this experiment were both quicker than those shown for words (631 ms) see figure 5.6. (at the end of this section). The seven millisecond difference was not however significant $F(1, 15) < 1$. There were also fewer errors for nonwords than for words, 3.4% compared to 3.8%, though this was not significant $F(1, 15) < 1$. For the relevant ANOVAs see tables 5.5. and 5.6. (in

appendix). This effect is not unexpected: the nonwordlike nonwords were easier to recognise as nonwords than the wordlike ones of Experiment 4 due to their visual dissimilarity from real words.

In most other respects this experiment produced the same results as the previous one: there was a highly significant main effect (details of significance see tables 5.5. and 5.6.) between reaction times for the two visual presentations, 'magno' (583 ms) 'parvo' (671 ms) $F(1, 15) = 49.56$, $p < .001$, though unlike the previous experiment more errors occurred for 'parvo' stimuli than 'magno' ones $F(1, 15) = 9.69$, $p = .007$.

As in the previous experiment, reaction times for the two lexical factors had significance levels of less than .001: frequency $F(1, 15) = 24.65$, $p < .001$; imageability $F(1, 15) = 23.23$, $p < .001$; frequency by imageability $F(1, 15) = 16.77$, $p < .001$. As in the previous experiments, the error rates were not significant: frequency $F(1, 15) = 4.06$, $p = .062$; imageability $F(1, 15) < 1$, n.s; frequency by imageability $F(1, 15) < 1$, n.s. Like in the previous experiments there was no interaction between channel and lexical factors for either reactions times or errors. (For the relevant ANOVAs see tables 5.7. and 5.8.)

One striking feature about the lexical factors is that word frequency had a diminished effect relative to

imageability in the second experiment compared to the first. In the first experiment low frequency concrete words had faster reaction times than high frequency abstract ones (respectively 612 ms compared to 626 ms) where as in the second they had slower ones (respectively 673 ms compared to 647 ms). A split plot ANOVA between the two experiments was carried out, (contained in table 5.9.). There was an significant effect of experiment upon frequency $F(1, 30) = 6.25$, $p = .018$, but not imageability $F(1, 30) = .15$, $p = .701$.

This is curious -- the same relative relation between high abstract and low concrete words found in the first experiment occurs between the second and the third (to be discussed below). Since both shared the use of wordlike nonwords, in contrast to the second which used unwordlike nonwords, this suggests that the type of nonwords used in lexical decision affected the relative impact upon response reaction times of word frequency and imageability. However an alternative explanation exists: imageability was blocked with 48 imageable (or abstract) words (and an equal number of nonwords) followed by 48 of the opposite kind; in contrast, high and low frequency words were presented unblocked. It could be that unblocked lexical factors have weaker effects than blocked ones when nonword judgements can be made upon visual clues.

An interaction occurred between 'channel' and the word factor in reaction times, $F(1, 15) = 7.24$, $p = .017$. However unlike the previous experiment where such an interaction also occurred, nonword decisions were not greatly different from word ones -- indeed 'magno' nonwords were marginally faster than 'magno' words -- 'magno' words (593 ms), 'magno' nonwords (573 ms); 'parvo' words (668 ms) and 'magno' nonwords (674 ms).

In Experiment 4, an interaction also occurred between 'channel' and word/nonword judgements but since in this experiment nonword responses were also much slower than word ones a general prolongation of reaction times could have effected the most delayed response (which was the 'parvo' nonwords) thus causing the interaction. This however cannot explain the results of the present experiment because of the similar reaction times of nonwords to words. However, the 'parvo' stimuli were more delayed than the 'magno' so though this rules out an explanation based upon a simple effect of perceptual delay upon responses it does not rule out a more complex delay effect in which the difference between words and nonword reaction times increases with longer reaction times. Experiment 6 also produced some relevant information and further discussion upon this matter is left until section 5.5.2.

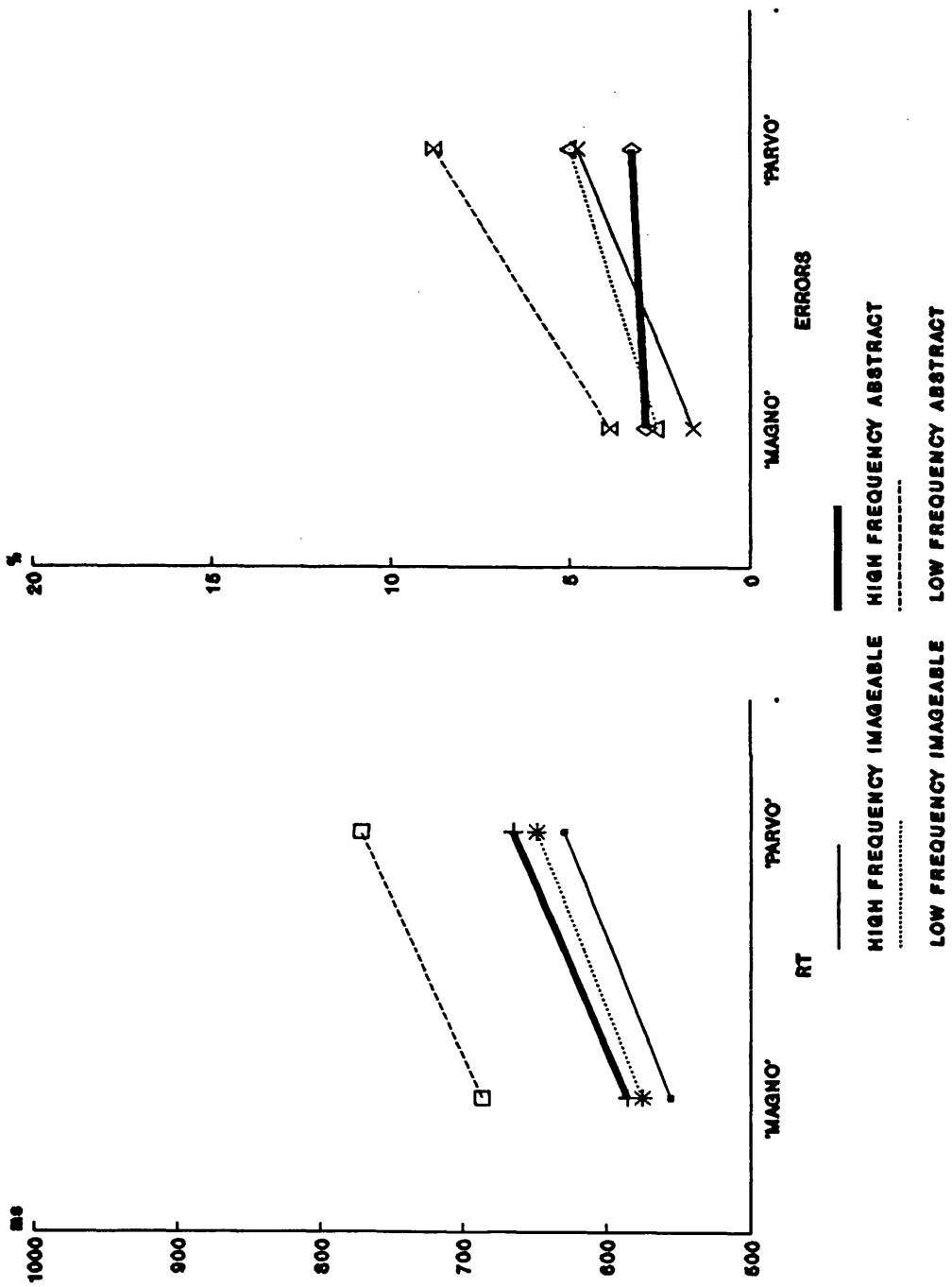


Figure 5.5. Experiment 5. Lexical factors and the two channels. Left: reaction times; right: errors.

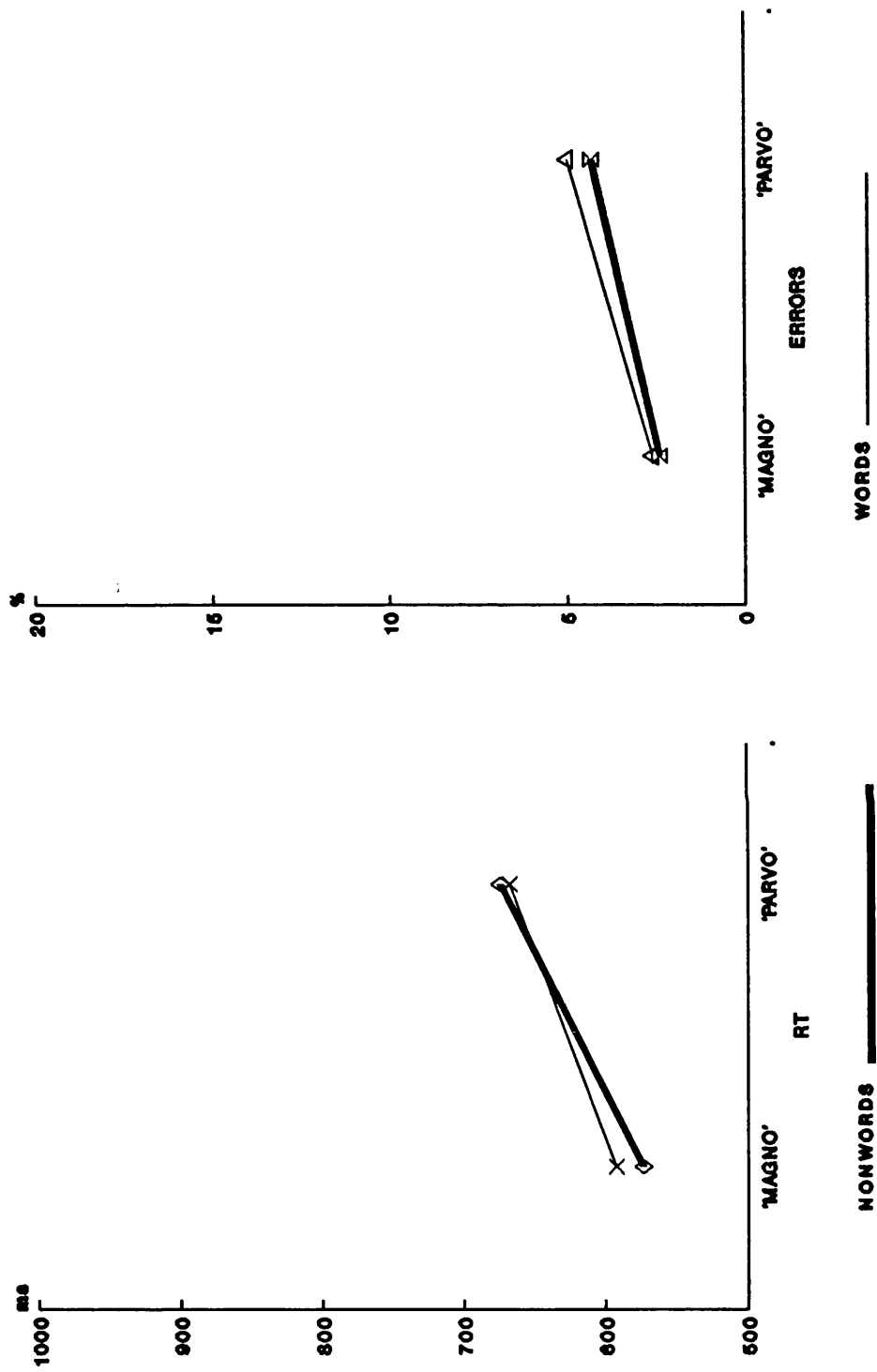


Figure 5.6. Experiment 5. Word and nonwords. Left: reaction times; right: errors.

5.4.4. Experiment 6.

A second variation of the first lexical decision experiment was carried out. The counterphase stimuli might have been creating unknown effects upon lexical decisions. One possibility was that it was responsible for the large imageability and frequency effects.

The counterphase stimuli were replaced with static ones. The original intention was to present the two images making up the counterphase image an equal number of times in each of the conditions. Unfortunately, a programming error resulted only in one of them being used. This is unlikely however to have affected the results. The two images making up the counterphase image are identical except for reversed polarity, (black letters upon white, vs white letters upon black). Research upon polarity shows it does not influence legibility for normal readers (Legge, Rubin and Scheske, 1987). However, some evidence suggests it effects reading where light scattering occurs in the ocular media of the eye as in certain forms of severe visually impairment (Rubin and Legge, 1989). None of the subjects had severe visual impairment.

Method: Experiment 6.

As in the previous two experiments 192 words and 192 wordlike nonwords were randomly mixed and presented

sequentially in the two 'magno' and 'parvo' 'channel' conditions. Unlike the previous stimuli the 'magno' and 'parvo' stimuli were static. However both the 'magno' and 'parvo' stimuli were like those of the previous two experiments in regard to size and colour -- indeed they were consisted of the same bitimages but presented statically (the reasons for this were discussed above).

Statistical analysis.

The main effect of 'channel' and word/nonwords will be discussed last. The results for the two lexical factors were much like those for the above two experiments: highly significant as main effects but without sign of a significant interaction between them and the visual channels. For frequency $F(1, 15) = 163.12$, $p < .001$, (reaction times) and $F(1, 15) = 37.29$, $p < .001$, (errors) and for imageability $F(1, 15) = 60.6$, $p < .001$, (reaction times) and $F(1, 15) = 32.29$, $p < .001$, (errors). Their interaction was highly significant for reaction times $F(1, 15) = 22.07$, $p < .001$, and errors $F(1, 15) = 16.97$, $p = .001$. (The relevant ANOVAs are in tables 5.11 and 5.12, see also figures 5.7.a and 5.7.b). There was no interaction between lexical factors and 'channel': for reaction times, frequency by channel: $F(1, 15) < 1$, n.s.; for imageability by channel: $F(1, 15) < 1$, n.s.; for channel by frequency by imageability: $F(1, 15) < 1$, n.s. The results were similar for the error data: imageability by channel $F(1, 15) = 1.72$, $p = .21$; for

imageability by channel $F(1, 15) < 1$, n.s. and channel by frequency by imageability $F(1, 15) = 2.16$, $p = .163$. These results will be discussed further in the context of a split plot with Experiment 4. The details of means for the various word and lexical factors for the 16 subjects are in the appendixes C.4.a and C.4.b.

Figure 5.7.b. Experiment 6. Graphs illustrating the main effect of 'channel' upon lexical factors.

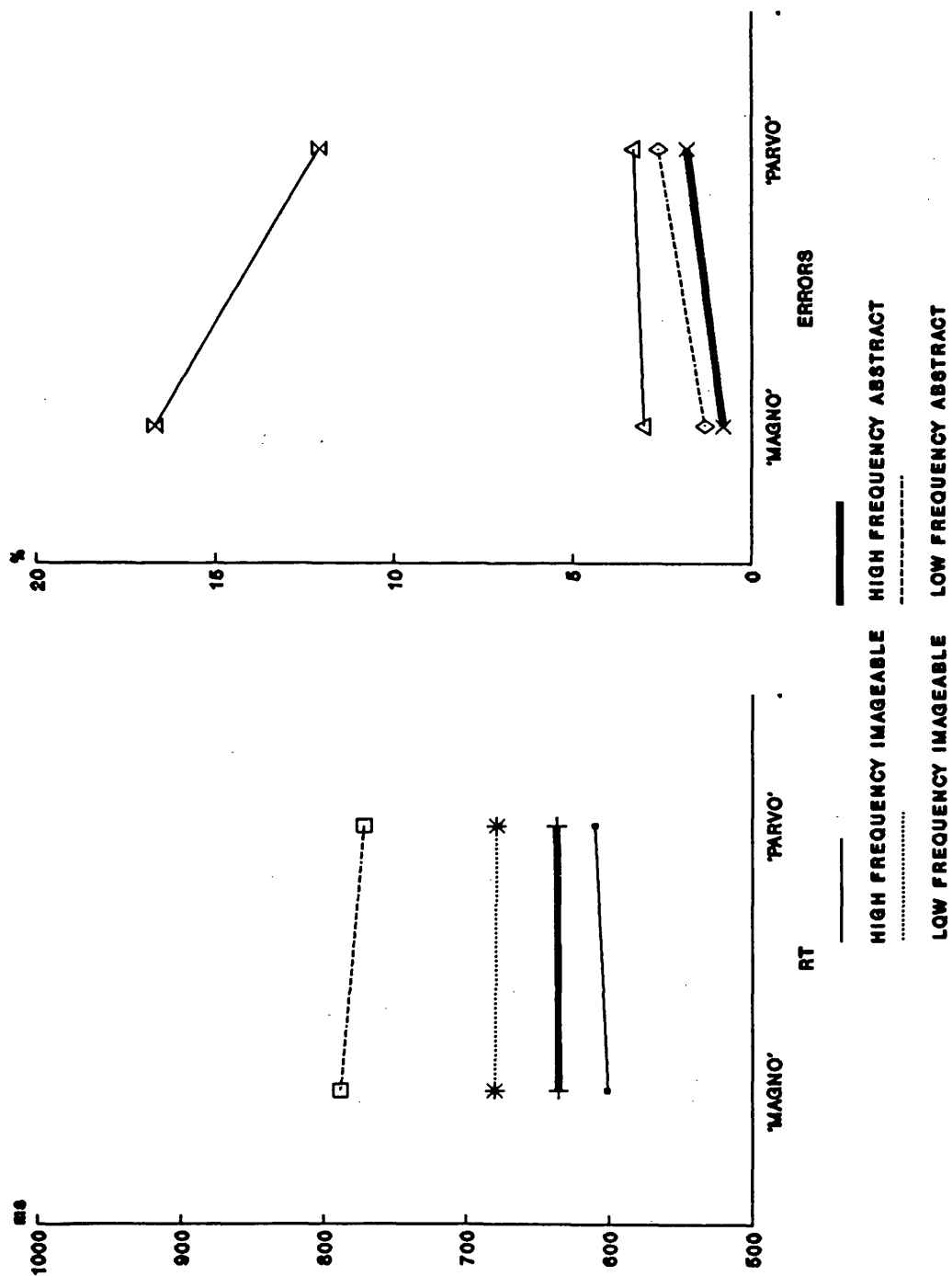
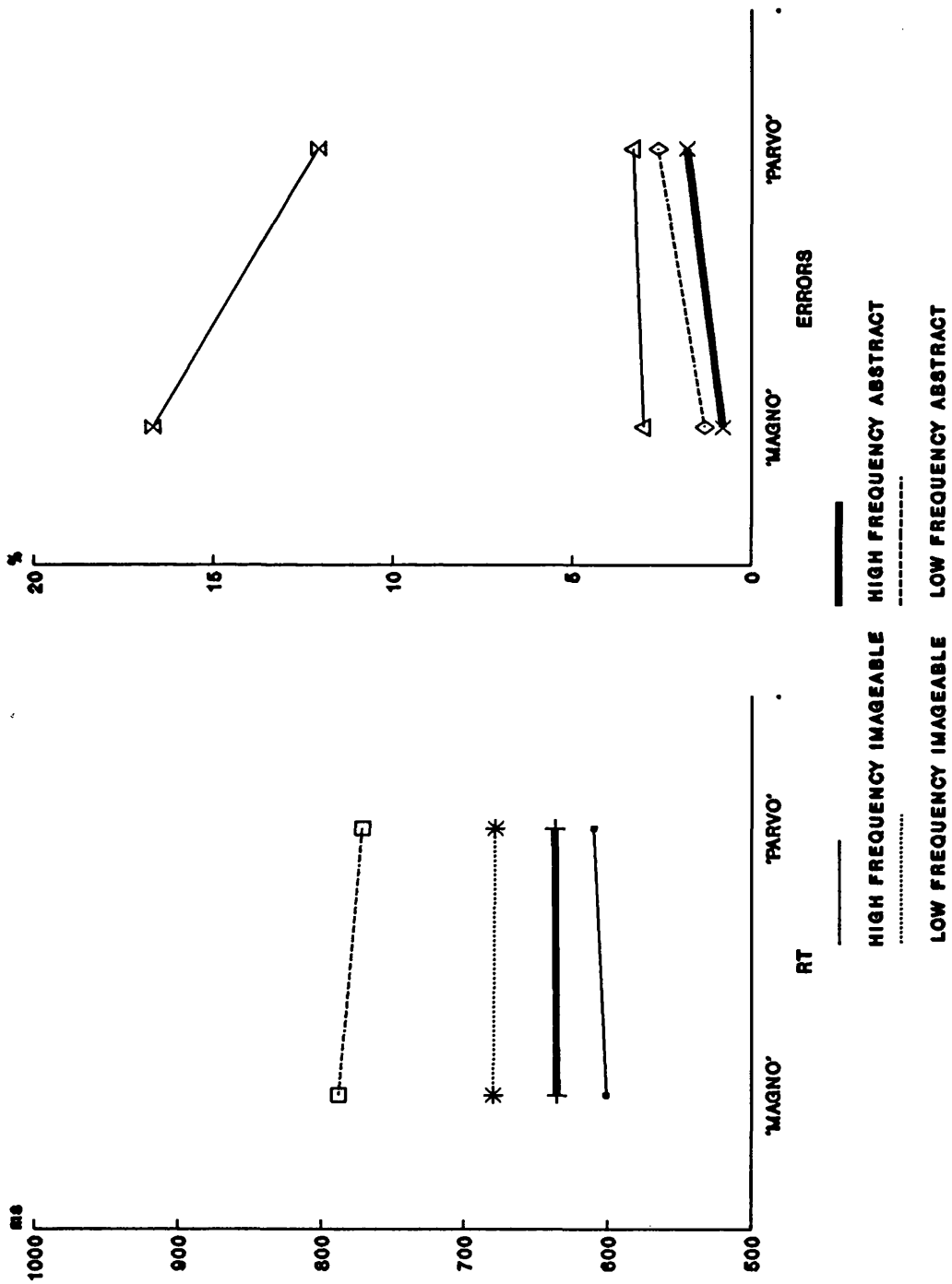


Figure 5.7.b. Experiment 6. Graphs illustrating the main effect of 'channel' upon lexical factors.



5.5. 'Magno' and 'Parvo' - A new interpretation.

5.5.1. Problems

Other aspects of the results for Experiment 6 are more interesting since they suggest a more complex situation than the above hypothesised situation where 'magno' and 'parvo' presentation conditions are the sole factors isolating the visual channels.

The reason is that, in contrast to the first two experiments, no 'channel' main effect occurred in Experiment 6 either for reaction times or error percentages. The word means and errors for the 'magno' and 'parvo' visual presentations respective were 661 ms and 662 ms and 4.2% and 4.3%. For nonwords they were 747 ms and 779 ms and 5.8% and 6.3%. Statistically, there was no significant effect for reaction times, $F(1, 15) = 3.14$, $p = .097$; for errors, $F(1, 15) = .33$, $p = .573$, (see ANOVA tables 5.9 and 5.10).

The dramatic nature of this non-interaction can be seen in figures 5.8.a. and 5.8.b. Further table 5.1 (below them) compares the difference between the 'channel' means of this experiment with equivalent ones from the previous two experiments presented above and below it.

Figure 5.8.a. Lexical factors and spatial frequency effects in Experiments 4 and 6 compared.

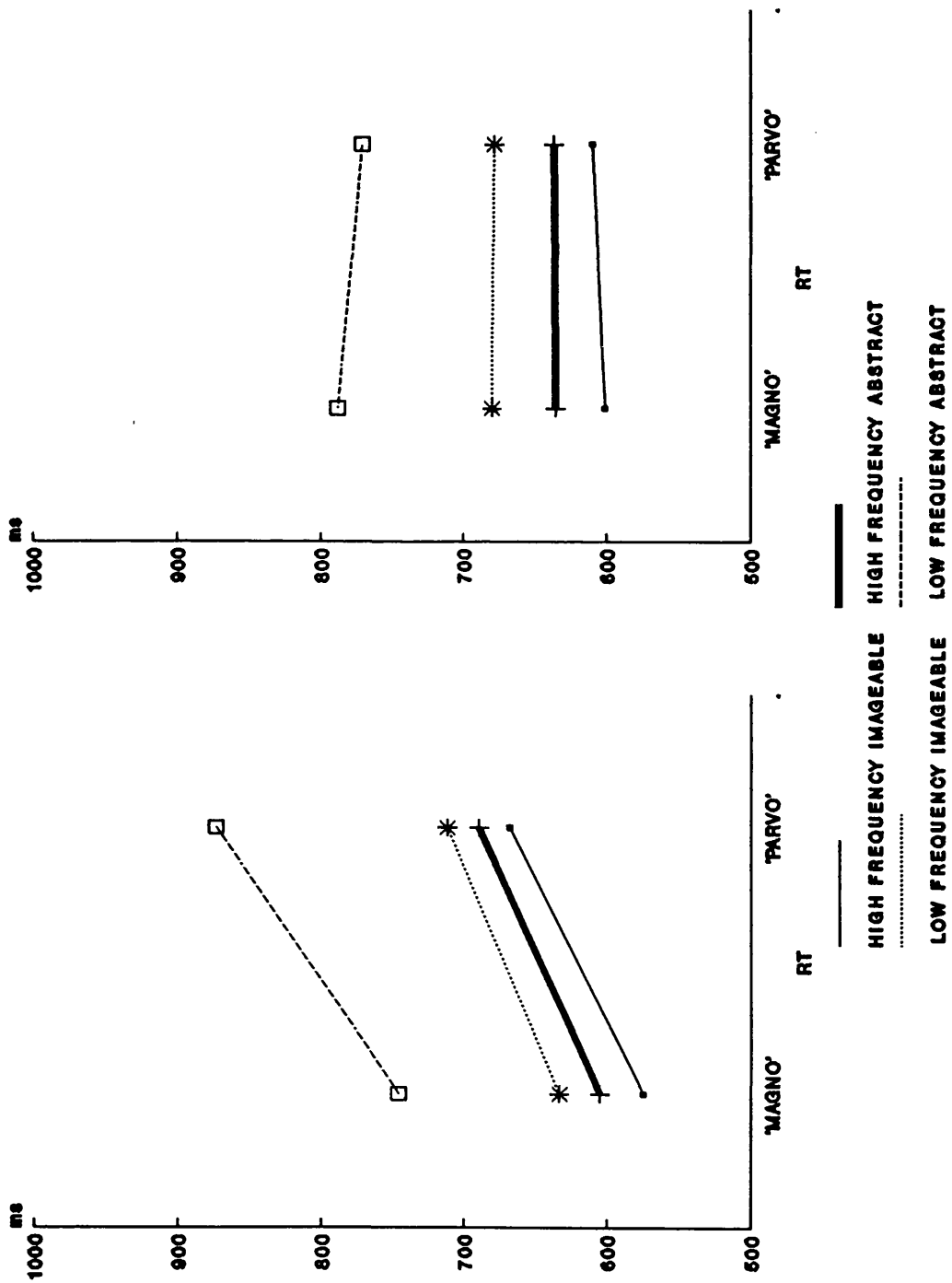


Figure 5.8.b. Interaction between counterphase (Experiment 4): static (Experiment 6) and 'magno' and 'parvo'. Top two lines: nonwords, bottom two: words. The same data is used in each graph.

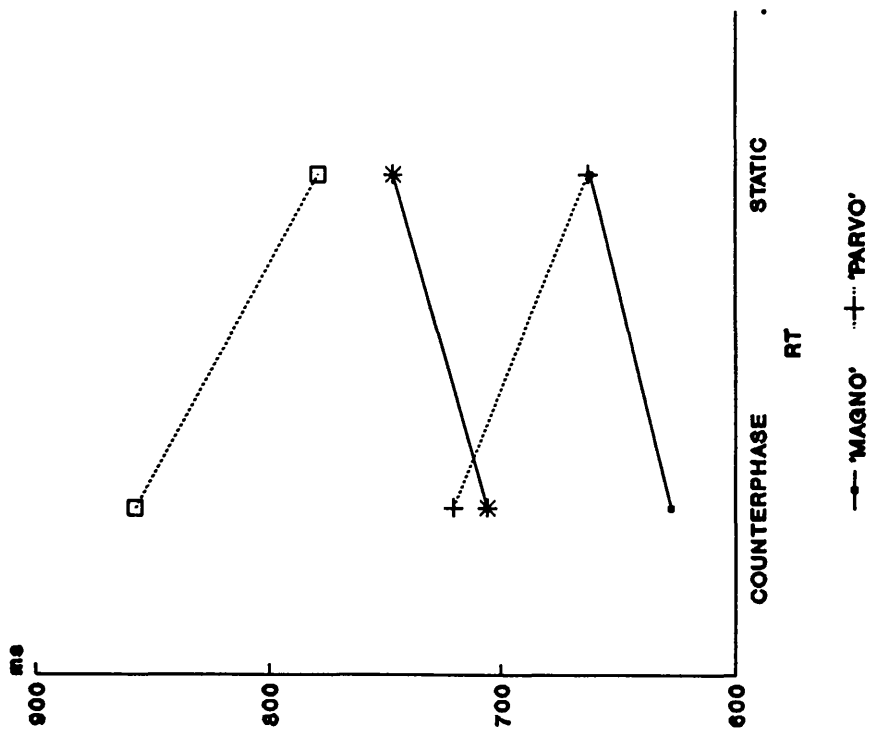
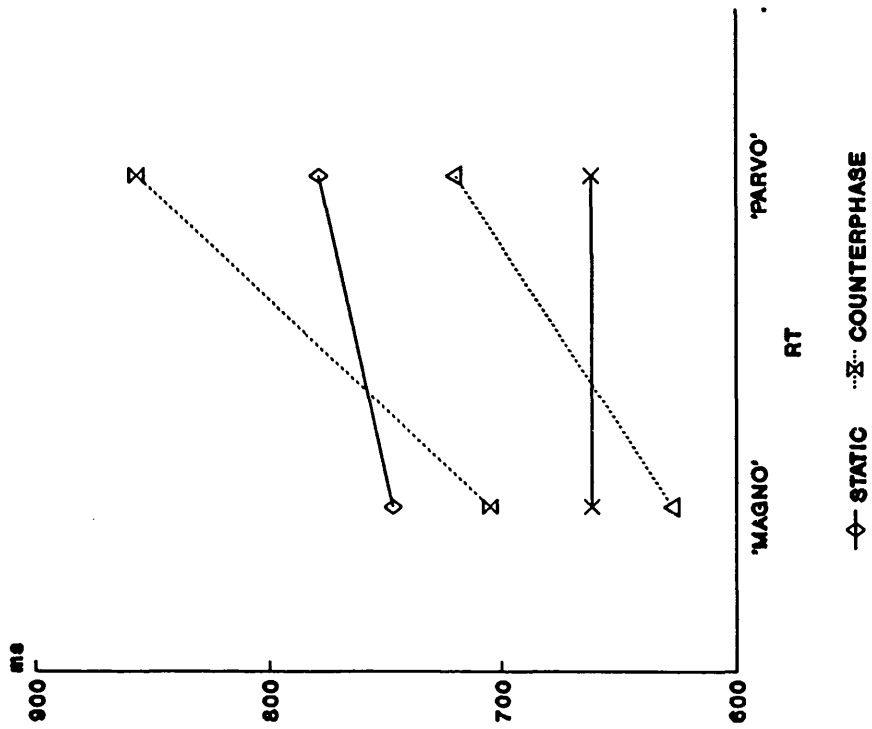


Table 5.1. Differences in the three lexical decision experiments between the means of the various conditions: words, nonwords and lexical factors compared.

	word	nonword	HIGH FREQ		LOW FREQ	
			IMG	ABST	IMG	ABST
Exp 4.						
'magno'	627	705	575	605	633	746
'parvo'	720	857	668	689	712	874
'magno'-'parvo'	93	152	113	84	79	128
Exp 5.						
'magno'	593	573	556	586	576	687
'parvo'	668	674	629	665	648	771
'magno'-'parvo'	75	101	75	79	72	84
Exp 6.						
'magno'	661	747	602	636	680	788
'parvo'	662	779	610	637	678	772
'magno'-'parvo'	1	22	8	1	2	16

To explore this further, several split plot ANOVAs, tables 5.13. (reaction times) and 5.14 (errors) were carried out to compare this static experiment with the first counterphase one (comparisons with the second one were inappropriate as it used a different type (nonwordlike) of nonwords).

The split plots reveal that the main effect for reaction time data for the channel were highly significant $F(1, 30) = 56.9, p < .001$, while this was not the case for the error data $F(1, 30) = 2.05, p = .162$. This effect was entirely due to the first experiment as can be seen from the graph of the data in figure 5.8.b. Confirming this and the differences between the means in the ANOVA table 5.13 (reaction times) and ANOVA table 5.14 (errors), the experiment factor and visual presentation conditions showed

an strong interaction: $F(1, 30) = 33.6, p < .001$ for reaction times (though not for errors, $F(1, 30) < 1$ n.s.).

Looking at the left graph in figure 5.8.b. it can be seen that part of the interaction between the experiment factor and 'channel' is due to the 'magno' presentation being faster during counterphase presentation (in the first experiment) than when presented statically (in the third). This is an odd effect since it suggests that visually modifying words by presenting them in counterphase might make them easier to see. In the chapter 1, section 1.3., I reviewed work which suggested that the magno (transient) channel played no part in word recognition. The evidence reviewed in chapter 2, section 2.4.2. suggests that visual processing of high frequency stimuli is restricted to the magno channel. Here we have words and nonwords presented in a very fast counterphase -- 17.5 Hz that are easier to respond to than when the equivalent word and nonword stimuli are presented statically.

The experiment factor by 'channel' interaction can not be due to an effect of different reaction times between the two experiments as these were not significantly different. There was no significant effect for the experiment factor $F(1, 30) = .22, n.s.$; nor was there an interaction between the word/nonword factor and experiment, $F(1, 30) = .06, n.s.$ The error data supported these findings: the experiment factor had no effect, $F(1, 30) = 2.91, p = .098$, and there

was no interaction between the experiment factor and words/nonwords $F(1, 30) < 1$ n.s.

This interaction between 'channel' and counterphase/static presentation and stimuli presentation suggests that the theoretical rationale behind the experiments needs reinterpreting. The two visual presentations were putatively called 'magno' and 'parvo' after the visual channels they attempted to isolate. There were good theoretical reasons for this: the characteristics making them up were those known from previous research to functionally isolate the two channels.

Suppose another factor existed in the experiments but which isolated the magno channel -- and did so much more powerfully than the factors in the putatively named 'magno' presentation. This additional factor would interact selectively with these the 'magno' and 'parvo' presentations. The argument is as follows. First, it would not affect the 'magno' presentation of words since it would act similarly to it in blocking the parvo channel. However it would make the perception of 'parvo' presented words difficult: since it would block the perception of stimuli in the parvo channel while the 'parvo' presentation would block perception in the magno channel thus blocking the perception of stimuli in both channels. Therefore an unplanned and expected magno blocking factor present in one experiment but not another would make the 'parvo' stimuli in the experiment

in which it was present difficult to perceive compared to the one in which it was absent. This could show up in reaction times.

This I suggest happened between Experiments 4 and 6. Isoluminosity and high spatial frequency (characteristics of the 'parvo' stimuli) restricted the perception of stimuli by the magno channel without affecting parvo channel perception. Counterphase (see comments below and chapter 2, section 2.4.2.) I propose is a magno channel restricting factor. When the 'magno' and 'parvo' stimuli were presented statically their effect upon perceiving stimuli would be small because they could be seen relatively unhindered through at least one channel: the 'parvo' stimuli could be seen through the parvo channel and the 'magno' ones through the magno one. However when counterphase was added the perception of stimuli in the 'parvo' condition was blocked both in the magno channel (as in static presentation by 'parvo' presentation) and in the parvo channel by the counterphase. The 'magno' stimuli were unaffected because like the counterphase they act to restrict the parvo channel leaving the magno channel unhindered to perceive the stimuli. Indeed they might have been advantaged. (For a diagrammatic illustration of this argument see figure 5.9 at the end of section 5.5.2.

The mistake that led to this situation was the assumption based upon the work of Livingstone and Hubel that

the two different rates of counterphase isolated the two channels (see chapter 2, section 2.4.1.). The 'parvo' stimuli were counterphased at a slightly slower rate (12.5 Hz) than the 'magno' stimuli (17.5 Hz) and this was judged sufficient to allow the parvo channel to see 'parvo' stimuli (I reasoned this following Livingstone and Hubel's idea that heterochromatic flicker was seen by the parvo channel thus since heterochromatic flicker could be seen at this rate then the parvo channel could see other stimuli). This situation is more complex as I indicated in chapter 2, section 2.4.2. and it is unlikely that the parvo channel can see quickly alternated stimuli.

Though the experiment was not intended to end in this situation it not entirely undesirable. For the interaction between counterphase and the two 'channel' provides evidence that the channels were affecting stimuli perception. In the conclusion there is a discussion about what can and can not be inferred from these experiments concerning the relationship between the channels and the 'magno' and 'parvo' presentations named after them.

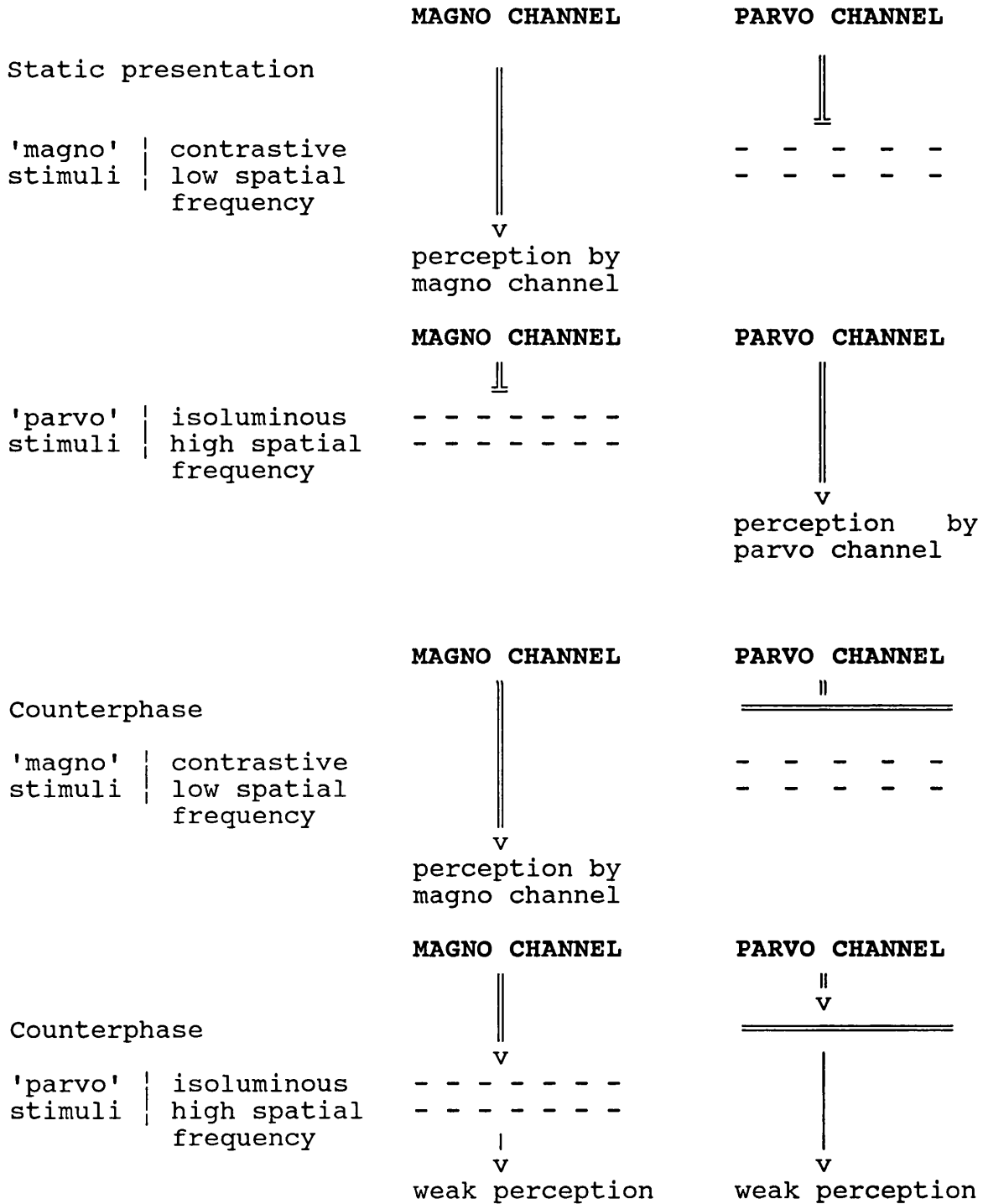
5.5.2. Experiments 4 and 6: In the light of the new interpretation.

