CRITICAL DURATION, CONTRAST SENSITIVITY, AND SPECIFIC READING DISABILITY

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Being a dissertation submitted as a partial requirement for the degree of Master of Psychology within the University of Tasmania. Department of Psychology.

DECEMBER, 1979

ABSTRACT

Critical durations and contrast sensitivities for sine-wave gratings of four different spatial frequencies were measured in normal and disabled readers. Two groups, each of ten subjects, with an average age of 14 years, and matched as to sex, age, IQ, and socio-economic status, were used. The results showed that while critical duration for controls increases significantly with spatial frequency, this is not so for disabled readers, suggesting that the two groups may differ in terms of the temporal properties of their spatial frequency channels. It was also found, for stimulus durations approximately equal to fixation durations, that disabled readers were relatively less sensitive than were controls at low to medium spatial frequencies. At all durations there was a marked contrast sensitivity loss at 4 c/deg. Controls, in respect of both critical duration and contrast sensitivity function, produced results similar to those found in other studies on normal adult subjects.

The suggestion of spatial frequency-selective differences in critical duration and the clear finding of such differences in contrast sensitivity may indicate a fundamental abnormality in the visual-temporal integration of spatial stimuli. The existence of such qualitative differences in children at this comparatively mature age renders a developmental explanation unlikely. An explanation discounting visual perceptual differences seems even more untenable.

The present study does not preclude a multi-factorial etiology for SRD; it does, however, indicate that abnormality in spatial frequency-specific channels of visual information processing is one factor which can now confidently be included.

SOURCES STATEMENT

The present thesis describes original research undertaken in the Department of Psychology, University of Tasmania. To the best of my knowledge and belief, any theories and techniques not my own have been acknowledged in the text.

Mary E. Blackwood
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Signature

ACKNOWLEDGEMENTS

Acknowledgements are due to a number of people, without whose support and encouragement this thesis could have been neither attempted nor completed.

I am indebted to my supervisor, Dr. W.J. Lovegrove, who suggested the topic, and took great care in reading, and advising on, the manuscript. His support was invaluable.

Research Assistant Alison Bowling was unfailingly helpful in the analysis of the data, and took a lively interest throughout. Her expertise was essential to the preparation of this thesis.

My fellow students from the Honours year in the Psychology Department provided constant encouragement, and my involvement in their weekly seminar introduced me to visual perception. The considerable task of acquiring familiarity with the area was greatly facilitated by their theoretical interest, and personal friendship.

Thanks are also due to the staff of the High School, and, of course, to the children themselves, whose co-operation was a key factor to the success of the testing.

I would like to thank Mrs. S. McCabe, who typed the manuscript.

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C O N T E N T S

CHAPTER 1.

SPECIFIC READING DISABILITY : THEORETICAL BACKGROUND

1.1 Extent and nature of Specific Reading Disability (SRD)

The complex task of reading and the associated problem of reading difficulty have attracted close attention for many years; indeed, since the introduction of more generally available education there has been at least some awareness that this ability is not automatic, and that some individuals fail to master reading, in spite of apparently normal general ability. In 1896 "A case of congenital word blindness" was reported in The British Medical Journal (Morgan, in Hepworth, 1971, p.2). Interpretations of the phenomenon vary; there is still controversy over whether it exists at all (Rutter and Yule, 1975) except as an effect of the lower end of the normal curve, but where it is accepted as a discrete entity, reasons for its existence have been postulated by psychologists, neurologists and educationalists; some of these theories will be briefly examined after a consideration of the magnitude and nature of the problem.

Changes in nomenclature have been legion. Word blindness, dyslexia, strephosymbolia, learning difficulty and specific reading disability (SRD) are amongst the labels which have been attached to the phenomenon, and the meaning varies slightly. The present study, using the latter term, defines children with SRD as those who, despite at least average intellectual ability, fail to acquire normal reading skills in the absence of gross neurological, educational, or behavioural impairment. In this partial paraphrase of the World Federation of Neurology definition (Critchley 1970), the emphasis shifts to the specificity of the disability: reading rather than "learning", and excludes those children with apparent accompaniments to reading problems such as brain damage, primary emotional disturbance, or educational neglect, which may denote more general difficulties. For the purposes of the present study children whose reading ability, as measured on a standard test, falls two years or more below chronological age, given normal intelligence, will be classified as SRD's.

Estimates of the incidence of the problem vary; for example, Bachmann in 1927 claims 1%, Traxler in 1949 25% (Malmquist, 1958), and this variability undoubtedly reflects the different parameters which have defined the group, themselves reflecting the contemporary prevailing view of the importance of the problem.

Current estimates of the incidence in the school population vary considerably; Rutter and Yule (1975) find a geographical variation from 3.5% in ten year olds on the Isle of Wight, to 6% in London for the same age group. It would seem that figures vary with chronological age as well; 4.5% of fourteen year olds on the Isle of Wight showed specific reading retardation. Bearing the variability of these estimates in mind, Gardner's (1973) summarizing comment may serve as well as any: "a significant number of people seem to have serious difficulties learning to read" (p. 63).

It seems likely (Rutter & Yule, 1975) that this "significant number" includes not only the lower end of a normal distribution in reading ability, but also those individuals with whom this study is concerned: those with specific reading disability.

The distinctions between general reading backwardness and specific reading retardation have been clearly articulated by Rutter and Yule (1975). SRD's show a different sex distribution, with a high proportion of male children; have significantly fewer neurological abnormalities, and higher IQ's when compared with children who are generally backward in reading.

1.2 General theories of Specific Reading Disability

A range of explanations has been offered to account for specific reading disability, although some include it in the general analysis of reading failure. It is interesting to note that the focus of these theories is once again narrowing. The broadly-based general explanations popular up until the last few years construed SRD as part of a larger problem such as developmental lag, (Critchley 1964), educational deficit (Schonell 1945), emotional disturbance (Blanchard 1946), or motivational problems (Staats, 1968). The early focus was very narrow indeed: W. Pringle Morgan, in 1896, suggested that a lesion in, or defective development of, the left angular gyrus of the brain was responsible for his reported case of wordblindness. Current perceptual theories, which may perhaps in their specificity have more in common with Dr. Morgan's,[1] are outlined, following a presentation of the important kinds of alternative theories to date.

A useful organization of earlier theories is provided in Hepworth (1971), drawing on Fabian (1955). This analysis divides theories according to their centre of interest: school, child, family, or organic function.

1.2.1 School-centred theories:

Although most researchers (e.g., Critchley, 1964; Hepworth 1971) would concede that inappropriate or inadequate school programmes contribute to reading difficulties, few would place full responsibility for SRD on the school, except perhaps Schonell (1945). However, this approach has underpinned the major efforts of Education Departments to counter reading difficulties, and the typical course suggested for an SRD child is remediation in the school setting. In the past this has

1. Preston, Guthrie and Childs (1974) in studying visual evoked responses, implicate once again the left angular gyrus.

meant intensive teaching, usually still employing the method currently in vogue at that school. Critchley (1964) remarks that patient teaching in an old fashioned way is still the method of choice in reading remediation. This approach is being modified, and new methods include the use of entirely different teaching procedures, although these are outside the scope of the present discussion, which intends merely to point out that the school centred approach, theoretically espoused by so few, has in fact dominated remedial action for SRD, seen in the attitude that although orthodox schooling has failed, more intensive and individualized orthodox schooling nonetheless holds the answer.

1.2.2 <u>Child-centred theories</u>:

The broad thrust of these theories is that some personality variable or emotional state is centrally implicated in SRD. The psychoanalytic position, of historical interest only, describes reading in this way: "The book symbolizes the mother, the author, the father ... now comes the reader, the son, hungry, voracious and defiling in his turn, eager to force his way into his mother ..." (Strachey, 1930, on p.18 Hepworth, 1971). Under this orientation an understandable repression and guilt causes SRD, and psychoanalytically generated insight will release the energy necessary to read. This curious assertion has little basis in evidence.

A further example of this group of theories, although it could hardly be less similar in orientation, is the behavioural approach, regarded as promising by Rachman (1962) and developed largely by Staats (1968). Briefly, this view holds that speech, itself a discriminative stimulus, becomes associated with written words which then become discriminative stimuli, eliciting the reading response. If inadequate or inappropriate reinforcement systems are operating in the individual child or the environment, the response will not be acquired. Reading is construed as an operant behaviour, and the application of reinforcement principles is regarded as fundamental to the remedial process. While Staats and his colleagues (1964, 1965, 1970), report considerable success with this method, it is difficult to see motivational problems as the whole answer, in the face of the data on visual perception, visual and verbal processes, and memory, to be presented later. It is notable that subsequent work in this area (e.g. Umansky & Umansky, 1976) has concentrated on "culturally deprived" children, where lack of motivation can reasonably be posited as a factor contributing to reading backwardness, though not necessarily to reading retardation, using Rutter and Yule's (1975) distinction. Most writers accept lack of motivation as one of the contributing factors in any reading difficulty (Esson, 1967, p.219, refers whimsically to "infirmity of purpose"), but it is impossible to disentangle cause and effect in this area, and the pragmatically appealing stance is that long experience of failure is likely to reduce motivation, and that Staats' results represent the effect of maximising motivation (a perfectly reasonable activity) while not necessarily adding to our understanding of the acquisition of reading.

1.2.3 Family-centred theories:

While there is evidence that reading disability runs in families (Hepworth 1971, Critchley 1964, Malmquist 1958), the importance of the genetic component in SRD has, according to Rutter and Yule, (1975) been very much overstressed. They argue that there is "a genetic component in reading generally" but that the specific genetic arguments for the inheritance of a specific condition of developmental dyslexia "must be rejected" in favour of a multi-factorial view which is far more strongly supported (p. 193).

SRD as an index to family psychopathology would be accepted by few researchers these days, but early psychoanalysts such as Fabian and Blanchard (1946, in Hepworth, 1971) proposed psychoanalytic family therapy as the most suitable method of remediation. The inequalities of society, with the family as the focus, have been implicated in the deprivation syndrome (Richardson, in Sapir & Nitzburg, 1973). In a typical setting of poor nourishment, lack of early stimulation and limited educational opportunity, the deprivation syndrome will frequently produce reading backwardness as part of a psychosocially determined outcome. While this kind of "reading disability" is not the present concern of this study, it is mentioned as the contemporary representative of the "family-centred" approach.