Two questions follow from this reanalysis. First, given that counterphase restricts processing to the magno channel, did this affect lexical processing as indexed by the lexical factors of word frequency and imageability? Second, the attributes of spatial frequency and near-isoluminosity were designed to separate processing in the two visual channels. Did they have an effect above that done by counterphase. Is there any evidence independent of counterphase that they effected lexical processing?

For the answer to this the interaction of lexical factors and counterphase/static presentation were analyzed. The appropriate split plot ANOVAs were done (see ANOVA tables 5.15 and 5.16). Not surprisingly given the strong main effects in the individual experiments for frequency and imageability (and their interaction), their main effects (and interaction) in the split plot were highly significant. However there were no significant interactions between them and the experiment factor: for frequency, $F(1, 30) < 1$, ns, for imageability, $F(1, 30) = 1.78$, $p = .192$, for the frequency by imageability interaction, $F(1, 30) = 3.63$, $p = .067$. This suggests that counterphase had no effect compared to static presentation upon lexical factors.

The third experiment provides evidence that the original 'magno' and 'parvo' presentation conditions might have had some effect, albeit a minor one, upon cognitive processing. In the first two experiments an interaction existed between visual presentation and word and nonword judgements. Since in these experiments, the 'parvo' presentation in general delayed word and nonword decision times, the channel by word/nonword interaction could have been due to an effect secondary to delay, rather than some genuine cognitive effect of the two visual presentations upon lexical decision.

Figure 5.9. Illustration of the magno and parvo channel effects between the first and third experiments in terms of the various factors blocking and permitting visual perception.



In the third experiment the two channels produced

roughly the same reaction times across word and nonword responses. In the 'magno' and 'parvo' presentation conditions were respectively 661 and 662 ms; for nonwords they were 747 and 779 ms. Error scores between them were also roughly the same; for words 4.2% and 4.3%; for nonwords, 5.8% and 6.3%. Thus an interaction between them is unlikely to be secondary to perceptual delay effecting the difference between word/nonword reaction times. This would strongly indicate some cognitive effect by them upon the lexical decision process. Such an interaction was present $F(1, 15) = 5.25, p = .037$. This effect did not interact with counterphase stimuli presentation of the two experiments: $F(1, 30) = 1.24, p = .274$). The nature of this effect will be explored further in the following section upon the letter length effects.

5.6. Letter length effects.

In normal visual presentation strong letter effects are restricted to wordlike nonwords (Frederiksen & Kroll, 1976; Seymour, 1987a; 1987b). (It should be noted there is some evidence, Seymour, (1987a & 1987b), of a slight effect for words but this is much smaller than the comparable one for nonwords). Length effects however can be induced with unfamiliar visual presentation such as zig zag distortion, vertical format and presentation to the left visual field (Ellis, Young & Anderson, 1988). The three above experiments were analyzed to see whether the various visual presentations ('magno', 'parvo' and counterphase) affected letter length effects. The reaction times for four, five and six letter stimuli were analyzed. Linear contrasts were computed for length and its interactions with the word/nonword factor.

5.6.1. Experiment 4

The length effects for the first experiment in view of previous research were interesting. This experiment's nonwords were wordlike thus a strong letter length could be expected for them, while no (Frederiksen & Kroll, 1976, page 372), or slight, (Seymour, 1987a, page 36) length effect for words could be expected from the evidence of past research. A split plot ANOVA with linear contrasts was done on reaction times for the data of experiment 4 (see table 5.19. and

figure 5.10). A minor length effect was found both for words and nonwords $F(2, 30) = 10.79, p < .001$. A look at the graph in figure 5.7 suggests this was mainly due to the nonwords, an observation supported by the existence of an interaction between word/nonword and the linear component of the letter effect $F(1, 30) = 4.42, p = .045$. However the length effect appears to be less than that previously reported. Though nonwords showed a stronger length effect compared to words the significance level ($p = .045$) was not dramatic. Further, from the graph it appears that both words and nonwords were showing length effects. The length effect here is later analyzed in the context of the length effect of the third experiment where the words and nonwords were presented statically (and thus approximated more closely previous research).

The apparent reduction of the length effect compared to previous research is surprising given that it might be argued that the visual presentation used here was visually unfamiliar and so might have induced more dramatic length effects than for normally presented stimuli. Previous presentation of words in the left visual field (Ellis, Young & Anderson, 1988) and a distorted (Seymour, 1987a; 1987b) induced length effects for words and increased length effects for nonwords. Thus counterphase stimuli do not appear to induce a cognitive need for those processes (such as parsing and abstract letter storage discussed above) which are thought to produce letter length effects.

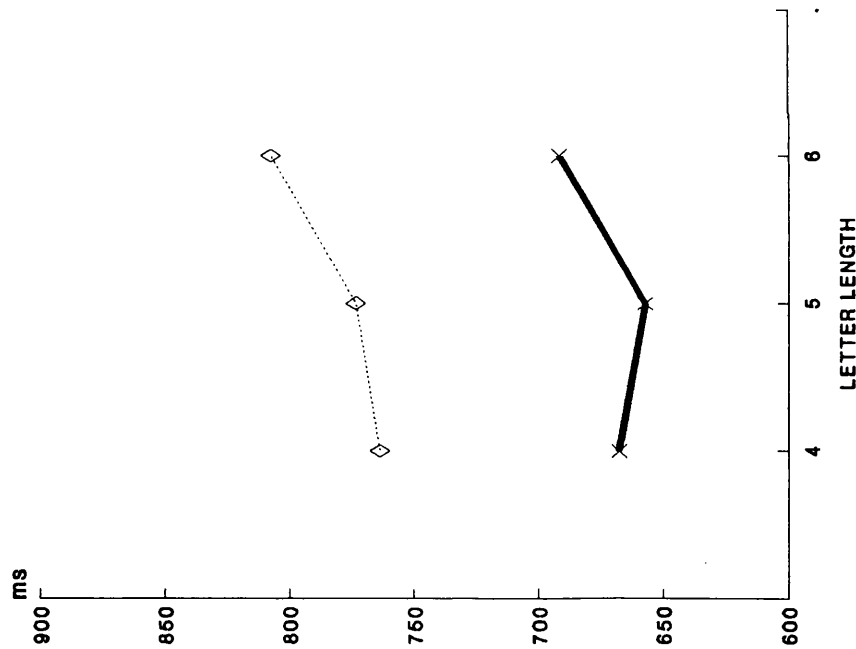
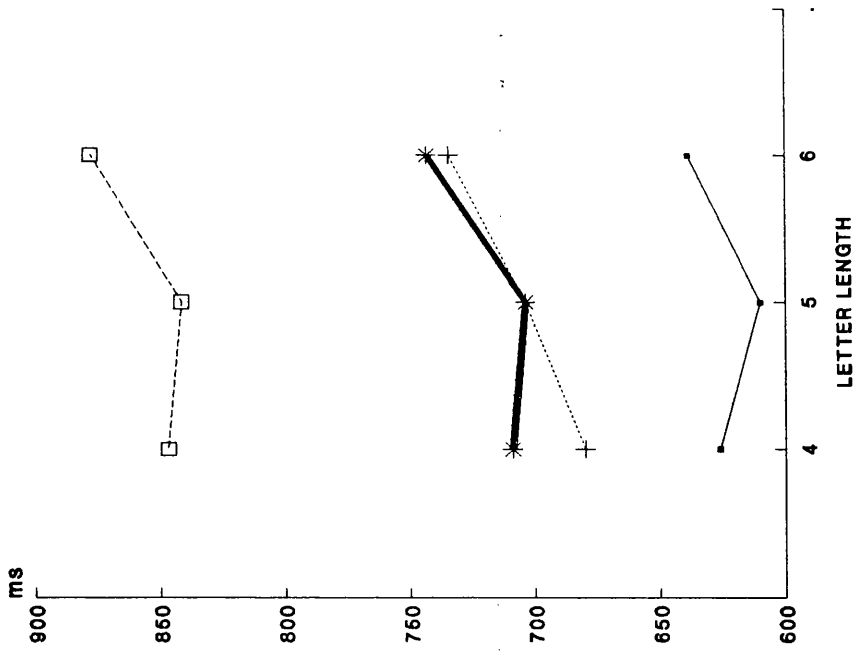


Figure 5.10. Experiment 4: Letter length effects for reaction times. Left: words (solid lines) vs nonwords (broken lines). Right: 'channel', words ('magno' = fine, 'parvo' = solid); nonwords ('magno' = fine broken, 'parvo' = coarse broken).

5.6.2. Experiment 5

A split plot ANOVA with linear contrasts was carried for the reaction times of experiment 5 (see table 5.20. and figure 5.11). Experiment 5 was like the first lexical decision experiment except that nonwordlike nonwords were used. Previous research has shown that nonwordlike nonwords do not have a length effect. This has been explained in terms of their visual dissimilarity to words providing a quick clue to them being nonwords (Seymour, 1987a; 1987b).

As with normal presentation there was no linear length effect for words or nonwords. There was however a minor quadratic effect $F(1, 30) = 5.54, p = .025$, which did not interact with any of the other factors. It is not clear what it means and since the effects of the second experiment are of less interest than the other two it is not discussed further.

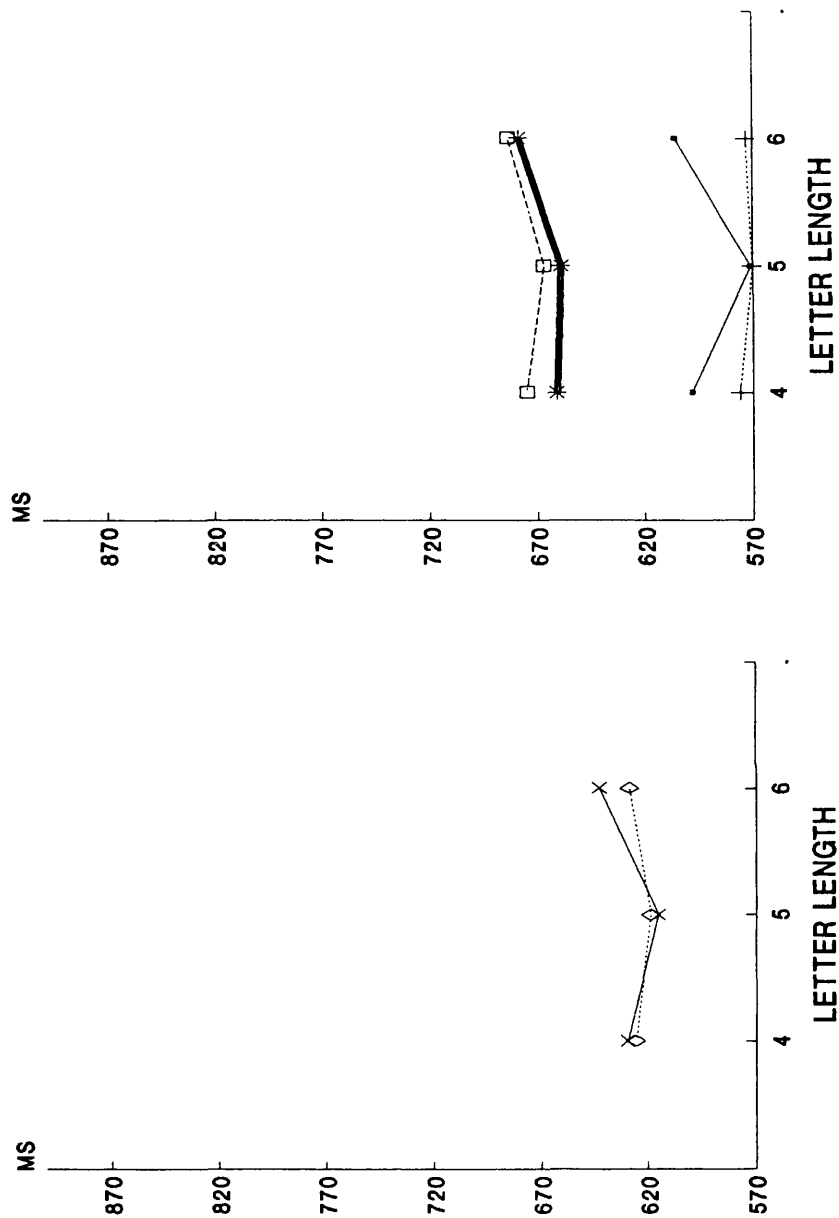


Figure 5.11. Experiment 5: Letter length effects for reaction times. Left: words (solid lines) vs nonwords (broken lines). Right: 'channel', words ('magno' = fine, 'parvo' = solid); nonwords ('magno' = fine broken, 'parvo' = coarse broken).

5.6.3. Experiment 6

The first two lexical decision experiments used counterphase stimuli while the third experiment did not and so provides a comparison with previous research. Like the first experiment it used wordlike nonwords. Its effects followed those of statically presented stimuli found in previous research with there being a strong nonword length for nonwords with a weak or absence length effect for words see ANOVA table 5.21 and figure 5.12.

There was a highly significant effect of length upon reaction times $F(2, 30) = 13.67, p < .001$. The graph suggests this was due to the nonwords -- something supported by the strong interaction between length and words/nonwords $F(2, 30) = 10.16, p < .001$. The length effect contained both linear and quadratic components. Visual inspection of the graph suggests the quadratic component belongs to the words and the linear to the nonwords. The word length interaction was strong with there being a linear but not quadratic component present in the nonwords but not the words $F(1, 30) = 20.27, p < .001$ (compare this with the equivalent linear component of the counterphase words and nonwords $F(1, 30) = 4.42, p = .045$). A split plot is carried out below to see if counterphase had an effect upon the nonword length effect.

Unlike previous research these experiments tried to restrict processing to the magno and parvo channels. Did these attempts affect the letter length effect?

'Channel' interacted in Experiment 6 with the linear component of length $F(1, 30) = 4.91, p = .034$. The right hand graph (figure 5.9) suggests the possible existence of a three way interaction in this experiment between word/nonword, length and 'channel' in the right graph. In experiment 4, this interaction was nearly significant ($p = .051$). Therefore the ANOVA was expected to yield a interaction for experiment 6. However, surprisingly the ANOVA did not hint at even a trend $F(2, 30) < 1, ns$.

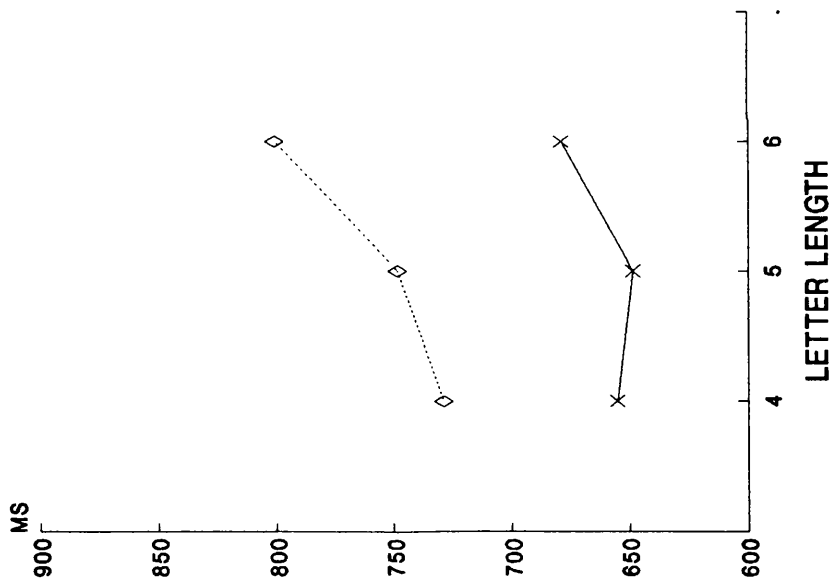
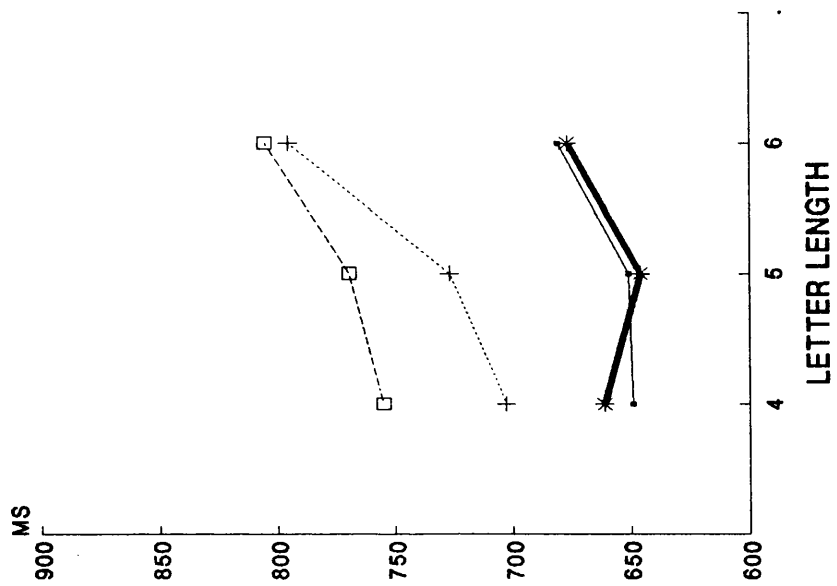


Figure 5.12. Experiment 6: Letter length effects for reaction times. Left: words (solid lines) vs nonwords (broken lines). Right: 'channel', words ('magno' = fine, 'parvo' = solid); nonwords ('magno' = fine broken, 'parvo' = coarse broken).

5.6.4. Experiments 4 and 6 compared.

Visual inspection of the graphs for Experiments 4 and 6 suggests that the length effect for nonwords in Experiment 6 was greater than in Experiment 4. As noted, their respective ANOVA support this: the linear component for the interaction between word/nonword and length effect for Experiment 4 was $F(1, 30) = 4.42, p = .045$, while for Experiment 6 it was $F(1, 30) = 20.27, p < .001$. A split plot ANOVA (table 5.22) was carried out to find out whether there was an interaction between experiment and the length effect. There was indeed such an interaction $F(1, 60) = 4.06, p = .048$, suggesting that counterphase reduced the length effect normally associated with statically presented nonwords. As noted, visual distortion normally increases length effects (or makes them present when normally absent). Here is a visual distortion in contrast which does the opposite: reduces an expected length effect.

Visual inspection of the two graphs for Experiments 4 and 6 suggests a possible interaction between 'channel' and the nonword length effect. The split plot ANOVA in table 5.19. supports its existence: there was a just off significant trend for the interaction of experiment by 'channel' and the linear component of the length effect, $F(1, 60) = 2.91, p = .059$.

The finding of an interaction between letter length, wordness and 'channel' is interesting in the light of the interaction found with the three experiments and word and nonword reaction times. There was a consistent effect of 'channel' and slower nonword responses found across these three experiments. The finding of the above noted nearly significant interaction between 'channel', word/nonword and letter length suggests that some of this effect could be to the effect of 'channel' upon nonwords (though not all, since the effect 'channel' upon word/nonword was much larger $F(1, 60) = 13.18, p = .001$, than the linear component of its effect upon word/nonword and length, $F(1, 60) = 2.91, p = .059$). Further, there was no 'channel' effect upon length for Experiment 5 though there was one in this experiment for word/nonwords.

5.6.5. Conclusions: Letter length.

Letter length results were important in showing that unfamiliar visual presentations of letter strings could reduce the length effect for wordlike nonwords. This was quite an unexpected expected finding in view of previous research. It could suggest a need to revise our understanding of length effects for normally presented nonwords. This length effect has been suggested to relate parsing of them into sublexical units (Seymour, 1987a; 1987b) or their buffering in a abstract letter storage (Ellis, Young & Anderson, 1988). It would appear that these

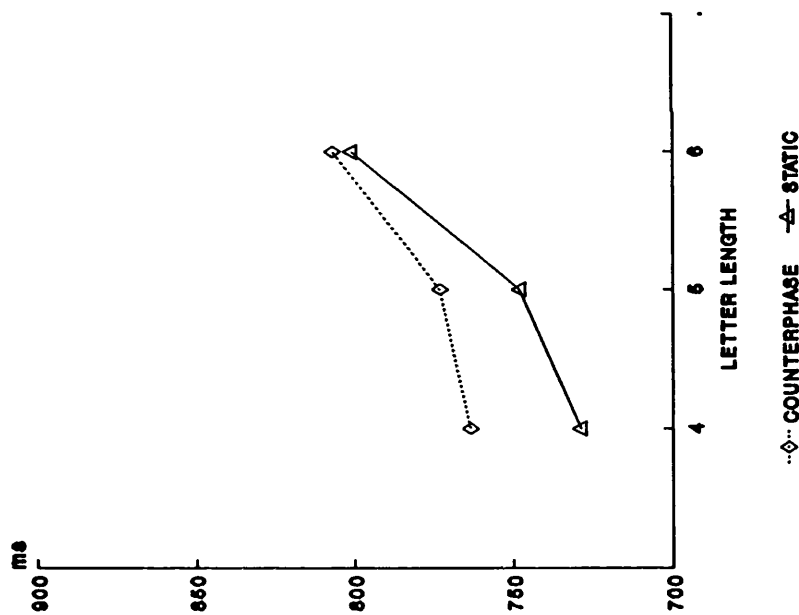
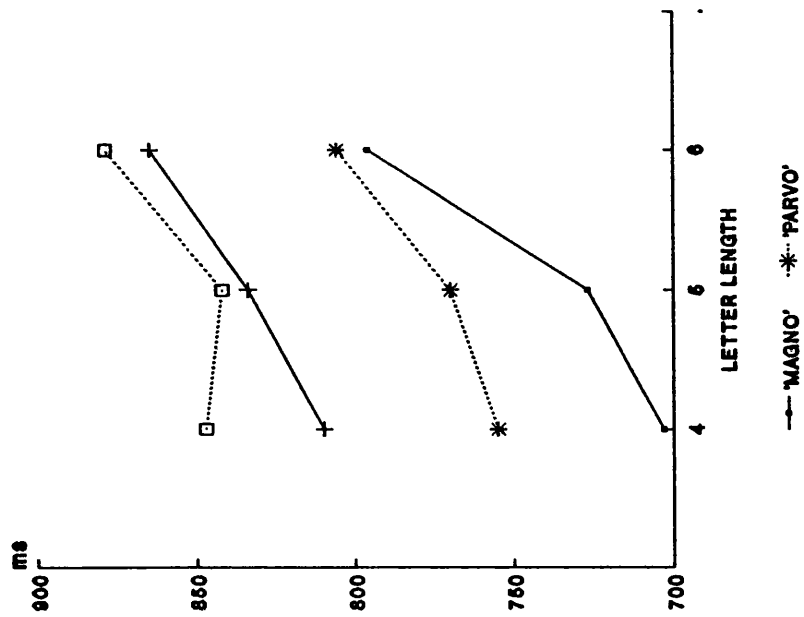


Figure 5.13. Length effects for counterphase and static nonwords compared. Left graph: 'magno' and 'parvo' combined; right graph: top counterphase (not the 'magno' line for ease of presentation has been moved up 130 ms); bottom static.

processes can be modified.

However it is premature to suggest that length effects were abolished or even reduced since the mechanisms by which they were created might only have been changed. Length effects were still present. Moreover it is possible that they were not reduced but masked by another secondary process. An examination of the graphs in figure 5.10. show that reduced length effects coincided with more delayed responses. It is possible that counterphase and 'parvo' perception of stimuli caused a trade off between letter length and duration such that general longer reactions reduced length effects. (This might happen if, for instance, there was a fixed time component to the process producing the length effect whose processing duration could be traded off with a letter length variable time component).

5.7. Conclusions.

The observations upon the lexical decision experiments divide into two: those related to the questions which motivated the experiments and those related to unexpected findings.

Two important questions motivated the research: first, did the 'magno' and 'parvo' have any effects upon their namesake visual channels? Second, if they did, did these effects have any effect upon lexical processes?

5.7.1. The 'magno' and 'parvo' stimuli and the two visual channels.

The answer to the first question has two parts, concerning respectively, the planned 'magno' and 'parvo' presentations and the unplanned effects of counterphase. The problem with evaluating the two 'channels' is that they could have affects unrelated to interaction with the two channels through purely effecting the ease of seeing stimuli. In the first two experiments there was a strong main effect of 'channel' but this could have been due to the 'parvo' stimuli being harder to see than any cognitive affect of it upon the visual channels.

Though in these experiments no interaction was found between 'channel' and the lexical factors (word frequency and imageability) there was one with word/nonwords. However, this could have been an indirect effect of a general delay caused by the 'parvo' stimuli upon visual processing. It might be that stimuli that are more difficult to see show greater differences between word and nonword reaction times. This, rather than any effect upon the two visual channels, could explain the observed interactions. However, the results of the third experiment are difficult to attribute to delay. The words and nonword responses to 'magno' and 'parvo' were roughly of the same duration but nonetheless they showed an effect of 'channel'. Of course to attribute this affect to the effects of the 'magno' and 'parvo' visual

presentations upon the two visual channels is premature. All this shows is that the two 'channels' had a cognitive rather than a delay related effect. It does not show that this cognitive effect is attributable to a direct effect upon processing between the two visual channels of the stimuli.

However that they did is not an entirely unreasonable conclusion.

First, the visual presentations labelled 'magno' and 'parvo' were created using research findings upon visual characteristics shown in other contexts to isolate the two channels. It is not unreasonable to assume that some of these effects might have transferred to the stimuli used in the present experiment.

Second, the visual characteristics of the 'magno' and 'parvo' stimuli interacted with counterphase in a way consistent with them isolating their respective channels. As noted, one of the mistakes of the present experiments was to follow the work of Livingstone and Hubel (1988) upon counterphase and the two visual channels. They attributed the different frequencies associated with monochromatic (17.5 Hz) and heterochromatic fusion (12.5 Hz) with different temporal sensitivities of the two visual channels. Other explanations however of this phenomena are possible (explained in chapter 2, section 2.4.1.1.) and other

research findings suggest the parvo channel cannot process fast counterphase whether 17.5 or 12.5 Hz.

In effect this research suggests that the parvo channel has difficulties perceiving stimuli presented in fast counterphase. As noted above the magno channel would already find perception of 'parvo' difficult due to their high spatial frequency and isoluminosity (the 'parvo' stimuli were after all designed to block the magno channel but not to restrict their perception by the parvo channel). Thus the effect of counterphase upon 'parvo' stimuli would be to block perception in both channels. Evidence for this difficulty was found in the interaction between Experiments 4 and 6. This suggests that the visual traits of spatial frequency and isoluminosity did have an effect upon parvo channel perception. Of course, the present experiments cannot say which visual attribute (spatial frequency or isoluminosity), or possibly an interaction between them was responsible.

Unfortunately, even if it is reasonable to suggest the 'magno' and 'parvo' stimuli interacted with the two visual channels this does not mean that they selectively impaired channel processing as intended. It could be that the parvo channel processed the 'magno' stimuli after an initial transfer of their images from this channel (see chapter 2, section 2.3.4.). Further, it could be that the processing between the two channels are not functionally independent.

It might be that both channels attempted to process the 'parvo' stimuli (stimuli designed to be processed exclusively in the parvo channel) but instead of the magno channel processing them as intended the parvo channel processed them but with more difficulty.

5.7.2. The two visual channels and lexical processing.

The above arguments suggest there is some probability that the 'magno' and 'parvo' stimuli interacted with the two visual channels, though it far from clear they interact as planned. Did they affect the lexical processing of words? There is no evidence that they did. If lexical processing is indexed by word frequency and imageability effects than the absence of any interaction with these lexical factors by 'magno' and 'parvo' suggests lexical processing was unaffected by attempts to manipulate the visual channels. Similarly, while counterphase seems to have affected the processing of words and nonwords in the parvo channel it had no effect upon the lexical factors.

However one factor was found to effect lexical processing. Unexpectedly, nonwordlike nonwords in experiment 5 were found to reduce the effect of one of the lexical factors - word frequency - upon lexical decisions. It however had no effect upon imageability. Because the two lexical factors were confounded with random and blocked presentation it is however not clear whether it was this or

their nature as lexical factors which effected reaction times. This result is surprising and lacks an obvious explanation.

Though the two visual presentations did not affect lexical factors they did affect the decision times for words compared to nonwords. In contrast, while counterphase has no effect upon lexical factors it also had no effect upon word judgement.

Both counterphase and the 'channel' factor affected length effects. However these were paradoxically in that they reduced (though not completely) the normally expected length effect associated with wordlike nonwords. This is interesting since it goes counter to expectation. However, these length reducing effects also increased general reaction times. Thus it is possible that counterphase and the channel factors change not the length effects but the trade offs within this process. For instance, imagine that the process responsible for length effects that has a fixed time component and one which varies with letter length. Length effects could be reduced by extending the fixed time component at the expense of the variable one. This would produce the observed results.

However the fact length effects were changed suggests attempts to affect visual channel perception were affecting

early stages in word recognition where length effects are generated.

This suggests that while attempts to manipulate the visual processing of words might not effect lexical processes they might affect prelexical ones. The next chapter directly investigates the prelexical component of the reading process.

6.1. Introduction.

The previous chapter's experiments failed to find that visual channel manipulations affected lexical processing (through effects either upon frequency or imageability). However these experiments showed the possible existence of interactions between these manipulations and stimulus length and word versus nonword classifications. These effects were suggested to be possibly prelexical in origin -- suggesting that the channel manipulations may possibly affect earlier stages in the reading process. One prelexical process is the formation of abstract letter codes. This chapter reports an experiment designed to directly investigate the effect of visual channel manipulations upon the formation of these codes. It differs from the previous chapter in that it uses a different method of blocking the two visual channels. Discussion in chapter 5, section 5.5. (and also chapter 2, section 2.4.2.) suggested that counterphase blocked the parvo channel; further that this was a more effective means of channel manipulation than the other factors used for the experiments reported in chapter 5. However, since counterphase only blocks the parvo channel, only conjectures concerning the magno channel can be investigated. The basic question of this chapter is therefore limited to the role of the magno channel in the formation of abstract letter

identities. Does blocking the magno channel impair their processing?

6.1.1. Abstract letter identities

Several models of reading (Coltheart, 1981; Morton & Patterson, 1987) have postulated the existence of an early stage of visual processing which pre-processes the visual aspects of written words for output to the later lexical reading processes. One approach suggests that this visual preprocessing transforms visual input into abstract letter identities (Coltheart, 1981; Morton & Patterson, 1987) or something akin to them (McClelland, 1977). These are case-independent, font-independent, non-phonological and non-visual representations of letters -- for instance, all the following {C,c,Ꞥ,Ꞥ and ˆ} become converted by this process into the same abstract Cee letter identity. The evidence for the existence of an early process producing abstract letter identities is partially cognitive neuropsychological -- certain acquired dyslexics show a preserved ability to read case alternated writing which can be best understood in terms of the existence of such a visual analysis system (Morton & Patterson, 1987). However, work upon normals has been interpreted with the context of reading involving a stage of abstract letter identity formation. This interpretation (due to Coltheart, 1981) is built upon earlier work involving letter matching. I discuss this before turning to the Coltheart's ideas.

6.2. The letter matching task

6.2.1. Posner's contribution

Letter matching was selected as the task to probe the formation of abstract letter identities.

Interest in letter matching originates with Michael Posner (Posner, Boies, Eichelman & Taylor, 1969; Posner & Mitchell, 1967; Posner, 1978). Posner was not concerned with the formation of abstract letter identities but to find the time sequence of the different processing levels involved in carrying out a simple classification task. To this achieve this end, he created 'a single experimental paradigm .. which provided an opportunity to observe processing at different levels within the same experiment' (page 392) (Posner & Mitchell, 1967).

The experimental paradigm used two letters. The subject was given them (either simultaneously or successively with a variable delay) and depending whether they matched asked to press one of two keys (same or different). They were given two types of instruction on how to classify letter matches as same or different. The first consisted of an instruction to match as same only those letter pairs that were physically identical (the physical rule), for example, AA or aa but not Aa or AD. The second instruction asked the subject to match letter pairs as identical only if they

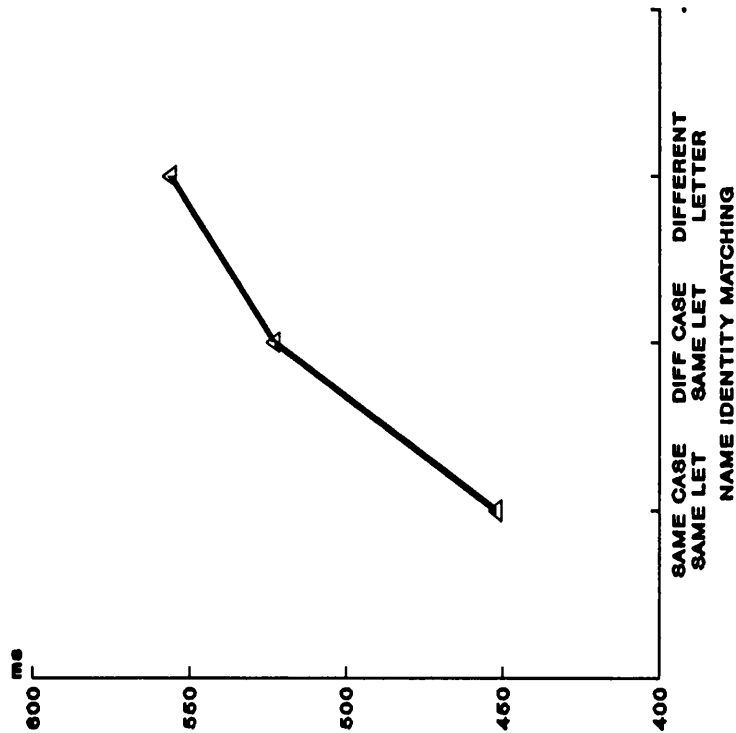
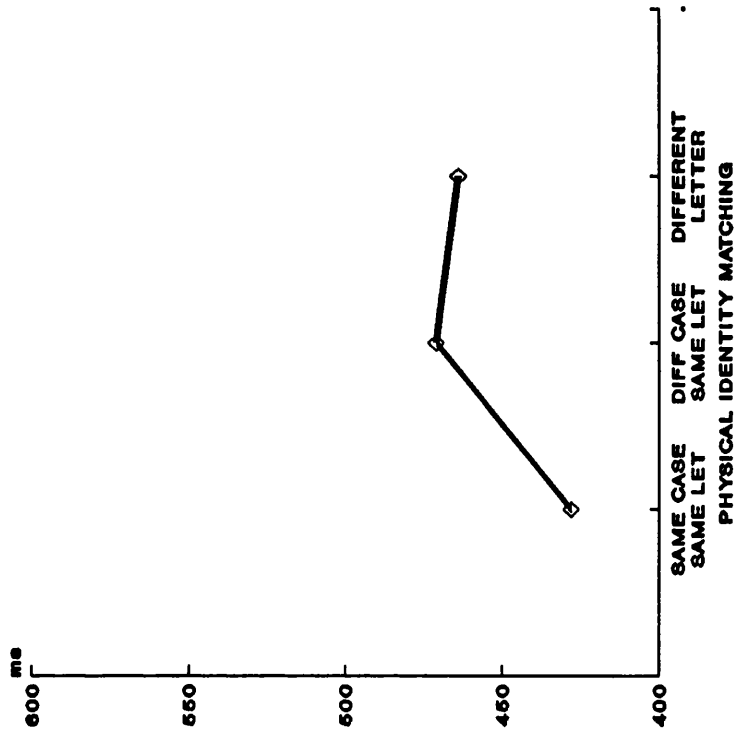
shared the same name, (the name rule), for example, AA or Aa but not AD or Ad. In effect, the two rules ask subjects to either to ignore letter case (the first rule) or make judgements upon visual similarity or dissimilarity (the second one).

For name identity rule matching Posner (and Mitchell, 1967) found that the same responses to the physically identical AA letter pairs were faster than the same response to Aa ones. This he attributed to the existence of two stages of letter encoding. First, a stage creating a visual code which suffices to match physically identical letters (like AA or aa). Second, he hypothesised the existence of an acoustic code which was needed to match different case (and so visually different) letter pairs like Aa or aA. The extra stage of processing needed for creating the acoustic code he conjectured explained the delay found on name matching.

Posner also found for difference judgements that name identity rule matches were longer than physical identity rule ones. This he attributed to the fact that different responses for physical rule matches could be determined solely upon visual feature differences. However this is not possible for name rule matches since upper and lower case letters are the visually different but have to be treated as identical (thus for the name rule visual difference is not a good guide to letter classification). This has the effect, according to Posner, of making the difference classification

of letter pairs of the name rule depend upon acoustic codes. In contrast, for the physical rule correct matching can be done purely on visual similarities and dissimilarities -- thus requiring only visual codes. But the formation of the acoustic code requires (according to Posner) extra time and so produces delayed responses for different classifications for matching by the name identity rule compared to matching by the physical identity rule (see figure 6.1.). This idea further supported, according to Posner, the above idea that there were two encodation stages involved in letter matching.

Figure 6.1. Posner and Mitchell (1968) data for the name identity match rule (left) and physical match rule right.



6.2.2. Abstract letter identities in the letter matching task

Max Coltheart (1981) has criticised Posner for implying that the name identity matching occurs at the level of a letter's name. He suggests the alternative that these matches are made using abstract letter identities (I provide the full quotation since though the paper is widely cited it is in a journal Visible Language which is fairly obscure and does not normally report psychological work).

'This means that the list of three codes given earlier [semantic, phonological and visual] is not exhaustive ... There must be at least one additional possible code. I suggest that this fourth kind of code used the identities of the letters -- Abstract identities in the sense that neither the phonological representations nor the visual forms of the letters are being used.

If it is conceded that one can judge that **A** and **a** are the same without using name codes (using ALIs [abstract letter identities] instead), this has certain consequences for the interpretation of the past decades's work on visual same-different matching.'
(Coltheart, 1981 page 250).

The replacement of acoustic or phonological encoding by abstract letter identity coding suggests that a new

interpretation is needed of the Posner letter matching task. Some elements of his work remain unchanged: for instance, the fast same-name same-case letter match AA is still explained by Posner's suggestion of a visual code. However, in the revised interpretation Posner's explanation (a) concerning the delay of Aa matching compared to AA matching is attributed not to the creation of a phonological code but the creation an abstract letter identity one. And similarly (b) concerning the delay for matching different letters Ad according to the name rule compared to the physical rule is attributed to the need to encode letters in terms of their abstract letter identities rather than in terms of their phonology induced by the Posner rule.