1.2.4 Organ-centred theories:

With the longest and most respectable history, these theories began with the late nineteenth century proposition already mentioned, that lesions or defects in development at specific sites in the brain produced reading disability. The concept of minimal brain dysfunction, associated with slight but diagnostically important neurological impairment, evidenced by clumsiness, mixed laterality, and the like, was influential in the view of reading disability by the 1960's. McDonald Critchley (1964, 1970) and Delacato (in Dechant, 1970) for example, though differing in some premises, have authoritatively claimed that specific reading disability is the overt aspect of neurological immaturity or disorganization, and that a clear syndrome of "developmental dyslexia" can be discerned. These views have now been impressively challenged by Rutter and Yule, 1975, who found the accompanying neurological symptoms predominated in those children classified as "backward readers", i.e., children whose reading fell below chronological age but not mental age; these children may well represent the lower end of the normal curve. Rutter and Yule found a specific group showing reading "retardation", i.e., reading achievement below mental age. This group showed associated abnormalities only in speech and language; the suggestion is that in the view of developmental dyslexia held by Critchley, these diagnostically separate groups have been confused, for speech and language deficits have been placed, with poor co-ordination and so on, in the constellation of "neurological" symptoms. Rutter and Yule argue instead for a separate specific disability in reading, multi-factorially determined, with organic impairment no more than a possible contributing factor.

These general theories no longer command wide acceptance, but they frame the historical context for this thesis.

1.3 Specific deficit theories

The tendency of modern researchers to focus on more limited aspects of processing and their contribution to specific reading disability, arises from the striking and common finding of apparent processing differences in SRD children when compared with normals. While these measured differences have inspired a range of theoretical explanations, to be discussed in the sections immediately following, their practical implication has been the generation of numerous diagnostic tests based on "perceptual ability" (e.g., the Marianne Frostig Developmental Test of Visual Perception, 1961; the Illinois Test of Psycholinguistic Abilities [ITPA], Kirk & McCarthy 1968) as an underlying mechanism to reading ability, and the implementation of programmes which include visual-motor exercises and laterality exercises, such as Delacato's, in a general context of reading remediation.

The area yields a vast amount of data, often inconsistent, which is far from being integrated satisfactorily. A useful categorization of approaches derives from considering the theories in terms of the specific deficits they propose, and the following section presents them in that framework.

1.3.1 Developmental Deficit Theories:

In keeping with Critchley's notion of cerebral immaturity, these theories espouse the idea of perceptual immaturity. An important early study was carried out by Silver and Hagin (in Young & Lindsley, 1970). In assessing the visual discrimination of children with SRD, a defective ability to orient a figure in space correctly, defects in visual motor function and visual memory deficits are regarded as essentially symptomatic of a lower level of maturation of brain function. Because the problem is presented as largely a matter of neurophysiologic maturation, then specific training to remediate reading difficulties will include improving the accuracy of perceptual input to enhance this maturation. The idea of lack of maturation had been proposed earlier by Vernon (1957), whose view of SRD would include perceptual immaturity within a general picture of developmental lag. This view has a good deal in common with Critchley's.

A more cautious conclusion is offered by Lyle and Goyen (1975, p.676), who state that "it is not unlikely ... that a maturational factor is involved in the perceptual deficit manifested by retarded readers in tachistoscopic tasks". In examining the visual-perceptual deficit in retarded readers, Lyle and Goyen found that speed of exposure of response cards and not level of complexity, was the crucial variable, with faster exposures (10 msec, 1 sec) producing a significantly poorer performance in SRD's. Because they used only young children (6.5 yr. to 7.5 yr) and because their earlier studies

(1968 and 1971) indicated that visual-perceptual deficits are found only in SRD's aged under 8.5 years, Lyle and Goyen (1975) propose a maturational component in the deficit studied.

The perceptual developmental delay hypothesis is supported too by Satz, Rardin and Ross (1971) who found, like Lyle and Goyen, that skills of visual motor integration were poorly developed in young SRD's, but that these skills were finally acquired, the older SRD's showing a normal performance. Lovegrove and Brown (1978) found significantly longer visual processing times in SRD's than in normal matched controls, which differences decreased with age. This is consistent with developmental deficit theories, though it should be noted that the finding was restricted to one of two experiments; the second will be discussed later.

These theories, showing early visual perceptual differences between SRD's and normal readers, differences which disappear with age, require some further causative explanation for the apparent continuation of SRD into adolescence and even adulthood. Indeed, there may be a slight increase in the prevalence of SRD with age (Rutter & Yule 1975). Lack of motivation due to repeated experience of failure is the clear candidate for this position, but cannot be totally satisfactory, since strenuous remedial efforts along conventional lines, combined with appropriate reinforcements, while frequently successful (Staats & Butterfield, 1965), still leave a proportion of mature SRD's. Developmental deficit hypotheses may account for the early failure to acquire reading, but not for the continuation of that failure.

1.3.2 Visual-verbal deficit theories:

The probability that observed perceptual deficits in SRD children are in fact a product of verbal deficits, that is, are cognitive in origin, has been strongly argued by several researchers. This alternative conceptualization is put consistently, for example, by Vellutino.

Drawing on a number of his own studies (1973, 1974, 1975), Vellutino (1977) claims to provide evidence that SRD issues primarily from dysfunction in the verbal identification of letters and words and not from distortion in perceiving their visual features. Vellutino finds no visual deficit in SRD children. It is proposed to look at one study in detail before presenting Vellutino's conclusions.

Vellutino, Steger and Kandel (1975b) tested 34 poor and normal readers on an apparent variety of tachistoscopic tasks. The children were required to reproduce in written and then oral form, where appropriate, displays containing three designs, three digits, scrambled letter sets containing three, four or five letters, or single words varying from three to five letters. The finding of no difference in design or digit reproduction is presented as evidence for absence of visual deficit; but the clear criticism is that the displays involve too few symbols to point up a visual deficit, for example in sequencing, and that only gross perceptual deficit would produce a difference. Whatever the deficit of SRD's, it is unlikely to result in such an easily measured difference; and the reading task is, of course, visually very much more complex. The verbal material produced no significant difference when three scrambled letters were displayed, although trends toward difference are ignored; similarly trends toward the superiority of normal readers, when longer displays are involved, were not subjected to statistical analysis. Other studies of Vellutino and his associates share the problem of presenting stimuli of dubious relevance to reading, and where the stimuli approximate more closely to reading in terms of the sequential processing, e.g., five-item stimuli (Vellutino et al, 1975a), poor readers do perform comparatively poorly.

Vellutino construes these differences as attributable to a verbal deficiency, believing that a visual deficit would show up throughout and not merely on longer displays, and that the difficulty experienced by poor readers in pronouncing and spelling the stimuli compared with their (apparent) visual competence suggests a verbal and not a visual deficit. The problem, however, lies in the nature of the visual task he is assessing, and in his view of reading which ignores the temporal integration necessary. In a review article, Vellutino (1977b) claims that due to the limited number of letters in the alphabet and the number of recurring combinations such as 'ing', the visual demands in reading are ultimately minimal. It could be said that, given the number of different combinations which can occur over sequences of letters and words, the visual-temporal demands are ultimately infinite. More detailed reference will be made to the spatial-temporal interaction later; the argument for a frank verbal labelling deficit, however, selectively ignores evidence for subtle visual deficit, at least as a contributor; ignores the possibility of visual-temporal deficit, and ignores too the observation of adequate verbal labelling in other areas (such as the ability to recognize and name objects rather than words). Vellutino's work does not exclude by any means the possibility of visual sequencing deficit or temporal integration problems, despite his interpretation that it does.

The conclusions offered by Vellutino and his colleagues have been criticized by Fletcher and Satz (1979) on more specific grounds: the face validity of the tasks which incorporate both recognition and memory components; the use of a visual-verbal copying task to draw inferences about visual perceptual processes involved in reading where the similarity is questionable, and the assumption that word pronunciation represents verbal mediation alone. Fletcher and Satz argue that word pronunciation could involve several different phonological and semantic strategies, and poor performance on such a task with its close correspondence to the reading task may merely be replicating reading, where poor performance is axiomatic for SRD's. Fletcher and Satz highlight, too, the criticism mentioned earlier: the selective ignoring of discrepant results. Their conclusion is that a unitary deficit hypothesis is not only premature as a simplistic interpretation of a highly complex phenomenon, but fails to incorporate even its own discrepancies, as well as the evidence from other researchers. Vellutino's response (1979), clarifies some of these issues, for instance that in his view a verbal deficit is not tantamount to a unitary and simplistic deficit, but represents a linguistic deficiency of variable complexity. He concedes, too, that the serial deficit notion has not been adequately conceptualized and evaluated. However, the fundamental thrust of the criticism of his work on methodological grounds is not altered by the theoretical acrobatics displayed subsequently.

Clifton-Everest (1974) compared recognition performance on a tachistoscopically presented task between backward and normal readers. Line patterns were used, and the recognition task involved identifying as the same or different, two stimuli separated by various durations above three seconds with an interpolated task involving auditory digit recognition. No significant difference between the groups emerged; indeed, recognition performance was overall so low as to support the idea that visual memory of meaningless stimuli not amenable to verbalization cannot play an important role in reading.

Clifton-Everest (1976) subsequently reports an experiment showing deficient analysis of written words in SRD's; there were striking differences from normal readers in the ease of identifying letter sequences within long words, that is, on performance where verbalization is involved. Clifton-Everest, very much more cautiously than Vellutino, proposes a linguistic deficit that precludes suitable verbal codes being selected to supplement information that is held visually. Again, the problem of suitably complex visual material arises. The finding of a similar performance between groups in the 1974 study may derive not from the fact that the material is free of a verbal component, but from the fact that it is simple, non-sequential processing that is required. Witelson's research (1977), for example, indicates adequate spatial performance in SRD children, with comparatively poor linguistic performance. And Clifton-Everest's 1976 research is also open to the interpretation that the apparently cognitive analysis may depend in the first instance, on visual sequencing analysis. Clifton-Everest sees this probability, and concedes that there is some relation between failure to acquire skills of visual analysis, and severe reading disability, but he sees these skills as primarily cognitively based, and as specific to the reading task where verbalization is required.

1.3.3 Theories of integration deficit :

In 1882, Abbott (reported by Birch & Lefford, in Sapir & Nitzburg, 1973) demonstrated that the frog is unable to modify its response of striking at a fly, except by gustatory feedback. A tactual pain stimulus (sharp spikes around an impaled fly) failed to alter the visually determined response of striking. The importance of intersensory integration in the development of reading skills has frequently been emphasised. Butters and Brody (1968) regard visual-auditory inter-sensory associations as fundamental to reading because the written word must arous its appropriate auditory associate if it is to be successfully read.

It is known that intersensory integration supersedes unimodal sensory responses as one ascends the vertebrate series from fish to man. But with gross integration intact, the more subtle areas of integration which could have implications for reading, may be impaired in SRD children. Findings of this kind are reported for "brain-damaged" children, by Birch and Lefford, in Sapir and Nitzburg, (1973). They found that although these children[1] differed little from normals in their performance on the easy task of visual discrimination and the comparatively unsophisticated integration of visual and haptic modalities, marked differences were found when the level of integration and analysis required was increased (e.g., to visual-kinaesthetic). In a rather more directly relevant study, Birch and Belmont (1964) investigated auditory-visual integration in retarded readers. The task involved the selection of a spatial pattern of dots which corresponded to an auditory stimulus; the performance of retarded readers was significantly poorer than that of normal readers. Their interpretation of the results implies an integration deficit, but an important omission, the failure to screen for subtle visual dysfunction, allows the interpretation they concede: "the obtained differences in intersensory performance could occur if deficiencies existed in the functioning of either of the sensory modalities". The only children excluded were those with "significant uncorrected visual disturbance" (p.859). I would seem, then, that the evidence for a defect in integration is far from unequivocal, and that the possibility of deficit in one modality alone is not eliminated; indeed, may provide the most parsimonious explanation.

In a similarly relevant study which also investigated integrative functioning, Blank and Bridger (in Sapir & Nitzburg, 1973) examined the conversion of visual-temporal information (in this case, a series of flashed lights) to visual-spatial patterns (selecting a pattern corresponding to what had been seen). SRD's, although equally able in a task requiring visual-spatial recall, were significantly poorer at the task involving integration. Blank and Bridger interpret their findings as a difficulty in applying verbal labels, leading to poor intramodal transfer. This implies an even more sophisticated area of inefficiency, the

1. including a group of children with "delayed speech development" who, if Rutter and Yule (1975) are correct, are at risk for SRD.

cognitive component. The research on integration then, while generally refining the focus of attention to perceptual processes, remains inconclusive, since the processes examined are by definition multi-determined, allowing the possibility of subtle visual dysfunction, cognitive inefficiency, integration deficits, or a combination. This range of interpretations reflects the complexity of the problem of SRD.

A re-interpretation of the intermodal approach to information processing is offered by Bryden (1972) who argues that the more important shift occurs in the transfer of information from spatial to temporal modes rather than from one modality to another. It is possible to construe much of the research purporting to assess intermodal integration in these terms: Birch and Belmont (1964) provide as strong evidence for temporal-spatial problems as they provide for auditory-visual, since they presented a sequence of stimuli (temporal) and required a selection of corresponding spatial stimuli. The utilization of different modalities may be irrelevant compared with the temporal-spatial transfer. This possibility has direct bearing on the present research, to be discussed in the next chapter.

1.3.4 Memory deficit theories:

The finding that SRD children show significant differences from normals in early stages of visual processing has been reported by Stanley and Hall (1973a), while a difference in recall of letter arrays after brief presentation, specifically leading to a deduction of visual memory deficit, has been found by the same authors (1973b).

Stanley (in Deutsch & Deutsch, 1975), summarizes the view that SRD may be connected with abnormalities at the very early stages in visual processing.

Outlining the relevance, already pointed out by Young and Lindsley (1970), of visual information processing to the study of reading disability, Stanley refers to the importance of iconic storage, or visual information store (VIS).

This rapidly decaying representation is transferred into short-term memory (STM) and subsequently in more manageable proportions to long-term memory (LTM). All these processes are clearly involved in the acquisition of reading skills, and abnormalities here represent a basic deficit, which could account for reading disability.

Using the method of temporal separation threshold, where VIS is measured as the interstimulus interval (ISI) at which two stimuli are reported, Stanley found SRD children to have significantly longer VIS than normal readers. He also measured transfer from VIS to STM using backward masking tasks, and found significantly longer processing times, while STM differences, measured by sequential memory tasks from the ITPA, indicated a lower level of STM. Spatial transform ability was found to be similar. The overall picture from Stanley's results, is of the scan and retrieval processes (VIS, and VIS to STM) in SRD children being markedly slower than in normals; and Stanley argues that this slowness of processing probably accounts for the difficulty that SRD children experience with sequential memory tasks. The integration of the results on STM itself is less clear. Stanley concludes that there are specific deficits at the early stages in visual information processing, and that these deficits can be construed as memory deficits; but he advises further research to clarify the precise nature of the inter-relationship of such deficits.

A more complex view of the role of memory is offered by Kolers (1975), who regards pattern analysing disability as measured by recognition of graphemic patterns, as characteristic of reading disability.

He claims that reading disabled children differ in the ability to analyse and remember graphemic patterns, but not in the ordinary visual perceptual sense, the level of performance being cognitive. There are serious methodological problems with this study in that no controls for intelligence were applied and it is dubious whether SRD children were in fact tested. His study is mentioned only as an example of an entirely different view of the level at which memory is implicated, contrasting with Stanley's highly specific findings on very early visual memory processes.

Stanley's emphasis on these processes has a good deal in common with the immediate background to the present study, to be presented in the next section.

CHAPTER 2.

VISUAL INFORMATION PROCESSING, SPECIFIC READING DISABILITY, AND THE PRESENT STUDY.

CHAPTER 2.

VISUAL INFORMATION PROCESSING, SPECIFIC READING DISABILITY, AND THE PRESENT STUDY

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2.1 Contrast and related concepts: definitions

An important characteristic of visual stimuli is spatial frequency, defined as the number of cycles of a sine-wave grating per degree of visual angle. A stimulus of repeated cycles of spatial frequency is called a grating, and the number of cycles (one dark and one light bar) subtended in one degree of visual angle at the eye is the spatial frequency of that grating. In everyday visual terms, spatial frequency corresponds to the information received as to such features of stimuli as size, and generality or detail.

A sine-wave grating in which luminance varies is a mathematically simple stimulus which can be changed in the laboratory, with reference to such features as spatial frequency and contrast. The contrast of a sine-wave grating is defined as $\frac{L_{max}-L_{min}}{L_{max}+L_{min}}$, where L is the luminance of a point on the screen (Kulikowski & Tolhurst, 1973).

Amongst the measures which can be derived from response to a grating is threshold contrast, which is the level of contrast required in order to just detect a grating. Human threshold contrast across spatial frequencies is often expressed as the contrast sensitivity function (CSF), where sensitivity is the reciprocal of threshold contrast. This function is regarded as an important visual perceptual measurement; Sekuler (1974), in his analysis of spatial vision, calls the contrast sensitivity function "a quick and useful summary of the overall response of the visual system" (p.207); moreover, he points to research (Campbell & Green, 1965) which uses the contrast sensitivity function to summarize not only the whole eye-brain system response, but selected portions of it.

The human contrast sensitivity function defines sensitivity to various spatial frequencies, and normally takes the form represented in the following diagram:

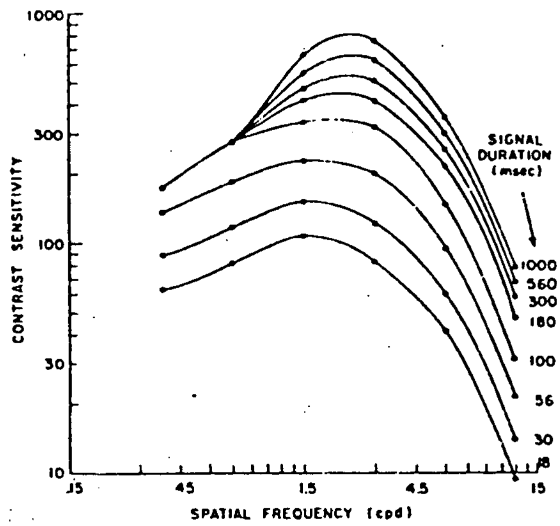


Fig.1: Contrast sensitivity functions for different signal durations. Values have been plotted as contrast sensitivity, the reciprocal of threshold contrast, as a function of spatial frequency. Smooth curves have been drawn through the points. The 8 sets of data are for the signal durations, in msec, as indicated. (Legge 1978)

2.2 Psychophysical evidence for spatial frequency channels

The discovery that retinal ganglion cells in the cat (Enroth-Cugell & Robson, 1966) and neurons in the monkey cortex (Campbell, Cooper, Robson & Sachs, 1969) respond selectively to a limited range of spatial frequencies, has led to the hypothesis that the human visual system is similarly organized, with spatial frequency-specific processing. Substantial evidence supports this notion.

Pantle and Sekuler (1968) point out that the ability of an adapting pattern, with a given spatial frequency, to affect the visibility of a test grating, with the same or some other spatial frequency, reflects the extent to which the perception of both gratings depends on common mechanisms. Hence the assessment of commonality of processing mechanisms for different stimuli can be carried out on this basis, using procedures known as masking techniques. Pantle and Sekuler's experiment, using 33 combinations of adaptation and test patterns, found significant differences in luminance threshold as a function of spatial frequency, and maximum masking effects, represented by peaks of luminance threshold, where spatial frequencies of adaptation and test gratings were approximately similar. The latter effect demonstrated some commonality; an adaptation grating of 1.05 c/deg, for example, affected test gratings of both .35 and 1.05 c/deg, maximally, suggesting that the mechanisms mediating the detection of these gratings was similar. It also demonstrated differences, in that higher frequency adaptation gratings produced maximum masking for comparable test gratings. This provides evidence for differentially tuned spatial frequency mechanisms which are, however, limited in number.