A further change concerns the delay of the Aa over the AA and Ad letter matches for the name rule compared to the physical one. Posner found that for the physical rule the reactions times to Aa classification responses were greater than those for AA classification responses. It is difficult to interpret this in Posner's data because different letter matches were even more delayed than either of these two matches -- it could be due to Aa matches taking longer because the judgement of visually different letters takes longer than similar ones. However, other researchers have found reactions times for Aa classification responses take longer than those for AA or Ad classification responses even though the Ad responses are as fast or faster than AA ones (Carrasco, Kinchla & Figueroa, 1988). Preliminary

experiments not reported here (and the experiment reported in this chapter) have also found AD and Ad letter matches to be faster than Aa or AA letter matches¹. This raises the question why subjects are delayed spotting that two letters are different when this is due to case (as between Aa and Ad), as to when this is due to letter identify (as between AA and AD). In the physical rule, a subject needs only to identify that two letters are visually different therefore the time required to match two visually different letters such as Aa and Ad should roughly be the same². One possible explanation is that an automatic generation of abstract letter identities occurs and that the codes so produced interferes with the spotting of visual differences between letters.

There is a precedence for interference in matching. In these tasks, the encoding of stimuli often generates redundant codes which interfere with their matching. For instance, an interference occurs in the auditory matching of rhymes due to coactivated orthographic codes -- words which are orthographically dissimilar such as dune-moon take longer to judge as similar (847 ms) than orthographically similar ones such as dune-tune (769 ms) (Seidenberg & Tanenhaus, 1979: Experiment 3). Thus if abstract letter codes are coactivated in the letter matching task this could cause Aa letter pairs to take longer to notice as a visually different letter pair than Ad letter pairs because of an

interference from abstract letter identity codes generated with the visual ones.

6.3. Experiment 7

6.3.1. Rationale

The above theories of letter matching for name identity and physical identity suggest that both abstract letter identity and visual codes are generated when letter pairs are matched. Are either of these codes restricted to one or other of the two visual channels? The use of counterphase to disable the parvo channel might provide a means to find out.

One problem is that there is a need to trade off the number of visual presentations of letters that can be presented in a session and the use of one or two rules (for a within subject designed experiment). It was decided to use only one rule and four visual presentations: both letters static, both in counterphase and two with one static and one counterphase letter (one on the left, the other on the right).

The physical rule was selected. If the counterphase interfered with the formation of abstract letter identities then the delay of the Aa matching to relative to Ad matching should disappear since the delayed response of the Aa to the Ad letter matching caused by interference effects of

abstract letter identities should cease if their formation was in any way disrupted.

6.3.2. Stimuli

Four letters A, D, R and T were used. They were selected on the grounds that compared to other potential letters, they were less phonetically confusable and appeared to offer the greatest dissimilarity between upper case and lower case. (Lower case letters with descenders were excluded because the descenders would have extended outside the dimensions of the images used to create the counterphase letters).

Four letters were used to create four sets of 96 letter pairs balanced to represent every letter permutation. The 96 were made up as follows: four groups (for the four letters) of 24. Since each letter has two cases this divides them in to two groups of 12 for each case. Each of these letters was matched with one of the other three letters in both of its cases -- making six. Another six need to be created (to balance the numbers to prevent an excess of different letter responses) with letters of the same character to match with them. In total, 384 letter pairs were used.

6.3.3. Method

The recruitment and procedure for running subjects was similar to that used for the lexical decision task experiments. Subjects were recruited from psychology and geography undergraduates, postgraduates and research assistants. They were asked whether they suffered from epilepsy, migraine and dyslexia. The subjects were sat 60 cm away from the screen.

The experiment started by the subject being told that they would be doing a letter matching task in which two letters would appear either side of a fixation point. If the two letters were the same, they might have the same or a different case. They were to press the red button (placed in their dominant hand) if they were visually identical. If the letters were not visually identical they were to press a black button (placed in their nondominant hand). They were told that the experiment would last about 15 minutes and that there would be a break half way through. They were further told that it was normal to make some mistakes but they were not to worry about them, nonetheless they should aim to be as accurate and as fast as possible.

The experiment was initiated with a practice session of 17 pair matches. The rule was explained to the subjects if need be with a card with the various letter combinations and appropriate buttons responses illustrated. The experimenter

closely observed the subject, verbally rewarding them if they were correct in their response and reminding them of the rule if they were unaware when they made a mistake.

6.4. Analysis of results -- Experiment 7.

6.4.1. Fallacy of language-as-a-fixed-effect

The previous reporting of experiments upon letter matching have been motivated by a wish to make generalisations to the letter processing of all letters not just the ones used in the experiment. However, the statistical analysis offered fails to make allowance for the fact that they used only a few letters of a much larger pool of potential letters to which they were generalising their results. They ignored what Clark (1973) called the problem of fixed and random effects: they treated the letters as fixed effects whereas because they were sampled from a much larger pool they were random ones. This has to be taken into account or at least acknowledged.

In the reporting of results this can be done in two ways. First, by reporting not only repeated measures ANOVA done across subjects (which treats subjects as a random effect) but repeated ANOVA done across the four letters (which treats letters as a random effect). Second, to evaluate a F value known as $\min F'$ from the F values obtained from these subject and item analysis. $\min F'$ is not the

proper F value which takes into account the variance due to subjects and letters (items). That F value is too complex to calculate as Clark (1973) notes (particularly in the presence of missing data).

In the following analysis, $\min F'$ values are given where both subject and item (letter) analysis are significant at the .05 level.

6.4.2. Terminology

Creating sharp, appropriate and readily understandable names for the various conditions and letter matches was a problem. The simplest (though not ideal) method of representing the four presentation conditions represent them using two signs for the static and counterphase (flicker) presentations: **S** and **fl**, respectively. These signs are placed either side of a mark representing a fixation point +; this is to represent whether the letters were presented on the right or the left. Using this convention the condition where both letters were in counterphase is represented as **fl+fl**, where the left one was in counterphase and the right one was static as **fl+S**, where the right letter was static and the left one was in counterphase as **S+fl**, and where both were static as **S+S**. Occasionally I refer to **fl+fl** as double flicker and **S+S** as double static. The initial analysis combined these presentations into two factors: cross made of same (**fl+fl** and **S+S** -- same because the letters used the same

method of presentation) and cross (S+fl and fl+S -- cross because the method of presentation was crossed between the letters); and side made of left flicker (fl+fl and fl+S -- the left letter was presented in flicker) and left static (S+fl and S+S -- the left letter was presented statically).

6.4.3. Contrasts.

There were four presentations each with four match conditions. On the basis of previous work, there was an interest in the significance of certain comparisons between the match conditions. The above theory and research suggested the most useful comparisons were between AA and Aa (referred in the ANOVA tables in the appendix as letters -- since they share the same letter), and Aa and Ad (referred to in the ANOVA tables as case because they share the same case).

6.5. Findings -- Experiment 7

6.5.1. Double static

One of the four conditions presented only static letters. The graph of its results are similar to those found previously (Carrasco, 1988) for letter matching. However the means were not all significantly different. In particular, though there was a 28 ms difference between Ad (509 ms) and AA (481 ms) letter matching this was not significant by

either subjects $F(1, 27) < 1$, ns, or items $F(1, 9) = < 1$, ns, see the ANOVA tables in the appendix 6.1. and 6.3. However, errors were significant by subjects $F(1, 27) = 9.12$, $p = .005$, and by items $F(1, 9) = 8.97$, $p = .018$; $\text{min}F'(1, 15) = 6.75$, $p = .02$. The difference between Aa match and Ad match (447 ms) was significantly different both by subjects $F(1, 27) = 31.51$, $p < .001$; and items $F(1, 9) = 28.06$, $p < .001$; $\text{min}F'(1, 51) = 6.75$, $p = .012$.

An examination of the error scores suggested the possible existence of a speed-accuracy trade off for AA letter matching since faster reaction times were also more inaccurate. However an examination of the right hand graph in figure 6.2. which illustrates the errors for other conditions shows a general trend that ranks longer reaction times (in the right hand graph) with greater errors for the AA letter match response. The same-letter same-case response unlike the others required a yes response rather than a no one. Subjects commented that they found this made them make more errors (their hands automatically tended to press the no button even if they had spotted they should make a yes response). Further, an examination of the graph in figure 6.3 (and the data table 6.1 which follows the two graphs 6.2. and 6.3.) shows that more errors occurred in the S+S condition for the letter R than for the rest added together -- it accounted for 61% of total errors. However, the reaction times for the letter R were higher in the AA (487 ms) than in the Aa one (483 ms). This questions whether

the quicker response times for AA compared to Aa were actually due to a time trade off with errors.

Figure 6.2 Experiment 7. Reaction times (left) and errors (right) to the all static presentation of letters.

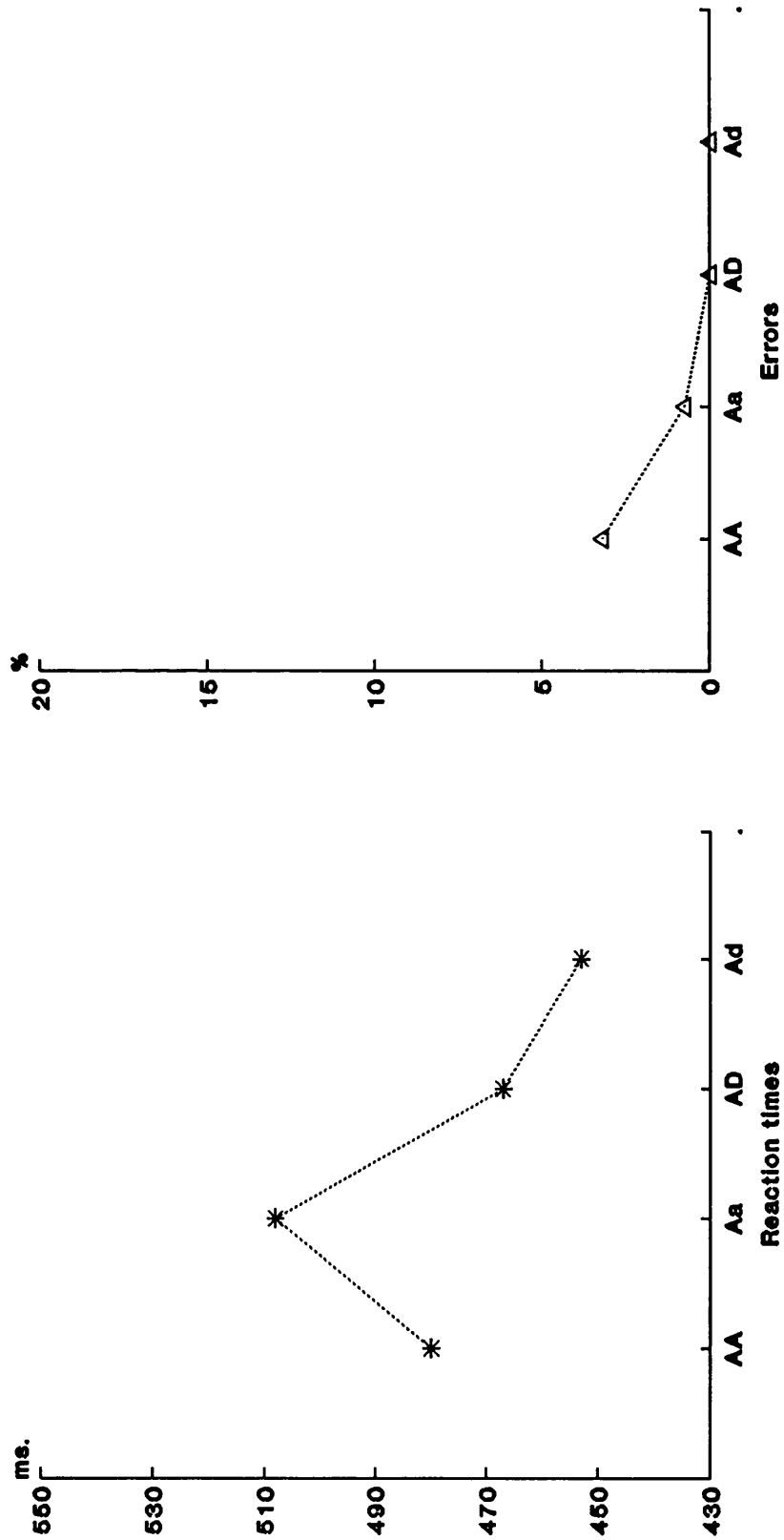


Figure 6.3. Experiment 7: both letters static presentation; reaction times (left) and errors (right) for the four letters.

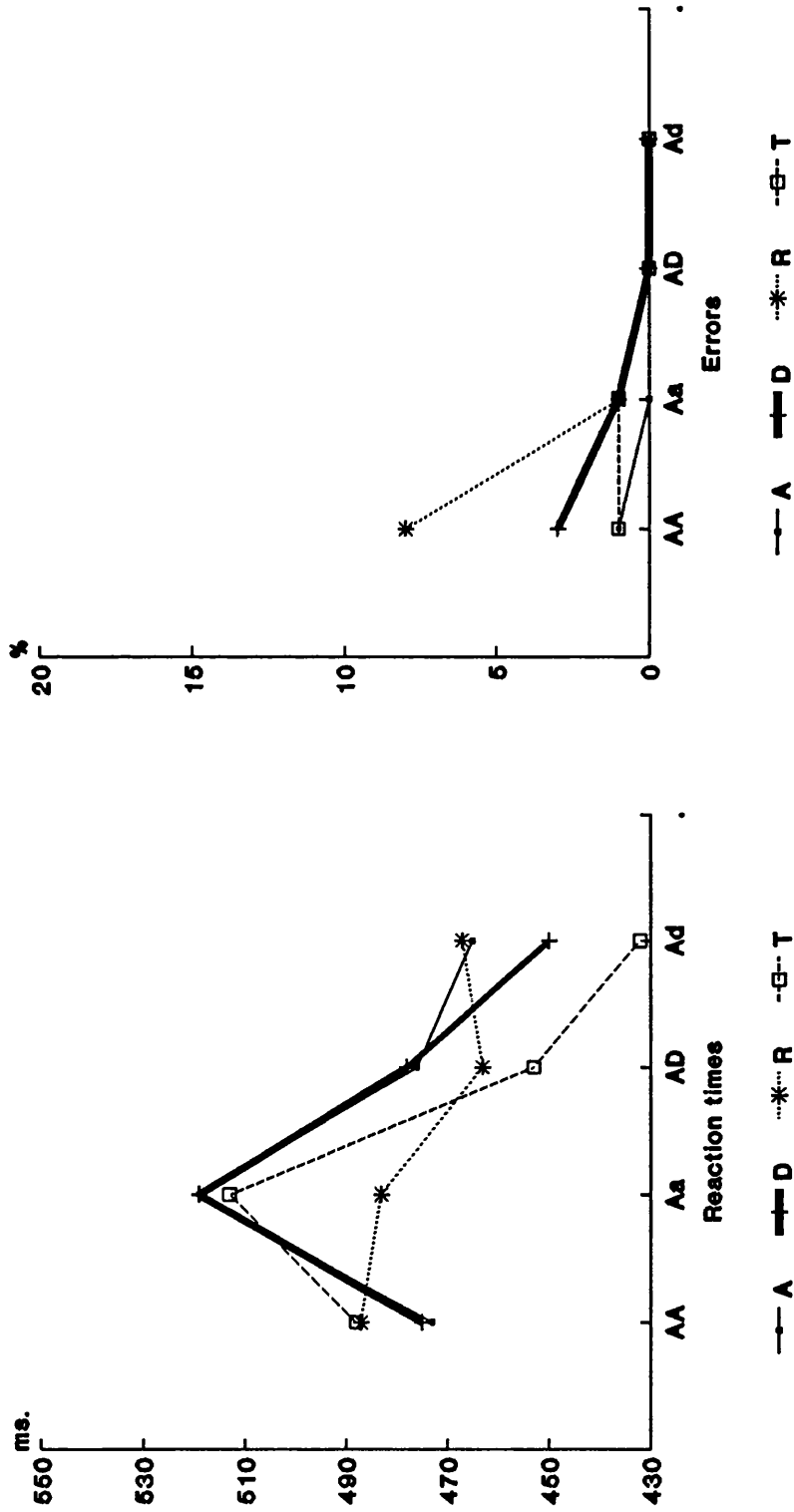


Table 6.1. Experiment 7: means, Sds and percentage errors for the four letters and four letter matches

	<u>Same letter</u>				<u>Different letter</u>				
	<u>AA</u>		<u>Aa</u>		<u>AD</u>		<u>Ad</u>		
S+S									
A	473	(78)	1 519	(117)	0 476	(83)	0 465	(81)	0
D	475	(69)	3 519	(111)	1 478	(94)	0 450	(63)	0
R	487	(85)	8 483	(100)	1 463	(81)	0 467	(90)	0
T	488	(82)	1 513	(96)	1 453	(94)	0 432	(63)	0
	481		3.3 509		0.8 468		0.0 454		0.0
fl+fl									
A	489	(67)	3 517	(122)	1 459	(83)	1 465	(82)	0
D	509	(88)	1 507	(100)	3 453	(84)	1 463	(70)	0
R	527	(91)	8 492	(108)	1 481	(95)	0 444	(82)	0
T	518	(82)	8 526	(106)	3 459	(96)	1 465	(89)	0
	511		5.0 511		2.0 463		0.7 459		0.0
fl+s									
A	538	(68)	13 490	(127)	1 476	(114)	0 440	(83)	0
D	526	(77)	15 468	(123)	1 460	(102)	0 453	(83)	0
R	543	(98)	15 517	(153)	1 453	(108)	0 460	(88)	0
T	530	(77)	20 543	(152)	3 434	(85)	0 433	(101)	0
	534		15.7 505		1.5 456		0.0 447		0.0
S+fl									
A	542	(102)	11 524	(142)	0 486	(101)	0 487	(110)	0
D	537	(105)	5 534	(133)	0 472	(110)	0 457	(96)	0
R	517	(72)	8 513	(136)	0 472	(98)	0 482	(122)	1
T	549	(81)	15 533	(143)	1 475	(80)	0 491	(103)	0
	536		9.8 526		0.3 476		0.0 479		0.3

6.5.2. All presentation conditions

In previous research upon (and in the present experiment) the reaction times for static letters for Aa classification responses was delayed compared to responses to other letter pairs (AA, AD and Ad). However this pattern of reaction times was not for responses in this experiment in which, one or both, of the letter pair letters was counterphased as AA classifications were delayed (or equal) to Aa ones. The AA judgements (515 ms) over all conditions were slower by 4 ms than compared with reaction times to Aa matches (511 ms). This difference was in the opposite

direction to that found with static letters and highly significant both by subjects $F(1, 27) = 22.5, p < .001$, and items $F(1, 9) = 30.78, p < .001$; $\text{minF}'(1, 39) = 6.75, p = .013$. Over all four conditions, reaction times between different-letters were like the previous results with static presentation.

Thus a result occurred contrary to previous research: AA judgements are longer not quicker than Aa ones. However a look at the graph in figure 6.4. shows that this contrast (unlike the one involving different letters) contained much variation due to the presentation conditions.

Figure 6.4. Experiment 7. Reaction times (left) and errors (right) for the four letter presentations.

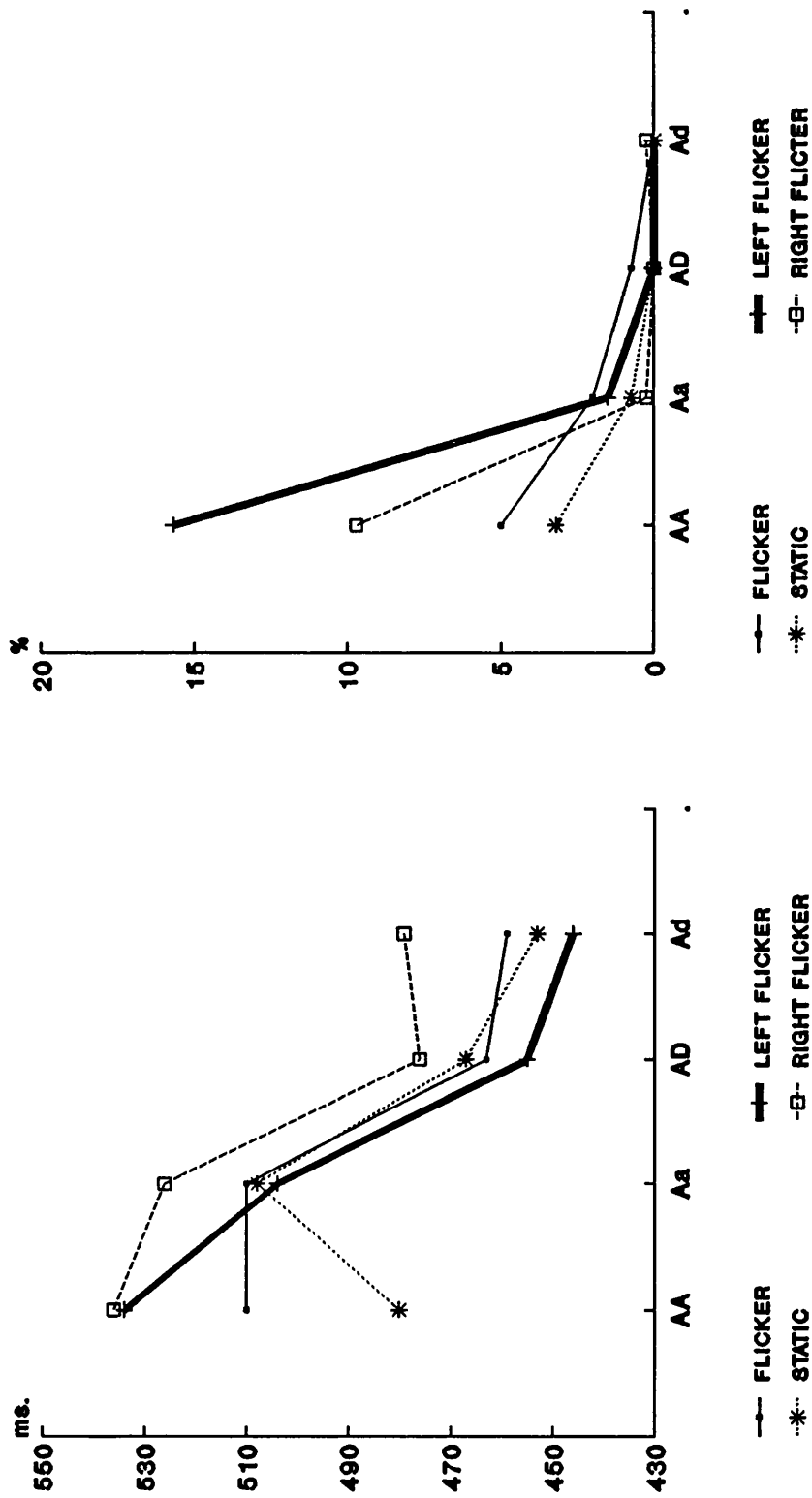
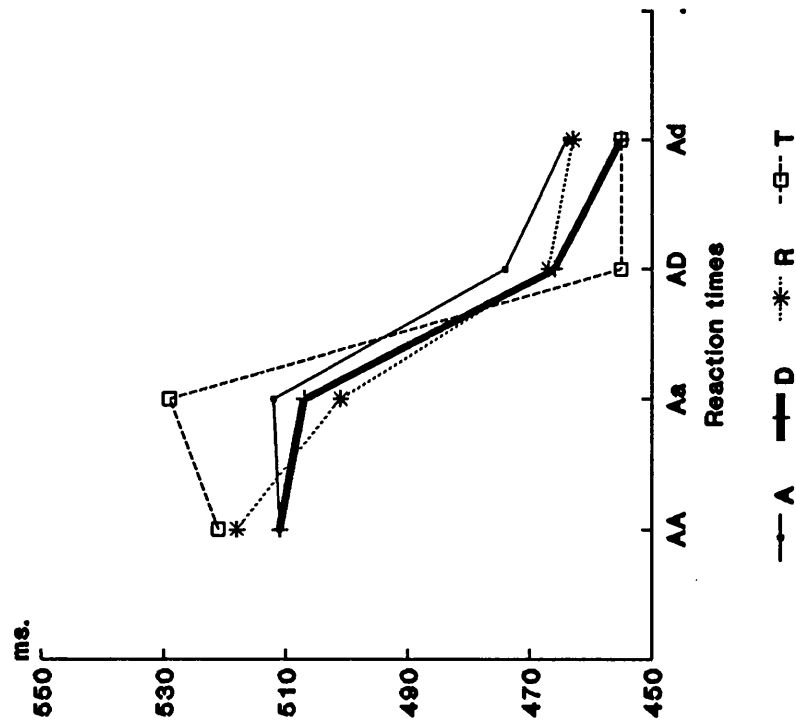
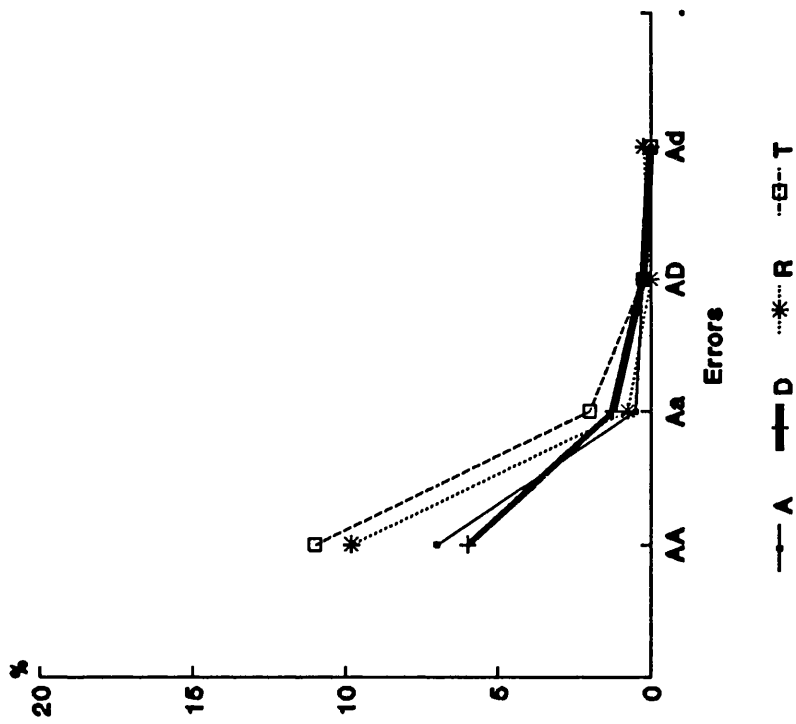


Figure 6.5. Experiment 7: Reaction times (left) and errors (right) all conditions collapsed.



This variation was explored by factoring the four presentation conditions into a same (either both flicker or both static)/different (one flicker and one static) presentation factor labelled in the ANOVA as cross; and another factor known as side for whether there was a flicker (or static) presentation on the left (see tables 6.5., 6.6., 6.7. and 6.8 in the appendix). Both factors interacted with the letter contrast (AA and Aa) but not the case contrast (Aa and Ad). The cross factor will be discussed first. See figures 6.6 and 6.7.

6.5.3. Cross factor

The cross factor was created by collapsing together the two matches which used the same presentation (double static **S+S** and double flicker **fl+fl**) and contrasting them with the two presentations containing both a flickering and a static letter (**fl+S** and **S+fl**). Though the factor was a trend by subjects $F(1, 9) = 3.74, p = .084$; and significant by items $F(1, 3) = 33.45, p = .01$; an examination of the graphs in figures 6.6, 6.7 (the four letters uncrossed) and 6.5. (the four letter crossed) show that they differed chiefly in the AA match judgement. When matching visually identical letters one of which was flickering and the other static, responses were longer and less accurate than when matching letters both of which were either flickering or static. This interaction was significant for reaction times both by subjects $F(1, 27) = 11.97, p = .002$; and items $F(1, 9) = 12.24, p = .009$; $\min F'(1, 27) = 6.05, p = .02$; and errors by subjects $F(1, 27) = 18.23, p < .001$; and items $F(1, 9) = 49.19, p < .001$; $\min F'(1, 16) = 13.3, p = .002$.

From the graphs of reaction times this interaction can be seen to be due to a delay for crossed letters matches. One can imagine two kinds of explanation. First, it might have been due to the encoding of the letters: counterphase letters and static letters might be encoded in different codes which do not translate easily into the other. This could have made them difficult to match. However this

explanation might be judged unlikely given it is not clear why translating codes for letter matching should be harder when letters are the same (as for AA letter matches) than when they are different (as for Aa, AD and Ad letter matches). However if physical rule matches AA use positive visual matching with different classification responses made using negative visual matching this would suggest that counterphase disrupts only the former processes -- those that are responsible for making positive visual matches.

An alternative explanation is that flicker is automatically or inadvertently used as a visual feature: when one of the two letters was flickering, it is mistakenly perceived to possess a visual difference absent compared to when they are both flickering or both static. Dealing with this interference either delays or causes errors. This phenomenon would have only affected AA matches: for the other letter matches this would have only added to an already present visual difference between the letters.

6.5.4. Side factor

Side is an artificial factor collapsing fl+fl and fl+S in one group, left flicker and in the other S+fl and S+S, left static. Neither halves of the interaction are theoretically linked in obvious ways. It was not significant over the four matches for reaction times: by subjects $F(1, 9) = 2.19, p = .173$ or items $F(1, 3) = 2.12, p = .241$. However it was for errors: by subjects $F(1, 9) = 5.6, p = .042$; and by items $F(1, 3) = 20.12, p = .021$; minF'(1, 5) = 4.38, $p = .09$ (trend). The difference between the errors from the graph appear to be concentrated in the AA match condition. The left flicker (fl+fl and fl+S) was longer and less accurate than the left static (S+fl and S+S) in the AA when compared to the Aa match (figures 6.8. and 6.9.). This interaction was significant for reaction times: by subjects $F(1, 27) = 17.19, p < .001$; by items $F(1, 9) = 7.21, p = .025$; minF'(1, 36) = 5.08, $p = .03$; and errors: by subjects $F(1, 27) = 3.17, p = .086$ (trend); by items $F(1, 9) = 47.75, p < .001$. However, from the graph this would appear to be due to individual component presentations. Thus further analysis turned to looking at the four presentations in more detail.

Figure 6.8. Experiment 7: Crossed factor: reaction times (left); errors (right).

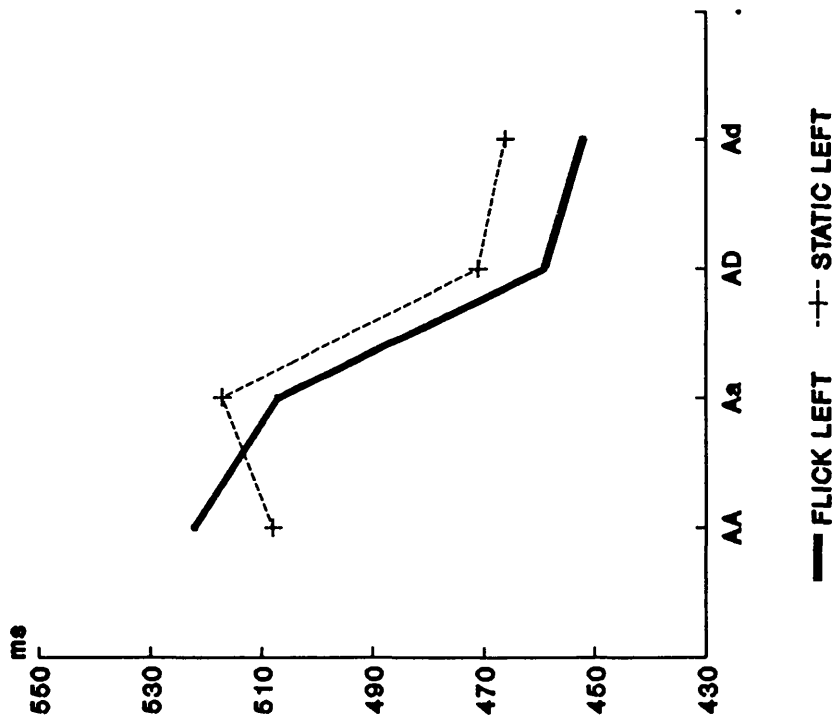
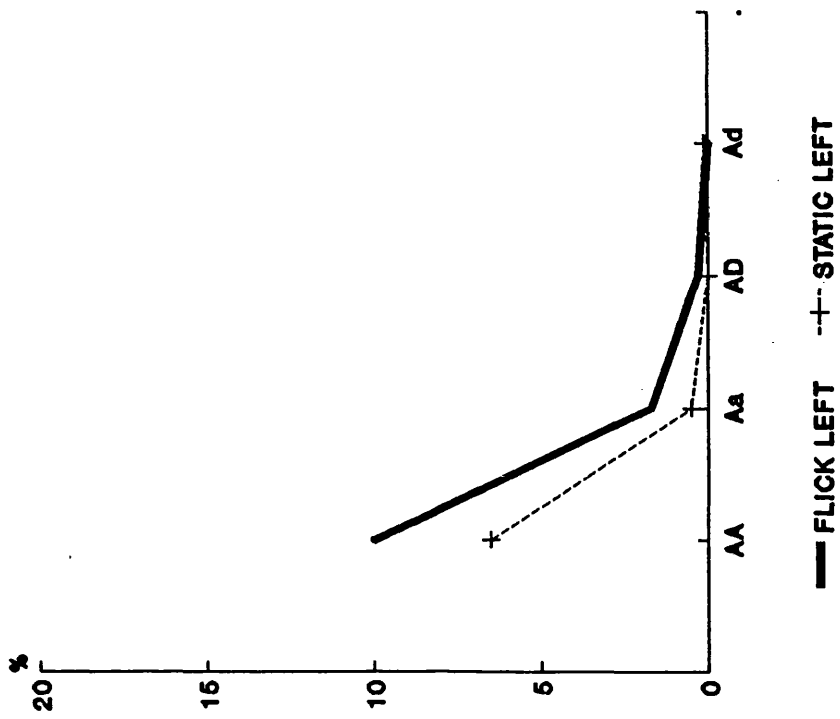
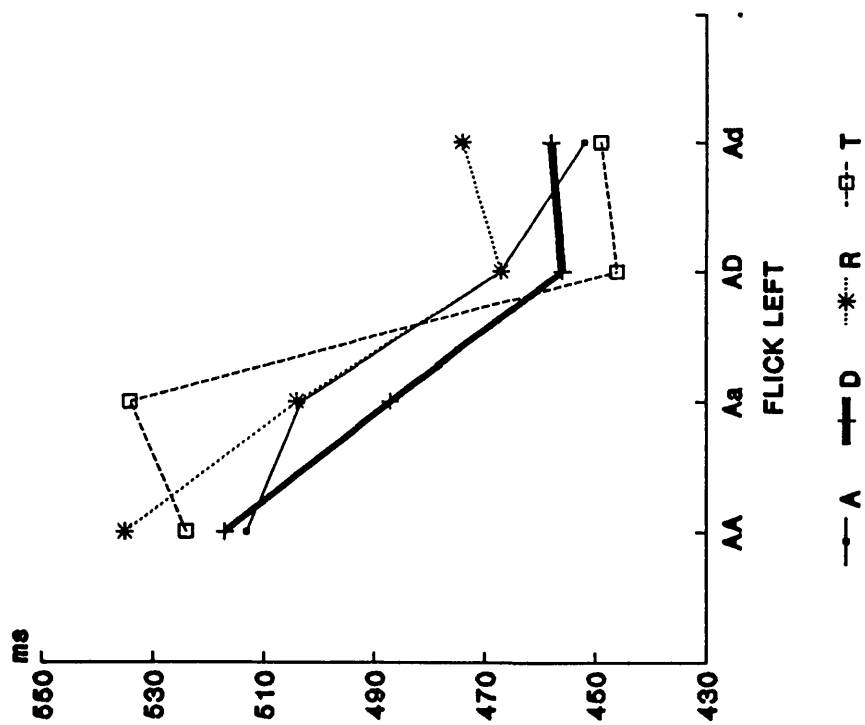
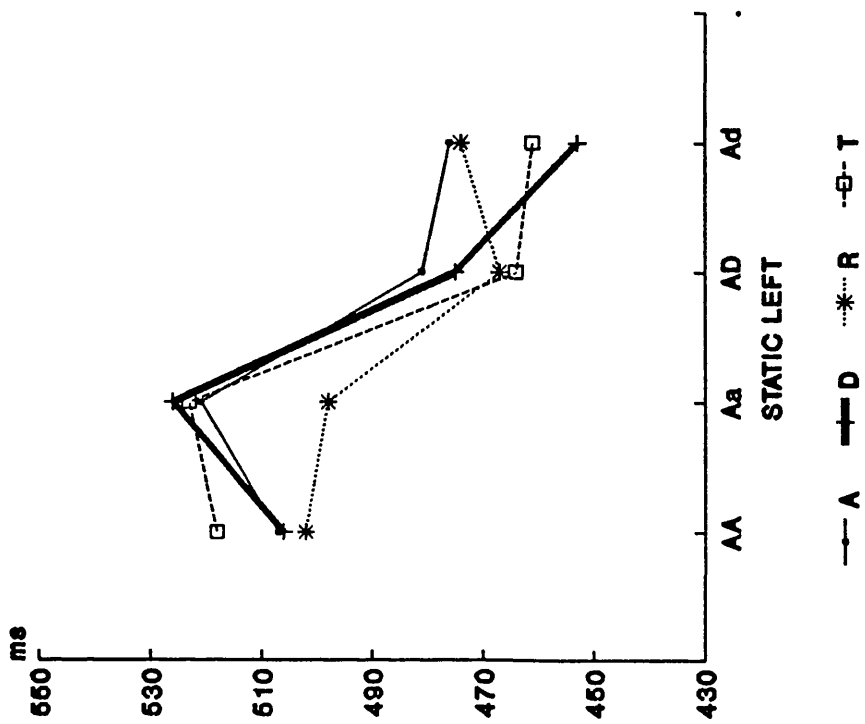


Figure 6.9. Experiment 7: Crossed factor by letters:
Reaction times (left) and errors (right).



6.5.5. Double flicker (fl+fl) and double static (S+S)

Looking at the graphs in figure 6.6. the interesting comparisons can be seen to occur between the double flicker letters and the double static ones and between the two crossed (flicker and static) matches. These are, in effect, factors hidden within the cross factor discussed above. Separate ANOVAs were carried out to compare (a) the double flicker and double static (ANOVA tables 6.9., 6.10. [by subjects]; 6.11, 6.12. [by items]) and (b) the fl+S and S+fl presentations (tables 6.13, 6.14. [by subjects], 6.15., 6.16. [by items]).

In the AA letter match, the pair of flickering letters had a reaction time of 510 ms, while the pair of static letters had a reaction time of 480 ms -- a difference of 30 ms. In contrast, for the Aa letter match, they had roughly the same reaction time (511 ms and 509 ms, respectively). In the ANOVAs for reaction times restricted to these two conditions a trend existed by subjects $F(1, 27) = 4.15$, $p = .052$ but not by items $F(1, 9) = 2.94$, $p = .121$, for the flicker to be slower overall than in the static presentation. However there was a significant difference between the above two reaction time means both by subjects $F(1, 27) = 6.78$, $p = .015$, and items $F(1, 9) = 6.67$, $p = .03$, $\text{minF}'(1, 27) = 3.36$, $p = .078$ (trend). The errors for this contrast were not however significant: by subjects $F(1, 27) = 0.24$, $p = .625$; items $F(1, 9) = 0.92$, $p = .363$.