Blakemore and Campbell (1969) showed an adaptation effect on contrast sensitivity function, using sinusoidal gratings of varying spatial frequency with respect to the test stimulus. Their findings imply "channels tuned to spatial frequencies ranging from 3 c/deg up to the upper limit of resolution at about 48 c/deg" (Campbell, 1974,p.97). Campbell and Kulikowski (1966), in a simultaneous masking study, found that masking effects on threshold contrast were very much reduced when test and masking gratings differed in spatial frequency; Campbell and Maffei (1970), measuring evoked potential from the visual area of the scalp, determined that thresholds, represented by electrical signals, were selectively sensitive to spatial frequency and to orientation. Even the well-known McCollough after-effect[1] has been shown (Stromeyer, 1972) to be spatial frequency-specific.

On the basis of the above evidence, Campbell argues that the visual system may perform a spatial frequency analysis on the Fourier or

1. Following viewing of vertical black gratings on one colour, a complementary coloured after-effect is perceived on a vertical test grating of black and white.

sine-wave components of the input stimuli. While the argument presented in this thesis does not rely on the visual system performing such an analysis, it does depend on the notion of separate spatial frequency channels. On these, the evidence seems clear that, in the words of Sachs, Nachmias and Robson (1971, p.1183) that "the human visual system contains several sensory channels, each selectively sensitive to a different, moderately narrow range of spatial frequencies".

2.3 Temporal properties of spatial frequency channels

2.3.1 Visual persistence and reaction time:

Considerable research supports the view that the spatial frequency-specific channels differ in their temporal properties.

Visual information store (VIS) or visual persistance (VP) has been mentioned in an earlier section in relation to Stanley's work. This measure refers to the temporal properties of very early visual processing, corresponding to the time for which an image persists after stimulus offset. Meyer and Maguire (1977) measured the persistence produced by gratings of various spatial frequency, and showed that persistence increased with spatial frequency in an approximately linear fashion. This finding has been replicated consistently. (Lovegrove, Heddle & Slaghuis, in press; Bowling, Lovegrove & Mapperson, 1979).

An easily accessible measure of general visual temporal functioning is offered by reaction time, where the subject is required to press a switch as soon as a grating is seen. Reaction time has also been shown to vary with spatial frequency, so that longer reaction times are found with higher spatial frequency (Breitmeyer, 1975; Vassilev & Mitov 1976; and Lupp, Hauske & Wolf 1976).

2.3.2 Bloch's Law:

The fact that the visual system deals with stimuli in discrete time periods (Haber & Hershenson, 1973) makes temporal processing an important feature of vision research. The reciprocity of time and intensity was first investigated by Bloch (1885), and is represented by the equation Ixt=k, where I is the intensity, t the duration of the stimulus, and k a constant. This basic law, Bloch's Law, underlies a wide variety of perceptual phenomena, and, with visual persistence and reaction time, is a fundamental visual perceptual measure.

According to Bloch's Law, this reciprocity breaks down if the duration of the pulse is too long; the upper limit of the reciprocity is called the "critical duration", explained by Haber and Hershenson (1973) as "the duration beyond which adding more time ceases to have any effect". (p.121).

This reciprocity means that the intensity level required in order to detect a stimulus (the threshold) will decrease as the duration of stimulus exposure increases, up to the critical duration, which as a general rule, is about 100 msec, but which varies according to stimulus conditions which will be considered in detail later.

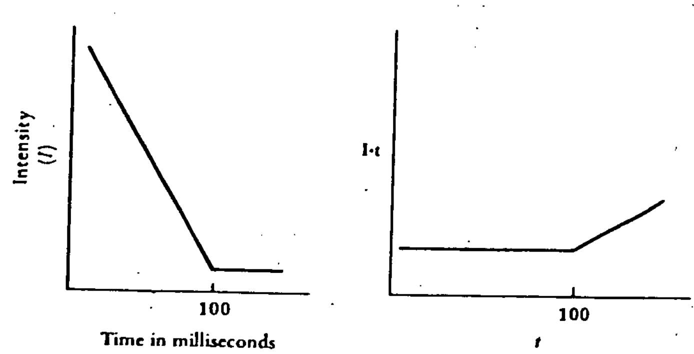


Fig. 2: Two ways of illustrating Bloch's Law showing the range over which time and intensity are reciprocally related. (Haber & Hershenson 1973)

It has also been clearly established that the same phenomenon exists when contrast level, rather than luminance of a pulse, is the dependant variable (Breitmeyer & Ganz, 1977).

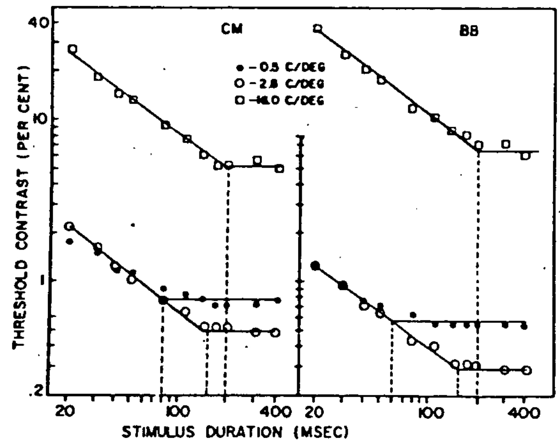


Fig. 3: Threshold contrast in per cent at spatial frequencies of 0.5, 2.8 and 16.0 c/deg as a function of stimulus duration. Both threshold contrast and stimulus duration are plotted along logarithmic co-ordinates in order to obtain linear functions indicating the contrast-duration reciprocity at each spatial frequency. (Breitmeyer & Ganz, 1977)

The examination of Bloch's Law as a function of spatial frequency supplies not only information about the temporal integration of the system, but also provides a measure of contrast sensitivity at various durations.

Like other temporal measures, those afforded by Bloch's Law also demonstrate spatial frequency-specific effects. Contrast sensitivity function varies with spatial frequency, though in a more complex way than either reaction time or visual persistence. This has been mentioned in an earlier section.

Critical duration, represented in the following diagram by the intersection of the two lines corresponding to threshold contrast at various durations, increases with spatial frequency.

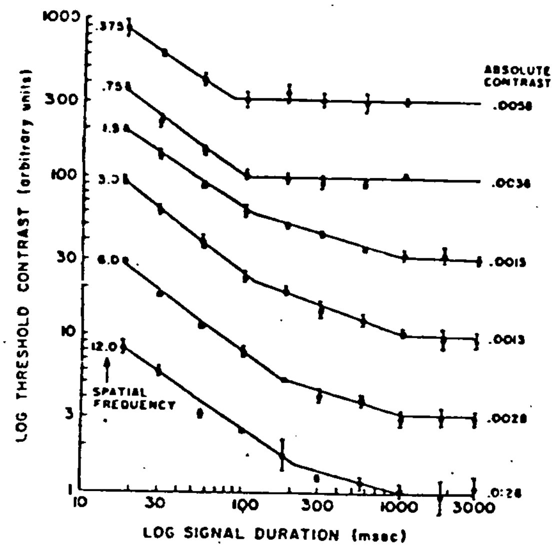


Fig. 4: Threshold as a function of duration. Contrast thresholds are plotted as a function of signal duration for 6 spatial frequencies. To facilitate display, the sets of data points have been vertically displaced and sequenced in order of spatial frequency. The ordinate values give the relative contrasts for points within a set. Absolute contrast of the asymptotic level of each curve is given at its right. Data points are the geometric means of 6 threshold estimates (18-1000 msec) or 4 estimates (1800 and 3000 msec) from 2 subjects. Threshold estimates were obtained from blocks of forced choice trials. Error bars represent ±1s.e. Each set of data has been fitted piecewise with straight line segments. (Legge, 1978)

Breitmeyer and Ganz (1977) found a similar increase in critical duration with spatial frequency.

These findings have led to the increasingly consistent conclusion that the human visual system is composed of channels, each channel responding to a narrow band of spatial frequencies and having characteristic temporal properties (Breitmeyer & Ganz, 1977; Campbell & Robson, 1968; Legge, 1978; Lovegrove, Heddle & Slaghuis, 1978, in press). The existence of "transient" and "sustained" mechanisms has been briefly alluded to, and the following section discusses these in more detail.

2.4 Transient and sustained mechanisms in visual information processing: Relevance to Bloch's Law

Enroth-Cugell and Robson (1966), in an electro-physiological study on the retinal ganglion cells of the cat, analysed spatial-summation properties in two distinct types of cells. Termed X and Y cells, they exhibited respectively linear and non-linear spatial summation; when temporal properties were considered (Cleland, Lubin & Levick, 1971), X and Y cells could be regarded as "sustained" and "transient" respectively. The X cells responded continuously to a steady test spot, in a characteristic "sustained" manner; the Y cells were observed to respond in a "transient" manner only to the onset or offset of a steady test spot; both cell types showed spatial frequency selectivity, with optimal responses of sustained cells occurring at a higher spatial frequency than for the transient cells. The correlate of this finding in the human visual system has been suggested by Breitmeyer and Ganz, (1976); Kulikowski and Tolhurst(1973), and Breitmeyer (1975).

These spatial frequency selective mechanisms have been described by Legge (1978) as two "distinct mechanisms" termed sustained and transient, after possible neural processes. The transient mechanisms respond best to rapid temporal changes, whereas the sustained mechanisms respond best to slow or slowly varying stimuli. Breitmeyer (1974) and Breitmeyer and Ganz (1977) summarize the relative properties of these two mechanisms:

Channels called "transient" operate at low to moderate spatial frequencies and are characterized by a transient response to the on and offset of a flashed stimulus of prolonged duration, and by a relatively high temporal resolution, as revealed by their greater sensitivity to flicker, rapid motion, and abrupt stimulus onset. Sustained channels, operating at moderate to high spatial frequencies, are characterized by a sustained response to a flashed stimulus of prolonged duration and by relatively poor temporal resolution.

In terms of threshold contrast, the implications of transient and sustained mechanisms are outlined by Legge (1978). Threshold for transient mechanisms should, beyond a relatively short critical duration, reach independence of signal duration, since they primarily respond only to stimulus onset and offset. Sustained mechanisms, on the other hand, would be expected to be characterized by an indefinite drop in threshold as a function of signal duration, because they continue to respond throughout stimulus presentation. While the use of the term "indefinite" is dubious, since the concept of critical duration, however long that duration is, must be accommodated, the outcome of this prediction is that low spatial frequency stimuli, insofar as they excite transient mechanisms, will produce shorter critical durations than will high spatial frequency stimuli, as has indeed been shown (Breitmeyer & Ganz, 1978). The lack of a clear dichotomy in Breitmeyer and Ganz's work arises, according to Legge, because even at the "low" spatial frequency (1.5 c/deg) used by Breitmeyer and Ganz, transient mechanisms may not be sufficiently involved. In an attempt to achieve less equivocal results, Legge examined contrast threshold considered as a function of duration over a range of spatial frequencies from .375 c/deg to 12 c/deg. He found the distinct qualitative differences represented by Fig. 4.

This important verification of the anticipated properties of sustained and transient mechanisms places Bloch's Law and contrast sensitivity function even more firmly in the range of temporal processes mediated through transient and sustained mechanisms. Critical duration acquires indeed a critical importance in the assessment of visual temporal processing. The preceding sections support the fundamental premise underlying the present study; that is, that both spatial and temporal processing are mediated by spatial frequency-specific channels which may be considered in terms of "sustained" and "transient" properties. The relationship between these channels provides a predictable response pattern in terms of spatial frequency.

The importance of such relative differences in ordinary visual tasks may not be great, but their importance to a task as complex as reading will be a matter for discussion in a later section. The stress at present is on the existence, in normal human subjects, of spatial frequency-specific channels with characteristic temporal properties which are related in theoretically consistent ways. The next section presents findings which imply differences in this pattern in SRD children.

2.5 Reading disability and spatio-temporal properties

Amongst the range of visual perceptual approaches to reading disability, of which several have been already mentioned, are the studies which examine stages of visual information processing such as visual persistence or VIS (Stanley & Hall, 1973b), transfer of information from VIS to short-term memory or STM (Stanley & Hall, 1973b, Lovegrove & Brown, 1978) and visual STM itself (Stanley & Hall, 1973a). Morrison, Giordani and Nagy (1977) show similar VIS durations for SRD's and controls, and Vellutino's findings, which have already been presented in an earlier section, imply no visual perceptual deficit in SRD's. However, a substantial amount of research finds differences at this basic level of early information processing, and Stanley's studies have been outlined in this context. It should be noted that there are inconsistencies in the direction of difference found; Stanley and Hall (1973b) show significantly longer VIS durations in SRD's when compared with controls, while Fisher and Frankfurter (1977) find shorter VIS durations in SRD's.

In view of the evidence on spatial frequency-specific temporal properties in visual processing, the possibility of abnormal interaction, in SRD children, of spatial frequency channels, bears investigation, particularly because the weight of evidence is for differences in precisely those early visual information processes which have been shown to be spatial frequency-specific.

The research providing evidence for an abnormal interaction is the immediate background for the present study.

Lovegrove and Brown (1978) found that VIS in 8 year old SRD's was, as expected, from Stanley and Hall's (1973b) study, significantly longer than controls, but that this difference decreased with age. This suggests (on first analysis) quantitative rather than qualitative differences. The interesting finding from the point of view of an argument for qualitative differences in temporal processing, however, derives from Experiment II of that study. Here, rate of transfer of information from VIS to short-term memory (STM) was investigated, and it was found that while both 8 year olds and 11 year olds transferred information at a significantly slower rate than controls, this difference, in fact, increased with age. The interpretation of simple developmental lag in temporal processing becomes highly questionable. These findings, however, were based on letter stimuli; the question remained as to whether such differences could be demonstrated using more general stimuli, the response to which would have clearer implications for fundamental deficit or abnormality. Lovegrove, Billing and Slaghuis (1978) investigated the effect of spatial properties of stimuli on visual processing, and found that processing of visual contour information at the level of the visual cortex, differed between SRD's and controls: SRD's showed higher levels of both visual contour orientation masking and the tilt aftereffect, as well as orientation differences in VIS duration. As was discussed earlier, it may be that in SRD children, the relative efficiencies of processing different kinds of spatial information is disturbed. Since there are clear links between processing of visual contour information, and spatial frequency processing (Campbell & Kulikowski, 1966), spatial frequency-specific effects on VIS were investigated.

Lovegrove, Heddle and Slaghuis (1979, in press), measured VIS duration as a function of spatial frequency. VIS duration was determined by the temporal separation between two successive stimuli at which subjects could discern a blank, the stimuli being sine-wave gratings at five spatial frequencies. The findings were that the disabled reading group had significantly longer durations of visual persistence then controls at 1, 2 and 4 cycles per degree; were similar at 8 cycles per degree, and at 12, had significantly shorter visual store durations. The authors state: "Whether specifically disabled readers have longer, shorter or the same durations of VIS as controls may depend on the dominant spatial frequencies contained in the stimuli in each [of the previous, apparently discrepant] experiment". It would seem that spatial frequency is having a differential effect on the temporal aspects (of which VIS, of course, if one) of visual processing, with SRD children.

In summary, it seems that for SRD children, there is the possibility of an abnormal interaction between spatial properties of stimuli and the temporal aspects of the processing of those stimuli, so that the expected patterns do not apply.

The discovery of qualitative as well as quantitative differences in the visual processing of children with reading disability can usefully be related to the reading process itself.

If contour orientation information is processed abnormally, (Lovegrove, Billing & Slaghuis, 1978), the orientation aspects of letter recognition might be expected to suffer. It is well established (Critchley 1964; Hepworth 1967) that reversals and inversions, essentially problems of orientation, are far more common in disabled readers than in their normally reading peers.

Rapid processing of peripheral information, conferred by a short VIS in low frequency channels, may serve a role in the visual guidance of central vision (Lovegrove, Heddle & Slaghuis, 1979, in press), with clear application to the reading task, which requires integration of successive fixations involving both central and peripheral vision. And it may also be speculated that relatively short VIS duration at high spatial frequencies would lead to relatively poor recognition of detail, although this remains unproven. The reading task requires both accuracy of detail, recognition and sophisticated integration of sequences of a broader kind, and difficulties in precisely those components of reading will be conferred by the kinds of distortions of visual processing suggested by this group of studies.

2.6 The present study

Bloch's Law, as has been outlined, affords several important measures:

(a) the critical duration at different spatial frequencies.

(b) threshold contrast, and hence its reciprocal, contrast sensitivity, at a range of spatial frequencies and durations of stimulus exposure.

(c) This can include a contrast sensitivity function corresponding to effectively unlimited duration, beyond which increased time has no effect. The latter would provide an "absolute" contrast sensitivity function.

Reference to the value of these measurements has already been made (Sekuler, 1974). They become even more relevant when it is recalled from earlier discussion that, in all of them, spatial frequency-specific effect have been established (Breitmeyer & Ganz, 1977; Legge, 1978).

The immediate background to the present study demonstrated spatial frequency-specific differences between SRD's and controls in the very early stages of visual processing. These differences, incidentally, may vary with contrast, since it has been shown (Bowling, Lovegrove & Mapperson, 1979) that the persistence of low contrast gratings is longer than that for high contrast gratings, an effect which increased with spatial frequency. It is also argued in that paper that integration time may be a basic component of visual persistence. Data on critical duration as a function of spatial frequency can be plotted to form a line of similar slope to the data on visual persistence. In view of the persistence differences found in SRD's, the contribution of critical duration to those differences bears investigation. Further unpublished research by Lovegrove (1978) implies spatial frequency-specific differences in threshold durations at constant contrast, between SRD's and normals, which, though reaching significance only at low spatial frequency, leads to the deduction that contrast exerts differential effects on SRD children. In conjunction with the data on persistence, the investigation of the relationship in SRD's, between critical duration and spatial frequency, as well as contrast sensitivity and spatial frequency, becomes therefore an important dimension in the study of the effect of spatial properties on temporal processes, since it is precisely that interaction which may be disturbed in SRD's. A study of the operation of Bloch's Law provides, of course, just such information.

CHAPTER 3.

METHOD AND RESULTS

Method

3.1 Subjects:

Ten experimental subjects were selected from amongst children known to have reading difficulties, who attended a special English class at a local High School. Children were selected according to the following criteria:

1. An intellectual ability within normal limits (IQ 85 or higher), as measured on an appropriate intelligence test. Most had been individually tested on a WISC or Binet, and all had a Ravens Progressive Matrices score.

2. Reading age, as measured on the accuracy scale of the Neale analysis of Reading Ability (1966), falling two years or more below chronological age.

3. Absence of physical, emotional or social disability which could be regarded as primary, and absence of obvious educational deficit (e.g., frequent school changes).

Children for the control group were selected from the school files, on the basis of matched sex, age, IQ and socioeconomic status, as measured by father's occupation.[1] All were reading at a level considered to be appropriate for their age.

1. Status taken from Congalton's matrix of socioeconomic status in Australia (1963). This ranks in two ways from Rank 1 (professional) to Rank 7 (unskilled); and from Rank 1 (upper class) to Rank 7 (working class).

All subjects were male. The average age of SRD's was 14.1 yrs, ranging from 12.3 yrs to 15.5 yrs; controls had an average age of 14.0 yrs, ranging from 12.2 yrs to 15.5 yrs. The average IQ in the SRD's was 99, in controls 100. Reading age in the SRD's averaged 9.4, and ranged from 7.9 yrs to 11.6 yrs. Details may be found in Appendix 1.

The matching procedure produced two groups which can be considered as highly similar. While it is not appropriate to "average" socio-economic status, because the ratings (e.g. 4.38) refer to two separate scales, the similarity of SES, obtained by individual matching of parental occupation, may be seen on Appendix 1. The highest SES for both groups was 1.92, and the lowest, 6.66 for SRD's and 6.56 for controls. Attendance at the same high school does not guarantee equivalence of SES, and this matching was felt to be of considerable importance. Research evidence (e.g. Rutter & Yule, 1975) supports the commonsense notion that low SES is correlated with reading backwardness, due probably to cultural deprivation and comparative lack of verbal stimulation. There is some likelihood that experimental S's may be presenting the results of low SES as specific reading disability, although IQ remains in the normal range. Any perceptual effects which are a product of this factor will, however, due to the matching procedure, be present to the same degree in the control group.