Above it was observed that a difference between AA and Aa existed between crossed and uncrossed presentations. It was suggested that this difference could be attributed to two mechanisms: (1), the AA response matching using visual codes whose functioning for making positive matches is interfered with by counterphase; or (2), flicker being automatically treated as a visual difference cue leading to delayed and less accurate responses to the AA match. The delay found here for the double flicker cannot be attributed to the second proposed mechanism since both letters were flickering. Since over the four match conditions double flicker letters were not delayed compared to the double static ones this cannot be due to the task of matching the double flicker letters being intrinsically harder. Thus the effect can be attributed to the difficulty of making same matches. This would be consistent with the first hypothesis that AA matches are made on a process using visual codes which are disrupted by counterphase.

6.5.6. Side of flicker factor

The graphs (figures 6.7. and 6.8.) for the two mixed presentations (S+fl and fl+S) are the opposite for the two unmixed ones (fl+fl and S+S). Instead of them being roughly the same except for the AA matches, for all the matches they are different except for this letter match group. Because the planned contrast was set up between the AA vs Aa matches, this was looked at.

For the AA vs Aa contrast they had roughly the same means (535 ms and 536 ms respectively) but there was a 21 ms difference between reaction times to the Aa vs Ad matches (505 ms and 526 ms, respectively). The ANOVAs failed to find this consistently significant: for subjects it was $F(1, 27) = 7.63, p = .01$; but not for items, $F(1, 9) = 2.59, p = .141$. However, the two presentations were different overall with the right side flickering letter being more difficult than the left one (as suggested by the graphs): by subjects $F(1, 9) = 11.81, p = .007$; and by items, $F(1, 3) = 11.99, p = .041, \text{min}F(1, 9) = 5.95, p = .027$.

6.5.7. Laterality effects

The interaction of side: right or left side on which the flickering letter appears introduces the issue of laterality. There are well known differences for the perception and processing of verbal stimuli in the left and right visual fields and thereby it is claimed right and left cerebral hemispheres. However, the stimuli were not designed to explore the effects of laterality upon letter matching. Research upon laterality requires that stimuli are presented at least one degree or more from the centre of fixation since the visual field is bilateral within its central two degrees. The outer edges of the 10 mm wide letters together with the 4 mm space between them made this edge (from the distance of 60 cm at which the subjects were positioned) to be at most 0.7° from the central fixation point. Thus both

letters were by a large margin within that part of the visual field seen by both hemispheres. Therefore from the point of view of conventional laterality research they were both seen within bilateral central vision. Further, the subject viewed them until they responded -- in normal laterality research stimuli are presented for only 200 ms or less since otherwise eye movements can shift the stimuli upon the other visual field. This point though is redundant (since they were in central vision) and is only made to emphasize the difficulty of interpreting the data in terms of laterality research.

6.6. Conclusions

Conclusions are confined to inferences which can be made from the one reported experiment. They are limited but interesting. The order of discussion is counterphase, abstract letter identities and finally the magno channel.

6.6.1. Counterphase

Depending upon classification response, the processes responsible for letter matching were and were not affected by counterphase.

First, letter matching is affected by counterphase but this effect is confined only to positive visual matching: AA matching differed according to whether the letters were

presented in counterphase or not. There were two effects depending upon whether both or only one of the letters was presented in counterphase. Presenting both letters in counterphase made responses longer than presenting them statically. However, presenting only one letter in counterphase made for an even longer response delay. This suggests that not only does counterphase affect the matching of AA letters but comparing across counterphase and static letters disrupts a second mechanism involved in letter matching.

Second, letter matching is not affected by counterphase but this effect is restricted to the processes responsible for negative matching: counterphase (except for the right side letter counterphase) does not affect the matching of Aa, AD, or Ad letter pairs. There is not even a trend for them being more difficult as with the AA letter pairs. Indeed, if anything, from the graph 6.3., the double counterphase and the left sided letter counterphase letter pairs (fl+fl and fl+S) look possibly quicker than double static letter pair matching.

This suggests that while counterphase does affect some aspects of letter matching it has does not affect other components. This is consistent with the idea that for physical identity classification letter matching involves two processes one confined to the matching of AA letter

pairs (affected by counterphase) and another to visually different letter pairs (not affected by counterphase).

6.6.2. Abstract letter identities

In the introduction it was suggested that the delay of Aa matches compared to AD and Ad ones is due to the coactivation of abstract letter identity codes which interfere with the judgement of visual difference. The failure to find any effect of the presentation conditions upon the delay of Aa matches compared to AD and Ad matches suggests that the interference of abstract letter identities was not decreased by counterphase. Thus counterphase could not have reduced the coactivation of abstract letter identity codes. This suggests that abstract letter identities form through either channel or that they form at some late stage in the visual system where they interact and exchange information.

6.6.3. Magno channel and letter matching

Though no specific evidence can be given from the work reported in this chapter for linking counterphase letters and the magno channel this is not an unreasonable supposition given the results of the previous chapter, section 5.5 and chapter 2, section 2.4.2. However, even assuming the putative identification of the counterphase

letter presentation and the blocking of the magno channel's processing of letters, the research reported here does not support a role for the magno channel in letter processing in word identification.

Consider what needs to exist for this to be the case. Letter matching would have to yield results which showed (1) that a particular type of letter match depended on was affected by abstract letter formation, (since abstract letter processing is a stage known to be involved in the letter perception used in word identification); and (2), that this letter matching (and by implication the formation of abstract letter identities) was affected by counterphase (and by inference magno channel processing). This did not happen. Instead, the results were interpreted above to suggest that counterphase inferences with the visual identification of same matches with the affect of abstract letter identity processes upon Aa letter matches unaffected by counterphase.

Some conclusions might tentatively drawn from the observed noneffects. Counterphase did not effect same-letter different-case Aa matches. It has been suggested both that (1) the delay of Aa letter pairs is due to abstract letter identities and that (2) counterphase limits visual processing to the magno channel. If both of these suggestions are correct (and some caution is needed as whether they are) this implies either that the magno channel

can form abstract letter identities or that abstract letter identities form in processes that take place after input from either visual channel since as noted in chapter 2, section 2.3.4. the magno and parvo channels interact after the lateral geniculate nucleus.

notes

1. There is a possible explanation for this difference. Posner ran his subjects over four days, the first of which was devoted to practice with number matching. Carrasco and I asked subjects to do the task only after a brief practice session. It is possible that Posner's subjects learnt with experience and over time to reduce the coactivation of abstract letter identity codes.

2. Posner claimed to have found that similar case matches such as Cc were quicker than dissimilar ones such as Ee. Carrasco et al (1988) failed to replicate this with a larger group of subjects.

7.1. Résumé

Written words are processed initially by the visual system. Some uncertainty exists as to whether the visual system plays any role in their recognition -- but this is a possibility. Several reasons support this possibility. (a) The letters of written words prior to their recognition become converted into abstract letter identities. These are visual (as opposed to phonological) codes devoid of visual details like case, font and size. The formation of these abstract letter identities occurs somewhere in the brain, the most likely place would seem be a neurological location which was able to process the visual details of letters and thus have the ability to remove them by abstraction. (b) It has been claimed by Posner and colleagues (Petersen, Fox, Posner, Minton & Raichle, 1988; Posner, Petersen, Fox & Raichle, 1988) upon the basis of PET imaging that the lexical recognition of words is located in part of the visual system: the extrastriate visual cortex. (c) Research using electrophysiological measurements of saccade-related brain potentials during reading (Marton & Szirtes, 1988) suggest that lexical responses appear simultaneously with visual responses suggesting that lexical and visual information are processed at the same time and so possibly together. The last two pieces of research are still preliminary and it may turn out that they are misleading;

however they are suggestive that the visual system has a role at some stage in the reading process.

The visual system has been claimed both by neurophysiologists (DeYoe & Van Essen, 1988; Livingstone, 1988; Livingstone & Hubel, 1987; 1988; Schiller & Logothetis, 1990; and Zeki & Shipp, 1988); neuroanatomists (Lee, Martin & Valberg, 1988; 1989a; 1989b; Lee, Pokorny, Smith, Martin & Valberg, 1990); and psychophysicists (Breitmeyer, 1984, chapter 6; Cleland, Dubin, & Luvick, 1971; Enroth-Cugell & Robson, 1966; Kulikowski & Tolhurst, 1973; Legge, 1978; Lennie, 1980) to be divided into two channels. This division has been suggested by neuroanatomists to originate in the retina and persist into the higher association areas of the cerebral cortex (Livingstone & Hubel, 1987; 1988).

Visual psychophysicists have argued that the two visual channels (which for convenience will be called magno and parvo, though other terms are in use in the literature) play different roles in reading (Breitmeyer 1980; 1982; 1983; 1984; in press; Breitmeyer & Ganz, 1976). Moreover they (Breitmeyer 1989; 1991; Lovegrove, Martin & Slaghuis, 1986; Lovegrove, Garzia, & Nicholson, 1990; Williams, LeCluyse & Bologna, 1990; Williams, Molinet & LeCluyse, 1989) have further claimed that most cases of dyslexia attributed at present to phonological dysfunction originate in a defective magno channel (though they use the term

'transient'). In the first chapter of this thesis I reviewed their work and noted a number flaws in it both in terms of explaining the role of the two channels in vision and the notion that a channel defect could be the cause of the majority of the cases of developmental dyslexia.

Moreover none of their research has involved the direct investigation of the two channels in the reading process. Thus their claims must be treated with some caution. They need to be verified by direct methods.

Direct methods for investigating the role of the two channels in cognitive tasks have been developed by neurophysiologists. The basis of their work has been to use the different visual processing characteristics of the two visual channels to block the perception of stimuli by one channel while not affecting that of the other. The magno channel has been argued to be colour blind while in contrast, the parvo channel has been suggested to be responsible for colour perception. Thus the use of stimuli of different colours but with the same luminosity has been used in an attempt to block the perception of stimuli by the magno channel. The parvo channel has been claimed to have a restricted temporal resolution while in contrast the magno channel has been claimed to a high one. Thus attempts have been made to block the perception of stimuli by the parvo channel while permitting their perception by the magno channel by presenting them in form -- counterphase -- which

to be visible requires their perception by processes with a high temporal resolution.

These techniques have been applied to a wide range of perceptual tasks to investigate the contribution of either of the two visual channels to their cognition (Livingstone & Hubel, 1987). However, they have not been applied to the direct investigation of the cognitive processing of reading material.

The application of such techniques to the investigation of reading processes was the topic of this thesis. However their application was not without problems. Indeed, one of the achievements of this thesis has been to uncover problems which future researchers in this and related fields must face.

To explore reading processes reaction time experiments were used. The use of reaction time experiments is an innovation over previous research using channel blocking. However, a problem was found. Reaction time experiments were combined with counterphase stimuli: the methods used to block channels took advantage of the differences between their capacity to temporally counterphase images (images whose polarity [black against white, white against black] alternates).

Though in theory counterphase images should be invisible to processes not capable of following the polarity alternation, in practice this is not the case. In chapter 4 it was shown that counterphase can be seen through other processes if following a visually blank field. These processes take advantage of the visual buffering of its initial frame. This buffering can however be blocked by the use of pre-mask. This phenomena has a double interest.

First it raises questions about the visual system and the iconic buffering of images - it was shown that a counterphase pre-mask was as good as a static one. Thus this suggests that the iconic buffer is indifferent to the polarity of the image. This puts constraints upon theories about the processes that might be involved in the visual buffering of images -- they have to be ones indifferent to image polarity.

Second, it suggests that it is not sufficient to present images in counterphase to restrict their perception to processes capable of resolving the counterphase's alternation. They must be preceded by a mask to block their noncounterphase perception. After finishing the research reported in this thesis, I learnt that V. S. Ramachandran in unpublished work had encountered similar problems and resorted to a similar solution involving masks.

This research was innovative in taking advantage of low cost hardware: a PC compatible fitted with a VGA controlled monitor. Since this hardware is readily available in most psychology departments there is and will be an increasing use of it in research. This hardware is designed for commercial rather than research use (this is one of the chief reasons for its low cost). At present several difficulties are known to exist in the use of this low cost hardware for research -- for instance, special precautions are needed to obtain millisecond timing.

This thesis discovered another problem related to the use of VGA monitors to create isoluminous stimuli. The luminosity control of the VGA is nearly sufficient for isoluminous research (colour luminosity can be controlled to about 2% contrast -- this is less than an ideal but acceptable for some purposes). In chapter 3, the existence of a cold pixel artifact was shown to occur at vertical luminosity boundaries. This effect is unnoticeable without special techniques and so its existence is likely to go unnoticed (indeed the results of one publication seem to have been compromised by it already). Since VGA monitors are readily available and offer sufficient luminosity control to study the effect of contrast upon vision and to create isoluminant stimuli it is likely that failure to appreciate the presence of this artifact will complicate (unless it is specifically counteracted) the results of researchers who

use this type of monitor. A technique was developed to minimise this artifact.

The quantitative results of research blocking the magno and parvo channels in the investigation of reading processes was in general unfruitful. However there is one significant qualitative observation: stimuli, both letters and whole words, were readily observable though the stimuli presentation was designed to block their perception by the parvo channel but to be perceptually transparent to the magno (transient) channel.

This suggests, in conflict, with the ideas of psychophysicists that the magno channel can participate actively in the recognition of words. This conclusion however needs to be qualified.

First, the methods used to block the parvo channel were putative -- though based upon neurophysiological research upon the two channels competencies -- there was little independent evidence that they actually worked.

Second, even if they did isolate as intended the two visual channels, there is still the possibility that there might be unknown processes which side step counterphase (the main method of channel isolation). One such process was found, others might plausibly exist.

Third, the two visual channels are not completely isolated from each other and there exists the possibility that visual information initially processed in the magno channel might transfer to the parvo channel. In chapter 2, I discussed the various anatomical interactions between the two visual channels. These occur after the two visual channels enter the visual cortex. It is possible if the visual processes responsible for letter and word recognition occur in this part of the brain that they can access visual input from either channel.

Thus this research raises the possibility that the magno channel can actively engage in the recognition of written material but this is only tentative as other interpretations cannot be ruled out.

The quantitative work upon the blocking of the two visual channels and reading processes was written up in chapters 5 and 6. The work in chapter 5 discussed the use of two visual presentations designed to block both channels. The work discussed in chapter 6, learning from the earlier work (described in chapter 5) used a presentation that only putatively blocked the parvo channel.

The work in chapter 5 explored the involvement of the two channels in lexical processing. Posner and colleagues (1988) have reported evidence to suggest that lexical processing takes place in the extrastriate cortex. Given the

two visual channels are to a substantial degree separate in this part of the visual system (though there are significant interactions between them) it was a plausible research question whether channel blockage differentially affected lexical processing. This possibility for instance could arise if lexical processing was confined to one but not the other visual channel. The research upon lexical decision found no effect of channel blockage upon factors thought to tap lexical processes (it should be noted controversy exists whether the lexical factors used actually affect lexical decision at the lexical processing stage).

However, analysis of the reaction time advantage of word classifications over nonword classifications and length effects suggest the involvement, probably at a prelexical stage, of the two channels in the reading process. There was a small comparative advantage for nonword classifications over word ones when done in parvo rather magno presentation. This advantage existed in two control experiments even though the general advantage of word classification over nonword classification differed considerably between them.

It is not clear where such an advantage might originate. However, one possibility might be affects upon the parsing of letter strings for nonword classifications. According to Seymour (1987a and 1987b) nonwords (but not words) need to be parsed into sublexical units. Ellis, Young and Anderson (1988) have suggested, not incompatibly with

Seymour, that nonwords are buffered in an abstract letter storage: inputting letters into this occurs sequentially and so causes a length effect. Words in this model are input in a different way which involves the parallel input of letters and so produces no length effect. In both models the process by which nonwords are inputted is responsible for the letter length effect, absent or of only a weak nature, found for words. Magno and parvo presentation did not interfere with this process in the way that other nonnormal visual presentations (such as zig-zag presentation) do by causing increased length effects. Rather than this counterphase presentation compared to static presentation reduced the length effect. This occurred by lengthening the reaction time responses of shorter words compared to longer ones. It is not clear what might explain this but it could be due to an additive component which occurs in parallel with the length effect and thus for longer letter strings is masked by the letter length effect and only apparent for shorter words. If this is indeed the case, the reason for it and its relationship to the two visual channels is completely unclear.

In chapter 6, the involvement of the two channels with letter matching was investigated. Coltheart (1981) has suggested that matching might occur through abstract letter identities rather than as has been previously suggested phonological codes (Posner 1986; Posner & Mitchell, 1967; Posner, Boies, Eichelman & Taylor, 1969). There are two

rules, classification of letters by name (for instance, AA and Aa are classified as same) and physical identity (for instance AA is classified as same but Aa is classified as different). The physical identity rule was used because preliminary work found that Aa matches took long longer than either AA or AD and Ad ones suggesting the presence of a possible interference of abstract letter identities in matching the visual similarity and dissimilarity of letter pairs. If blocking the parvo channel prevented or interfered with the formation of abstract letter identities this would abolish what I have interpreted as an interference effect.

The research failed (with one exception) to find any effect of parvo blocking upon letter matching. In particular no effect occurred for Aa matches. This suggests that letter matching processes are not in general effected by presentation designed to restrict processing to the magno channel.

The exception involved positive matches (AA). These became harder when presented in the parvo blocking condition. This suggests that the visual processes responsible for positive matches might depend to some degree upon processes in the parvo channel while those responsible for negative matches can occur in either channel. This result while of interest to a general understanding of the role of the two channels in matching is of limited interest however to understanding their role in the reading process.

This thesis has shown the practicality of applying techniques developed in neurophysiology to study the role of the two visual channels in the reading process. Unfortunately, the research using these techniques failed to find dramatic indications of the special involvement in the reading process of either channel. This paradoxically is of interest since according to the psychophysical approach the magno channel should have been incapable of processing written materials (Breitmeyer, 1980; 1982; 1983; 1984; in press; Breitmeyer & Ganz, 1976; Lovegrove & Brown, 1978; Lovegrove, Slaghuis, Bowling, Nelson & Geeves, 1986; Martin & Lovegrove, 1987; Martin & Lovegrove, 1988; May, Lovegrove, Martin & Nelson, 1991; Slaghuis & Lovegrove, 1986a; 1986b; 1987). As noted though, this conclusion must be tentative since there exists alternative explanations why the magno channel blocking stimuli were processed.

7.2. Further work

Nonetheless, this thesis has broken new ground. In doing this several lines of enquiry (not all of them relevant to the study of reading) suggest themselves as ways the work reported in thesis can be carried forward and developed.

7.2.1. Reaction time research and magno blocking

Studies upon channel blocking have concerned themselves mainly with qualitative report -- for instance whether an illusion or perceptual effect is present or not when a channel is blocked. This research has not used experiments involving reaction times. In consequence this research has been limited in several ways. (a) Reaction times provide an readily available independent variable for the study of interactions between dependent variables. (b) They open up the possibility for chromometric exploration of processing in the two channels. (c) It enables a wider range of questions to be investigated. For instance, the involvement of the two channels in the generation of various kinds of visual codes and the competence to do various manipulations upon them i.e. when making positive and negative match classifications.

7.2.2. Magno blocking and reading

The experiments described in this thesis represent only a small number of those which could be used to investigate reading processes. For instance, the effects of letter matching were studied only using the physical rule -- the name rule was left uninvestigated. It may be that more positive findings would emerge if the name rule was studied. The reduction of the length for nonwords in lexical decision needs to be more closely investigated. Is it robust generalising to stimuli other than those in this thesis?

7.2.3. Magno blocking and dyslexia

Strong claims have been made by Breitmeyer, Lovegrove and others (Breitmeyer 1989; 1991; Lovegrove, Martin & Slaghuis, 1986; Lovegrove, Garzia, & Nicholson, 1990; Williams, LeCluyse & Bologna, 1990; Williams, Molinet & LeCluyse, 1989) that dyslexics have impaired magno (transient) channels. The studies carried out in this thesis failed to find any major effect of magno blocking upon the letter or word perception of normal readers. Would this lack of effect of channel blocking also be shown in phonological dyslexics? There is a need to repeat the experimental tasks reported in this thesis using such subjects.

If dyslexia is due to a magno (transient) channel defect than dyslexics should find that visual manipulations designed to block the parvo channel impair their vision since this would force them to rely on the magno channel which according to Breitmeyer and Lovegrove is defective. For instance, phonological dyslexics should more than age and reading matched control readers find rapid counterphase writing difficult to read. In contrast, though they should show effects of attempts to block their magno (transient) channels these effects should not be greater than the effects of this blocking upon controls. For instance, phonological dyslexics should not find isoluminous writing more difficult to read (assuming with Livingstone and Hubel

that isoluminance blocks the magno [transient channel]) than normal readers.

Lovegrove has argued that it is phonological dyslexics that suffer from transient (magno) channel defects. Visual channel defects, however if they exist, should occur more with dyslexics with visual (or visual-spatial) problems. These were the group for which the techniques described in thesis were developed to study. However, it never progressed sufficiently to do this.

Precise descriptions of how this might be done cannot be given since the investigation of normals is incomplete. But broadly, visual dyslexics should be studied using the single case study approach in which visual channel defects are linked to their reading defects.

In conclusion, this thesis has prepared the ground for research seeking to dissociate the role of the two visual channels in reading processes, both of normals and dyslexics. It is not clear that such work further developing the ideas of this thesis will succeed. But much has been learnt that is needed for such work to take place.

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APPENDIXES

Section 1: ANOVA tables.

Table 4.1. Experiment 1: Repeated measures ANOVA, Errors (lum = monochromatic/heterochromatic factor).

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	3625.02	402.78		
lum	1	4489.35	4489.35	34.42	<.001
ERROR	9	1173.82	130.42		
hz	2	14573.43	7286.72	55.83	<.001
ERROR	18	2349.23	130.51		
lum.hz	2	1703.10	851.55	11.22	<.001
ERROR	18	1366.23	75.90		

Table 4.2. Experiment 1: Repeated measures ANOVA, Errors, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	890.70	98.97		
hz	2	3410.07	1705.03	26.72	<.001
mono	1	3405.07	3405.07	53.36	<.001
Deviations	1	5.00	5.00	0.08	0.783
ERROR	18	1148.60	63.81		

Table 4.3. Experiment 1: Repeated measures ANOVA, Errors, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	3908.1	434.2		
hz	2	12866.5	6433.2	45.11	<.001
hetero	1	6636.0	6636.0	46.53	<.001
Deviations	1	6230.4	6230.4	43.69	<.001
ERROR	18	2566.9	142.6		

Table 4.4. Experiment 1: Repeated measures ANOVA, Reaction times

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	797885.	88654.		
lum	1	197915.	197915.	7.04	0.026
ERROR	9	253054.	28117.		
hz	2	854120.	427060.	16.95	<.001
ERROR	18	453481.	25193.		
lum.hz	2	41428.	20714.	1.49	0.253
ERROR	18	250823.	13935.		

Table 4.5. Experiment 1: Repeated measures ANOVA, Reaction times, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	213411.	23712.		
hz	2	414144.	207072.	26.08	<.001
mono	1	411019.	411019.	51.77	<.001
Deviations	1	3125.	3125.	0.39	0.538
ERROR	18	142918.	7940.		

Table 4.6. Experiment 1: Repeated measures ANOVA, Reaction times, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	837527.	93059.		
hz	2	481404.	240702.	7.72	0.004
hetero	1	278393.	278393.	8.93	0.008
Deviations	1	203011.	203011.	6.51	0.020
ERROR	18	561386.	31188.		

Table 4.7. Experiment 2: Repeated measures ANOVA, Errors

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	3002.4	333.6		
lum	1	11844.1	11844.1	37.93	<.001
ERROR	9	2810.4	312.3		
hz	2	45138.5	22569.3	125.74	<.001
ERROR	18	3230.8	179.5		
lum.hz	2	4017.6	2008.8	13.63	<.001
ERROR	18	2652.4	147.4		

Table 4.8. Experiment 2: Repeated measures ANOVA, Errors, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	384.83	42.76		
hz	2	18656.07	9328.03	187.97	<.001
mono	1	18656.07	18656.07	375.93	<.001
Deviations	1	0.00	0.00	0.00	1.000
ERROR	18	893.27	49.63		

Table 4.9. Experiment 2: Repeated measures ANOVA, Errors, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	5427.9	603.1		
hz	2	30500.1	15250.0	55.01	<.001
hetero	1	23088.8	23088.8	83.29	<.001
Deviations	1	7411.3	7411.3	26.73	<.001
ERROR	18	4989.9	277.2		

Table 4.10. Experiment 2: Repeated measures ANOVA, Reaction times

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	464604.	51623.		
lum	1	71498.	71498.	3.62	0.089
ERROR	9	177711.	19746.		
hz	2	476962.	238481.	11.64	<.001
ERROR	18	368752.	20486.		
lum.hz	2	117056.	58528.	6.26	0.011
ERROR	15(3)	140286.	9352.		

Table 4.11. Experiment 2: Repeated measures ANOVA, Reaction times, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	211753.	23528.		
hz	2	468625.	234313.	13.14	<.001
mono	1	463409.	463409.	25.98	<.001
Deviations	1	5216.	5216.	0.29	0.595
ERROR	18	321075.	17837.		

Table 4.12. Experiment 2: Repeated measures ANOVA, Reaction times, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	423969.	47108.		
hz	2	155918.	77959.	6.94	0.007
hetero	1	139470.	139470.	12.41	0.003
Deviations	1	16447.	16447.	1.46	0.245
ERROR	15(3)	168563.	11238.		

Tables 4.13. Experiments 1 and 2: Repeated measures ANOVA, Errors

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	5880.0	5880.0	15.97	<.001
ERROR	18	6627.4	368.2		
lum	1	15458.7	15458.7	69.84	<.001
mask.lum	1	874.8	874.8	3.95	0.062
ERROR	18	3984.2	221.3		
hz	2	55368.8	27684.4	178.61	<.001
mask.hz	2	4343.2	2171.6	14.01	<.001
ERROR	36	5580.0	155.0		
lum.hz	2	4491.2	2245.6	20.12	<.001
mask.lum.hz	2	1229.6	614.8	5.51	0.008
ERROR	36	4018.6	111.6		

Table 4.14. Experiments 1 and 2: Repeated measures ANOVA, Errors, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	1109.40	1109.40	15.66	<.001
ERROR	18	1275.53	70.86		
hz	2	19003.33	9501.67	167.52	<.001
mono	1	19000.84	19000.84	335.00	<.001
Deviations	1	2.50	2.50	0.04	0.835
mask.hz	2	3062.80	1531.40	27.00	<.001
mask.mono	1	3060.30	3060.30	53.96	<.001
Deviations	1	2.50	2.50	0.04	0.835
ERROR	36	2041.87	56.72		

Table 4.15. Experiments 1 and 2: Repeated measures ANOVA, Errors, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	5645.4	5645.4	10.88	0.004
ERROR	18	9336.0	518.7		
hz	2	40856.6	20428.3	97.32	<.001
hetero	1	27240.5	27240.5	129.77	<.001
Deviations	1	13616.1	13616.1	64.87	<.001
mask.hz	2	2509.9	1254.9	5.98	0.006
mask.hetero	1	2484.3	2484.3	11.84	0.001
Deviations	1	25.6	25.6	0.12	0.729
ERROR	36	7556.8	209.9		

Table 4.16 Experiments 1 and 2: Repeated measures ANOVA, Reaction times

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	27881.	27881.	0.40	0.536
ERROR	18	1262359.	70131.		
lum	1	253289.	253289.	10.59	0.004
mask.lum	1	15844.	15844.	0.66	0.426
ERROR	18	430563.	23920.		
hz	2	1288495.	644248.	28.21	<.001
mask.hz	2	42158.	21079.	0.92	0.407
ERROR	36	822295.	22842.		
lum.hz	2	103864.	51932.	4.38	0.021
mask.lum.hz	2	54677.	27338.	2.31	0.115
ERROR	33(3)	391112.	11852.		

Table 4.17. Experiments 1 and 2: Repeated measures ANOVA, Reaction times, contrast for monochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	42880.	42880.	1.82	0.195
ERROR	18	425165.	23620.		
hz	2	873776.	436888.	33.90	<.001
mono	1	873643.	873643.	67.78	<.001
Deviations	1	133.	133.	0.01	0.920
mask.hz	2	8994.	4497.	0.35	0.708
mask.mono	1	785.	785.	0.06	0.806
Deviations	1	8208.	8208.	0.64	0.430
ERROR	36	463993.	12889.		

Table 4.18. Experiments 1 and 2: Repeated measures ANOVA, Reaction times, contrast for heterochromatic counterphase.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	3152.	3152.	0.04	0.834
ERROR	18	1261210.	70067.		
hz	2	573076.	286538.	12.95	<.001
hetero	1	405638.	405638.	18.34	<.001
Deviations	1	167438.	167438.	7.57	0.010
mask.hz	2	63930.	31965.	1.45	0.250
mask.hetero	1	11943.	11943.	0.54	0.468
Deviations	1	51987.	51987.	2.35	0.135
ERROR	33(3)	729952.	22120.		

Table 4.19. Experiments 1 and 2: Split plot repeated measures ANOVA, Time taken to read 20 letters.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	0.2801	0.2801	0.02	0.882
ERROR	18	220.7086	12.2616		
lum	1	32.8007	32.8007	30.63	<.001
mask.lum	1	0.2960	0.2960	0.28	0.606
ERROR	18	19.2758	1.0709		
hz	1	9.8179	9.8179	22.84	<.001
mask.hz	1	0.8959	0.8959	2.08	0.166
ERROR	18	7.7383	0.4299		
lum.hz	1	6.2863	6.2863	11.08	0.021
mask.lum.hz	1	2.4731	2.4731	4.36	0.091
ERROR	5(13)	2.8378	0.5676		

Table 4.20. Experiments 1 and 2. Split plot ANOVA. Percentage of errors which were missing responses.

	df.	s.s.	m.s.	v.r.	F pr.
mask	1	17328.0	17328.0	11.35	0.003
ERROR	18	27476.6	1526.5		
lum	1	19101.6	19101.6	35.40	<.001
mask.lum	1	572.0	572.0	1.06	0.317
ERROR	18	9713.0	539.6		
hz	2	54803.0	27401.5	65.08	<.001
mask.hz	2	7639.1	3819.6	9.07	<.001
ERROR	36	15157.6	421.0		
lum.hz	2	7406.7	3703.4	11.93	<.001
mask.lum.hz	2	4791.6	2395.8	7.72	0.002
ERROR	36	11178.0	310.5		

Table 4.21. Experiment 3. Errors. Repeated measures ANOVA comparison between the counterphase mask and the unmasked condition.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	5	2808.7	561.7		
lum	1	10626.0	10626.0	174.36	<.001
ERROR	5	304.7	60.9		
mask	1	10209.4	10209.4	180.14	<.001
ERROR	5	283.4	56.7		
lum.mask	1	2625.0	2625.0	7.74	0.039
ERROR	5	1696.7	339.3		

Table 4.22. Experiment 3. Errors. Repeated measures ANOVA comparison between the static mask and unmasked condition.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	5	1599.0	319.8		
lum	1	11704.2	11704.2	112.04	<.001
ERROR	5	522.3	104.5		
mask	1	10004.2	10004.2	73.63	<.001
ERROR	5	679.3	135.9		
lum.mask	1	2128.2	2128.2	13.76	0.014
ERROR	5	773.3	154.7		

Table 4.23. Experiment 3. Errors. Repeated measures ANOVA comparison between the counterphase mask and the static mask.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	5	1880.9	376.2		
lum	1	3243.4	3243.4	13.95	0.014
ERROR	5	1162.9	232.6		
mask	1	1.0	1.0	0.00	0.955
ERROR	5	1464.2	292.8		
lum.mask	1	26.0	26.0	0.18	0.690
ERROR	5	730.2	146.0		

Table 4.24. Experiment 3. Reaction time. Repeated measures ANOVA comparison between the counterphase mask and the unmasked condition

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	5	283651.	56730.		
lum	1	92952.	92952.	23.95	0.004
ERROR	5	19407.	3881.		
mask	1	349915.	349915.	7.11	0.056
ERROR	4(1)	196937.	49234.		
lum.mask	1	269.	269.	0.05	0.834
ERROR	3(2)	15431.	5144.		

Table 4.25. Experiment 3. Reaction time. Repeated measures ANOVA comparison between the static mask and the unmasked condition

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	5	111394.	22279.		
lum	1	50460.	50460.	6.48	0.052
ERROR	5	38935.	7787.		
mask	1	24832.	24832.	14.04	0.020
ERROR	4(1)	7075.	1769.		
lum.mask	1	9343.	9343.	1.23	0.383
ERROR	2(3)	15176.	7588.		

Table 4.26. Experiment 3. Reaction time. Repeated measures ANOVA comparison between the counterphase mask and the static mask.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	4(1)	440385.	110096.		
lum	1	68956.	68956.	3.23	0.147
ERROR	4(1)	85298.	21325.		
mask	1	215231.	215231.	3.64	0.129
ERROR	4(1)	236407.	59102.		
lum.mask	1	12209.	12209.	2.00	0.392
ERROR	1(4)	6114.	6114.		

Table 5.1. Experiment 4: Reaction times and word factor. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	33850578.52	1			
ERROR	665863.73	15	44390.92		
CHANNEL	241203.77	1	241203.77	58.83	.000
ERROR	61503.48	15	4100.23		
WORD	182649.39	1	182649.39	28.80	.000
ERROR	95139.86	15	6342.66		
CHANNEL BY WORD	14012.64	1	14012.64	8.38	.011
ERROR	25075.61	15	1671.71		

Table 5.2. Experiment 4. Errors and word factor. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	722.27	1			
ERROR	107.98	15	7.20		
CHANNEL	9.77	1	9.77	2.34	.147
ERROR	62.48	15	4.17		
WORD	1.89	1	1.89	.17	.687
ERROR	168.36	15	11.22		
CHANNEL BY WORD	2.64	1	2.64	.64	.435
ERROR	61.61	15	4.11		

Table 5.3. Experiment 4: Reaction times and lexical factors. Anova with subjects as random factor.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	60524752.53	1			
ERROR	882536.22	15	58835.75		
CHANNEL	294720.03	1	294720.03	38.68	.000
ERROR	114301.22	15	7620.08		
FRQ	366154.03	1	366154.03	63.97	.000
ERROR	85859.72	15	5723.98		
IMG	212552.00	1	212552.00	92.57	.000
ERROR	34442.25	15	2296.15		
CHANNEL BY FRQ	1582.03	1	1582.03	.61	.447
ERROR	38826.22	15	2588.41		
CHANNEL BY IMG	3280.50	1	3280.50	.81	.383
ERROR	60968.25	15	4064.55		
FRQ BY IMG	99235.12	1	99235.12	51.36	.000
ERROR	28980.13	15	1932.01		
CHANNEL BY FRQ BY IMG	6670.13	1	6670.13	2.46	.138
ERROR	40751.63	15	2716.78		

Table 5.4. Experiment 4. Errors and lexical factors. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	1762.70	1			
ERROR	254.93	15	17.00		
CHANNEL	9.57	1	9.57	.44	.518
ERROR	327.55	15	21.84		
FRQ	524.07	1	524.07	31.13	.000
ERROR	252.55	15	16.84		
IMG	244.76	1	244.76	10.66	.005
ERROR	344.37	15	22.96		
CHANNEL BY FRQ	4.13	1	4.13	.12	.731
ERROR	503.99	15	33.60		
CHANNEL BY IMG	29.07	1	29.07	2.48	.136
ERROR	175.55	15	11.70		
FRQ BY IMG	409.70	1	409.70	18.77	.001
ERROR	327.43	15	21.83		
CHANNEL BY FRQ BY IMG	10.70	1	10.70	.55	.468
ERROR	289.93	15	19.33		

Table 5.5. Experiment 5. Reaction time and word factor.
Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	25155240.25	1			
ERROR	619819.25	15	41321.28		
CHANNEL	123552.25	1	123552.25	49.56	.000
ERROR	37395.25	15	2493.02		
WORD	637.56	1	637.56	.71	.412
ERROR	13408.94	15	893.93		
CHANNEL BY WORD	2626.56	1	2626.56	7.24	.017
ERROR	5441.94	15	362.80		

Table 5.6. Experiment 5. Errors and word factor. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	777.02	1			
ERROR	245.73	15	16.38		
CHANNEL	78.77	1	78.77	9.69	.007
ERROR	121.98	15	8.13		
WORD	1.27	1	1.27	.11	.742
ERROR	169.48	15	11.30		
CHANNEL BY WORD	1.27	1	1.27	.11	.750
ERROR	179.48	15	11.97		

Table 5.7. Experiment 5. Reaction time and lexical factors.
Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	52375053.78	1			
ERROR	1399019.97	15	93268.00		
CHANNEL	191425.78	1	191425.78	33.31	.000
ERROR	86196.47	15	5746.43		
FRQ	120909.03	1	120909.03	24.65	.000
ERROR	73566.72	15	4904.45		
IMG	178353.78	1	178353.78	23.23	.000
ERROR	115169.97	15	7678.00		
CHANNEL BY FRQ	63.28	1	63.28	.10	.754
ERROR	9356.97	15	623.80		
CHANNEL BY IMG	621.28	1	621.28	.24	.630
ERROR	38443.97	15	2562.93		
FRQ BY IMG	56868.78	1	56868.78	16.77	.001
ERROR	50851.97	15	3390.13		
CHANNEL BY FRQ BY IMG	69.03	1	69.03	.11	.742
ERROR	9197.22	15	613.15		

Table 5.8. Experiment 5. Errors and lexical factors.
Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	1860.50	1			
ERROR	1158.75	15	77.25		
CHANNEL	195.03	1	195.03	4.25	.057
ERROR	688.22	15	45.88		
FRQ	60.50	1	60.50	4.06	.062
ERROR	223.75	15	14.92		
IMG	12.50	1	12.50	.45	.514
ERROR	420.25	15	28.02		
CHANNEL BY FRQ	13.78	1	13.78	.52	.481
ERROR	396.47	15	26.43		
CHANNEL BY IMG	3.78	1	3.78	.08	.783
ERROR	722.97	15	48.20		
FRQ BY IMG	18.00	1	18.00	.38	.546
ERROR	708.75	15	47.25		
CHANNEL BY FRQ BY IMG	38.28	1	38.28	1.39	.256
ERROR	412.47	15	27.50		

Table 5.9. Experiments 4 and 5, Split Plot ANOVA on reactions times and Lexical factors.

Source of Variation	SS	DF	MS	F	PROB
EXP45	147264.06	1	147264.06	1.94	.174
ERROR	2281556.19	30	76051.87		
CHAN	480595.56	1	480595.56	71.91	.000
EXP45 BY CHAN	5550.25	1	5550.25	.83	.369
ERROR	200497.69	30	6683.26		
FRQ	453939.06	1	453939.06	85.42	.000
EXP45 BY FRQ	33124.00	1	33124.00	6.23	.018
ERROR	159426.44	30	5314.21		
IMG	390156.39	1	390156.39	78.23	.000
EXP45 BY IMG	749.39	1	749.39	.15	.701
ERROR	149612.22	30	4987.07		
CHAN BY FRQ	1139.06	1	1139.06	.71	.406
EXP45 BY CHAN BY FRQ	506.25	1	506.25	.32	.579
ERROR	48183.19	30	1606.11		
CHAN BY IMG	3378.52	1	3378.52	1.02	.321
EXP45 BY CHAN BY IMG	523.27	1	523.27	.16	.694
ERROR	99412.22	30	3313.74		
FRQ BY IMG	153174.39	1	153174.39	57.56	.000
EXP45 BY FRQ BY IMG	2929.52	1	2929.52	1.10	.302
ERROR	79832.09	30	2661.07		
CHAN BY FRQ BY IMG	4048.14	1	4048.14	2.43	.129
EXP45 BY C BY F BY I	2691.02	1	2691.02	1.62	.213
ERROR	49948.84	30	1664.96		

Table 5.9. Experiment 6: Reaction time repeated measures ANOVA word vs nonword.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	32460081.89	1			
ERROR	316868.86	15	21124.59		
CHANNEL	4144.14	1	4144.14	3.14	.097
ERROR	19820.61	15	1321.37		
WORD	163923.77	1	163923.77	76.71	.000
ERROR	32052.98	15	2136.87		
CHANNEL BY WORD	4016.39	1	4016.39	5.25	.037
ERROR	11470.36	15	764.69		

Table 5.10. Experiment 6. Errors and word factor. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	1630.14	1			
ERROR	830.11	15	55.34		
CHANNEL	1.89	1	1.89	.33	.573
ERROR	85.36	15	5.69		
WORD	58.14	1	58.14	.85	.371
ERROR	1027.11	15	68.47		
CHANNEL BY WORD	.39	1	.39	.04	.837
ERROR	133.86	15	8.92		

Table 5.11. Experiment 6. Reaction times and lexical factors. Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	58361857.51	1			
ERROR	708726.87	15	47248.46		
CHANNEL	138.20	1	138.20	.02	.888
ERROR	101857.18	15	6790.48		
FRQ	376820.51	1	376820.51	163.12	.000
ERROR	34651.87	15	2310.12		
IMG	137484.57	1	137484.57	60.60	.000
ERROR	34030.30	15	2268.69		
CHANNEL BY FRQ	1533.20	1	1533.20	.99	.335
ERROR	23198.18	15	1546.55		
CHANNEL BY IMG	973.51	1	973.51	.48	.500
ERROR	30594.37	15	2039.62		
FRQ BY IMG	39515.63	1	39515.63	22.02	.000
ERROR	26919.24	15	1794.62		
CHANNEL BY FRQ BY IMG	134.07	1	134.07	.05	.834
ERROR	44001.80	15	2933.45		

Table 5.12. Experiment 6. Errors and lexical factors.
Repeated measures ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	2993.45	1			
ERROR	941.43	15	62.76		
CHANNEL	.38	1	.38	.03	.870
ERROR	206.99	15	13.80		
FRQ	1345.51	1	1345.51	37.14	.000
ERROR	543.37	15	36.22		
IMG	897.82	1	897.82	32.29	.000
ERROR	417.05	15	27.80		
CHANNEL BY FRQ	53.82	1	53.82	1.72	.210
ERROR	470.55	15	31.37		
CHANNEL BY IMG	17.26	1	17.26	.86	.369
ERROR	302.12	15	20.14		
FRQ BY IMG	679.88	1	679.88	16.97	.001
ERROR	600.99	15	40.07		
CHANNEL BY FRQ BY IM	27.20	1	27.20	2.16	.163
ERROR	189.18	15	12.61		

Table 5.13. Experiments 4 and 6: Reaction time and words and nonwords factor, Split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	66303370.12	1			
EXP46	7290.28	1	7290.28	.22	.641
ERROR	982732.59	30	32757.75		
SPAT	154290.13	1	154290.13	56.92	.000
EXP46 BY SPAT	91057.78	1	91057.78	33.59	.000
ERROR	81324.09	30	2710.80		
WORD	346320.03	1	346320.03	81.68	.000
EXP46 BY WORD	253.12	1	253.12	.06	.809
ERROR	127192.84	30	4239.76		
SPAT BY WORD	16516.53	1	16516.53	13.56	.001
EXP46 BY SPAT BY WORD	1512.50	1	1512.50	1.24	.274
ERROR	36545.97	30	1218.20		

Table 5.14. Experiments 4 and 6: Errors, words/nonwords, split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	2261.28	1			
EXP46	91.12	1	91.12	2.91	.098
ERROR	938.09	30	31.27		
SPAT	10.13	1	10.13	2.05	.162
EXP46 BY SPAT	1.53	1	1.53	.31	.581
ERROR	147.84	30	4.93		
WORD	40.50	1	40.50	1.02	.321
EXP46 BY WORD	19.53	1	19.53	.49	.489
ERROR	1195.47	30	39.85		
SPAT BY WORD	2.53	1	2.53	.39	.538
EXP46 BY SPAT BY WORD	.50	1	.50	.08	.784
ERROR	195.47	30	6.52		

Table 5.15. Experiments 4 and 6. Reaction times and lexical factors. Split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	118876771.9	1			
EXP46	9838.16	1	9838.16	.19	.670
ERROR	1591263.09	30	53042.10		
CHANNEL	141047.19	1	141047.19	19.58	.000
EXP46 BY CHANNEL	153811.04	1	153811.04	21.35	.000
ERROR	216158.40	30	7205.28		
FRQ	742936.25	1	742936.25	184.95	.000
EXP46 BY FRQ	38.29	1	38.29	.01	.923
ERROR	120511.59	30	4017.05		
IMG	345964.54	1	345964.54	151.58	.000
EXP46 BY IMG	4072.04	1	4072.04	1.78	.192
ERROR	68472.55	30	2282.42		
CHANNEL BY FRQ	.19	1	.19	.00	.992
EXP46 BY SPAT BY FRQ	3115.04	1	3115.04	1.51	.229
ERROR	62024.40	30	2067.48		
CHANNEL BY IMG	339.94	1	339.94	.11	.741
EXP46 BY SPAT BY IMG	3914.07	1	3914.07	1.28	.266
ERROR	91562.62	30	3052.09		
FRQ BY IMG	131995.97	1	131995.97	70.84	.000
EXP46 BY FRQ BY IMG	6754.79	1	6754.79	3.63	.067
ERROR	55899.37	30	1863.31		
CHANNEL BY FRQ BY IMG	2456.44	1	2456.44	.87	.359
EXP46 BY CHAN BY F BY I	4347.75	1	4347.75	1.54	.224
ERROR	84753.43	30	2825.11		

Table 5.16. Experiment 4 and 6: Errors and lexical factors. Split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	4675.14	1			
EXP46	81.00	1	81.00	2.03	.164
ERROR	1196.36	30	39.88		
CHAN	3.06	1	3.06	.17	.681
EXP46 BY CHAN	6.89	1	6.89	.39	.539
ERROR	534.55	30	17.82		
FRQ	1774.52	1	1774.52	66.89	.000
EXP46 BY FRQ	95.06	1	95.06	3.58	.068
ERROR	795.92	30	26.53		
IMG	1040.06	1	1040.06	40.98	.000
EXP46 BY IMG	102.52	1	102.52	4.04	.054
ERROR	761.42	30	25.38		
CHAN BY FRQ	14.06	1	14.06	.43	.516
EXP46 BY CHAN BY FRQ	43.89	1	43.89	1.35	.254
ERROR	974.55	30	32.48		
CHAN BY IMG	.77	1	.77	.05	.828
EXP46 BY CHAN BY IMG	45.56	1	45.56	2.86	.101
ERROR	477.67	30	15.92		
FRQ BY IMG	1072.56	1	1072.56	34.66	.000
EXP46 BY FRQ BY IMG	17.02	1	17.02	.55	.464
ERROR	928.42	30	30.95		
CHAN BY FRQ BY IMG	1.89	1	1.89	.12	.733
EXP46 BY C BY F BY I	36.00	1	36.00	2.25	.144
ERROR	479.11	30	15.97		

Table 5.17. Experiment 4 and 6: Errors and lexical factors. Split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	4675.14	1	4675.14	117.23	.000
EXP46	81.00	1	81.00	2.03	.164
ERROR	1196.36	30	39.88		
SPAT	3.06	1	3.06	.17	.681
EXP46 BY SPAT	6.89	1	6.89	.39	.539
ERROR	534.55	30	17.82		
FRQ	1774.52	1	1774.52	66.89	.000
EXP46 BY FRQ	95.06	1	95.06	3.58	.068
ERROR	795.92	30	26.53		
IMG	1040.06	1	1040.06	40.98	.000
EXP46 BY IMG	102.52	1	102.52	4.04	.054
ERROR	761.42	30	25.38		
SPAT BY FRQ	14.06	1	14.06	.43	.516
EXP46 BY SPAT BY FRQ	43.89	1	43.89	1.35	.254
ERROR	974.55	30	32.48		
SPAT BY IMG	.77	1	.77	.05	.828
EXP46 BY SPAT BY IMG	45.56	1	45.56	2.86	.101
ERROR	477.67	30	15.92		
FRQ BY IMG	1072.56	1	1072.56	34.66	.000
EXP46 BY FRQ BY IMG	17.02	1	17.02	.55	.464
ERROR	928.42	30	30.95		
SPAT BY FRQ BY IMG	1.89	1	1.89	.12	.733
EXP46 BY S BY F BY I	36.00	1	36.00	2.25	.144
ERROR	479.11	30	15.97		

Table 5.18. Experiments 4 and 6: Errors, words and nonwords, split plot ANOVA.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	2458.76	1	2458.76	41.24	.000
ERROR	894.37	15	59.62		
EXP45	1.76	1	1.76	.12	.731
ERROR	215.37	15	14.36		
CHANNEL	76.57	1	76.57	41.68	.000
ERROR	27.55	15	1.84		
WORD	35.07	1	35.07	1.01	.331
ERROR	521.55	15	34.77		
EXP45 BY CHANNEL	.38	1	.38	.05	.833
ERROR	124.74	15	8.32		
EXP45 BY WORD	18.76	1	18.76	3.03	.102
ERROR	92.87	15	6.19		
CHANNEL BY WORD	18.76	1	18.76	2.33	.148
ERROR	120.87	15	8.06		
EXP45 BY CHANNEL BY WORD	4.13	1	4.13	.30	.594
ERROR	209.49	15	13.97		

Table 5.19. Experiment 4: Letter length effects (four, five and six letter stimuli). Repeated measures ANOVA for reactions times.

SUBJECTS	101340938.0	1			
ERROR	2017381.15	15	134492.08		
WORD	571378.52	1	571378.52	27.74	.000
ERROR	308990.65	15	20599.38		
LENGTH	49368.79	2	24684.40	10.79	.000
lin		1	36856.1	16.11	.000
quad		1	12513.7	5.47	.026
ERROR	68648.54	30	2288.28		
CHAN BY WORD	36741.33	1	36741.33	7.51	.015
ERROR	73384.81	15	4892.32		
CHAN BY LENGTH	817.87	2	408.94	.23	.793
lin		1	7.0	.00	.950
quad		1	811.8	.46	.501
ERROR	53340.00	15	1778.0		
WORD BY LENGTH	4082.17	2	2041.08	2.97	.067
lin		1	3042	4.42	.045
quad		1	1040	1.51	.228
ERROR	20627.17	30	687.57		
CHAN BY WORD BY LEN	4760.79	2	2380.40	2.51	.098
lin		1	3938.3	4.15	.051
quad		1	822.5	0.87	.359
ERROR	28474.21	30	949.14		

Table 5.20. Experiment 5: Letter length effects (four, five and six letter stimuli). Repeated measures ANOVA for reactions times.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	75398026.69	1			
ERROR	1859528.31	15	123968.55		
CHAN	375417.19	1	375417.19	51.63	.000
ERROR	109078.81	15	7271.92		
WORD	1017.52	1	1017.52	.35	.565
ERROR	44114.15	15	2940.94		
LENGTH	11606.00	2	5803.00	3.43	.045
lin	2245.	1	2245.	1.33	.258
quad	9362.	1	9362.	5.54	.025
ERROR	50717.50	30	1690.58		
CHAN BY WORD	9157.69	1	9157.69	8.09	.012
ERROR	16980.31	15	1132.02		
CHAN BY LENGTH	1422.13	2	711.06	.66	.525
lin	1001.3	1	1001.3	.93	.343
quad	420.8	1	420.8	.39	.537
ERROR	32407.37	30	1080.25		
WORD BY LENGTH	2476.04	2	1238.02	1.42	.257
lin	850.8	1	850.8	.98	.331
quad	1625.3	1	1625.3	1.87	.182
ERROR	26128.79	30	870.96		
CHAN BY WORD BY LEN	1959.13	2	979.56	1.00	.378
lin	15.1	1	15.1	.02	.902
quad	1944.0	1	1944.0	1.99	.168
ERROR	29276.37	30	975.88		

Table 5.21. Experiment 6: Letter length effects (four, five and six letter stimuli). Repeated measures ANOVA for reactions times.

Source of Variation	SS	DF	MS	F	Prob
SUBJECTS	96815602.08	1			
ERROR	982117.08	15	65474.47		
CHAN	15516.02	1	15516.02	3.52	.080
ERROR	66077.15	15	4405.14		
WORD	471042.19	1	471042.19	71.35	.000
ERROR	99027.65	15	6601.84		
LENGTH	86622.01	2	43311.01	13.67	.000
lin	73345.	1	73345.	23.15	.000
quad	13278.	1	13278.	4.19	.049
ERROR	95041.82	30	3168.06		
CHAN BY WORD	13804.08	1	13804.08	5.85	.029
ERROR	35367.08	15	2357.81		
CHAN BY LENGTH	6291.26	2	3145.63	2.46	.102
lin	6272.	1	6272.	4.91	.034
quad	19.	1	19.	.02	.903
ERROR	38351.57	30	1278.39		
WORD BY LENGTH	18438.03	2	9219.02	10.16	.000
lin	18284.	1	18284.	20.27	.000
quad	54.	1	54.	.06	.809
ERROR	27212.14	30	907.07		
CHAN BY WORD BY LEN	2513.20	2	1256.60	.73	.492
lin	1365.	1	1365.	.79	.382
quad	1148.	1	1148.	.66	.422
ERROR	51974.64	30	1732.49		

Table 5.22. Experiments 4 and 6. Reaction time length effects: Split Plot ANOVA

Source of variation	f.	s.s.	m.s.	v.r.	F pr.
exp46	1	25840.	25840.	0.26	0.615
ERROR	30	2999498.	99983.		
word	1	1040001.	1040001.	76.47	<.001
exp46.word	1	2420.	2420.	0.18	0.676
ERROR	30	408018.	13601.		
chan	1	466070.	466070.	56.07	<.001
exp46.chan	1	256577.	256577.	30.87	<.001
ERROR	30	249381.	8313.		
length	2	132877.	66439.	24.35	<.001
Lin	1	107093.	107093.	39.25	<.001
Quad	1	25785.	25785.	9.45	0.003
exp46.length	2	3114.	1557.	0.57	0.568
Lin	1	3108.	3108.	1.14	0.290
Quad	1	6.	6.	0.00	0.964
ERROR	60	163690.	2728.		
word.chan	1	47793.	47793.	13.18	0.001
exp46.word.chan	1	2752.	2752.	0.76	0.391
ERROR	30	108769.	3626.		
word.length	2	18975.	9488.	11.90	<.001
Lin	1	18191.	18191.	22.82	<.001
Quad	1	784.	784.	0.98	0.325
exp46.word.length	2	3545.	1772.	2.22	0.117
Lin	1	3235.	3235.	4.06	0.048
Quad	1	310.	310.	0.39	0.535
ERROR	60	47839.	797.		
chan.length	2	3640.	1820.	1.20	0.307
Lin	1	3350.	3350.	2.21	0.142
Quad	1	290.	290.	0.19	0.663
exp46.chan.length	2	3470.	1735.	1.15	0.324
Lin	1	2930.	2930.	1.94	0.169
Quad	1	540.	540.	0.36	0.552
ERROR	60	90750.	1513.		
word.chan.length	2	4984.	2492.	1.86	0.165
Lin	1	4970.	4970.	3.71	0.059
Quad	1	14.	14.	0.01	0.920
exp46.word.chan.len	2	2290.	1145.	0.85	0.431
Lin	1	333.	333.	0.25	0.620
Quad	1	1957.	1957.	1.46	0.232
ERROR	60	80449.	1341.		

Table 6.1. Experiment 7: static only condition; Reaction times ANOVA with subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	66014.5	7334.9		
match	3	16131.3	5377.1	11.34	<.001
case	1	14851.2	14851.2	31.31	<.001
letter	1	6.0	6.0	0.01	0.911
Deviations	1	1274.0	1274.0	2.69	0.113
ERROR	27	12806.0	474.3		

Table 6.2. Experiment 7: static only condition; Errors ANOVA with subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	94.400	10.489		
match	3	86.400	28.800	4.38	0.012
case	1	7.200	7.200	1.09	0.305
letter	1	60.000	60.000	9.12	0.005
Deviations	1	19.200	19.200	2.92	0.099
ERROR	27	177.600	6.578		

Table 6.3. Experiment 7: static only condition; Reaction times ANOVA with characters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	337.2	112.4		
match	3	6590.2	2196.7	10.19	0.003
case	1	6050.0	6050.0	28.06	<.001
letter	1	0.2	0.2	0.00	0.978
Deviations	1	540.0	540.0	2.50	0.148
ERROR	9	1940.6	215.6		

Table 6.4. Experiment 7: static only condition; Errors ANOVA with characters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	9.500	3.167		
match	3	28.500	9.500	3.56	0.060
case	1	1.125	1.125	0.42	0.532
letter	1	22.042	22.042	8.27	0.018
Deviations	1	5.333	5.333	2.00	0.191
ERROR	9	24.000	2.667		

Table 6.5. Experiment 7. Reaction times with subjects as random factor.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	374581.3	41620.1		
side	1	1276.9	1276.9	2.19	0.173
ERROR	9	5246.6	583.0		
cross	1	6275.0	6275.0	3.76	0.084
ERROR	9	15015.7	1668.4		
match	3	100762.2	33587.4	38.21	<.001
case	1	55282.6	55282.6	62.89	<.001
letter	1	19783.5	19783.5	22.50	<.001
Deviations	1	25696.1	25696.1	29.23	<.001
ERROR	27	23735.5	879.1		
side.cross	1	7700.6	7700.6	18.05	0.002
ERROR	9	3839.9	426.7		
side.match	3	5162.7	1720.9	6.50	0.002
case	1	40.6	40.6	0.15	0.698
letter	1	4550.1	4550.1	17.19	<.001
Deviations	1	572.0	572.0	2.16	0.153
ERROR	27	7148.2	264.7		
cross.match	3	8204.6	2734.9	5.27	0.005
case	1	0.1	0.1	0.00	0.988
letter	1	6211.8	6211.8	11.97	0.002
Deviations	1	1992.7	1992.7	3.84	0.060
ERROR	27	14006.1	518.7		
side.cross.match	3	629.4	209.8	0.57	0.640
case	1	214.5	214.5	0.58	0.452
letter	1	0.5	0.5	0.00	0.971
Deviations	1	414.4	414.4	1.13	0.298
ERROR	27	9936.6	368.0		
Total	159	583521.6			

Table 6.6. Experiment 7: errors with subjects as random factor.

	df.	s.s.	m.s.	v.r.	F pr.
subjects	9	784.256	87.140		
side	1	77.006	77.006	5.60	0.042
ERROR	9	123.806	13.756		
cross	1	127.806	127.806	7.06	0.026
ERROR	9	163.006	18.112		
match	3	1914.219	638.073	9.23	<.001
case	1	39.200	39.200	0.57	0.458
letter	1	1591.350	1591.350	23.01	<.001
Deviation	1	283.669	283.669	4.10	0.053
ERROR	27	1866.969	69.147		
side.cross	1	5.256	5.256	0.55	0.475
ERROR	9	85.306	9.478		
side.match	3	87.219	29.073	1.39	0.266
case	1	12.800	12.800	0.61	0.440
letter	1	66.150	66.150	3.17	0.086
Deviation	1	8.269	8.269	0.40	0.534
ERROR	27	563.219	20.860		
cross.match	3	544.019	181.340	7.11	0.001
case	1	3.200	3.200	0.13	0.726
letter	1	464.817	464.817	18.23	<.001
Deviations	1	76.002	76.002	2.98	0.096
ERROR	27	688.419	25.497		
side.cross.match	3	41.169	13.723	1.61	0.211
case	1	0.800	0.800	0.09	0.762
letter	1	28.017	28.017	3.28	0.081
Deviations	1	12.352	12.352	1.45	0.239
ERROR	27	230.519	8.538		
Total	159	7302.193			

Table 6.7. Experiment 7: reaction times with items (characters) as random factors.

	df.	s.s.	m.s.	v.r.	F pr.
characters	3	298.6	99.5		
side	1	473.1	473.1	2.12	0.241
ERROR	3	668.1	222.7		
cross	1	2756.3	2756.3	34.51	0.010
ERROR	3	239.6	79.9		
match	3	42493.7	14164.6	46.82	<.001
case	1	22260.5	22260.5	73.58	<.001
letter	1	9282.7	9282.7	30.68	<.001
Deviations	1	10950.5	10950.5	36.20	<.001
ERROR	9	2722.7	302.5		
side.cross	1	3025.0	3025.0	14.82	0.031
ERROR	3	612.4	204.1		
side.match	3	2045.2	681.7	2.81	0.100
case	1	28.1	28.1	0.12	0.741
letter	1	1751.0	1751.0	7.21	0.025
Deviations	1	266.0	266.0	1.09	0.323
ERROR	9	2186.7	243.0		
cross.match	3	3788.3	1262.8	5.20	0.023
case	1	1.1	1.1	0.00	0.947
letter	1	2970.4	2970.4	12.24	0.007
Deviations	1	816.7	816.7	3.37	0.100
ERROR	9	2183.9	242.7		
side.cross.match	3	289.5	96.5	0.44	0.729
case	1	112.5	112.5	0.51	0.491
letter	1	0.7	0.7	0.00	0.957
Deviations	1	176.3	176.3	0.81	0.392
ERROR	9	1966.1	218.5		
Total	63	65748.9			

Table 6.8. Experiment 7: errors with items (characters) as random factors.

	df.	s.s.	m.s.	v.r.	F pr.
characters	3	22.297	7.432		
side	1	28.891	28.891	20.17	0.021
ERROR	3	4.297	1.432		
cross	1	62.016	62.016	15.94	0.028
ERROR	3	11.672	3.891		
match	3	774.797	258.266	47.91	<.001
case	1	9.031	9.031	1.68	0.228
letter	1	656.260	656.260	121.74	<.001
Deviations	1	109.505	109.505	20.31	0.001
ERROR	9	48.516	5.391		
side.cross	1	2.641	2.641	1.09	0.374
ERROR	3	7.297	2.432		
side.match	3	38.047	12.682	20.69	<.001
case	1	3.781	3.781	6.17	0.035
letter	1	29.260	29.260	47.75	<.001
Deviations	1	5.005	5.005	8.17	0.019
ERROR	9	5.516	0.613		
cross.match	3	237.172	79.057	18.78	<.001
case	1	0.781	0.781	0.19	0.677
letter	1	207.094	207.094	49.19	<.001
Deviations	1	29.297	29.297	6.96	0.027
ERROR	9	37.891	4.210		
side.cross.match	3	16.047	5.349	1.94	0.193
case	1	0.031	0.031	0.01	0.917
letter	1	12.760	12.760	4.64	0.060
Deviations	1	3.255	3.255	1.18	0.305
ERROR	9	24.766	2.752		
Total	63	1321.859			

Table 6.9. Experiment 7: Reaction times; flicker vs static judgements, subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	137217.0	15246.3		
cond	1	1353.0	1353.0	3.72	0.086
ERROR	9	3276.1	364.0		
match	3	36320.9	12107.0	26.26	<.001
case	1	27720.2	27720.2	60.13	<.001
letter	1	1912.0	1912.0	4.15	0.052
Deviations	1	6688.7	6688.7	14.51	<.001
ERROR	27	12447.9	461.0		
cond.match	3	3241.7	1080.6	3.29	0.036
case	1	34.2	34.2	0.10	0.749
letter	1	2227.4	2227.4	6.78	0.015
Deviations	1	980.1	980.1	2.98	0.095
ERROR	27	8865.6	328.4		

Table 6.10. Experiment 7: Errors; flicker vs static matches; subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	223.51	24.83		
cond	1	21.01	21.01	1.95	0.196
ERROR	9	97.11	10.79		
match	3	233.44	77.81	3.75	0.023
case	1	32.40	32.40	1.56	0.222
letter	1	168.03	168.03	8.09	0.008
Deviations	1	33.00	33.00	1.59	0.218
ERROR	27	560.94	20.78		
cond.match	3	7.84	2.61	0.16	0.924
case	1	3.60	3.60	0.22	0.645
letter	1	4.03	4.03	0.24	0.625
Deviations	1	0.20	0.20	0.01	0.912
ERROR	27	446.54	16.54		

Table 6.11. Experiment 7: reaction times; left vs right flicker, subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	252380.1	28042.2		
cond	1	7624.5	7624.5	11.81	0.007
ERROR	9	5810.4	645.6		
match	3	72645.9	24215.3	25.85	<.001
case	1	27562.5	27562.5	29.42	<.001
letter	1	24083.3	24083.3	25.71	<.001
Deviations	1	21000.1	21000.1	22.42	<.001
ERROR	27	25293.7	936.8		
cond.match	3	2550.4	850.1	2.79	0.059
case	1	220.9	220.9	0.73	0.402
letter	1	2323.2	2323.2	7.63	0.010
Deviations	1	6.3	6.3	0.02	0.886
ERROR	27	8219.2	304.4		

Table 6.12. Experiment 7: Errors, left vs right flicker, subjects as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
subjects	9	723.75	80.42		
cond	1	61.25	61.25	4.92	0.054
ERROR	9	112.00	12.44		
match	3	2224.80	741.60	10.04	<.001
case	1	10.00	10.00	0.14	0.716
letter	1	1888.13	1888.13	25.56	<.001
Deviations	1	326.67	326.67	4.42	0.045
ERROR	27	1994.45	73.87		
cond.match	3	120.55	40.18	3.12	0.042
case	1	10.00	10.00	0.78	0.386
letter	1	90.13	90.13	7.01	0.013
Deviations	1	20.42	20.42	1.59	0.218
ERROR	27	347.20	12.86		

Table 6.13. Experiment 7: reaction times, flicker vs static matches, letters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	22.6	7.5		
cond	1	552.8	552.8	3.05	0.179
ERROR	3	543.3	181.1		
match	3	15057.6	5019.2	16.84	<.001
case	1	11289.1	11289.1	37.87	<.001
letter	1	875.5	875.5	2.94	0.121
Deviations	1	2893.0	2893.0	9.71	0.012
ERROR	9	2682.8	298.1		
cond.match	3	1361.8	453.9	3.33	0.070
case	1	14.1	14.1	0.10	0.755
letter	1	910.0	910.0	6.67	0.030
Deviations	1	437.8	437.8	3.21	0.107
ERROR	9	1227.5	136.4		

Table 6.14. Experiment 7: Errors, flicker vs static matches, letters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	10.594	3.531		
cond	1	7.031	7.031	2.78	0.194
ERROR	3	7.594	2.531		
match	3	83.344	27.781	6.02	0.016
case	1	7.562	7.562	1.64	0.232
letter	1	63.021	63.021	13.66	0.005
Deviations	1	12.760	12.760	2.77	0.131
ERROR	9	41.531	4.615		
cond.match	3	3.344	1.115	0.61	0.627
case	1	1.563	1.563	0.85	0.380
letter	1	1.688	1.688	0.92	0.363
Deviations	1	0.094	0.094	0.05	0.826
ERROR	9	16.531	1.837		

Table 6.15. Experiment 7: reaction times, left vs right flicker, letters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	515.6	171.9		
cond	1	2945.3	2945.3	11.99	0.041
ERROR	3	737.1	245.7		
match	3	31224.3	10408.1	42.12	<.001
case	1	10972.6	10972.6	44.41	<.001
letter	1	11377.5	11377.5	46.05	<.001
Deviations	1	8874.3	8874.3	35.92	<.001
ERROR	9	2223.8	247.1		
cond.match	3	972.8	324.3	1.00	0.437
case	1	126.6	126.6	0.39	0.548
letter	1	841.7	841.7	2.59	0.142
Deviations	1	4.6	4.6	0.01	0.908
ERROR	9	2925.3	325.0		

Table 6.16. Experiment 7: Errors, left vs right flicker, letters as random factor.

	d.f.	s.s.	m.s.	v.r.	F pr.
char	3	23.375	7.792		
cond	1	24.500	24.500	18.37	0.023
ERROR	3	4.000	1.333		
match	3	928.625	309.542	62.08	<.001
case	1	2.250	2.250	0.45	0.519
letter	1	800.333	800.333	160.51	<.001
Deviations	1	126.042	126.042	25.28	<.001
ERROR	9	44.875	4.986		
cond.match	3	50.750	16.917	11.07	0.002
case	1	2.250	2.250	1.47	0.256
letter	1	40.333	40.333	26.40	<.001
Deviations	1	8.167	8.167	5.35	0.046
ERROR	9	13.750	1.528		

Section 2: Stimuli tables (Chapter 5).

Table B.1.a. The lexical decision task words, their frequency and imageability values (from the MRC data base) and their mean reaction time in milliseconds and error rate in percentage for each of three experiments.

Word	Img	Frq	Exp4		Exp5		Exp6	
BODY	614	276	609	0	663	0	567	0
BALL	622	110	576	0	596	0	603	0
PARTY	596	216	602	6	569	0	543	0
RADIO	613	120	602	6	647	0	658	0
MOTHER	638	216	582	0	584	0	596	0
PICTURE	581	162	572	6	589	0	593	0
HAND	598	431	577	0	615	12	614	0
TEAM	565	83	619	13	575	0	571	0
CHILD	619	213	599	0	643	0	657	0
BLOOD	620	121	603	0	584	0	554	0
LETTER	595	145	610	0	576	0	562	0
CATTLE	619	97	627	0	632	0	562	6
GIRL	634	220	629	0	589	6	669	28
ARMY	578	132	609	0	614	0	612	0
BLACK	589	203	574	0	673	0	644	0
PLANT	605	125	607	0	677	0	565	0
CHURCH	616	348	687	6	627	0	581	0
BRIDGE	608	98	651	6	595	0	604	7
NIGHT	607	411	621	13	618	6	631	12
HAIR	580	148	651	0	626	0	576	0
TABLE	582	198	621	0	684	6	616	0
HOTEL	597	126	613	0	537	6	604	7
RECORD	591	137	620	6	572	0	593	6
DOCTOR	600	100	627	0	584	0	566	0
CITY	605	393	599	0	611	0	613	0
DARK	586	185	632	0	747	6	586	7
HEART	617	173	550	0	558	0	626	6
EARTH	580	150	598	0	581	0	567	0
WINTER	621	83	646	6	596	0	615	12
WINDOW	602	119	653	0	653	0	635	18
BOOK	591	193	612	0	625	6	571	0
FIRE	634	187	658	6	609	0	567	6
LOVE	569	232	707	0	592	6	591	6
PAPER	590	157	642	0	621	0	598	0
FRIEND	587	133	610	0	652	6	590	14
MORNING	579	211	675	0	597	0	630	0
DOOR	599	312	600	0	603	6	547	6
FILM	562	96	621	0	579	0	688	6
MONEY	604	265	585	0	546	0	562	0
TEETH	611	103	599	6	597	0	558	6
PERSON	562	175	626	0	634	0	669	0
ISLAND	643	167	695	6	581	0	570	0
FACE	581	371	701	0	566	0	631	0
CLAY	575	100	637	13	653	6	584	0
BOARD	592	239	656	0	605	0	553	6
HORSE	624	117	610	0	562	0	570	0
FATHER	646	183	662	0	590	6	550	0
BATTLE	597	87	625	0	598	0	560	0

SEEN	351	279	641	0	674	0	651	6
EASY	321	125	566	6	594	0	586	0
SHOWN	273	166	751	0	633	0	593	0
CIVIL	317	91	757	6	697	6	634	18
RECENT	298	179	586	0	596	0	567	6
BECAME	261	246	644	0	635	0	617	0
TELL	350	268	621	0	632	6	678	0
ELSE	208	176	642	13	681	0	667	0
ISSUE	315	152	677	0	570	6	610	0
WORTH	275	94	653	0	658	0	571	0
AMOUNT	316	172	761	6	601	0	564	0
RESULT	324	244	609	0	576	12	652	0
KEEP	284	264	610	6	635	0	618	0
KEPT	300	186	639	0	695	0	674	12
ABOVE	346	296	713	0	601	0	670	7
USUAL	235	96	628	0	614	0	612	6
NORMAL	294	136	622	0	607	0	584	13
CHANCE	354	131	680	0	633	0	598	0
REAL	313	260	664	0	612	0	672	6
ORDER	352	376	643	6	621	6	594	6
CAUSE	282	130	659	0	634	0	643	0
CLAIM	321	98	699	0	622	13	631	0
ACTUAL	259	100	653	0	610	0	588	7
FORMER	283	131	747	0	640	0	582	6
SEEM	249	229	672	0	648	6	643	6
MAIN	309	119	681	0	660	6	610	0
LEAST	302	343	647	6	657	6	635	0
MEANT	282	100	653	0	610	0	618	0
METHOD	304	142	602	0	662	0	583	0
SIMPLE	344	161	646	0	612	0	660	0
FEEL	363	216	650	0	602	0	570	0
ABLE	284	216	647	0	566	6	604	6
BEGAN	251	312	784	0	692	0	626	6
WRONG	344	129	650	0	650	0	661	0
NEARLY	305	141	649	0	617	0	610	0
HARDLY	256	106	627	0	635	0	619	0
BEST	324	351	585	0	591	6	672	0
STAY	321	113	633	6	631	0	638	6
BASIC	271	171	583	0	663	0	591	0
ENTIRE	310	149	609	0	753	6	629	6
EFFECT	280	213	681	0	625	0	743	6
LATTER	256	114	667	0	686	0	631	6
EVER	273	345	608	0	682	0	656	6
GONE	313	195	614	0	625	6	671	6
TRIED	303	170	660	6	636	0	651	0
EQUAL	321	90	600	0	613	12	602	0
RETURN	293	180	625	0	619	0	617	6
APPEAR	341	118	590	0	647	6	635	6

LOOT	579	3	700	6	704	0	585	6
MOTH	577	1	787	6	707	18	604	6
GEESE	603	3	690	0	740	12	599	0
PUPPY	635	2	593	0	618	0	609	0
KENNEL	580	3	645	0	647	0	559	13
WALRUS	590	1	695	12	799	18	650	0
CHOP	575	3	689	7	595	0	612	12
PLUM	611	1	668	6	625	0	584	0
PEACH	613	3	608	0	647	0	576	6
HEDGE	583	2	640	6	689	0	591	6
BEAVER	612	3	689	7	817	0	586	0
WALLET	617	1	609	0	688	6	569	0
KITE	624	1	700	6	689	6	652	13
CUBE	575	1	655	0	623	0	547	12
CANAL	588	3	608	0	567	0	617	6
TRASH	599	2	663	7	696	6	562	6
SPIDER	597	2	612	0	694	6	596	0
MORGUE	589	1	785	6	801	12	655	6
FLEA	606	2	672	6	652	0	646	12
CLAW	600	1	703	0	685	0	575	0
THORN	600	3	781	0	690	13	660	12
ROBIN	615	2	623	0	612	0	581	0
TRIPOD	574	3	814	0	898	6	672	6
KETTLE	594	3	684	0	624	0	574	0
NUN	617	2	652	0	645	6	680	0
SURF	601	1	729	6	696	6	617	6
SPIKE	573	2	634	0	718	0	646	12
BOSOM	593	2	866	12	941	6	703	0
BEGGAR	593	2	694	0	700	0	649	13
PLIERS	588	1	842	12	832	13	794	13
CROW	578	2	688	0	636	6	584	0
LARK	573	2	718	0	633	6	608	0
BROOM	608	2	669	0	631	0	578	0
CIDER	626	2	705	6	645	0	689	0
ZIPPER	632	1	708	6	740	0	592	0
CARROT	577	1	664	0	656	0	616	0
MUG	574	1	581	0	634	0	627	7
HARP	621	1	672	0	659	0	667	0
FEAST	610	3	629	0	710	0	576	0
SNAIL	577	1	625	0	672	0	625	0
PIGEON	610	3	599	0	752	0	639	0
HOCKEY	593	1	629	7	603	6	638	6
GYM	613	1	714	0	701	0	648	13
FROG	617	1	614	0	628	0	613	0
JELLY	590	3	569	0	611	6	571	0
BUNNY	585	1	633	8	615	0	608	7
GALAXY	575	3	645	0	636	0	601	0
HELMET	620	1	652	0	634	0	614	0

FORE	340	7	837	14	717	31	717	0
PRIM	361	1	738	0	745	25	742	6
NADIR*	254	2	793	76	921	71	930	37
SYNOD*	229	1	756	56	899	31	819	53
DECREE	341	3	859	0	672	0	688	0
FALLACY	267	1	861	0	744	0	657	0
CITE*	331	7	1070	46	738	50	816	42
PROW*	307	1	916	53	852	68	777	26
FEINT	313	2	910	25	946	33	752	0
ALIAS	294	1	788	0	721	6	700	0
CANDID	337	3	739	6	741	0	707	0
SLOUGH	245	1	772	12	708	6	662	6
DRAB	340	5	776	0	835	12	718	6
AVID	325	1	772	28	991	12	841	12
PAEAN*	261	2	1150	69	842	85	845	50
AMITY*	205	1	1035	50	1160	25	690	13
FETISH	342	2	801	6	761	12	594	33
RENOWN	334	1	759	7	748	0	719	13
PALL	271	4	880	6	1002	46	646	0
IOTA*	322	1	1008	35	1156	50	714	42
PIQUE*	293	2	771	56	901	62	732	25
USURP*	262	1	882	33	923	46	1026	63
SERIAL	340	7	672	0	717	0	656	0
AURORA	345	2	807	13	907	26	817	0
LAIN*	328	4	885	40	841	53	732	6
SEAR	299	2	882	46	711	43	658	6
WREST	313	1	739	31	897	37	590	6
NOISY	215	6	801	6	631	0	612	12
INNATE	301	4	797	20	828	31	828	18
DESPOT	297	2	775	20	708	25	659	6
LEWD*	324	3	853	35	852	62	1034	18
CHOW*	326	2	950	13	931	50	732	0
CACHE*	303	1	804	57	853	60	736	6
AUDIT	253	4	755	0	734	6	639	6
DECEIT	338	2	730	0	731	0	604	7
RARITY	270	2	787	18	749	12	725	0
DOW*	316	1	993	75	951	100	769	7
GIST	262	1	929	37	968	43	806	25
OXIDE	337	3	808	13	828	0	744	25
TOPPED	348	7	766	0	789	6	733	0
THWART	324	3	867	20	857	43	900	31
SUFFIX	254	1	821	6	848	0	810	13
SAGA	345	7	791	13	751	18	713	6
LAX*	363	3	885	21	832	50	789	0
ACUMEN	229	1	922	20	938	26	809	0
EXCISE	287	4	941	14	862	0	684	7
TRUISM	292	3	895	6	735	37	968	13
ALLEGE	281	1	726	7	746	12	816	0

* Due to high error rates data from these stimuli were discarded.

Table B.1.b. The lexical decision task nonword stimuli, and the their mean reaction time in milliseconds and error rate in percentage for each of the three experiments. Note experiment 5 used a different set of nonwords (created by insertion of randomly chosen consonants in the vowel letters of the wordlike nonwords on the left). These nonwords and their experiment 5 means and errors are on the right. Note both lists of nonwords are matched for length with the words which appear in the previous table.