S's were generally very co-operative, considering the monotony of the task. This may have been due in part to the intermittent reinforcement of a preferred confectionery, and also to the free choice of subjects which could be evaded to participate in testing sessions. The lack of trends in the latter was surprising; Art and Music shared unpopularity with English and Mathematics.

3.2 Apparatus:

The inspection field was presented on a B.W.D. Model 539D oscilloscope (P31 Phosphor), viewed at a distance of 228 cm. At this distance the masking of the oscilloscope with an 8 cm. occluder provided a circular field, subtending 2^o of visual angle. The uniform-field luminance of the display was 2.2 cd/m^2.

The stimuli consisted of vertical sinusoidal gratings at four spatial frequencies generated in the manner described by Campbell and Green (1965). The contrast was varied using a B & K Precision 2810 digital voltmeter, adjustable in steps of .001. An interval timer was connected to control duration of stimulus.

Testing was carried out in a photographic dark room, at the High School. Every effort was made by teachers to ensure undisturbed conditions for the research programme, and a key was provided after the lunch-time disappearance of a quantity of reinforcements. Inevitably, however, there was a certain amount of noise in the passage outside, and the progress of testing was sometimes interrupted by curious students, or those anxious to offer their perceptual abilities for assessment. Conditions of luminance and apparatus setting were constant throughout, and the testing situation was generally very good.

3.3 Procedure:

Each subject was tested individually, and required approximately two hours of testing, administered in at least two sessions, generally on different days. Control and experimental subjects were alternated. All subjects had normal uncorrected vision, with better than 6/6 Snellen acuity.

Threshold contrast was determined for each of nine stimulus durations (40, 60, 80, 100, 150, 200, 300, 500 and 1000 msec.) at each of four spatial frequencies (2, 4, 12, and 16 c/deg.). The order of presentation of spatial frequencies was counterbalanced across subjects, and counterbalancing of order of duration presentation (from 40 to 1000 or 1000 to 40) was also carried out so that each subject was tested on two spatial frequencies at decreasing durations, and two at increasing durations. Details may be seen on Appendix 2. All spatial frequencies were thus tested at all durations in a cross-randomised manner.

The subject sat in a chair directly in front of the oscilloscope. No supporting brace was used. Instructions were standard throughout (Appendix 3) and were given during the dark adaptation period of five minutes.

The subject's task was to determine whether or not a grating was flashed on the screen, after the experimenter said "Now" and the subject pressed a switch. The foreperiod was held constant at 10 msec. throughout all trials and all subjects. The contrast threshold was determined using a blockwise tracking procedure adapted from Houlihan and Sekuler (1968), thus providing a measure of the miss and false alarm rates. Each block consisted of twelve trials with the target stimulus appearing, or a blank screen appearing, on six trials each, in random order. Contrast was held constant for each block and varied from block to block in steps of .005, except at contrast levels of .005 or below, where steps of .002 were used. Threshold contrast was judged to have been reached when the subject achieved 75% accuracy over a single block or bracketed this value between successive blocks. In order to determine the contrast for the first block, approximate threshold was determined using serial incrementation in steps of .005 from a clearly subthreshold contrast, until the subject detected the grating.

Results

3.4 Raw Data:

Raw scores took the form of contrast thresholds at the four spatial frequencies and nine durations specified, for the two groups, each with 10 S's. Because scores were in voltage readings, all thresholds were in terms of relative contrast. Appendix 4 shows the raw scores.

The miss rate (number of misses divided by total number of target trials) and the false alarm rate (number of false alarms divided by the total number of blank trials), were calculated for each S. The averages for each group are shown in Appendix 5. These were analysed by the Mann-Whitney U Test (Siegel, 1956), which revealed no significant differences in miss and false alarm rates between the two groups, indicating that the demonstrated differences to be reported, were not due to criterion differences.

The data available have been analysed in two ways, and results will be presented in two sections, dealing with critical duration (CD), and the contrast sensitivity function (CSF).

3.5 Critical Duration:

Log threshold was plotted against log duration in the manner used by Legge (1978), for each S at each spatial frequency. It was usually found that contrast threshold decreased with duration increase, in two stages, and that a straight line could be fitted to each component. Generally there was a steeply descending portion, followed by a less steeply descending portion. Lines were fitted to each component by linear regression, using the method of least squares, and the point of intersection was taken as an estimate of CD.

In all cases where a point of intersection was obtainable, the first slope was maximised, and the pivotal point included in both slopes. This strict criterion was applied to all S's in each condition to avoid shifts in criterion.

Eighty sets of data (20 S's at each of four spatial frequencies) were dealt with in this way. For 6 sets of data it was impossible to fit two lines to the points available, and here no CD was obtainable, and the statistical analysis treated these cases as missing data points. Because three of these were from each group, and they were spread across spatial frequencies, it is unlikely that they would have influenced the analysis.

CD's may be seen on Appendix 6, and Fig. 5 shows these means.

It can be seen that the control group showed a linear increase in CD with spatial frequency, as found by Legge (1978), while for SRD's this difference appears much less.

Regression lines can be plotted through the points on Fig. 5 to show the slope of each set of points. The equations for SRD's and controls respectively were:

$y = 124.1 + 4.6x$

and $y = 105.0 + 10.5x$

Fig. 6 presents those regression lines.

The regression coefficient for the control data at 10.5 agreed well with the regression coefficient of 11.1 obtained by Bowling, Lovegrove and Mapperson (1979) in normal adults, using data from Legge (1978) on critical duration.

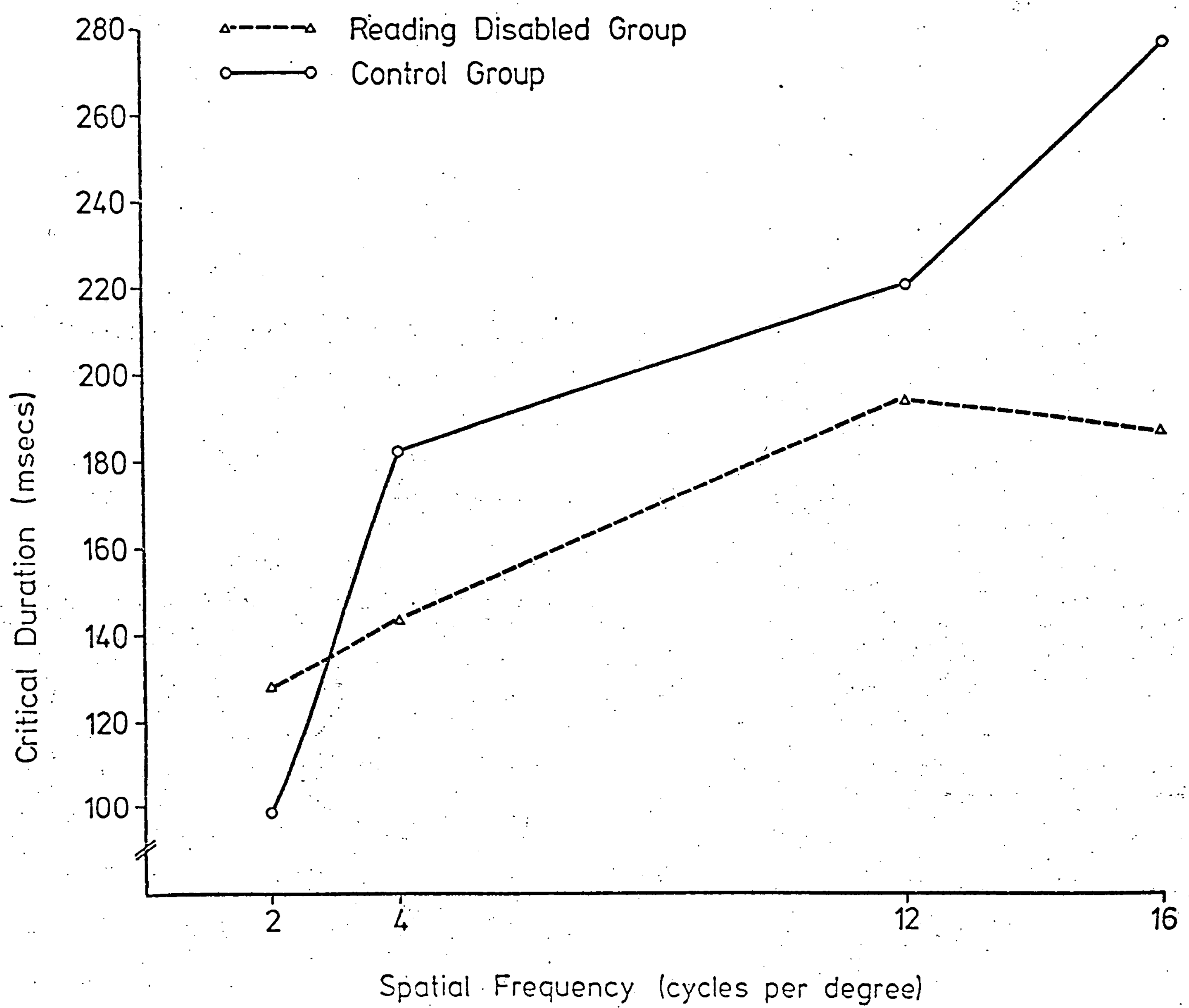


Fig. 5: Mean critical duration as a function of spatial frequency for the two groups.

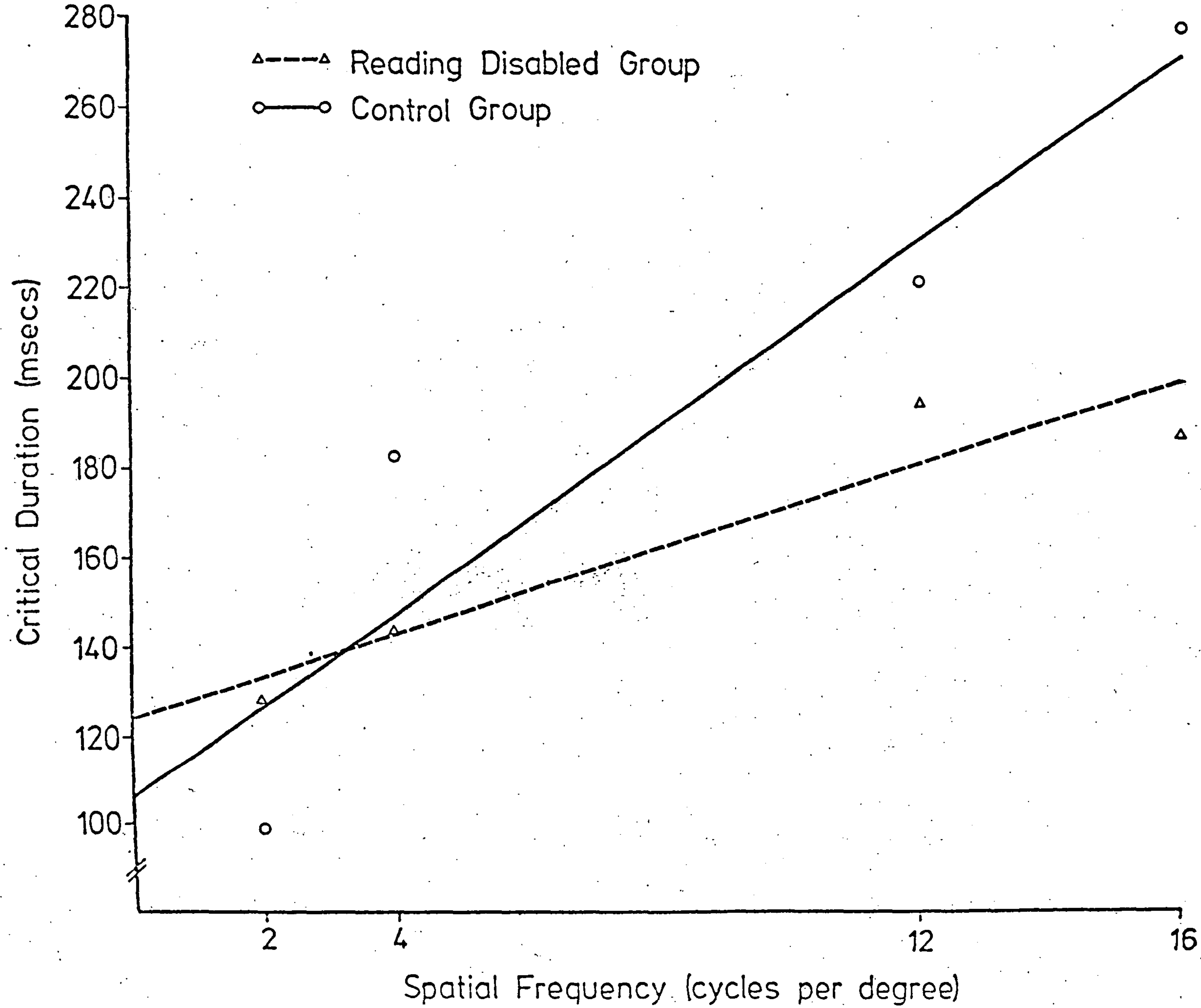


Fig. 6: Regression lines for mean critical duration as a function of spatial frequency.

Clearly the slope for SRD's was much flatter at 4.6 and the difference in slope approaches significance ($F(1,4) = 3.7$, $p = 0.12$)

Mean contrast thresholds for the two groups at each duration and each spatial frequency were also plotted, to produce graphs which may be compared with Legge's (1978) figure, on p.27 of the present study. These figures may be seen on Appendix 7.

For both groups relative slopes of the two components intersecting at CD were similar to Legge's with respect to spatial frequency. The typical picture was of a steep initial slope and relatively flat second slope at low spatial frequency, and at higher spatial frequency the two slopes, while remaining different, were less strikingly so. For SRD's the compression of CD's is evident.

3.6 Analysis of variance: CD

Because of the correlation between means and variance in all conditions, the data did not satisfy the homogeneity of variance assumption for analysis of variance. A log transformation was therefore carried out on the individual CD's. The summary of the analysis of variance is shown in Table 1.

A two-way analysis of variance with repeated measures on spatial frequency was carried out using Teddybear (Wilson, 1978), and the summary of the analysis of variance is seen on Table 1 on the following page.

There was a non-significant group effect ($F(1,18) = 2.5$, $p=0.13$), showing that, over all frequencies, the difference between CD's for SRD's and controls approaches but does not reach significance.

TABLE 1

Summary of Analysis of variance (critical duration)

Source of Variation	SS	df	MS	F	P
Groups	0.36	1	0.36	2.53	0.13
Frequency	4.92	3	1.64	6.97	0.0004
G x F	1.01	3	0.34	1.43	0.24
Error	15.26	66	0.23		
TOTAL	21.54	73	0.30		

The spatial frequency main effect was significant ($F(3, 54) = 6.97$, $p < 0.05$), indicating that across both groups, spatial frequency significantly affected CD. This is in line with previous reports, where CD increases in a linear fashion with spatial frequency. This effect of spatial frequency on CD is not significantly different in the two groups, though the group-frequency interaction ($F(3, 54) = 1.43$, $p = 0.24$) suggests a trend towards difference, which is supported by comparing the individual regression coefficients for each subject. The F test comparing individual slopes across groups ($F(1, 18) = 3.4$, $p = 0.08$), while regarded with caution, is significant on a one-tailed test.

There is further tentative support from the Duncan's test, showing, at the 0.01 level, that CD for controls increased significantly with spatial frequency. In the SRD's there is no difference at all ($p > 0.05$).

In summary, there is a trend towards a significant difference in CD's between groups as a function of spatial frequency, as might be expected from Fig. 6.

3.7 Contrast sensitivity function (CSF)

Contrast sensitivity was calculated as the reciprocal of contrast threshold, raw scores for which may be found in Appendix 4. Fig. 7 presents the mean CSF for SRD's and controls at all durations from 40 msec. to 1000 msec.

Analysis of variance on all CSF results is presented in Table 2, following. There was no main effect of groups ($F(1, 18) = 0.98$, $p > 0.05$), nor was there a significant group-frequency interaction ($F(3, 54) = 0.171$, $p > 0.05$). There was, however, a main effect of frequency, showing that spatial frequency significantly affects contrast sensitivity ($F(3, 54) = 252$, $p < 0.001$) Examination of Fig. 7 shows that contrast sensitivity peaked at 4 c/deg., given long durations, although controls and SRD's were different in this respect, which will be discussed shortly. It will also be observed that at shorter durations the function was clearly linear, contrast sensitivity decreasing with spatial frequency increase, without the peak at 4 c/deg mentioned earlier. These findings are consistent with previous data (Legge, 1978).

There was also a significant duration effect ($F(8, 144) = 63$, $p < 0.001$). Longer durations increased sensitivity, in keeping with expected results from Bloch's Law, which would predict decreasing contrast threshold with increasing durations.

TABLE 2

Summary of analysis of variance (contrast sensitivity)

Source of Variation	SS	df	MS	F	P
Groups (E)	0.05	1	0.05	0.99	0.33
Frequency (F)	1.75	3	0.58	252.57	0.00
Duration (D)	1.17	8	0.15	63.43	0.00
EF	0.01	3	0.00	0.17	0.92
ED	0.02	8	0.00	1.38	0.21
FD	0.48	24	0.02	8.62	0.00
EFD	0.01	24	0.00	0.21	0.99
S	0.98	18	0.05	23.59	0.00
Error	1.45	630	0.00		
TOTAL	5.91	719	0.01		

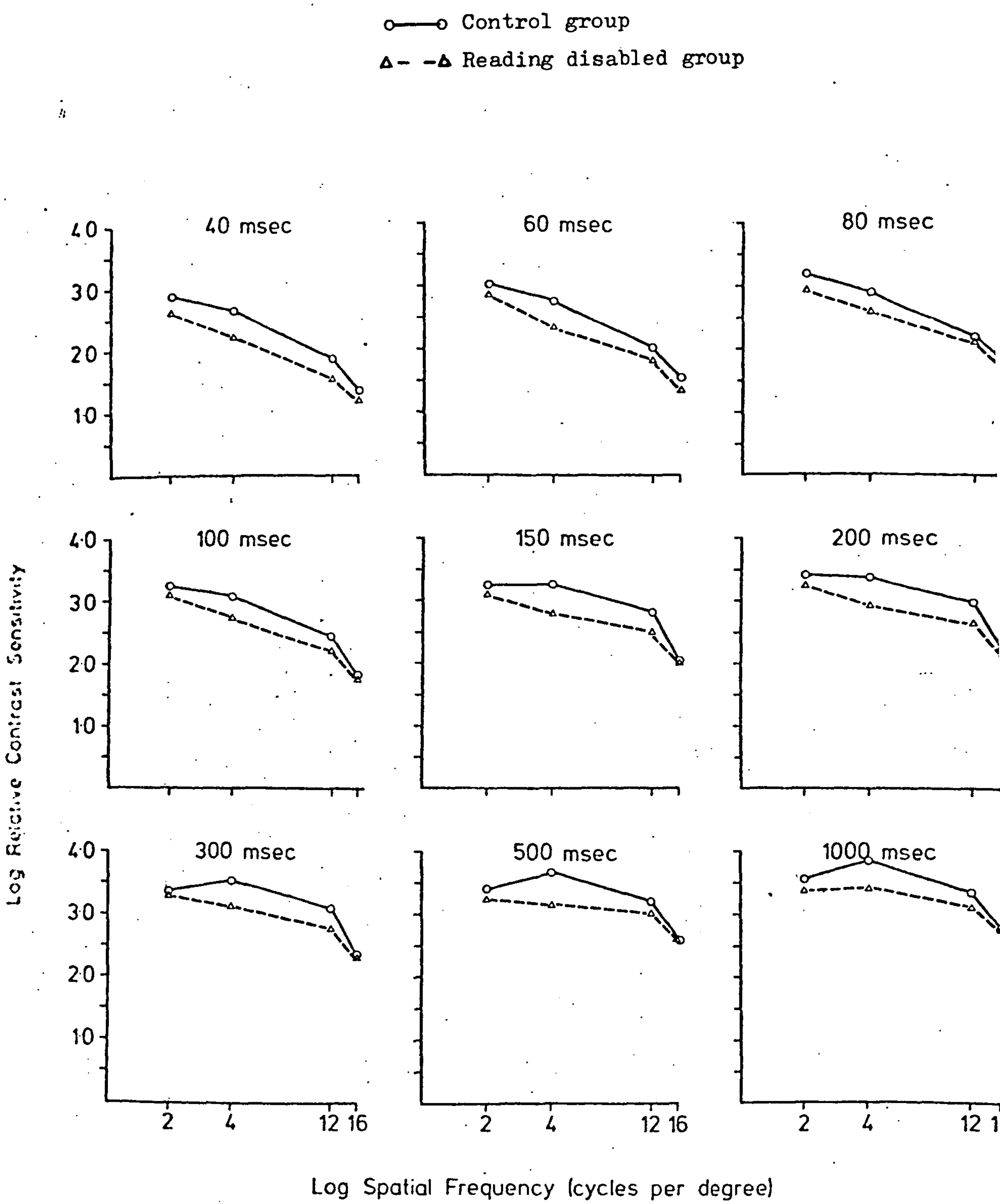


Fig. 7: Mean CSF for the two groups at the nine durations tested.