Nonword	Exp4		Exp6		Nonword	Exp5	
	mn	%	mn			mn	%
ATSRER	678	0	785	0	TTSRXR	614	7
BETRLLE	760	0	723	0	BVTRLJ	732	0
FOLBAR	723	0	749	0	FHLBKR	577	0
DRINT	857	7	805	0	DRLNT	650	7
INTYR	697	0	701	7	FNTBR	522	9
FEMIRY	825	0	960	0	FDMHRP	602	0
HIGARE	820	0	726	0	HFGPRD	572	0
ZOALD	705	0	782	0	ZNGLPD	626	12
GIME	888	0	857	0	GNMB	578	0
GOOT	746	9	785	6	GBZT	581	0
HIRTH	901	0	768	0	HWRTH	605	0
LUMYN	623	0	711	6	LGMHN	613	15
GOURNIL	716	0	713	6	GSKRNH	539	0
KNOF	734	0	673	6	KNGF	644	7
SEARN	769	0	754	6	SHPRN	682	7
HIFE	704	0	813	0	HCFV	632	7
LEWOR	649	0	641	0	LLWDR	650	0
KOWT	662	0	691	0	KJWT	543	0
BINUBE	753	0	716	0	BLNSBV	599	0
HAPAR	767	0	824	0	HCPDR	743	0
KEROOD	713	7	730	0	KSRTGD	658	15
WLACE	708	0	661	8	WLMCV	577	0
POONT	783	0	861	0	PNTNT	566	16
FURVE	712	7	728	20	FLRVW	637	9
TADTE	824	7	826	0	TGDTL	568	7
DALK	771	7	731	6	DPLK	666	0
WIPAN	782	7	800	0	WWPBN	620	0
EFTAID	789	0	678	0	WFTSPD	634	7
OWUY	847	0	677	0	WVDL	699	6
DIWN	724	0	794	0	DVWN	734	13
TARVY	730	0	714	13	TKRVN	762	0
JADTER	703	0	665	6	JRDTDR	600	0
VAWX	722	0	696	0	VVWX	568	0
FOID	752	0	758	6	FZRD	623	0
GRESS	788	8	764	6	GRVSS	652	18
HEACTS	906	0	764	6	HFLCTS	673	6
ILHAND	841	0	734	0	CLHTND	816	0
JUCT	737	0	744	0	JHCT	596	0
KNET	792	0	738	12	KNVT	642	13
TELOUR	794	0	727	6	TFLGJR	535	0
VAW	800	0	708	0	VGW	650	7
BROER	811	0	805	12	BRFHR	588	0
LITTIN	818	0	856	6	LWTTRN	707	13

MECCINE	913	7	1042	13	MRCCKN	588	0
TASWER	780	0	724	0	THSWGR	593	0
SIDDIL	794	0	637	14	SSDDVL	597	23
FAIJE	844	0	646	0	FJKJK	574	0
NAJE	608	8	663	0	NKJX	626	7
DEBER	692	0	707	0	DSBGR	619	0
IBNECT	764	0	701	6	DBNMCT	682	0
GERSAP	736	0	747	0	GTRSFP	580	0
SICTUDE	1017	0	846	0	SFCTSD	674	7
PLOASE	755	0	756	0	PLJJSG	620	0
NOF	664	0	664	0	NKF	617	0
JEPONT	712	7	814	0	JNPRNT	639	0
SNECKS	754	0	797	13	SNCKKS	660	7
SMORM	921	23	934	6	SMCRM	583	0
FOTE	729	0	681	0	FVTW	650	7
NATOR	712	7	748	0	NZTBR	659	0
DEAST	829	20	885	6	DWZST	593	7
EGANT	760	0	893	6	GGCNT	622	0
DASIT	775	0	700	0	DBSRT	593	0
HUREOU	748	0	680	0	HHRMRL	651	15
CHELTS	764	12	816	14	CHTLTS	761	14
TRUEL	793	15	900	6	TRHKL	663	0
JUB	778	7	790	6	JNB	591	0
RISPUT	769	7	848	14	RFSPT	658	0
EEGAR	858	0	784	0	BNGTR	653	0
ZUTE	694	0	830	6	ZVTS	733	0
FULE	798	13	828	12	FJLC	644	0
GLIVE	900	0	844	12	GLPVF	611	0
JUY	711	0	809	6	JDP	640	7
LUNLER	807	0	720	0	LCNLDR	561	7
JEBEL	843	7	654	12	JTBVL	756	13
MAMB	770	0	759	0	MXMB	601	0
SODGE	803	7	827	0	SXDGJ	624	6
MYRCEE	896	0	747	7	MCRCDH	612	6
HAVI	757	14	706	6	HJVN	576	6
ZEARL	742	7	671	0	ZRRRL	624	6
FUZL	667	0	683	0	FNZL	586	13
GURST	764	0	758	6	GVRST	710	6
NAZZ	646	0	693	0	NXZZ	543	0
NUNG	701	0	682	7	NCNG	697	0
FEAP	882	16	811	13	FDJP	571	0
JURT	769	0	707	13	JHRT	552	7
BLAIE	830	7	663	0	BLMCG	659	0
MONG	680	0	751	7	MWNG	624	0
DAOD	693	7	713	0	DJTD	596	0
YOME	645	0	686	12	TTMR	659	0
VEEZE	722	0	700	0	VMMZX	578	0
MEECH	734	13	808	0	MTCCH	586	0
YAIT	741	0	774	0	CGRT	669	0
NENT	837	0	726	7	NDNT	717	8
PHOYCE	803	6	789	6	PHSPCL	654	0
WOTE	873	7	796	0	WTTV	738	0
BREEM	738	37	838	13	BRRHM	545	0
BRUVE	865	0	712	0	BRTVV	620	0
KAIZE	679	7	630	6	KWZZR	615	0
FROOZE	761	26	856	20	FRDBZG	574	0

SHRET	800	7	702	0	SHRST	659	0
TRUFE	822	0	793	20	TRLFR	747	0
TOLPH	724	20	704	0	TPLPH	647	0
HAIK	811	0	793	0	HXRK	628	0
PAIT	910	14	717	0	PZDT	632	10
ZUPE	682	7	632	0	ZNPK	619	0
SNOCKS	911	0	877	21	SNFCKS	621	0
BIRL	871	0	804	13	BVRL	618	23
GOPH	665	0	704	0	GBPH	573	0
BERGE	838	0	857	25	BGRGL	669	0
PREET	826	0	774	18	PRZMT	583	23
WIRCH	776	0	676	6	WRRCH	660	0
BOOL	829	0	760	13	BWML	585	18
VIRCK	816	0	736	6	VCRCK	600	0
CROOP	1005	13	949	33	CRNRP	608	0
YOWND	725	0	722	7	SWWND	666	0
BAIP	715	0	634	0	BGHP	576	0
BEAL	914	0	834	25	BWLL	706	8
GOAP	757	0	715	7	GCVF	589	0
DEECE	795	0	731	0	DGNCH	609	0
CLUD	836	12	793	6	CLHD	747	0
BLEEF	730	0	860	13	BLBZF	695	0
FUES	949	25	772	12	FRDS	666	6
HIRTH	901	0	768	0	HRRTH	596	7
FAIJE	844	0	646	0	FBTJF	591	0
KLITES	923	0	796	7	KLRTDS	621	7
JURT	769	0	707	13	JPRT	548	0
DAOD	693	7	713	0	DNND	608	0
YOME	645	0	686	12	RLMN	707	7
BAIP	715	0	634	0	BWPP	651	7
VEEZE	722	0	700	0	VCRZK	599	7
ZOPE	682	0	712	0	ZPPP	678	0
MERSE	791	6	755	25	MXRSR	597	0
PRAX	717	8	690	21	PRZX	599	0
HEESE	935	7	719	0	HSVSH	659	14
PLEW	828	6	847	7	PLHW	617	0
TURTH	779	0	804	33	TPRTH	600	0
KERTH	736	0	703	6	KJRTH	619	0
TUDE	822	0	747	6	TKDS	598	6
JINJE	643	7	714	0	JFNJG	565	0
BURSE*	899	20	983	50	BVRSK	644	7
GEAD	779	7	711	6	GCRD	680	13
DIGHT	879	6	815	0	DPGHT	560	0
VULT	876	0	726	6	VBLT	555	6
MAWCH	791	0	659	0	MBWCH	552	0
WOITE	767	0	695	0	WNXTN	602	7
TELPH	752	0	818	0	TDLPH	587	20
POIN	883	14	799	18	PDCN	632	0
JOIL	899	7	699	13	JSXL	559	0
GOPT	649	0	691	0	GVPT	708	12
KIRE	775	9	698	0	KZRB	656	0
YOIND	698	7	706	0	CNKND	638	0
CLID	937	9	891	6	CLWD	711	0
BLOAF	774	0	710	0	BLVVF	638	7
VIZE	838	0	809	0	VLZP	603	0
NAAN	605	9	630	20	NSRN	644	0

BLI	705	0	779	0	BLB	644	0
MALK	876	0	781	0	MHLK	673	0
BAPPER	847	0	824	6	BKPPMR	709	0
BELTHY	780	0	885	7	BRLTHS	678	0
BODDER	759	0	908	20	BSDDXR	564	0
BOLLEN	844	7	791	18	BGLLNN	635	7
CARBER	832	0	882	20	CNRBGR	564	0
CONGUL	805	7	952	14	CJNGKL	556	0
COPPLE	807	15	1137	20	CTPPLB	609	0
CRONER	892	13	905	33	CRKNDR	562	7
CUGGLE	959	20	814	6	CMGGLF	680	0
DIBBEN	698	0	717	12	DKBBBN	640	0
BASSEN	782	0	813	13	BDSSPN	783	0
BROPER	708	0	770	0	BRSPFR	641	8
BUFFLE	1046	28	1127	28	BRFFLH	648	0
BUNNET	814	0	926	20	BZNNST	702	0
CALLET	876	0	916	13	CZLLGT	597	7
CLOMER	833	0	700	7	CLRMRR	597	0
COWDER	895	16	823	18	CJWDLR	636	0
CRUTLE	777	0	816	6	CRMTLR	760	0
DELTOR	857	7	879	13	DKLTJR	738	7
DIPPET	657	0	882	6	DSPPZT	551	0
DOPTEN	803	7	794	0	DHPTXN	532	6
PERTER	766	7	769	20	PTRTBR	630	0
PLUNKY	887	20	923	33	PLHNKC	601	0
PRADLE	852	0	907	0	PRHDLB	672	8
TRUGER	704	0	733	12	TRWGGR	615	0
PARBER	941	6	765	0	PMRBGR	628	0
PARDLE	798	6	890	12	PPRDLW	637	6
PEAMER	837	6	849	0	PWVMXR	656	8
DILKER	726	0	689	6	DTLKBR	574	0
PODDER	905	7	892	12	PSDDGR	608	0
PORTEN	705	0	870	33	PTRTLN	720	0
PRANTY	849	0	887	18	PRXNTW	592	0
TANDER	962	12	806	21	THNDSR	683	0
TASPER	802	0	834	6	TLSPMR	547	15
TEAGLE	781	0	863	6	TPJGLN	614	0

* Excluded from analysis due to 50% error.

APPENDIX C (Chapter 5).

Table C.1.a. Experiment 4. Means and error rates for words and nonwords.

'magno'				'parvo'			
words		nonwords		words		nonwords	
mn	%	mn	%	mn	%	mn	%
615	3	683	2	713	5	908	3
448	1	499	4	524	8	608	3
691	4	774	0	842	1	972	3
559	2	658	4	582	1	693	2
535	3	754	3	575	2	839	5
677	3	897	4	744	1	993	6
578	2	697	2	663	4	847	1
603	1	622	3	597	3	661	5
602	6	680	3	631	0	731	1
723	1	818	4	902	0	1267	5
698	2	766	6	728	1	952	3
608	4	704	5	648	1	700	5
643	0	679	4	672	2	874	5
690	3	735	1	913	8	956	6
612	2	700	7	679	0	764	1
<u>754</u>	<u>1</u>	<u>861</u>	<u>4</u>	<u>859</u>	<u>0</u>	<u>945</u>	<u>2</u>
627	3.0	705	2.9	720	3.5	857	4.1

Table C.1.b. Experiment 4: Subject means, standard deviations and percent errors across conditions

		'MAGNO'												'PARVO'																
		HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ								
		HA		LA		LC		HA		LA		HC		HA		LA		HC		HA		LA		LC		HA		LA		
RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	
537	85	0	615	175	0	642	168	0	717	110	17	608	92	0	643	148	0	718	195	0	718	195	0	831	227	15				
424	58	0	438	61	0	449	62	0	496	76	7	466	65	0	485	64	13	502	87	0	502	87	0	555	89	6				
616	123	4	645	123	0	759	182	8	774	128	5	741	168	0	684	85	0	773	112	0	773	112	0	956	312	0				
518	46	0	552	71	0	572	92	0	628	124	13	568	51	0	624	91	0	636	109	8	636	109	8	872	320	11				
507	62	4	533	49	0	547	118	0	563	49	11	781	204	0	805	186	0	655	69	4	655	69	4	782	168	15				
633	93	9	667	157	4	704	115	0	705	146	0	863	206	0	833	241	0	881	260	4	881	260	4	1073	349	17				
506	46	0	539	95	0	622	252	4	673	123	5	594	99	0	720	314	0	682	228	0	682	228	0	874	178	13				
572	87	0	556	69	0	639	214	4	698	239	0	578	75	0	594	96	0	611	96	0	611	96	0	754	150	17				
554	69	0	588	76	0	613	102	8	695	140	23	664	99	4	642	67	0	686	115	0	686	115	0	779	124	14				
580	93	0	669	168	0	718	215	6	1102	430	0	763	228	8	738	170	0	882	258	0	882	258	0	964	282	14				
674	212	9	656	232	0	610	102	0	920	254	0	731	209	8	727	134	0	775	178	8	775	178	8	868	199	7				
594	85	0	609	109	8	613	74	8	624	133	0	627	70	0	678	219	4	673	103	8	673	103	8	901	390	11				
561	82	4	641	115	4	614	103	8	848	200	29	632	110	4	680	127	8	648	98	0	648	98	0	833	195	7				
643	102	0	615	65	0	682	83	0	947	307	21	671	95	0	670	59	0	757	99	0	757	99	0	888	282	5				
524	50	5	608	142	0	622	174	0	717	145	5	611	70	8	690	101	0	682	73	4	682	73	4	929	301	20				
751	210	0	745	125	0	727	119	0	828	101	7	788	116	0	817	134	0	827	106	0	827	106	0	1117	307	22				
575		2.2	605		1.0	633		2.9	746		8.9	668		2.0	689		1.6	712		2.3	874		12.1							

Table C.2.a. Experiment 5. Means and error rates for words and nonwords.

'magno'				'parvo'			
words		nonwords		words		nonwords	
mn	%	mn	%	mn	%	mn	%
702	3	734	1	650	3	731	3
569	2	620	4	569	3	614	5
786	2	872	2	730	2	913	1
536	2	661	8	515	1	621	2
599	4	627	1	513	0	594	1
476	2	553	1	483	3	559	5
524	6	581	6	558	3	644	3
635	6	698	1	572	3	668	5
511	9	592	5	496	2	587	7
603	1	642	5	554	7	623	1
671	0	875	1	661	1	912	2
456	0	500	5	472	1	511	2
510	0	564	7	484	2	530	5
630	1	650	4	634	1	702	5
737	1	821	1	720	3	895	1
<u>536</u>	<u>2</u>	<u>692</u>	<u>8</u>	<u>564</u>	<u>3</u>	<u>682</u>	<u>1</u>
593	2.6	573	2.4	668	5.0	674	4.3

Table C.2.b. Experiment 5: Subject means, standard deviations and percent errors across conditions

		'MAGNO'												'PARVO'											
		HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ			
		HA		LC		LA		HC		HA		LC		LA		HC		HA		LC		LA			
RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%		
601	112	0	719	181	4	662	138	4	909	447	6	672	198	4	777	215	0	675	111	0	881	467	0		
580	135	0	540	130	0	548	98	4	640	142	7	594	98	8	619	131	8	602	106	0	678	171	0		
700	123	4	723	213	0	730	188	4	1069	398	0	738	198	0	925	268	0	796	206	8	1216	275	0		
512	65	0	528	114	4	520	71	4	614	189	0	631	170	4	631	95	4	615	82	8	826	224	22		
580	120	4	568	80	0	627	131	0	635	108	16	590	72	0	620	71	0	619	104	4	728	105	0		
446	52	0	475	64	4	485	57	4	504	60	0	521	96	0	538	74	0	584	221	4	572	101	0		
502	92	4	513	133	0	534	171	14	559	118	6	584	101	0	579	158	8	556	112	8	632	127	13		
565	109	13	692	248	4	576	129	0	774	306	7	691	153	16	671	113	16	703	125	0	776	57	61		
530	94	0	487	78	13	482	60	8	557	64	16	589	85	8	555	93	0	579	86	8	676	183	6		
598	95	0	566	105	4	587	141	0	686	198	0	619	126	4	618	98	0	606	97	12	760	164	6		
601	71	0	651	179	0	678	131	0	787	137	0	771	134	0	850	168	0	865	210	0	1109	348	6		
425	69	0	463	75	0	471	89	0	471	100	0	489	75	4	511	57	4	485	76	8	524	95	5		
473	38	0	525	68	0	484	53	0	574	93	0	548	69	0	562	72	4	535	76	16	626	140	5		
589	59	0	599	64	0	615	83	0	751	221	5	596	64	17	641	91	0	644	72	0	745	177	0		
652	200	0	759	320	4	687	131	0	949	378	0	802	245	0	780	212	0	817	194	4	908	211	0		
545	106	0	564	129	2	523	80	0	505	83	0	632	108	12	757	203	8	694	264	0	681	133	16		
556		1.6	586		2.9	576		2.6	687		3.9	629		4.8	665		3.3	648		5.0	771		8.8		

Table C.3.a. Experiment 6. Means and error rates for words and nonwords.

'magno'				'parvo'			
words		nonwords		words		nonwords	
mn	%	mn	%	mn	%	mn	%
682	0	718	1	880	9	827	3
622	3	672	6	676	0	761	3
614	8	586	4	726	3	750	5
772	4	755	2	828	0	838	2
618	6	681	5	702	2	762	1
593	7	633	5	717	1	725	3
830	1	680	0	819	2	849	2
616	2	670	6	658	1	736	3
556	4	591	2	607	1	682	3
670	7	682	6	862	3	891	9
880	4	812	8	905	5	895	1
692	2	682	5	708	1	732	1
552	3	545	2	660	2	672	6
651	2	677	3	749	7	791	3
643	4	616	3	722	2	757	3
<u>592</u>	<u>0</u>	<u>587</u>	<u>0</u>	<u>730</u>	<u>3</u>	<u>792</u>	<u>3</u>
661	4.2	747	5.8	662	4.3	779	6.3

Table C.3.b. Experiment 6: Subject means, standard deviations and percent errors across conditions

		'MAGNO'												'PARVO'																																																																																																																																																																																																																																																																																																																																																																																																									
		HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ				HIGH FRQ				LOW FRQ																																																																																																																																																																																																																																																																																																																																																																																																	
		HA		LC		LA		HC		HA		LC		LA		HC		HA		LC		LA		HC		HA		LC		LA																																																																																																																																																																																																																																																																																																																																																																																									
RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%	RT	SD	%																																																																																																																																																																																																																																																																																																																																																																																							
639	217	0	655	163	0	734	198	12	737	147	35	703	203	8	679	156	13	721	191	4	808	249	26	572	147	0	573	106	0	707	237	0	642	103	23	592	115	0	634	140	0	742	260	4	784	158	29	543	142	0	593	102	0	613	132	8	806	167	29	511	72	0	649	193	4	604	145	8	599	92	6	687	124	4	768	152	0	759	175	0	987	205	20	710	164	0	677	106	4	752	193	0	931	302	5	523	97	0	602	155	0	709	268	0	667	141	33	624	174	4	610	123	0	725	356	0	878	320	26	542	87	0	576	72	4	600	137	4	758	211	30	565	75	4	617	98	0	640	89	8	785	253	12	834	309	0	738	218	0	829	238	4	949	525	0	602	85	0	651	135	0	711	217	0	815	151	0	599	110	4	594	117	0	609	122	4	694	119	0	640	140	0	633	89	4	673	106	4	779	211	22	509	60	0	526	122	0	592	141	8	621	111	11	553	91	0	546	69	0	561	72	0	814	480	13	582	85	4	644	178	8	679	214	0	918	275	23	608	129	0	643	157	0	748	187	8	786	214	22	786	287	0	871	322	4	914	370	4	995	263	11	791	241	4	833	193	13	761	170	8	895	246	6	660	108	0	711	134	4	683	109	0	732	98	6	636	66	0	686	140	4	699	104	4	724	115	16	499	72	0	508	67	0	572	142	0	669	160	16	517	65	4	507	63	0	594	158	0	582	163	7	585	56	0	607	63	0	659	120	0	827	226	13	621	66	0	666	121	0	692	130	4	755	132	11	533	75	0	644	178	0	638	127	4	836	336	17	550	73	4	594	86	0	654	114	0	714	120	14	533	55	0	558	124	0	581	113	0	772	206	0	536	42	0	565	60	0	578	75	0	696	214	0	602		.8	636		1.3	680		3.0	788		16.7	610		1.8	637		2.6	678		3.3	772		13.4

Table D.1. (Chapter 6) Experiment 7. Individual means, SDs and error percentages for the ten subjects in the four conditions.

		<u>Same letter</u>				<u>Different letter</u>			
AA		Aa		AD		Ad			
Flicker Flicker									
450	(48)	4	449 (81)	4	416 (54)	0	415 (47)	0	
446	(65)	8	425 (90)	8	396 (98)	0	377 (44)	0	
551	(105)	0	550 (126)	0	509 (77)	0	500 (60)	0	
499	(59)	33	515 (107)	0	426 (73)	0	417 (71)	0	
557	(100)	0	563 (135)	0	506 (85)	4	513 (89)	0	
514	(61)	0	518 (84)	0	444 (65)	0	457 (54)	0	
560	(76)	0	562 (85)	0	548 (91)	0	553 (70)	0	
479	(60)	0	512 (121)	8	490 (91)	0	453 (70)	0	
479	(56)	4	506 (83)	4	441 (67)	4	426 (54)	0	
<u>558</u>	<u>(56)</u>	<u>4</u>	<u>498 (93)</u>	<u>0</u>	<u>459 (70)</u>	<u>4</u>	<u>479 (69)</u>	<u>0</u>	
509		5.3	510	2.4	464	1.2	459	0.0	
Flicker Static									
457	(63)	4	410 (73)	0	404 (60)	0	382 (53)	0	
460	(76)	41	414 (99)	4	376 (94)	0	396 (78)	0	
560	(76)	16	581 (140)	0	483 (51)	0	460 (51)	0	
519	(54)	29	396 (81)	4	369 (51)	0	390 (53)	0	
568	(70)	4	572 (113)	0	505 (78)	0	533 (90)	0	
516	(67)	25	483 (75)	0	445 (80)	0	418 (42)	0	
595	(64)	4	588 (144)	0	580 (140)	0	555 (103)	0	
530	(61)	20	522 (162)	8	449 (81)	0	420 (58)	0	
542	(63)	8	520 (162)	0	459 (73)	0	443 (55)	0	
<u>560</u>	<u>(87)</u>	<u>4</u>	<u>550 (142)</u>	<u>4</u>	<u>485 (100)</u>	<u>0</u>	<u>467 (89)</u>	<u>0</u>	
531		15.5	504	2.0	456	0.0	446	0.0	
Static Static									
408	(53)	0	422 (75)	0	407 (69)	0	406 (61)	0	
436	(58)	16	415 (78)	4	372 (56)	0	388 (104)	0	
508	(61)	0	556 (88)	0	471 (39)	0	489 (49)	0	
487	(33)	4	485 (87)	4	432 (78)	0	417 (53)	0	
522	(66)	0	538 (140)	0	536 (88)	0	495 (72)	0	
463	(74)	8	537 (82)	0	511 (103)	0	463 (74)	0	
542	(107)	0	547 (87)	0	513 (42)	0	503 (68)	0	
454	(82)	4	561 (130)	4	480 (76)	0	436 (49)	0	
468	(69)	0	495 (82)	0	458 (76)	0	473 (70)	0	
<u>510</u>	<u>(55)</u>	<u>4</u>	<u>524 (77)</u>	<u>0</u>	<u>494 (92)</u>	<u>0</u>	<u>465 (47)</u>	<u>0</u>	
480		3.6	508	1.2	467	0.0	456	0.0	
Static Flicker									
469	(57)	8	413 (73)	0	422 (69)	0	396 (31)	0	
452	(67)	45	401 (97)	0	389 (85)	0	379 (72)	0	
564	(86)	4	605 (125)	0	540 (85)	0	520 (73)	0	
525	(78)	8	423 (75)	0	440 (94)	0	423 (50)	0	
593	(109)	4	644 (114)	0	552 (136)	0	559 (132)	0	
507	(86)	4	500 (86)	0	477 (62)	0	496 (84)	0	
586	(53)	4	613 (145)	0	517 (87)	0	571 (125)	0	
538	(88)	16	543 (136)	0	470 (76)	0	473 (64)	0	
503	(76)	0	561 (117)	4	469 (55)	0	447 (57)	4	
<u>586</u>	<u>(80)</u>	<u>4</u>	<u>566 (116)</u>	<u>0</u>	<u>484 (73)</u>	<u>0</u>	<u>527 (129)</u>	<u>0</u>	
532		9.7	527	0.4	476	0.0	479	0.4	

Section 3: PROGRAMS

Timer program (Brysbaert, Bovens, d'Ydewalle & Calster, 1989)

```
type strin = string[80];
```

```
var xtel,gtel : integer;
```

```
procedure newint;  
  interrupt;  
  begin  
    inc(gtel);  
    inline($b0/$20/$e6/$20);  
  end;
```

```
procedure fast;  
  begin  
    inline($fa);           {disable interrupts}  
    port[$43] := $36;      {channel 3}  
    port[$40] := $a9;      {new divisor}  
    port[$40] := $04;  
    inline($fb);           {enable interrupts}  
  end;
```

```
procedure slow;  
  begin  
    inline($fa);           {disable interrupts}  
    port[$43] := $36;      {channel 3}  
    port[$40] := $00;      {new divisor}  
    port[$40] := $00;  
    inline($fb);           {enable interrupts}  
  end;
```

PROGRAM USED IN CHAPTER 4

PROGRAM experiment_3_masking_investigation;

uses Dos, Crt, graph;

{\$i c:\tp\timer.vga}

{\$i c:\tp\instal.pas}

CONST

```
pal_num : ARRAY[0..15] OF byte =
(0,1,2,3,4,5,20,07,56,57,58,59,60,61,62,63);
lets : ARRAY[0..9] OF char =
('C','D','J','K','L','N','X','Z','T','P');
pix_red : ARRAY[0..5] OF byte = (14,15,11,12,10,13);
pix_grn : ARRAY[0..5] OF byte = (11,12,14,15,13,10);
pix_cn1 : ARRAY[0..5] OF byte = (0,0,5,4,6,0);
pix_cn2 : ARRAY[0..5] OF byte = (5,4,0,0,0,6);
```

VAR

```
add_mask,change_page,xg : byte;
xn,yn,rnd,n,r,balance,stime,c1,l,cc,hx,hy,q,c2,qq,xx1,h1,h2,
h,stim_len,xc,fill,mnrt1,mnrt2,let,portresult,portresult2,
pos,w,wx,c,t1,t2,t3,t4,s,ctime1,ctime2,size,step,xcol,start,
finish,hdigit,col1,g,col2,xpos,i,ii,xb1,xb2,ctime,x2,y2,
count,mn,error,err1,err2,xz,err,temptc,dely2,z,j,xx,
stim_size_brd,stim_high_brd,stim_size_narr,rndd,rndx,x1,
char_size,x,y,y1,p,code,block_balance,charsize,ct,wx1,wx2,
wy1,wy2,stim_balance,stim_size,stim_high_narr,conx,stim_wid,
space,endx,aa,a,con,stim_high,xred,xxcol,xgrn,r1,r2,g1,g2,o1
,o2 : integer;
int1Csave,blank,image5,image1,image2,image3,image4 : pointer;
image : ARRAY [0..3,0..9] OF pointer;
mask : ARRAY [0..7] OF pointer;
infile,outfile : text;
ch : char;
key : ARRAY [0..179] OF char;
sizebrd,sizenarr,v,v1,v2 : word;
result,rt : ARRAY [0..383] OF integer;
let_info : ARRAY [0..1,0..25,0..1] OF byte;
pixcol : ARRAY [0..5] OF byte;
xlet,stim_str,namefile{,st1tp,st2tp} : STRING;
stim,cond : ARRAY [0..179] OF byte;
str1 : STRING[7];
str2 : STRING[3];
str3 : STRING[4];
rnd2 : ARRAY[0..9,0..5] OF byte;
rnd1 : ARRAY[0..9] OF byte;
rndq : ARRAY[0..99] OF integer;
condm,cond : ARRAY[0..95] OF byte;
match : ARRAY [0..383] OF byte;
cnd : ARRAY[0..383,0..1] OF byte;
cun : ARRAY [0..9,0..5] OF byte;
```

PROCEDURE filename;

BEGIN

```

gotoxy(1,1);
Write('Name for file ');
REPEAT
UNTIL keypressed;
Readln(input,namefile);
Write('colour intensity ');
REPEAT
UNTIL keypressed;
Readln(input,xcol);
END;

PROCEDURE stimgen;
BEGIN;
  FOR qq:= 0 TO 2 DO
    BEGIN;
      FOR c:= 0 TO 5 DO
        BEGIN;
          FOR q:=0 TO 9 DO
            BEGIN;
              rnd1[q] := 99;
            END;
          FOR q:=0 TO 9 DO
            BEGIN;
              REPEAT;
                rnd := random(10);
              UNTIL rnd1[rnd]=99;
              rnd1[rnd] := q;
            END;
          FOR x:= 0 TO 9 DO
            BEGIN;
              stim[(qq*60)+x+(c*10)] := rnd1[x];
            END;
          END;
        END;
      END;
    FOR q:=0 TO 9 DO
      FOR c:= 0 TO 5 DO
        BEGIN;
          rnd2[q,c] := 99;
        END;
      FOR q:=0 TO 9 DO
        BEGIN;
          FOR c:=0 TO 5 DO
            BEGIN;
              REPEAT;
                rnd := random(6);
              UNTIL rnd2[q,rnd]=99;
              rnd2[q,rnd] := c;
            END;
          END;
        END;
      FOR qq:= 0 TO 2 DO
        BEGIN;
          FOR x:= 0 TO 9 DO
            BEGIN;
              q := -1;
              FOR c:= 0 TO 5 DO
                BEGIN;

```

```

        REPEAT;
            q := q+1;
            UNTIL stim[q+(qq*60)]=x;
            cond[q+(qq*60)] := rnd2[x,c];
        END;
    END;
END;

PROCEDURE colours;
BEGIN;
    setrgbpalette(0,0,0,0);
    setrgbpalette(1,63,38,63);
    setrgbpalette(2,xcol-14,38-7,0);
    setrgbpalette(pal_num[3],xcol-5,38-2,0);
    setrgbpalette(pal_num[4],xcol+4,38+4,0);
    setrgbpalette(pal_num[5],xcol+0,38+0,0);
    setrgbpalette(pal_num[6],xcol,38,0);
    setrgbpalette(pal_num[7],xcol-10,38-5,0);
    setrgbpalette(pal_num[8],xcol-12,38-6,0);
    setrgbpalette(pal_num[9],xcol-14,38-9,0);
    setrgbpalette(pal_num[10],xcol,0,0);
    setrgbpalette(pal_num[11],xcol+1,00,0);
    setrgbpalette(pal_num[12],xcol+4,00,0);
    setrgbpalette(pal_num[13],00,38,0);
    setrgbpalette(pal_num[14],00,38+0,0);
    setrgbpalette(pal_num[15],00,38+4,0);
END;

PROCEDURE SaveResults;
BEGIN;
    Assign(outfile,'c:\mask\exp1\'+'namefile+'all.dat');
    Rewrite(outfile);
    FOR x := 0 TO 179 DO
        BEGIN;
            writeln(outfile,lets[stim[x]],' ',key[x]:5,
                cond[x],
                rt[x]:5,result[x]:2)
        END;
    close(outfile);
END;

PROCEDURE clock;
BEGIN;
    getintvec($8,int1Csave);
    setintvec($8,@newint);
    fast;
    gtel := 0;
END;

PROCEDURE clockreset;
BEGIN;
    slow;
    setintvec($8,int1Csave);
END;

```

```

PROCEDURE raster;
BEGIN;
  REPEAT
    UNTIL (((port[memw[$40:$63]+6] AND 8) = 0) OR
(port[$201]=179));
  REPEAT
    UNTIL (((port[memw[$40:$63]+6] AND 8) <> 0) OR
(port[$201]=179));
END;

```

```

PROCEDURE square_fill(image_number,page : byte);
BEGIN;
  count := -1;
  setactivepage(page);
  setvisualpage(page);
  setfillstyle(1,0);
  bar(0,0,getmaxx,getmaxy);
  FOR y:= 0 TO 7 DO
    FOR x:= 0 TO 9 DO
      BEGIN;
        count := count+1;
        putimage((stim_size_brd*x),(stim_high_brd*y),
image[image_number+page,rndq[count]]^,0);
      END;
    END;
END;

```

```

PROCEDURE squares(image_number : byte);
BEGIN;
  FOR x:= 0 TO 8*10 DO
    BEGIN;
      rndq[x] := 99;
    END;
  FOR xx:= 0 TO 7 DO
    FOR x:= 0 TO 9 DO
      BEGIN;
        REPEAT;
          r := random(10);
          UNTIL rndq[r+(xx*10)]=99;
          rndq[r+(xx*10)] := x;
        END;
        square_fill(image_number,0);
        square_fill(image_number,1);
      END;
    END;
END;

```

```

PROCEDURE loop;
BEGIN;
  ch := '9';
  qq := 0;
  ctime := 2;
  REPEAT;
    IF ctime>0
      THEN BEGIN;
        REPEAT;
          setvisualpage(0);
          FOR xg:= 1 TO ctime DO

```



```

                BEGIN;
                raster;
            END;
            setvisualpage(1);
            FOR xg:= 1 TO ctime DO
                BEGIN;
                raster;
                END;
            UNTIL keypressed;
        END;
    IF ctime=0
        THEN BEGIN;
            setvisualpage(qq MOD 2);
            REPEAT;
            UNTIL keypressed;
        END;
    ch := readkey;
    stime := 0;
    IF ch='5'
        THEN qq := qq+1;
    IF ch='+'
        THEN ctime := ctime+1;
    IF ((ch='-')AND(ctime>0))
        THEN ctime := ctime-1;
    IF ch='/'
        THEN ctime1 := ctime;
    IF ch='*'
        THEN ctime2 := ctime;
    IF ((ch='7')AND(xcol<59))
        THEN BEGIN;
            xcol := xcol+3;
            colours;
        END;
    IF ((ch='1')AND(xcol>4))
        THEN BEGIN;
            xcol := xcol-3;
            colours;
        END;
    IF ((ch='8')AND(xcol<62))
        THEN BEGIN;
            xcol := xcol+1;
            colours;
        END;
    IF ((ch='2')AND(xcol>2))
        THEN BEGIN;
            xcol := xcol-1;
            colours;
        END;
    IF ch='9'
        THEN BEGIN;
            squares(2);
        END;
    IF ch='3'
        THEN BEGIN;
            squares(0);
        END;

```

```

FOR change_page:= 0 TO 1 DO
  BEGIN;
    setactivepage(change_page);
    gotoxy(79,1);
    write(xcol);
    gotoxy(79,2);
    IF ctime>0
      THEN write(ctime)
      ELSE write('0');
    gotoxy(79,3);
    write(ch);
  END;
UNTIL ((ch='p')OR(ch='P'));
END;

PROCEDURE narr_image;
BEGIN;
  coll := pixcol[5];
  col2 := pixcol[4];
  setfillstyle(1,pixcol[5]);
  bar(0,0,stim_size+5,stim_high);
  setcolor(pixcol[4]);
  outtextxy(4,3,str1);
  s := 0;
  FOR x:= 2 TO stim_size+5 DO
    FOR y:= 1 TO stim_high DO
      BEGIN
        xn := getpixel(x-1,y);
        yn := getpixel(x,y);
        IF ((xn=pixcol[4])AND(yn=pixcol[5]) AND (y MOD 2
          =0)AND(s=0))
          THEN BEGIN;
            putpixel(x-1,y,pixcol[4]);
            putpixel(x-1,y,pixcol[2]);
            putpixel(x-0,y,pixcol[2]);
            putpixel(x+1,y,pixcol[1]);
            putpixel(x+2,y,pixcol[5]);
            s := 1;
          END;
        IF ((xn=pixcol[5])AND(yn=pixcol[4])AND(y MOD 2 =
          0)AND(s=0))
          THEN BEGIN;
            putpixel(x-1,y,pixcol[5]);
            putpixel(x-0,y,pixcol[0]);
            putpixel(x+1,y,pixcol[3]);
            putpixel(x+2,y,pixcol[4]);
            s := 1;
          END;
        IF ((xn=pixcol[4])AND(yn=pixcol[5])AND(y MOD 2
          =1)AND(s=1))
          THEN BEGIN;
            putpixel(x-2,y,pixcol[4]);
            putpixel(x-1,y,pixcol[2]);
            putpixel(x,y,pixcol[1]);
            putpixel(x+1,y,pixcol[0]);
            putpixel(x+2,y,pixcol[5]);

```

```

        s := 0;
    END;
    IF ((xn=pixcol[5])AND(yn=pixcol[4])AND(y MOD 2 =
1)AND(s=1))
    THEN BEGIN;
        putpixel(x-2,y,pixcol[5]);
        putpixel(x-1,y,pixcol[0]);
        putpixel(x,y,pixcol[3]);
        putpixel(x+1,y,pixcol[4]);
        s := 0;
    END;
END;

PROCEDURE target;
BEGIN;
    settextstyle(0,0,2);
    setcolor(0);
    setfillstyle(1,2);
    bar(wx1,wy1,wx2,wy2);
    outtextxy((wx1+wx2) DIV 2-(textwidth('+') DIV 2),
(wy1+wy2) DIV 2- (textwidth('+') DIV 2),'+');
    settextstyle(1,0,10);
END;

PROCEDURE draw_box;
BEGIN;
setcolor(0);
line(x1-1,y1-1,x1+stim_size_brd-3+1,y1-1);
line(x1+stim_size_brd-3+1,y1-1,x1+stim_size_brd-3+1,
y1+stim_high_brd-4+1);
line(x1+stim_size_brd-3+1,y1+stim_high_brd-4+1,x1-1,
y1+stim_high_brd-4+1);
line(x1-1,y1+stim_high_brd-4+1,x1-1,y1-1);
END;

PROCEDURE prepare_clock_and_page(page :byte);
BEGIN;
    raster;
    clock;
    x := 0;
    port[$201] := 0;
    setvisualpage(1-page);
    setactivepage(page);
END;

PROCEDURE wait;
BEGIN;
    REPEAT;
    UNTIL gtel>((ctime+1)*14)-2;
    clockreset;
END;

PROCEDURE mask_before_flashing_letter(page,mask_number :
byte);
BEGIN;

```

```

prepare_clock_and_page(page);
putimage(x1,y1,mask[mask_number]^,0);
wait;
END;

PROCEDURE flashing_letters(contrast_colour :byte);
BEGIN;
port[$201] := 0;
prepare_clock_and_page(0);
draw_box;
prepare_clock_and_page(1);
draw_box;
wait;
IF add_mask=1
  THEN BEGIN;
    IF contrast_colour= 0
      THEN ctime := 2;
    IF contrast_colour= 2
      THEN ctime := 3;
    mask_before_flashing_letter(0,0+contrast_colour);
    mask_before_flashing_letter(1,1+contrast_colour);
    mask_before_flashing_letter(0,0+contrast_colour);
    mask_before_flashing_letter(1,1+contrast_colour);
    mask_before_flashing_letter(0,0+contrast_colour);
    mask_before_flashing_letter(1,4+contrast_colour);
    mask_before_flashing_letter(0,4+1+contrast_colour);
  END;
IF add_mask=2
  THEN BEGIN;
    mask_before_flashing_letter(0,0+contrast_colour);
    ctime := 0;
    mask_before_flashing_letter(0,1+contrast_colour);
    mask_before_flashing_letter(0,0+contrast_colour);
    mask_before_flashing_letter(0,1+contrast_colour);
    mask_before_flashing_letter(0,0+contrast_colour);
    mask_before_flashing_letter(0,4+contrast_colour);
    mask_before_flashing_letter(0,4+1+contrast_colour);
  END;
ctime := 0;
prepare_clock_and_page(1);
putimage(x1,y1,image[0+contrast_colour,stim[i]]^,0);
wait;
prepare_clock_and_page(0);
putimage(x1,y1,image[1+contrast_colour,stim[i]]^,0);
wait;
clock;
REPEAT;
  setvisualpage(0);
  FOR x:= 0 TO ctime DO
    BEGIN;
      raster;
    END;
  setvisualpage(1);
  FOR x:= 0 TO ctime DO
    BEGIN;
      raster;

```

```

        END;
        portresult := port[$201];
UNTIL portresult = 179;
rt[i] := gtel;
setvisualpage(0);
setactivepage(0);
setactivepage(1);
putimage(x1,y1,mask[4+contrast_colour]^,0);
setactivepage(0);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
clockreset;
gtel := 0;
END;

PROCEDURE keycheck;
BEGIN;
    REPEAT;
        ch := readkey;
        IF ((ch>='a')AND(ch<='z'))
            THEN ch := upcase(ch);
UNTIL ((ch>='A')AND(ch<='Z'))OR (ch=#13)OR (ch='/');
IF NOT(lets[stim[i]]=ch)
    THEN result[i] := 1;
IF lets[stim[i]]=ch
    THEN result[i] := 0;
key[i] := ch;
END;

PROCEDURE practice;
BEGIN;
    count := 0;
    REPEAT
        target;
        clock;
        rndx := random(200);
        REPEAT
            UNTIL ((gtel>rndx+800));
            clockreset;
            i := count;
            stim[i] := random(10);
            add_mask := random(3);
            IF count=0
                THEN BEGIN;
                    ctime := 0;
                    flashing_letters(0);
                END;
            IF count=1
                THEN BEGIN;
                    ctime := 0;
                    flashing_letters(0);
                END;
            IF count=2
                THEN BEGIN;
                    ctime := 0;
                    flashing_letters(0);

```

```

    END;
IF count=3
    THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
    END;
IF count=4
    THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
    END;
IF count=5
    THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
    END;
count := count+1;
IF count=6
    THEN count := 0;
    ch := readkey;
UNTIL ((ch='e')OR(ch='E'));
END;

PROCEDURE experiment;
BEGIN;
    h1 := textwidth(' ')+2;
    h2 := textheight(' ');
    wx1 := (getmaxx DIV 2)-stim_size;
    wx2 := (getmaxx DIV 2)+stim_size;
    wy1 := (getmaxy DIV 2)-stim_high;
    wy2 := (getmaxy DIV 2)+stim_high;
    x1 := ((wx1+wx2) DIV 2)-(stim_size_brd) DIV 2;
    y1 := ((wy1+wy2) DIV 2)-(stim_high_brd DIV 2);
    practice;
    FOR i:= 0 TO 179 DO
        BEGIN;
            target;
            clock;
            rndx := random(100);
            REPEAT
                UNTIL ((gtel>rndx+600));
            clockreset;
            str1 := lets[stim[i]];
            gotoxy(77,25);
            write(i:3);
            add_mask := cond[i] MOD 3;
            IF cond[i]=0
                THEN BEGIN;
                    ctime := 0;
                    flashing_letters(0);
                END;
            IF cond[i]=1
                THEN BEGIN;
                    ctime := 0;
                    flashing_letters(0);
                END;
        END;
    END;

```

```

    IF cond[i]=2
      THEN BEGIN;
        ctime := 0;
        flashing_letters(0);
      END;
    IF cond[i]=3
      THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
      END;
    IF cond[i]=4
      THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
      END;
    IF cond[i]=5
      THEN BEGIN;
        ctime := 0;
        flashing_letters(2);
      END;
    keycheck;
  END;
END;

PROCEDURE make_blank_colour_page(colour,active,visual:byte);
BEGIN;
  setactivepage(active);
  setvisualpage(visual);
  setfillstyle(1,colour);
  bar(0,0,getmaxx,getmaxy);
END;

PROCEDURE
create_image(letter_condition,letter_number,h:byte);
BEGIN;
  getmem(image[letter_condition,letter_number],sizebrd);
  narr_image; getimage(3,4,stim_size_brd,stim_high_brd,
  image[letter_condition,letter_number]^);
END;

PROCEDURE create_mask(letter_condition : byte);
BEGIN;
  settextstyle(0,0,14);
  str1 := #177;
  getmem(mask[letter_condition],sizebrd);
  narr_image; getimage(3,4,stim_size_brd,stim_high_brd,
  mask[letter_condition]^);
  Settextstyle(0,0,10);
  getmem(mask[4+letter_condition],sizebrd);
  narr_image; getimage(3,4,stim_size_brd,stim_high_brd,
  mask[4+letter_condition]^);
  settextstyle(0,0,6);
END;

PROCEDURE lettergen;
BEGIN;

```

```

setvisualpage(1);
setactivepage(1);
settextjustify(0,2);
settextstyle(0,0,6);
stim_size := textwidth('W');
stim_high := textheight('W');
stim_size_brd := textwidth('W')-1;
stim_high_brd := textheight('W')-5;
sizebrd := imagesize(2,3,stim_size_brd,stim_high_brd);
FOR xx:= 0 TO 5 DO
  BEGIN;
    pixcol[xx] := pix_cn2[xx];
  END;
FOR z:=0 TO 9 DO
  BEGIN
    str1 := lets[z];
    create_image(0,z,0);
  END;
create_mask(0);
FOR xx:= 0 TO 5 DO
  BEGIN;
    pixcol[xx] := pix_cn1[xx];
  END;
FOR z:=0 TO 9 DO
  BEGIN
    str1 := lets[z];
    create_image(1,z,1);
  END;
create_mask(1);
setfillstyle(1,0);
bar(0,0,stim_size_brd,stim_high_brd);
FOR xx:= 0 TO 5 DO
  BEGIN;
    pixcol[xx] := pix_red[xx];
  END;
FOR z:=0 TO 9 DO
  BEGIN;
    str1 := lets[z];
    create_image(2,z,0);
  END;
create_mask(2);
FOR xx:= 0 TO 5 DO
  BEGIN;
    pixcol[xx] := pix_grn[xx];
  END;
FOR z:=0 TO 9 DO
  BEGIN;
    str1 := lets[z];
    create_image(3,z,1);
  END;
create_mask(3);
make_blank_colour_page(2,0,0);
make_blank_colour_page(2,1,0);
settextstyle(0,0,6);
END;

```



```

BEGIN
    initialize;
    setgraphmode(1);
    xcol := 58;
    ctime := 1;
    xgrn := 38;
    stimgen;
    colours;
    make_blank_colour_page(0,1,0);
    lettergen;
    squares(2);
    loop;
    make_blank_colour_page(0,0,0);
    Filename;
    make_blank_colour_page(2,0,0);
    make_blank_colour_page(2,1,0);
    Experiment;
    saveResults;
    make_blank_colour_page(2,0,0);
    setcolor(0);
    settextstyle(0,0,2);
    outtextxy((640 DIV 2) - (textwidth('FINISH') DIV 2),
    ((wy1+wy2) DIV 2), 'THANKS');
    REPEAT;
        ch := readkey;
    UNTIL ch=' ';
END.

```

PROGRAM 1 USED IN CHAPTER 5

PROGRAM preliminary_colour_mixer_for_lex_dec;

uses Dos, Crt, graph;

{ \$i c:\tp\timer.vga }
{ \$i c:\tp\instal.pas }

CONST

 letters : ARRAY[0..25] OF char =
('A', 'B', 'C', 'D', 'E', 'F', 'G', 'H', 'I', 'J', 'K', 'L', 'M', 'N', 'O',
, 'P', 'Q', 'R', 'S', 'T', 'U', 'V', 'W', 'X', 'Y', 'Z');

VAR

 sizenarr, s, c, qq, pn2, pn1, p0, p1, p2, p3, p4, z, size, xcol, col1,
 col2, ctime, x2, y2, xx, yy, x1, x, y, y1, p, stim_size, stim_high
 : integer;
 ch : char;
 image : ARRAY [0..25, 0..1] OF pointer;
 str1 : STRING;
 rndseq : ARRAY[0..34] OF byte;

PROCEDURE narr_image(col, stim_size, stim_high: byte;
 str1: STRING);

CONST

 pixcol : ARRAY[0..1, 0..6] OF byte =
 ((8, 9, 10, 11, 12, 13, 14), (12, 13, 14, 15, 8, 9, 10));

VAR

 pn2, pn1, p0, p1, p2, p3, y, x, incol, incol1, incol2, incol3, outcol,
 outcol1, outcol2, outcol3 : byte;

BEGIN;

 incol := pixcol[col, 0];
 incol1 := pixcol[col, 1];
 incol2 := pixcol[col, 2];
 incol3 := pixcol[col, 3];
 outcol := pixcol[col, 4];
 outcol1 := pixcol[col, 5];
 outcol2 := pixcol[col, 6];
 outcol3 := pixcol[1-col, 3];
 setfillstyle(1, outcol);
 bar(0, 0, stim_size+5, stim_high);
 setcolor(incol);
 outtextxy(2, -1, str1);
 outtextxy(3, -1, str1);
 FOR x:= 1 TO stim_size-1 DO
 FOR y:=0 TO stim_high DO
 BEGIN;
 pn2 := getpixel(x-2, y);
 pn1 := getpixel(x-1, y);
 p0 := getpixel(x, y);
 p1 := getpixel(x+1, y);
 p2 := getpixel(x+2, y);
 p3 := getpixel(x+3, y);
 IF (((pn2=outcol) OR (pn2=outcol1))

```

        AND((pn1=outcol)OR(pn1=outcol1)OR(pn1=outcol2)))
        AND(p0=incol) AND(p1=incol)
    THEN BEGIN;
        putpixel(x-2,y,outcol1);
        putpixel(x-1,y,outcol2);
        putpixel(x,y,incol2);
        putpixel(x+1,y,incol1);
    END;
IF (((pn2=incol)OR(pn2=incol1)))
    AND((pn1=incol)OR(pn1=incol1)OR(pn1=incol2)))
    AND(p0=outcol)AND(p1=outcol)
    THEN BEGIN;
        putpixel(x-2,y,incol1);
        putpixel(x-1,y,incol2);
        putpixel(x,y,outcol2);
        putpixel(x+1,y,outcol1);
    END;
IF (((pn2=outcol)OR(pn2=outcol1)OR(pn2=outcol2))
    AND((pn1=outcol)OR(pn1=outcol1)OR(pn1=outcol2))
    AND((p0=incol)OR(p0=incol1)OR(p0=incol2))
    AND((p1=incol)OR(p1=incol1)OR(p1=incol2))
    AND((p2=outcol)OR(p2=outcol1)OR(p2=outcol2))
    AND((p3=outcol)OR(p3=outcol1)OR(p3=outcol2)))
    THEN BEGIN;
        putpixel(x-2,y,outcol1);
        putpixel(x-1,y,outcol2);
        putpixel(x,y,incol3);
        putpixel(x+1,y,incol3);
        putpixel(x+2,y,outcol2);
        putpixel(x+3,y,outcol1);
    END;
IF (((pn2=incol)OR(pn2=incol1)OR(pn2=incol2))
    AND((pn1=incol)OR(pn1=incol1)OR(pn1=incol2))
    AND((p0=outcol)OR(p0=outcol1)OR(p0=outcol2))
    AND((p1=incol)OR(p1=incol1)OR(p1=incol2))
    AND((p2=incol)OR(p2=incol1)OR(p2=incol2)))
    THEN BEGIN;
        putpixel(x-2,y,incol1);
        putpixel(x-1,y,incol2);
        putpixel(x,y,outcol3);
        putpixel(x+1,y,incol2);
        putpixel(x+2,y,incol1);
    END;
END;
END;
END;

```

```

PROCEDURE colours(xcol : byte);
CONST
    pal_num : ARRAY[0..15] OF byte =
        (0,1,2,3,4,5,20,07,56,57,58,59,60,61,62,63);
BEGIN;
    setrgbpalette(pal_num[0],0,0,0);
    setrgbpalette(pal_num[1],0,0,0);
    setrgbpalette(pal_num[2],xcol-14,38-7,0);
    setrgbpalette(pal_num[3],xcol-5,38-2,0);
    setrgbpalette(pal_num[4],xcol-2,38-1,0);

```

```

setrgbpalette(pal_num[5],xcol,38,0);
setrgbpalette(pal_num[6],xcol-24,38-17,0);
setrgbpalette(pal_num[7],xcol-30,38-21,0);
setrgbpalette(pal_num[8],xcol,0,0);
setrgbpalette(pal_num[9],xcol+1,00,0);
setrgbpalette(pal_num[10],xcol+2,00,0);
setrgbpalette(pal_num[11],xcol+4,0,0);
setrgbpalette(pal_num[12],00,38,0);
setrgbpalette(pal_num[13],00,38+1,0);
setrgbpalette(pal_num[14],00,38+2,0);
setrgbpalette(pal_num[15],0,38+3,0);
END;

PROCEDURE gcolours(xcol : byte);
CONST
  pal_num : ARRAY[0..15] OF byte =
    (0,1,2,3,4,5,20,07,56,57,58,59,60,61,62,63);
BEGIN;
  setrgbpalette(pal_num[2],xcol-14,38-7,0);
  setrgbpalette(pal_num[8],xcol,0,0);
  setrgbpalette(pal_num[9],xcol+1,00,0);
  setrgbpalette(pal_num[10],xcol+2,00,0);
  setrgbpalette(pal_num[11],xcol+4,0,0);
  setrgbpalette(pal_num[12],00,38,0);
  setrgbpalette(pal_num[13],00,38+1,0);
  setrgbpalette(pal_num[14],00,38+2,0);
  setrgbpalette(pal_num[15],0,38+3,0);
END;

PROCEDURE raster;
BEGIN;
  REPEAT
    UNTIL (((port[memw[$40:$63]+6] AND 8) = 0) OR
      (port[$201]=227)OR(port[$201]=179));
    REPEAT
      UNTIL (((port[memw[$40:$63]+6] AND 8) <> 0) OR
        (port[$201]=227)OR(port[$201]=179));
    END;
  END;

PROCEDURE startloop;
BEGIN;
  FOR x:= 0 TO 34 DO
    BEGIN;
      rndseq[x] := random(26);
    END;
  FOR s:=0 TO 1 DO
    BEGIN;
      c := -1;
      setactivepage(s);
      FOR x:= 19 TO 23 DO
        FOR y:= 9 TO 11 DO
          BEGIN;
            c := c+1;
            putimage((x*(stim_size+2)),(y*stim_high),
              image[rndseq[c],s]^,0);
          END;
        END;
      END;
    END;
  END;

```

```

        END;
        colours(xcol);
END;

PROCEDURE loop;
BEGIN;
    ch := '9';
    startloop;
    qq := 0;
    REPEAT;
        IF ctime>0
            THEN BEGIN;
                REPEAT;
                    FOR s:= 0 TO 1 DO
                        BEGIN;
                            setvisualpage(s);
                            FOR x:= 1 TO ctime DO
                                BEGIN;
                                    raster;
                                END;
                            END;
                        UNTIL keypressed;
                    END;
                IF ctime=0
                    THEN BEGIN;
                        setvisualpage(qq MOD 2);
                        REPEAT;
                            UNTIL keypressed;
                        END;
                    ch := readkey;
                    IF ch='5'
                        THEN qq := qq+1;
                    IF ((ch='+')AND(ctime<10))
                        THEN ctime := ctime+1;
                    IF ((ch='-')AND(ctime>0))
                        THEN ctime := ctime-1;
                    IF ((ch='7')AND(xcol<59))
                        THEN BEGIN;
                            xcol := xcol+3;
                            qcolours(xcol);
                        END;
                    IF ((ch='1')AND(xcol>4))
                        THEN BEGIN;
                            xcol := xcol-3;
                            qcolours(xcol);
                        END;
                    IF ((ch='8')AND(xcol<62))
                        THEN BEGIN;
                            xcol := xcol+1;
                            qcolours(xcol);
                        END;
                    IF ((ch='2')AND(xcol>2))
                        THEN BEGIN;
                            xcol := xcol-1;
                            qcolours(xcol);
                        END;
                END;
    END;

```

```

        gotoxy(1,1);
        setactivepage(qq MOD 2);
        write(xcol);
        UNTIL ((ch='p')OR(ch='P'));
END;

PROCEDURE gen_image(s,pix_number :byte);
BEGIN;
    getmem(image[z,s],sizenarr);
    narr_image(pix_number,stim_size,stim_high,str1);
    getimage(0,0,stim_size+2,stim_high,image[z,s]^);
END;

PROCEDURE gen_letters;
BEGIN;
    settextstyle(2,0,7);
    stim_size := textwidth('W')+1;
    stim_high := textheight('W');
    sizenarr := imagesize(0,0,stim_size+2,stim_high);
    FOR z:=0 TO 25 DO
        BEGIN;
            str1 := letters[z];
            gen_image(0,0);
            gen_image(1,1);
        END;
    END;
END;

BEGIN
    initialize;
    setgraphmode(1);
    xcol := 56;
    ctime := 2;
    colours(xcol);
    gen_letters;
    setactivepage(0);
    setvisualpage(0);
    setfillstyle(1,2);
    bar(0,0,640,360);
    setactivepage(1);
    setvisualpage(1);
    bar(0,0,640,360);
    loop;
    colours(xcol);
    setvisualpage(0);
    setactivepage(0);
    setfillstyle(1,2);
    bar(x1,y1,x2,y2);
    setcolor(0);
    REPEAT;
        ch := readkey;
    UNTIL ch=' ';
END.

```

PROGRAM 2 (MAIN) USED IN CHAPTER 5

PROGRAM lexical_decision_exp; {used for experiment4}

uses Dos, Crt, graph;

{\$i c:\tp\timer.vga}
{\$i c:\tp\instal.pas}

CONST

```

mov0 : ARRAY[0..23,0..1] OF byte =
((0,4),(0,5),(0,6),(1,7),(2,8),(3,9),(4,10),(5,10),(6,10),(7
,9),(8,8),(9,7),(10,6),(10,5),(10,4),(9,3),(8,2),(7,1),(6,0)
,(5,0),(4,0),(3,1),(2,2),(1,3));
mov1 : ARRAY[0..19,0..1] OF byte = ((1,4),(1,5),(1,6),
(2,7),(3,8),(4,9),(5,9),(6,9),(7,8),(8,7),(9,6),(9,5)
),(9,4),(8,3),(7,2),(6,1),(5,1),(4,1),(3,2),(2,3));
mov2 : ARRAY [0..15,0..1] OF byte =
((2,4),(2,5),(2,6),(3,7),(4,8),(5,8),(6,8),(7,7),(8,6),(8,5)
,(8,4),(7,3),(6,2),(5,2),(4,2),(3,3));
mov3 : ARRAY [0..11,0..1] OF byte =
((3,4),(3,5),(3,6),(4,7),(5,7),(6,7),(7,6),(7,5),(7,4),(6,3)
,(5,3),(4,3));
mov4 : ARRAY [0..7,0..1] OF byte =
((4,4),(4,5),(4,6),(5,6),(6,6),(6,5),(6,4),(5,4));
letters : ARRAY[0..25] OF char =
('A','B','C','D','E','F','G','H','I','J','K','L','M','N','O'
,'P','Q','R','S','T','U','V','W','X','Y','Z');
stim_pract : ARRAY[0..13] OF STRING[7] = ('HICISS','ALIVE',
'ONAIT','BIRD','ILAKE','BENCH','CANAL','ZENCH','DANIL','CURE
','CYRE','DISCUSS','ZOX','SINGER');
pal_num : ARRAY[0..15] OF byte =
(0,1,2,3,4,5,20,07,56,57,58,59,60,61,62,63);
lets : ARRAY[0..10] OF char =
('C','J','K','L','S','D','V','X','Z','P',' ');
pix_red : ARRAY[0..5] OF byte = (14,15,11,12,10,13);
pix_grn : ARRAY[0..5] OF byte = (11,12,14,15,13,10);
pix : ARRAY[0..1,0..6] OF byte =
((6,5,3,2,7,9,0),(0,9,7,2,3,5,6));
block : ARRAY [0..15,0..31] OF byte = (
(0,16,1,17,8,24,9,25,2,18,3,19,10,26,11,27,4,20,5
,21,12,28,13,29,6,22,7,23,14,30,15,31),
(1,17,0,16,9,25,8,24,3,19,2,18,11,27,10,26,5,21,4,
20,13,29,12,28,7,23,6,22,15,31,14,30),
(2,18,3,19,10,26,11,27,4,20,5,21,12,28,13,29,6,22,
7,23,14,30,15,31,0,16,1,17,8,24,9,25),
(3,19,2,18,11,27,10,26,5,21,4,20,13,29,12,28,7,23,
6,22,15,31,14,30,1,17,0,16,9,25,8,24),
(4,20,5,21,12,28,13,29,6,22,7,23,14,30,15,31,0,16,
1,17,8,24,9,25,2,18,3,19,10,26,11,27),
(5,21,4,20,13,29,12,28,7,23,6,22,15,31,14,30,1,17,
0,16,9,25,8,24,3,19,2,18,11,27,10,26),
(6,22,7,23,14,30,15,31,0,16,1,17,8,24,9,25,2,18,3,
19,10,26,11,27,4,20,5,21,12,28,13,29),
(7,23,6,22,15,31,14,30,1,17,0,16,9,25,8,24,3,19,2,
18,11,27,10,26,5,21,4,20,13,29,12,28),

```

```

(8,24,9,25,0,16,1,17,10,26,11,27,2,18,3,19,12,28,
13,29,4,20,5,21,14,30,15,31,6,22,7,23),
(9,25,8,24,1,17,0,16,11,27,10,26,3,19,2,18,13,29,
12,28,5,21,4,20,15,31,14,30,7,30,6,22),
(10,26,11,27,2,18,3,19,12,28,13,29,4,20,5,21,14,30
,15,31,6,22,7,23,8,24,9,25,0,16,1,17),
(11,27,10,26,3,19,2,18,13,29,12,28,5,21,4,20,15,31
,14,30,7,23,6,22,9,25,8,24,1,17,0,16),
(12,28,13,29,4,20,5,21,14,30,15,31,6,22,7,23,8,24,
9,25,0,16,1,17,10,26,11,27,2,18,3,19),
(13,29,12,28,5,21,4,20,15,31,14,30,7,23,6,22,9,25,
8,24,1,17,0,16,11,27,10,26,3,19,3,18),
(14,30,15,31,6,22,7,23,8,24,9,25,0,16,1,17,10,26,
11,27,2,18,3,19,12,28,13,29,4,20,5,21),
(15,31,14,30,7,23,6,22,9,25,8,24,1,17,0,16,11,27,
10,26,3,19,2,18,13,29,12,28,5,21,4,20));

```

VAR

```

xgrn,c1,1,cc,hx,hy,q,c2,qq,xx1,h1,h2,h,stim_len,xc,fill,
mnr1,mnr2,let,portresult,rnd,pos,w,wx,c,ctime1,ctime2,
size,step,xcol,hdigit,coll,g,col2,xpos,i,ii,xb1,xb2,ctime,
x2,y2,count,mn,error,err1,err2,xz,err,tempct,dely2,z,j,xx,
stim_size_brd,stim_high_brd,stim_size_narr,rndd,rndx,x1,
char_size,x,y,y1,p,code,block_balence,charsize,wx1,wx2,wy1,
wy2,stim_balence,stim_size,stim_high_narr,conx,stim_wid,
space,endx,match,aa,a,con,stim_high,xred,xxcol : integer;
int1Csave,blank,image5,image1,image2,image3,image4 :
pointer;
image : ARRAY [0..3,0..25] OF pointer;
infile,outfile : text;
k,ch : char;
sizebrd,sizenarr,v,v1,v2 : word;
xlet,stim_str,namefile,st1tp,st2tp : STRING;
cond,condtp : ARRAY [0..383] OF integer;
Stim : ARRAY [0..383] OF STRING[7];
stimtp,non,stimin,stimfile,nontp:ARRAY [0..383]OF STRING[7];
stim_in : ARRAY [0..31,0..5] OF STRING[7];
result,rt : ARRAY [0..383] OF integer;
str1 : STRING[7];
str2 : STRING[3];
str3 : STRING[4];
rndno : ARRAY[0..5] OF byte;
rndseq : ARRAY[0..11] OF byte;
rndseq2 : ARRAY[0..23] OF byte;
rndseq3 : ARRAY[0..383] OF byte;
condw : ARRAY[0..191] OF byte;
cond2 : ARRAY [0..95] OF byte;
sm : ARRAY [0..95] OF STRING[7];
sp : ARRAY [0..95] OF STRING[7];
let_info : ARRAY [0..1,0..25,0..1] OF byte;
pixcol : ARRAY [0..5] OF byte;

```

PROCEDURE filename;

BEGIN

Write('Name for file ');

REPEAT


```

UNTIL keypressed;
Readln(input,namefile);
Write('block balance ');
REPEAT
UNTIL keypressed;
Readln(input,block_balance);
Write('colour intensity ');
REPEAT
UNTIL keypressed;
Readln(input,xcol);
END;

PROCEDURE stiminput;
BEGIN
assign(infile,'c:\mp\exp1\gr2_non1.pas');
reset(infile);
  FOR x := 0 TO 191 DO
    BEGIN;
    Readln(infile, nontp[x]);
    END;
  FOR x:=0 TO 191 DO
    BEGIN;
    non[x] := '';
    END;
  FOR x:= 0 TO 191 DO
    BEGIN;
    REPEAT;
    rnd := random(192);
    UNTIL non[rnd]='';
    non[rnd] := nontp[x];
    END;
Assign(infile,'c:\mp\exp1\grp1_wr2.pas');
Reset(infile);
BEGIN;
  FOR x:= 0 TO 191 DO
    BEGIN;
    endx := 1;
    Readln(infile,str1,ch,str2,ch,str3);
    IF str1[endx]=' '
      THEN BEGIN;
        REPEAT;
        delete(str1,endx,1);
        UNTIL NOT(str1[endx]=' ');
        END;
    stimfile[x] := str1;
    val(str2,j,code);
    val(str3,j,code);
    END;
  FOR x:= 0 TO 191 DO
    BEGIN;
    IF x MOD 6 = 0
      THEN BEGIN;
        FOR c:= 0 TO 5 DO
          BEGIN;
            rndno[c] := 9;
          END;
        END;
      END;
    END;

```

```

        FOR c:= 0 TO 5 DO
            BEGIN;
                REPEAT
                    rnd := random(6);
                    UNTIL rndno[rnd]=9;
                    rndno[rnd] := c;
                END;
            END;
            stim_in[x DIV 6,rndno[x MOD 6]] := stimfile[(x MOD6)
            +(block[block_balance, x DIV 6]*6)];
        END;
    FOR g:= 0 TO 7 DO
        BEGIN;
            FOR xx:= 0 TO 11 DO
                BEGIN;
                    rndseq[xx] := 99;
                END;
            FOR xx:= 0 TO 11 DO
                BEGIN;
                    REPEAT;
                        rnd := random(12);
                        UNTIL rndseq[rnd]=99;
                        rndseq[rnd] := xx;
                    END;
                FOR xx:= 0 TO 11 DO
                    BEGIN;
                        cond2[(g*12)+xx] := rndseq[xx];
                    END;
                END;
            FOR g:= 0 TO 7 DO
                FOR x:= 0 TO 5 DO
                    BEGIN
                        sm[(g*12)+cond2[(g*12)+x]] := stim_in[(g*4),x];
                        sm[(g*12)+cond2[(g*12)+x+6]] :=stim_in[(g*4)+1,x];
                        sp[(g*12)+cond2[(g*12)+x]] := stim_in[(g*4)+2,x];
                        sp[(g*12)+cond2[(g*12)+x+6]] :=stim_in[(g*4)+3,x];
                    END;
                END;
            END;
        FOR xx:=0 TO 95 DO
            BEGIN;
                rndseq[0] := 9;
                rndseq[1] := 9;
                FOR x:= 0 TO 1 DO
                    BEGIN;
                        REPEAT;
                            rnd := random(2);
                            UNTIL rndseq[rnd]=9;
                            rndseq[rnd] := x;
                        END;
                    condw[(xx*2)] := rndseq[0];
                    condw[(xx*2)+1] := rndseq[1];
                END;
            FOR xx:=0 TO 191 DO
                BEGIN;
                    rndseq[0] := 9;
                    rndseq[1] := 9;

```

```

FOR x:= 0 TO 1 DO
  BEGIN;
    REPEAT;
      rnd := random(2);
      UNTIL rndseq[rnd]=9;
      rndseq[rnd] := x;
    END;
  rndseq3[(xx*2)] := rndseq[0];
  rndseq3[(xx*2)+1] := rndseq[1];
END;
c1 := -1;
c2 := -1;
FOR x:= 0 TO 191 DO
  BEGIN;
    IF condw[x]=0
      THEN BEGIN;
        c1 := c1+1;
        stimp[x] := sm[c1];
      END;
    IF condw[x]=1
      THEN BEGIN;
        c2 := c2+1;
        stimp[x] := sp[c2];
      END;
  END;
END;
c1 := -1;
c2 := -1;
FOR x:= 0 TO 383 DO
  BEGIN;
    IF rndseq3[x] = 0
      THEN BEGIN;
        c1 := c1+1;
        stim[x] := stimp[c1];
        cond[x] := condw[c1];
      END;
    IF rndseq3[x] = 1
      THEN BEGIN;
        c2 := c2+1;
        stim[x] := non[c2];
        cond[x] := condw[191-c2];
      END;
  END;
END;

PROCEDURE colours;
BEGIN;
  setrgbpalette(0,0,0,0); {black}
  setrgbpalette(1,xcol,00,00);
  setrgbpalette(2,xcol-14,38-7,0); {bkgrnd olive}
  setrgbpalette(pal_num[3],xcol-5,38-2,0);
  setrgbpalette(pal_num[4],xcol-5,38-2,0);
  setrgbpalette(pal_num[5],xcol-2,38-1,0);
  setrgbpalette(pal_num[6],xcol,38,0);
  setrgbpalette(pal_num[7],xcol-24,38-17,0);
  setrgbpalette(pal_num[8],xcol-25,38-17,0);
  setrgbpalette(pal_num[9],xcol-30,38-21,0);

```

```

setrgbpalette(pal_num[10],xcol,0,0);
setrgbpalette(pal_num[11],xcol+1,00,0);
setrgbpalette(pal_num[12],xcol+2,00,0);
setrgbpalette(pal_num[13],00,38,0);
setrgbpalette(pal_num[14],00,38+1,0);
setrgbpalette(pal_num[15],00,38+2,0);
END;

PROCEDURE SaveResults;
BEGIN;
  Assign(outfile,'c:\exp\data\'+namefile+'expl.dat');
  Rewrite(outfile);
  FOR x := 0 TO 383 DO
    BEGIN;
      writeln(outfile,stim[x]:9,x:4, {presentation no}
              cond[x]:2, {condition}
              rt[x]:5,result[x]:2) {rt, error 0=no 1=yes}
    END;
  close(outfile);
END;

PROCEDURE clock;
BEGIN;
  getintvec($8,int1Csave);
  setintvec($8,@newint);
  fast;
  gtel := 0;
END;

PROCEDURE clockreset;
BEGIN;
  slow;
  setintvec($8,int1Csave);
END;

PROCEDURE results;
BEGIN;
  rt[i] := gtel;
  IF portresult =179
    THEN result[i] := 0;
  IF portresult =227
    THEN result[i] := 1;
  IF ((portresult <>179)AND(portresult<>227))
    THEN result[i] := 2;
END;

PROCEDURE raster;
BEGIN;
  REPEAT
    UNTIL (((port[memw[$40:$63]+6] AND 8) = 0) OR
    (port[$201]=227)OR(port[$201]=179));
  REPEAT
    UNTIL (((port[memw[$40:$63]+6] AND 8) <> 0) OR
    (port[$201]=227)OR(port[$201]=179));
END;

```

```

PROCEDURE narr_image;
BEGIN;
  col1 := pixcol[5];
  col2 := pixcol[2];
  setfillstyle(1,pixcol[5]);
  bar(0,0,stim_size+5,stim_high);
  setcolor(pixcol[2]);
  outtextxy(2,-1,str1);
  outtextxy(3,-1,str1);
  FOR y:=0 TO stim_high DO
    FOR x:= 1 TO stim_size-1 DO
      BEGIN;
        IF z=8
          THEN BEGIN;
            IF ((getpixel(x-2,y)=col2) AND
              (getpixel(x-1,y)=col2) AND (getpixel(x,y)=col2)
              AND (getpixel(x+1,y)=col2) AND
              (getpixel(x+2,y)=col2) AND (getpixel(x+3,y)=col2))
              THEN BEGIN;
                putpixel(x-2,y,pixcol[5]);
                putpixel(x-1,y,pixcol[5]);
                putpixel(x,y,pixcol[2]);
                putpixel(x+1,y,pixcol[2]);
                putpixel(x+2,y,pixcol[5]);
                putpixel(x+3,y,pixcol[5]);
              END;
            END;
            IF ((getpixel(x-1,y)=col1) AND
              (getpixel(x,y)=col2) AND (getpixel(x+1,y)=col2)
              AND (getpixel(x+2,y)=col2) AND
              (getpixel(x+3,y)=col2) AND (getpixel(x+4,y)=col1))
              THEN BEGIN;
                putpixel(x-1,y,pixcol[1]);
                putpixel(x,y,pixcol[3]);
                putpixel(x+1,y,pixcol[2]);
                putpixel(x+2,y,pixcol[2]);
                putpixel(x+3,y,pixcol[2]);
                putpixel(x+4,y,pixcol[1]);
              END;
            END;
            IF ((getpixel(x-1,y)=col1) AND
              (getpixel(x,y)=col2) AND (getpixel(x+1,y)=col2)
              AND (getpixel(x+2,y)=col2) AND
              (getpixel(x+3,y)=col1))
              THEN BEGIN;
                putpixel(x-1,y,pixcol[1]);
                putpixel(x,y,pixcol[3]);
                putpixel(x+1,y,pixcol[2]);
                putpixel(x+2,y,pixcol[2]);
                putpixel(x+3,y,pixcol[1]);
              END;
            END;
            IF ((y MOD 2 = 0) AND (getpixel(x-1,y)=col1) AND
              (getpixel(x,y)=col2) AND (getpixel(x+1,y)=col2)
              AND (getpixel(x+2,y)=col1))
              THEN BEGIN;
                putpixel(x-1,y,pixcol[1]);
                putpixel(x,y,pixcol[2]);
              END;
        END;
      END;
    END;
  END;

```

```

        putpixel(x+1,y,pixelcol[3]);
        putpixel(x+2,y,pixelcol[1]);
    END;
IF ((y MOD 2 = 1) AND (getpixel(x-1,y)=col1) AND
(getpixel(x,y)=col2) AND (getpixel(x+1,y)=col2)
AND (getpixel(x+2,y)=col1))
THEN BEGIN;
    putpixel(x-1,y,pixelcol[0]);
    putpixel(x,y,pixelcol[3]);
    putpixel(x+1,y,pixelcol[3]);
    putpixel(x+2,y,pixelcol[0]);
    END;
IF ((getpixel(x-1,y)=col1) AND
(getpixel(x,y)=col2) AND
(getpixel(x+1,y)=col2) AND (getpixel(x+2,y)=col2))
THEN BEGIN;
    putpixel(x-1,y,pixelcol[1]);
    putpixel(x,y,pixelcol[2]);
    putpixel(x+1,y,pixelcol[2]);
    putpixel(x+2,y,pixelcol[2]);
    END;
IF ((getpixel(x-1,y)=pixelcol[3]) AND
(getpixel(x,y)=pixelcol[2]) AND
(getpixel(x+1,y)=pixelcol[2]) AND
(getpixel(x+2,y)=col1
) AND (getpixel(x+3,y)=col1))
THEN BEGIN;
    putpixel(x-1,y,pixelcol[2]);
    putpixel(x,y,pixelcol[2]);
    putpixel(x+1,y,pixelcol[2]);
    putpixel(x+2,y,pixelcol[1]);
    putpixel(x+3,y,pixelcol[0]);
    END;
IF ((getpixel(x-2,y)=col2) AND
(getpixel(x-1,y)=col2) AND (getpixel(x,y)=col2)
AND (getpixel(x+1,y)=col2) AND
(getpixel(x+2,y)=col1) AND (getpixel(x+3,y)=col1))
THEN BEGIN;
    putpixel(x-1,y,pixelcol[2]);
    putpixel(x,y,pixelcol[2]);
    putpixel(x+1,y,pixelcol[3]);
    putpixel(x+2,y,pixelcol[1]);
    putpixel(x+3,y,pixelcol[0]);
    END;
END;
END;
END;

PROCEDURE broad_image;
BEGIN;
    setactivepage(0);
    setvisualpage(0);
    setfillstyle(1,pix[h,0]);
    bar(0,0,stim_size+5,stim_high+5);
    setcolor(pix[h,1]);
    FOR x:= 0 TO 23 DO
        BEGIN;

```

```

        outtextxy(mov0[x,0]+1,mov0[x,1]-7,str1);
    END;
setcolor(pix[h,2]);
FOR x:= 0 TO 19 DO
    BEGIN;
        outtextxy(mov1[x,0]+1,mov1[x,1]-7,str1);
    END;
setcolor(pix[h,3]);
FOR x:= 0 TO 15 DO
    BEGIN;
        outtextxy(mov2[x,0]+1,mov2[x,1]-7,str1);
    END;
setcolor(pix[h,4]);
FOR x:= 0 TO 11 DO
    BEGIN;
        outtextxy(mov3[x,0]+1,mov3[x,1]-7,str1);
    END;
setcolor(pix[h,5]);
FOR x:= 0 TO 7 DO
    BEGIN;
        outtextxy(mov4[x,0]+1,mov4[x,1]-7,str1);
    END;
setcolor(pix[h,6]);
FOR x:= 0 TO 7 DO
    BEGIN;
        outtextxy(5+1,5-7,str1);
    END;
END;

PROCEDURE magno_maker(stim_str :STRING);
BEGIN;
    str1 := stim_str;
    xpos := -(stim_size DIV 2);
    setvisualpage(0);
    setactivepage(1);
    size :=
imagesize(0,0,stim_size_brd*length(str1),stim_high_brd);
    getmem(image1,size);
    FOR c:=1 TO length(stim_str) DO
        BEGIN;
            xlet := copy(stim_str,c,1);
            q := -1;
            REPEAT;
                q := q+1;
            UNTIL xlet=letters[q];
            putimage((c-1)*stim_size_brd,0,image[0,q]^,0);
        END;
    getimage(0,0,stim_size_brd*length(str1),stim_high_brd,
            image1^);

    getmem(image2,size);
    FOR c:=1 TO length(stim_str) DO
        BEGIN;
            xlet := copy(stim_str,c,1);
            q := -1;
            REPEAT;
                q := q+1;

```

```

        UNTIL xlet=letters[q];
        putimage((c-1)*stim_size_brd,0,image[1,q]^,0);
    END;
getimage(0,0,stim_size_brd*length(str1),stim_high_brd,
        image2^);

    setfillstyle(1,0);
    bar(0,0,stim_size_brd*length(str1),stim_high_brd);
    setactivepage(0);
END;

PROCEDURE parvo_maker(stim_str :STRING);
BEGIN;
    str1 := stim_str;
    xpos := -(stim_size DIV 2);
    setvisualpage(0);
    setactivepage(1);
    size :=
imagesize(0,0,stim_size_narr*length(str1),stim_high);
    getmem(image3,size);
    FOR c:=1 TO length(stim_str) DO
        BEGIN;
            xlet := copy(stim_str,c,1);
            q := -1;
            REPEAT;
                q := q+1;
            UNTIL xlet=letters[q];
            putimage((c-1)*stim_size_narr,0,image[2,q]^,0);
        END;
    getimage(0,0,stim_size_narr*length(str1),stim_high,image3^);
    getmem(image4,size);
    FOR c:=1 TO length(stim_str) DO
        BEGIN;
            xlet := copy(stim_str,c,1);
            q := -1;
            REPEAT;
                q := q+1;
            UNTIL xlet=letters[q];
            putimage((c-1)*stim_size_narr,0,image[3,q]^,0);
        END;
    getimage(0,0,stim_size_narr*length(str1),stim_high,image4^);
    setfillstyle(1,0);
    bar(0,0,(stim_size_narr+10)*length(str1),stim_high_narr);
    setactivepage(0);
END;

PROCEDURE target;
BEGIN;
    settextstyle(0,0,2);
    setcolor(0);
    setfillstyle(1,2);
    bar(wx1,wy1,wx2,wy2);
    outtextxy((wx1+wx2) DIV 2-(textwidth('+') DIV 2),
    (wy1+wy2) DIV 2- (textwidth('+') DIV 2),'+');
    settextstyle(1,0,10);
END;

```



```

PROCEDURE magnoflash;
BEGIN;
  raster;
  clock;
  x := 0;
  port[$201] := 0;
  setvisualpage(0);
  setactivepage(1);
  setfillstyle(1,6);
  bar(wx1,wy1,wx2,wy2);
  putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_brd)
  DIV 2,((wy1+wy2)DIV 2)-(stim_high_brd DIV 2),image1^,0);
  REPEAT;
  UNTIL gtel>26;
  clockreset;
  raster;
  clock;
  setvisualpage(1);
  setactivepage(0);
  setfillstyle(1,0);
  bar(wx1,wy1,wx2,wy2);
  putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_brd)
  DIV 2,((wy1+wy2)DIV 2)-(stim_high_brd DIV 2),image2^,0);
  REPEAT;
  UNTIL gtel>26;
  REPEAT;
    setvisualpage(0);
    FOR x:= 0 TO ctime DO
      BEGIN;
        raster;
      END;
    setvisualpage(1);
    FOR x:= 0 TO ctime DO
      BEGIN;
        raster;
      END;
  UNTIL ((port[$201] = 227)OR(port[$201] = 179));
  portresult := port[$201];
  results;
  clockreset;
  setvisualpage(0);
  setactivepage(0);
  setfillstyle(1,2);
  bar(wx1,wy1,wx2,wy2);
  gtel := 0;
  freemem(image1,size);
  freemem(image2,size);
END;

```

```

PROCEDURE parvoflash;
BEGIN;
  raster;
  clock;
  x := 0;
  port[$201] := 0;
  setvisualpage(0);

```

```

setactivepage(1);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
setfillstyle(1,13);
bar(((wx1+wx2) DIV 2)-(8*stim_size_narr) DIV 2,
((wy1+wy2)DIV 2)-(stim_high_narr),(((wx1+wx2)
DIV 2)+(8*stim_size_narr) DIV 2),((wy1+wy2)
DIV 2)+(stim_high_narr));
putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_narr)
DIV 2,
((wy1+wy2)DIV 2)-(stim_high_narr DIV 2),image3^,0);
REPEAT;
UNTIL gtel>40;
clockreset;
raster;
clock;
setvisualpage(1);
setactivepage(0);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
setfillstyle(1,10);
bar(((wx1+wx2) DIV 2)-(8*stim_size_narr) DIV 2,
((wy1+wy2)DIV 2)-(stim_high_narr),(((wx1+wx2)
DIV 2)+(8*stim_size_narr) DIV 2),((wy1+wy2)
DIV 2)+(stim_high_narr));
putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_narr)
DIV 2,((wy1+wy2)DIV 2)-(stim_high_narr DIV 2),image4^,0);
REPEAT;
UNTIL gtel>40;
REPEAT;
    setvisualpage(0);
    FOR x:= 0 TO ctime DO
        BEGIN;
            raster;
        END;
    setvisualpage(1);
    FOR x:= 0 TO ctime DO
        BEGIN;
            raster;
        END;
UNTIL ((port[$201] = 227)OR(port[$201] = 179));
portresult := port[$201];
results;
clockreset;
setvisualpage(0);
setactivepage(0);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
gtel := 0;
freemem(image3,size);
freemem(image4,size);
END;

PROCEDURE break;
BEGIN;
    colours;

```

```

setactivepage(0);
setvisualpage(0);
setfillstyle(1,2);
bar(wx1,wy1,wx1,wy2);
setcolor(0);
settextstyle(0,0,2);
outtextxy((640 DIV 2) - (textwidth('BREAK') DIV 2),
(350 DIV 2),'BREAK');
REPEAT;
  ch := readkey;
UNTIL ch=' ';
setfillstyle(1,2);
bar(wx1,wy1,wx1,wy2);
END;

```

```

PROCEDURE practice;
BEGIN;
  i := -1;
  REPEAT;
    i := i+1;
    stim_str := lets[i];
    stim_str := stim_pract[i MOD 14];
    clock;
    IF i MOD 2 = 0
      THEN magno_maker(stim_str);
    IF i MOD 2 = 1
      THEN parvo_maker(stim_str);
    target;
    rndx := random(200);
    REPEAT;
    UNTIL ((gtel>rndx+1000));
    clockreset;
    IF i MOD 2 = 0
      THEN BEGIN;
        ctime := 1;
        magnoflash;
      END;
    IF i MOD 2 = 1
      THEN BEGIN;
        ctime := 2;
        parvoflash;
      END;
    ch := readkey;
    UNTIL ((ch='e')OR(ch='E'));
  END;

```

```

PROCEDURE experiment;
BEGIN;
  h1 := textwidth(' ')+2;
  h2 := textheight(' ');
  hx := getmaxx DIV 2;
  wx1 := (getmaxX DIV 2)-(150);
  wx2 := (getmaxX DIV 2)+(150);
  wy1 := (getmaxY DIV 2)-(30);
  wy2 := (getmaxY DIV 2)+(30);
  hy := ((wy1+wy2)DIV 2)-(textheight(' ') DIV 2);

```

```

bar(wx1,wy1,wx2,wy2);
practice;
FOR i:= 0 TO 383 DO
  BEGIN;
    stim_str := stim[i];
    clock;
    IF cond[i] MOD 2 = 0
      THEN magno_maker(stim_str);
    IF cond[i] MOD 2 = 1
      THEN parvo_maker(stim_str);
    target;
    rndx := random(200);
    REPEAT
    UNTIL ((gtel>rndx+1000));
    clockreset;
    IF cond[i] MOD 2 = 0
      THEN BEGIN;
        ctime := 1;
        magnoflash;
      END;
    IF cond[i] MOD 2 = 1
      THEN BEGIN;
        ctime := 2;
        parvoflash;
      END;
    IF i MOD 100 = 99
      THEN break;
  END;
END;

PROCEDURE lettergen;
BEGIN;
  setvisualpage(0);
  setactivepage(0);
  setttextjustify(0,2);
  setttextstyle(2,0,16);
  stim_size := textwidth('W');
  stim_high := textheight('W');
  stim_size_brd := textwidth('W')+4;
  stim_high_brd := textheight('W')+5;
  FOR z:=0 TO 25 DO
    BEGIN
      str1 := letters[z];
      sizebrd := imagesize(0,0,stim_size_brd,stim_high_brd);
      getmem(image[0,z],sizebrd);
      h := 0;
      broad_image;
      getimage(0,0,stim_size_brd,stim_high_brd,image[0,z]^);
    END;
  FOR z:=0 TO 25 DO
    BEGIN
      str1 := letters[z];
      getmem(image[1,z],sizebrd);
      h := 1;
      broad_image;
      getimage(0,0,stim_size_brd,stim_high_brd,image[1,z]^);
    END;
  END;

```

```

    END;
    setfillstyle(1,0);
    bar(0,0,stim_size_brd,stim_high_brd);
    settextstyle(2,0,7);
    stim_size := textwidth('W')+1;
    stim_high := textheight('W');
    stim_size_narr := textwidth('W')+1;
    stim_high_narr := textheight('W');
    setvisualpage(1);
    FOR z:=0 TO 25 DO
        BEGIN;
            str1 := letters[z];
            sizenarr := imagesize(0,0,stim_size+2,stim_high);
            getmem(image[2,z],sizenarr);
            h := 2;
            FOR xx:= 0 TO 5 DO
                BEGIN;
                    pixcol[xx] := pix_red[xx];
                END;
            narr_image;
            getimage(0,0,stim_size+2,stim_high,image[2,z]^);
        END;
    FOR z:=0 TO 25 DO
        BEGIN;
            str1 := letters[z];
            size := imagesize(0,0,stim_size+2,stim_high+12);
            FOR xx:= 0 TO 5 DO
                BEGIN;
                    pixcol[xx] := pix_grn[xx];
                END;
            getmem(image[3,z],size);
            h := 3;
            narr_image;
            getimage(0,0,stim_size+2,stim_high,image[3,z]^);
        END;
    setfillstyle(1,0);
    bar(0,0,stim_size_narr+10,stim_high_narr);
    setactivepage(0);
END;

BEGIN
    initialize;
    setgraphmode(1);
    Filename;
    stinput;
    colours;
    setactivepage(0);
    setvisualpage(0);
    setfillstyle(1,0);
    bar(0,0,640,360);
    lettergen;
    Experiment;
    saveResults;
END.

```

```

PROGRAM posner_experiment;

uses Dos, Crt, graph;

{$i c:\tp\timer.vga}
{$i c:\tp\instal.pas}

CONST
  casem : ARRAY[0..1,0..3] OF byte = ((0,0,1,1),(0,1,0,1));
  diff  : ARRAY[0..3,0..2] OF byte = ((1,2,3),(0,2,3),
                                       (0,1,3),(0,1,2));
  letsno : ARRAY[0..1,0..3] OF byte = ((0,1,2,3),(0,1,2,3));
  lets  : ARRAY[0..1,0..3] OF char = (('A','D','R','T'),
                                       ('a','d','r','t'));

VAR
  cc1,cc2,cc3,cc4 : ARRAY[0..3] OF byte;
  x,d,displace,s,balance,xxx,l,i1,i2,i3,m1,w,m2,m3,m,cc,block,
  hx,hy,qq,xx1,h1,h2,h,stim_len,xc,fill,mnrt1,mnrt2,
  let,portresult,portresult2,pos,wx,stim_size_brd,
  stim_high_brd, t1,t2,t3,t4,xtime,ctime1,ctime2,size,step,
  xcol,start,finish,stim_size_narr,stim_high_narr,
  hdigit,coll,g,col2,xpos,i,ii,xb1,xb2,ctime,x2,y2,count,mn,er
  ror,err1,err2,xz,err,tempct,dely2,j,rndd,rndx,x1,char_size,
  y1,p,code,block_balance,charsize,wx1,wx2,wy1,wy2,
  stim_balance,conx,stim_wid,space,endx,aa,a,
  con,xred,xxcol : integer;
  infile,outfile : text;
  k,ch : char;
  v,v1,v2 : word;
  result,rt : ARRAY [0..383] OF integer;
  let_info : ARRAY [0..1,0..25,0..1] OF byte;
  xlet,stim_str,namefile,str1,st1tp,st2tp : STRING;
  condtp,condtpn : ARRAY [0..383] OF integer;
  rnd,xx,c,q,c1,c2,c3,c4 : integer;
  rndno : ARRAY[0..11] OF byte;
  rndseq,rndseqp : ARRAY[0..47] OF byte;
  rndseq2,stm,stopd,stm,stopm : ARRAY[0..47] OF byte;
  rndseq3,mpcross : ARRAY[0..383] OF byte;
  st1,st2,st3,st4,stat,tstat,stat2 : ARRAY[0..383] OF integer;
  Stim,tstim,stim,stimd : ARRAY [0..383,0..1] OF byte;
  condm,cond : ARRAY[0..95] OF byte;
  cond,rndc,match,cnd4,tmatch : ARRAY [0..383] OF integer;
  spm,spd,spm,smd,cpm,cpd,cmm,cmd : ARRAY [0..47,0..1] OF
  byte;
  cm,cd : ARRAY [0..95,0..1] OF byte;
  cnd,tcnd : ARRAY[0..383,0..1] OF byte;
  rnds : ARRAY[0..3,0..11] OF byte;
  str2 : STRING[3];
  str3 : STRING[4];
  image : ARRAY [0..7,0..25] OF pointer;
  maskp,maskm : ARRAY [0..1] OF pointer;
  z,y,stim_size,stim_high : integer;
  sizebrd,sizenarr,sizetemp : word;
  blank,image5,image1,image2,image3,image4 : pointer;
  temp : pointer;

```

```

PROCEDURE filename;
BEGIN
  Write('Name for file ');
  REPEAT
  UNTIL keypressed;
  Readln(input,namefile);
  IF namefile[1]=' '
    THEN BEGIN;
      write('error');
      REPEAT;
        ch := readkey;
      UNTIL ch=#13;
    END;
END;

PROCEDURE stinput;
BEGIN
  FOR x:= 0 TO 383 DO
    BEGIN;
      rndc[x] := 999;
    END;
  FOR x:= 0 TO 383 DO
    BEGIN;
      REPEAT;
        rnd := random(384);
      UNTIL rndc[rnd]=999;
      rndc[rnd] := x;
    END;
  FOR x:=0 TO 383 DO
    BEGIN;
      cnd4[x] := rndc[x] DIV 96;
      stim[x,0] := (rndc[x] MOD 96) DIV 24;
      IF (rndc[x] MOD 24) < 12
        THEN stim[x,1] :=
          diff[(rndc[x] MOD 96) DIV 24,
            (rndc[x] MOD 6) DIV 2];
      IF (rndc[x] MOD 24) > 11
        THEN stim[x,1] := stim[x,0];
      IF (rndc[x] MOD 12) < 6
        THEN cnd[x,0] := 0;
      IF (rndc[x] MOD 12) > 5
        THEN cnd[x,0] := 2;
      cnd[x,1] := (rndc[x] MOD 2)*2;
      IF stim[x,0]=stim[x,1]
        THEN match[x] := 0
        ELSE match[x] := 1;
      IF x MOD 2 = 0
        THEN BEGIN;
          rnd := random(2);
          IF rnd = 0
            THEN BEGIN;
              stat[x] := rndc[x] MOD 2;
              stat[x+1] := rndc[x+1] MOD 2;
            END;
          IF rnd = 1
            THEN BEGIN;

```

```

                                stat[x] := rndc[x+1] MOD 2;
                                stat[x+1] := rndc[x] MOD 2;
                                END;
                                cond[x] := 0;
                                END;
                                END;
                                END;
                                END;

PROCEDURE SaveResults;
BEGIN;
  Assign(outfile, 'c:\newexp\posner\' + namefile + 'p.dat');
  Rewrite(outfile);
  FOR x := 0 TO 383 DO
    BEGIN;
      IF cnd[x,0]=cnd[x,1]
        THEN xx := 0
        ELSE xx := 1;
      IF stat[x]>0
        THEN xxx := 8
        ELSE xxx := 0;
      writeln(outfile, stim[x,0], '', stim[x,1]:7, (cond[x]
        DIV 2)+xx)+xxx+(match[x]*4): 3, rt[x]:5,
        result[x]:2, cnd4[x]:2, match[x]:2, cnd[x,0]:2,
        cnd[x,1]:2, stat[x]:2, stat2[x]:2);
    END;
  close(outfile);
END;

PROCEDURE results;
BEGIN;
  rt[i] := gtel;
  IF ((portresult =179){ and (match[i]=0)})
    THEN result[i] := 0;
  IF ((portresult =227){ and (match[i]=0)})
    THEN result[i] := 1;
  IF ((portresult <>179)AND(portresult<>227))
    THEN result[i] := 2;
  portresult := 0;
END;

PROCEDURE colours(xcol : byte);
CONST
  pal_num : ARRAY[0..15] OF byte =
  (0,1,2,3,4,5,20,07,56,57,58,59,60,61,62,63);
BEGIN;
  setrgbpalette(pal_num[0],0,0,0);
  setrgbpalette(pal_num[1],0,0,0);
  setrgbpalette(pal_num[2],xcol-14,38-7,0);
  setrgbpalette(pal_num[3],xcol-5,38-2,0);
  setrgbpalette(pal_num[4],xcol-2,38-1,0);
  setrgbpalette(pal_num[5],xcol,38,0);
  setrgbpalette(pal_num[6],xcol-24,38-17,0);
  setrgbpalette(pal_num[7],xcol-30,38-21,0);
  setrgbpalette(pal_num[8],xcol,38,0);
  setrgbpalette(pal_num[9],xcol+1,38+1,0);
  setrgbpalette(pal_num[10],xcol+2,38+1,0);

```



```

    setrgbpalette(pal_num[11],xcol+4,38+2,0);
    setrgbpalette(pal_num[12],0,0,0);
    setrgbpalette(pal_num[13],0,0,0);
    setrgbpalette(pal_num[14],0,0,0);
    setrgbpalette(pal_num[15],0,0,0);
END;

PROCEDURE targetp;
BEGIN;
    settextstyle(0,0,1);
    setfillstyle(1,2);
    setcolor(0);
    bar(wx1,wy1,wx2,wy2);
    outtextxy((wx1+wx2) DIV 2-(textwidth('+') DIV 2),
    (wy1+wy2) DIV 2- (textwidth('+') DIV 2),'+');
END;

PROCEDURE clock;
VAR
    int1Csave : pointer;
BEGIN;
    getintvec($8,int1Csave);
    setintvec($8,@newint);
    fast;
    gtel := 0;
END;

PROCEDURE clockreset;
VAR
    int1Csave : pointer;
BEGIN;
    slow;
    setintvec($8,int1Csave);
END;

PROCEDURE button_press;
BEGIN;
    results;
    clockreset;
    setvisualpage(0);
    setactivepage(0);
    setfillstyle(1,2);
    bar(wx1,wy1,wx2,wy2);
    gtel := 0;
END;

PROCEDURE raster;
BEGIN;
    REPEAT
        UNTIL (((port[memw[$40:$63]+6] AND 8) = 0) OR
        (port[$201]=227)OR(port[$201]=179));
        REPEAT
            UNTIL (((port[memw[$40:$63]+6] AND 8) <> 0) OR
            (port[$201]=227)OR(port[$201]=179));
END;

```

```

PROCEDURE video_reverse;
BEGIN;
  setvisualpage(0);
  FOR x:= 0 TO ctime DO
    BEGIN;
      raster;
    END;
  setvisualpage(1);
  FOR x:= 0 TO ctime DO
    BEGIN;
      raster;
    END;
END;

PROCEDURE static_page(p1,p2,p3,p4,p5,p6 : integer);
BEGIN;
  setvisualpage(p1);
  setactivepage(p2);
  IF s= p3
    THEN setfillstyle(1,2);
  IF s= p4
    THEN setfillstyle(1,2);
  bar(wx1,wy1,wx2,wy2);
END;

PROCEDURE flash_page(f1,f2,f3 : integer);
BEGIN;
  setvisualpage(f1);
  setactivepage(f2);
  setfillstyle(1,2);
  bar(wx1,wy1,wx2,wy2);
END;

PROCEDURE magno_bar;
BEGIN;
  bar(((wx1+wx2) DIV 2)-(length(str1)*stim_size_brd) DIV 2,
    ((wy1+wy2) DIV 2)-(stim_high_brd DIV 2),((wx1+wx2) DIV
2)+(length(str1)*stim_size_brd)
  DIV 2,
    ((wy1+wy2) DIV 2)+(stim_high_brd DIV 2));
END;

PROCEDURE narrow_mask_placement(image_number :byte);
BEGIN;
  putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_brd)
DIV 2)+displace,
  ((wy1+wy2) DIV 2)-(stim_high_brd DIV 2),
  maskm[image_number]^,0);
  putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_brd)
DIV 2)-displace,
  ((wy1+wy2) DIV 2)-(stim_high_brd DIV 2),
  maskm[image_number]^,0);
END;

PROCEDURE magnostaticmask;
BEGIN;

```

```

    narrow_mask_placement(0);
    clock;
    REPEAT
    UNTIL gtel>200;
    clockreset;
END;

PROCEDURE broad_mask_placement(image_number :byte);
BEGIN;
    putimage(((wx1+wx2) DIV 2)-(length(str1)*stim_size_narr)
DIV 2,
    ((wy1+wy2)DIV 2)-(stim_high_narr DIV 2),maskp[s]^,0);
END;

PROCEDURE surround;
BEGIN;
    IF s= 1
    THEN setfillstyle(1,2);
    IF s= 0
    THEN setfillstyle(1,2);
    bar(wx1,wy1,wx2,wy2);
END;

PROCEDURE magno_image(m1,m2,m3 : byte);
BEGIN;
    putimage(((wx1+wx2) DIV 2)-(stim_size_brd DIV 2)+displace,
    ((wy1+wy2)DIV 2)-(stim_high_brd DIV 2),
    image[cond[i]+cnd[i,m1]+m2,stim[i,m3]]^,0);
END;

PROCEDURE flash;
BEGIN;
    clock;
    setactivepage(1);
    displace := d;
    magno_image(0,1-s,0);
    displace := -d;
    magno_image(1,s,1);
    REPEAT
    UNTIL gtel>40;
    clockreset;
    raster;
    setvisualpage(1);
    setactivepage(0);
    clock;
    displace := d;
    magno_image(0,s,0);
    displace := -d;
    magno_image(1,1-s,1);
    REPEAT
    UNTIL gtel>40;
END;

PROCEDURE static;
BEGIN;

```

```

clock;
setactivepage(1);
displace := d;
magno_image(0,s,0);
displace := -d;
magno_image(1,s,1);
REPEAT
UNTIL gtel>40;
clockreset;
raster;
setvisualpage(1);
setactivepage(0);
clock;
displace := d;
magno_image(0,s,0);
displace := -d;
magno_image(1,s,1);
REPEAT
UNTIL gtel>40;
END;

```

```

PROCEDURE leftflash;
BEGIN;
  clock;
  setactivepage(1);
  displace := d;
  magno_image(0,s,0);
  displace := -d;
  magno_image(1,1-s,1);
  REPEAT
  UNTIL gtel>40;
  clockreset;
  raster;
  setvisualpage(1);
  setactivepage(0);
  clock;
  displace := d;
  magno_image(0,s,0);
  displace := -d;
  magno_image(1,s,1);
  REPEAT
  UNTIL gtel>40;
END;

```

```

PROCEDURE rightflash;
BEGIN;
  clock;
  setactivepage(1);
  displace := d;
  magno_image(0,1-s,0);
  displace := -d;
  magno_image(1,s,1);
  REPEAT
  UNTIL gtel>40;
  clockreset;
  raster;

```

```

setvisualpage(1);
setactivepage(0);
clock;
displace := d;
magno_image(0,s,0);
displace := -d;
magno_image(1,s,1);
REPEAT
UNTIL gtel>40;
END;

```

```

PROCEDURE magnostatic2;
BEGIN;
  setcolor(0);
  setactivepage(0);
  outtextxy((wx1+wx2) DIV 2-(textwidth('+') DIV 2),
  (wy1+wy2) DIV 2- (textwidth('+') DIV 2),'+');
  setactivepage(1);
  outtextxy((wx1+wx2) DIV 2-(textwidth('+') DIV 2),
  (wy1+wy2) DIV 2- (textwidth('+') DIV 2),'+');
  setvisualpage(1);
  setactivepage(1);
  raster;
  magnostaticmask;
  raster;
  setactivepage(0);
  x := 0;
  port[$201] := 0;
  IF cnd4[i]=0
    THEN flash;
  IF cnd4[i]=1
    THEN leftflash;
  IF cnd4[i]=2
    THEN static;
  IF cnd4[i]=3
    THEN rightflash;
  REPEAT;
    video_reverse;
    portresult := port[$201];
  UNTIL ((portresult = 227)OR(portresult = 179));
  button_press;
END;

```

```

PROCEDURE magnoflash2;
BEGIN;
  raster;
  magnostaticmask;
  raster;
  clock;
  x := 0;
  port[$201] := 0;
  flash_page(0,1,5);
  magno_image(1,0,1);
  REPEAT;
  UNTIL gtel>26;
  clockreset;

```

```

raster;
clock;
flash_page(1,0,1);
magno_image(1,1,1);
REPEAT;
UNTIL gtel>26;
REPEAT;
    video_reverse;
    portresult := port[$201];
UNTIL ((portresult = 227)OR(portresult = 179));
button_press;
END;

PROCEDURE break;
BEGIN;
    settextstyle(0,0,2);
    setactivepage(0);
    setvisualpage(0);
    setfillstyle(1,2);
    bar(wx1,wy1,wx1,wy2);
    setcolor(0);
    outtextxy((640 DIV 2) - (textwidth('BREAK') DIV 2),
((wy1+wy2) DIV 2), 'BREAK');
    REPEAT;
        ch := readkey;
    UNTIL ch=#13;
    setfillstyle(1,2);
    bar(wx1,wy1,wx1,wy2);
END;

PROCEDURE newstart;
BEGIN;
    settextstyle(0,0,1);
    colours(xcol);
    setactivepage(0);
    setvisualpage(0);
    setfillstyle(1,2);
    bar(wx1,wy1,wx1,wy2);
    setcolor(0);
    outtextxy((640 DIV 2) - (textwidth('NEW RULE') DIV 2),
((wy1+wy2) DIV 2), 'NEW RULE');
    REPEAT;
        ch := readkey;
    UNTIL ch='r';
    setfillstyle(1,2);
    bar(wx1,wy1,wx1,wy2);
END;

PROCEDURE present_stimuli;
BEGIN;
    displace := 20;
    d := displace;
    IF cnd4[i]=0
    THEN BEGIN;
        s := 0;
        stat2[i] := 2;

```

```

        END;
    IF cnd4[i]=1
        THEN BEGIN;
            c1 := c1+1;
            s := c1 MOD 2;
            stat2[i] := s;
        END;
    IF cnd4[i]=2
        THEN BEGIN;
            c2 := c2+1;
            s := c2 MOD 2;
            stat2[i] := s;
        END;
    IF cnd4[i]=3
        THEN BEGIN;
            c2 := c3+1;
            s := c3 MOD 2;
            stat2[i] := s;
        END;
    gotoxy(1,1);
    write(s:2);
    targetp;
    clock;
    rndx := random(100);
    REPEAT
    UNTIL ((gtel>rndx+600));
    clockreset;
    magnostatic2;
END;

```

```

PROCEDURE practice;
BEGIN;
    s := 0;
    REPEAT;
        count := 0;
        REPEAT
            i := random(181)+191;
            count := count+1;
            present_stimuli;
        UNTIL count=17;
        REPEAT;
            ch := readkey;
        UNTIL ((ch=#13)OR(ch='e'));
    UNTIL ch='e';
END;

```

```

PROCEDURE initialize_exp;
BEGIN;
    h1 := textwidth(' ')+2;
    h2 := textheight(' ');
    hx := getmaxx DIV 2;
    wx1 := (getmaxX DIV 2)-(50);
    wx2 := (getmaxX DIV 2)+(50);
    wy1 := (getmaxY DIV 2)-(30);
    wy2 := (getmaxY DIV 2)+(30);
    hy := ((wy1+wy2)DIV 2)-(textheight(' ') DIV 2);

```

```

bar(wx1,wy1,wx2,wy2);
REPEAT;
  i := random(191);
UNTIL cond[i]=0;
ctime := 0;
magnoflash2;
setactivepage(1);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
setactivepage(0);
setfillstyle(1,2);
bar(wx1,wy1,wx2,wy2);
ctime := 1;
END;

PROCEDURE experiment(start, finish : integer);
BEGIN;
  practice;
  c1 := 0;
  c2 := 0;
  FOR i:= start TO finish DO
    BEGIN;
      present_stimuli;
      IF i = 96
        THEN break;
      IF i = 192
        THEN break;
      IF i = 192+96
        THEN break;
    END;
  END;

PROCEDURE narr_image(col,stim_size,stim_high : byte;str1 :
STRING);
CONST
pixcol : ARRAY[0..1,0..6] OF byte =
((8,9,10,11,12,13,14),(12,13,14,15,8,9,10));
VAR
pn2,pn1,p0,p1,p2,p3,y,x,incol,incol1,incol2,incol3,outcol,
outcol1,outcol2,outcol3 : byte;
BEGIN;
  incol := pixcol[col,0];
  incol1 := pixcol[col,1];
  incol2 := pixcol[col,2];
  incol3 := pixcol[col,3];
  outcol := pixcol[col,4];
  outcol1 := pixcol[col,5];
  outcol2 := pixcol[col,6];
  outcol3 := pixcol[1-col,3];
  setfillstyle(1,outcol);
  bar(0,0,stim_size+5,stim_high);
  setcolor(incol);
  outtextxy(2,-1,str1);
  outtextxy(3,-1,str1);
  FOR x:= 1 TO stim_size-1 DO

```



```

FOR y:=0 TO stim_high DO
  BEGIN;
    pn2 := getpixel(x-2,y);
    pn1 := getpixel(x-1,y);
    p0 := getpixel(x,y);
    p1 := getpixel(x+1,y);
    p2 := getpixel(x+2,y);
    p3 := getpixel(x+3,y);
    IF ((pn2=outcol)OR(pn2=outcol1))
      AND((pn1=outcol)OR(pn1=outcol1)OR(pn1=outcol2))
      AND(p0=incol) AND(p1=incol)
    THEN BEGIN;
      putpixel(x-2,y,outcol1);
      putpixel(x-1,y,outcol2);
      putpixel(x,y,incol2);
      putpixel(x+1,y,incol1);
    END;
    IF (((pn2=incol)OR(pn2=incol1))
      AND((pn1=incol)OR(pn1=incol1)OR(pn1=incol2))
      AND(p0=outcol)AND(p1=outcol)
    THEN BEGIN;
      putpixel(x-2,y,incol1);
      putpixel(x-1,y,incol2);
      putpixel(x,y,outcol2);
      putpixel(x+1,y,outcol1);
    END;
    IF (((pn2=outcol)OR(pn2=outcol1)OR(pn2=outcol2))
      AND((pn1=outcol)OR(pn1=outcol1)OR(pn1=outcol2))
      AND((p0=incol)OR(p0=incol1)OR(p0=incol2))
      AND((p1=incol)OR(p1=incol1)OR(p1=incol2))
      AND((p2=outcol)OR(p2=outcol1)OR(p2=outcol2))
      AND((p3=outcol)OR(p3=outcol1)OR(p3=outcol2))
    THEN BEGIN;
      putpixel(x-2,y,outcol1);
      putpixel(x-1,y,outcol2);
      putpixel(x,y,incol3);
      putpixel(x+1,y,incol3);
      putpixel(x+2,y,outcol2);
      putpixel(x+3,y,outcol1);
    END;
    IF (((pn2=incol)OR(pn2=incol1)OR(pn2=incol2))
      AND((pn1=incol)OR(pn1=incol1)OR(pn1=incol2))
      AND((p0=outcol)OR(p0=outcol1)OR(p0=outcol2))
      AND((p1=incol)OR(p1=incol1)OR(p1=incol2))
      AND((p2=incol)OR(p2=incol1)OR(p2=incol2))
    THEN BEGIN;
      putpixel(x-2,y,incol1);
      putpixel(x-1,y,incol2);
      putpixel(x,y,outcol3);
      putpixel(x+1,y,incol2);
      putpixel(x+2,y,incol1);
    END;
  END;
END;
END;

```

```

PROCEDURE broad_image(h,stim_size,stim_high : byte; str1 :

```

```

STRING);
CONST
  mov0 : ARRAY[0..23,0..1] OF byte = ((0,4),(0,5),(0,6),
(1,7),(2,8),(3,9),(4,10),(5,10),(6,10),(7,9),(8,8),(9,7),
(10,6),(10,5),(10,4),(9,3),(8,2),(7,1),(6,0),(5,0),(4,0),
(3,1),(2,2),(1,3));
  mov1 : ARRAY [0..19,0..1] OF byte = ((1,4),(1,5),(1,6),
(2,7),(3,8),(4,9),(5,9),(6,9),(7,8),(8,7),(9,6),(9,5),
(9,4),(8,3),(7,2),(6,1),(5,1),(4,1),(3,2),(2,3));
  mov2 : ARRAY [0..15,0..1] OF byte = ((2,4),(2,5),(2,6),
(3,7),(4,8),(5,8),(6,8),(7,7),(8,6),(8,5),(8,4),(7,3),
(6,2),(5,2),(4,2),(3,3));
  mov3 : ARRAY [0..11,0..1] OF byte = ((3,4),(3,5),(3,6),
(4,7),(5,7),(6,7),(7,6),(7,5),(7,4),(6,3),(5,3),(4,3));
  mov4 : ARRAY [0..7,0..1] OF byte = ((4,4),(4,5),(4,6),
(5,6),(6,6),(6,5),(6,4),(5,4));
  pix : ARRAY[0..1,0..6] OF byte = ((5,4,3,2,6,7,1),
(1,7,6,2,3,4,5));
VAR
  b: byte;
BEGIN;
  setfillstyle(1,pix[h,0]);
  bar(0,0,stim_size+5,stim_high+5);
  setcolor(pix[h,1]);
  FOR b:= 0 TO 23 DO
    BEGIN;
      outtextxy(mov0[b,0]+1,mov0[b,1]-7,str1);
    END;
  setcolor(pix[h,2]);
  FOR b:= 0 TO 19 DO
    BEGIN;
      outtextxy(mov1[b,0]+1,mov1[b,1]-7,str1);
    END;
  setcolor(pix[h,3]);
  FOR b:= 0 TO 15 DO
    BEGIN;
      outtextxy(mov2[b,0]+1,mov2[b,1]-7,str1);
    END;
  setcolor(pix[h,4]);
  FOR b:= 0 TO 11 DO
    BEGIN;
      outtextxy(mov3[b,0]+1,mov3[b,1]-7,str1);
    END;
  setcolor(pix[h,5]);
  FOR b:= 0 TO 7 DO
    BEGIN;
      outtextxy(mov4[b,0]+1,mov4[b,1]-7,str1);
    END;
  setcolor(pix[h,6]);
  FOR b:= 0 TO 7 DO
    BEGIN;
      outtextxy(5+1,5-7,str1);
    END;
END;

PROCEDURE gen_narr_image(s,pix_number :byte);

```

```

BEGIN;
  getmem(image[s,z],sizenarr);
  narr_image(pix_number,stim_size,stim_high,str1);
  getimage(0,0,stim_size+2,stim_high,image[s,z]^);
END;

PROCEDURE gen_narr_mask(s,pix_number :byte);
BEGIN;
  getmem(maskp[z],sizenarr);
  narr_image(pix_number,stim_size,stim_high,str1);
  getimage(0,0,stim_size+2,stim_high,maskp[z]^);
END;

PROCEDURE gen_broad_image(s,pix_number :byte);
BEGIN;
  getmem(image[s,z],sizebrd);
  broad_image(pix_number,stim_size,stim_high,str1);
  getimage(0,0,stim_size_brd,stim_high_brd,image[s,z]^);
END;

PROCEDURE gen_broad_mask(s,pix_number :byte);
BEGIN;
  str1 := '.';
  getmem(temp,sizetemp);
  broad_image(z,stim_size,stim_high,str1);
  getimage(1,4,11,17,temp^);
  FOR x:=0 TO 2 DO
    FOR y:=0 TO 2 DO
      BEGIN;
        putimage(0+(x*10),0+(y*12),temp^,0);
      END;
    getmem(maskm[z],sizebrd);
    getimage(0,0,stim_size_brd,stim_high_brd,maskm[z]^);
  END;

PROCEDURE lettergen;
BEGIN;
  setttextjustify(0,2);
  setttextstyle(2,0,16);
  stim_size := textwidth('W');
  stim_high := textheight('W');
  stim_size_brd := textwidth('W')+4;
  stim_high_brd := textheight('W')+5;
  setactivepage(0);
  setvisualpage(1);
  sizebrd := imagesize(0,0,stim_size+4,stim_high+5);
  FOR z:=0 TO 3 DO
    BEGIN
      str1 := lets[0,z];
      gen_broad_image(0,0);
      gen_broad_image(1,1);
    END;
  FOR z:=0 TO 3 DO
    BEGIN
      str1 := lets[1,z];
      gen_broad_image(2,0);
    END;
  END;

```

```

    gen_broad_image(3,1);
END;
settextstyle(2,0,6);
sizetemp := imagesize(1,4,11,17);
settextstyle(2,0,7);
stim_size := textwidth('W')+1;
stim_high := textheight('W');
stim_size_narr := textwidth('W')+1;
stim_high_narr := textheight('W');
sizenarr := imagesize(0,0,stim_size,stim_high);
FOR z:=0 TO 3 DO
    BEGIN;
        str1 := lets[0,z];
        gen_narr_image(4,0);
        gen_narr_image(5,1);
    END;
FOR z:=0 TO 3 DO
    BEGIN
        str1 := lets[1,z];
        gen_narr_image(6,0);
        gen_narr_image(7,1);
    END;
str1 := #177;
FOR z:=0 TO 1 DO
    BEGIN
        gen_narr_mask(z,z);
    END;
END;

PROCEDURE mask_maker;
BEGIN;
    settextstyle(2,0,16);
    stim_size_brd := textwidth('W')+4;
    stim_high_brd := textheight('W')+5;
    sizebrd := imagesize(0,0,stim_size_brd,stim_high_brd);
    settextstyle(2,0,6);
    sizetemp := imagesize(1,4,11,17);
    FOR z:=0 TO 1 DO
        BEGIN
            str1 := '.';
            getmem(temp,sizetemp);
            h := z;
            broad_image(z,stim_size_brd,stim_high_brd, str1);
            getimage(1,4,11,17,temp^);
            FOR x:=0 TO 2 DO
                FOR y:=0 TO 2 DO
                    BEGIN;
                        putimage(0+(x*10),0+(y*12),temp^,0);
                    END;
                getmem(maskm[z],sizebrd);
                getimage(0,0,stim_size_brd,stim_high_brd,maskm[z]^);
            END;
        END;
    END;

BEGIN
    initialize;

```

```

xcol := 56;
setgraphmode(1);
Filename;
stinput;
colours(xcol);
lettergen;
mask_maker;
setactivepage(0);
setvisualpage(0);
setfillstyle(1,0);
bar(0,0,640,360);
initialize_exp;
Experiment(0,383);
saveResults;
setvisualpage(0);
setactivepage(0);
setfillstyle(1,2);
bar(x1,y1,x2,y2);
setcolor(0);
settextstyle(0,0,1);
outtextxy((640 DIV 2)-(textwidth('FINISH')
DIV 2),((wy1+wy2) DIV 2)
{-(stim_high div 2)}, 'THANKS');
REPEAT;
    ch := readkey;
UNTIL ch=' ';
END.

```