There was a significant frequency-duration interaction effect ($F (24, 432) = 8.6$, $p < 0.001$), indicating that duration exerted differential effects on the sensitivity to each of the four spatial frequencies used, and, in the manner described above, altered the apparent CSF, which is clearly seen in the Fig. 7. The addition of time increased sensitivity most noticeably at 4 c/deg., to produce peak sensitivity there by 1000 msec in both groups.

Even though there was no main effect of groups, nor an interaction between groups and frequency, the CSF at each duration bore examination, especially in view of the apparent consistent differences between SRD's and controls at all durations (Fig. 7).

The pattern of sensitivity for each group was of considerable interest, hence analyses were carried out on the interaction of orthogonal components, separated into linear, quadratic and cubic.

This is necessary because the analysis of variance shown in Table 2 collapses means of contrast sensitivity across all the durations. It can be argued that such a procedure would be expected only to reach significance when differences are both considerable, and evenly distributed. Little meaning can be attached to the failure to find overall differences by this method.

More importantly, the clear pattern differences on the graphs suggest a difference in shape of function at different durations rather than consistent quantitative differences across all spatial frequencies. An orthogonal analysis tests the significance of this apparent effect.

Examination of the graphs reveals that control data were consistent throughout with Legge's (1978) findings. CSF changed from a linear function decreasing with spatial frequency at short durations, to a quadratic function peaking at 4 c/deg. at longer durations.

Sensitivity at all spatial frequencies increased with increased duration.

The results of the analysis for each duration are presented separately below.

i) 40 msec. duration

The summary of analysis of variance is presented in Table 3, following. The analysis of variance showed a significant main effect of groups ($F(1,18) = 4.49$, $p < 0.05$), indicating that SRD's were less sensitive than controls. At 4 c/deg. and 2 c/deg., the differences were significant ($T = 3.76$, $p < 0.001$ and $T = 2.12$, $p < 0.05$, respectively).

The linear trend was significant ($F(1,18) = 213.36$, $p < 0.001$), with a non-significant quadratic ($F(1, 18) = 1.98$, $p > 0.05$) trend, indicating that, overall, there was a significant linear decrease in sensitivity with increasing spatial frequency. Although the cubic trend reached significance ($F(1, 18) = 4.75$, $p < 0.05$), this result was unsupported by significance at any other shorter durations, while the linear trend persisted at the 0.001 level, clearly representing the dominant function at short durations. The two groups demonstrate similar shapes of functions; there was no significant interaction between groups and frequency ($F(3, 54) = 1.82$, $p > 0.05$), nor was there significant interaction between orthogonal components. In particular, there was no significant difference in quadratic trend ($F(1, 54) = 1,56$, $p > 0.05$), indicating no difference in shapes of functions.

Duncan's Multiple Range Test showed spatial frequency-specific differences either at or near significance, within both groups. This latter effect occurred at each of the durations tested, and is reflected in the analysis of variance for mean contrast sensitivities, summarized in Table 2.

TABLE 3

Summary of analysis of variance at 40 msec.

Source of Variation	SS	df	MS	F	P
Groups (E)	134.51	1	134.51	4.49	0.05
S within Groups	539.21	18	29.96	3.46	0.00
Frequency (F)	1901.30	3	633.77	73.36	0.00
L	1843.18	1	1843.18	213.36	0.00
Q	17.10	1	17.10	1.98	0.17
C	41.03	1	41.03	4.75	0.03
Frequency x Groups (ExF)	47.18	3	15.73	1.82	0.15
L	20.91	1	20.91	2.42	0.13
Q	13.49	1	13.49	1.56	0.22
C	12.78	1	12.78	1.48	0.22
S between Groups	466.49	54	8.64		
TOTAL	3088.69	79	39.10		

ii) 60 msec stimulus duration

The summary of analysis of variance at this duration is presented in Table 4. Both functions were significantly linear ($F(1, 18) = 145.42$, $p < 0.001$), and the analysis of orthogonal components was similar to that at 40 msec. There was no main effect of groups ($F(1, 18) = 1.66$, $p > 0.05$). T-tests indicated a significant difference at 4 c/deg ($T = 2.79$, $p < 0.01$), and there was no significant difference for other spatial frequencies. Significant differences at a single spatial frequency must be regarded with caution when there is no main effect, nor an interaction effect, as is the case here; the importance, however, of results at 4 c/deg in particular, will be referred to later. The frequency effect is significant ($F(3, 54) = 49.67$, $p < .001$).

iii) 80 msec stimulus duration

The analysis of variance summary table is presented in Table 5.

Again, there was no main effect of groups ($F(1, 18) = 0.59$, $p > 0.05$), nor an interaction effect, with either frequency or orthogonal components. The functions remained linear, with no significant quadratic ($F(1, 18) = 0.88$, $p > 0.05$) or cubic ($F(1, 18) = 1.23$, $p > 0.05$) trends, and the shape of the functions for the two groups was similar, as there were no interaction effects on orthogonal components. The difference at 4 c/deg approached significance ($T = 1.72$, $p = 0.09$), and the main frequency effect was, again, significant ($F(3, 54) = 31.32$, $p < 0.001$).

iv) 100 msec stimulus duration

The summary of analysis of variance may be seen on Table 6.

TABLE 4

Summary of analysis of variance at 60 msec.

Source of Variation	SS	df	MS	F	P
Groups (E)	80.61	1	80.61	1.66	0.21
S within Groups	875.30	18	48.63	2.50	0.00
Frequency (F)	2895.55	3	965.28	49.67	0.00
L	2825.62	1	2825.62	145.42	0.00
Q	68.16	1	68.16	3.51	0.76
C	1.77	1	1.77	0.09	0.76
Frequency x Groups (E x F)	82.27	3	27.42	1.41	0.24
L	4.92	1	4.92	0.25	0.62
Q	21.15	1	21.15	1.09	0.30
C	56.20	1	56.20	2.89	0.09
S between Groups	1049.26	54	19.43		
TOTAL	4982.99	79	63.08		

TABLE 5

Summary of analysis of variance at 80 msec

Source of Variation	SS	df	MS	F.	P
Groups (E)	58.97	1	58.97	0.59	0.45
S within Groups	1788.29	18	99.35	2.10	0.00
Frequency (F)	3113.93	3	1037.98	31.32	0.00
L	3043.99	1	3043.99	91.85	0.00
Q	29.04	1	29.04	0.88	0.35
C	40.91	1	40.91	1.23	0.27
Frequency x Groups (E x F)	94.11	3	31.37	0.95	0.42
L	55.44	1	55.44	1.67	0.20
Q	0.20	1	0.20	0.01	0.94
C	38.47	1	38.47	1.16	0.29
S between Groups	1789.57	54	33.14		
TOTAL	6344.87	79	86.64		

The analysis produced similar results to those at 80 msec, with a significant frequency effect ($F\ (3, 54) = 34.01,\ p < 0.001$), a significant overall linear trend ($F\ (1, 18) = 101.18,\ p < 0.001$), and similar shaped linear functions in both groups. The difference between groups approached significance at 4 c/deg ($T = 1.83,\ p = 0.07$).

The group difference found at 40 msec, in view of the fact that it did not occur again at the succeeding durations of 60, 80 and 100 msec, should be viewed with caution. The similarity of the graphs would lead one to expect consistency of this finding, and it is probable therefore, that a significant difference has occurred at 40 msec by chance, as a reflection of the large number of comparisons.

Up to this duration, the most consistent effect was the difference at 4 c/deg, where SRD's showed lower sensitivities at or near significance at all durations, even though their overall sensitivity was not less.

Linear functions have applied so far for both groups.

v) 150 msec stimulus duration

The analysis of variance summary is presented on Table 7. This was the first duration at which a quadratic function for CSF could be observed, although it was slightly less than significant ($F\ (1, 18) = 3.46,\ p = 0.06$). However, the two groups differed significantly in terms of the quadratic component of the function ($F\ (1, 54) = 4.79,\ p < 0.05$), and it is clear from the graphs that while there was a quadratic function in controls, there was a linear function in SRD's. This tendency persists to 1000 msec. At 4 c/deg and 12 c/deg, sensitivity differences between groups were significant ($T = 3.78,\ p = 0.001$; $T = 2.12,\ p < 0.05$ respectively), and despite the main effect of groups, these differences can be interpreted as contributing to the group interaction on quadratic function. Again, there was a significant effect of frequency ($F\ (3, 54) = 25.66,\ p < 0.001$).

TABLE 6

Summary of analysis of variance at 100 msec

Source of Variation	SS	df	MS	F	P
Groups (E)	126.71	1	126.71	1.071	0.31
S within Groups	2130.40	18	118.36	3.26	0.00
Frequency (F)	3695.01	3	1231.67	34.01	0.00
L	3669.35	1	3664.35	101.18	0.00
Q	4.17	1	4.17	0.11	0.73
C	26.49	1	36.49	0.73	0.40
Frequency x Groups (E x F)	51.93	3	17.31	0.48	0.69
L	18.62	1	18.62	0.51	0.47
Q	29.85	1	24.85	0.69	0.41
C	8.45	1	8.45	0.23	0.53
S between Groups	1955.59	54	36.21		
TOTAL	7959.64	79	100.75		

TABLE 7

Summary of analysis of variance at 150 msec.

Source of Variation	SS	df	MS	F	P
Groups (E)	483.58	1	483.58	3.02	0.10
S within Groups	2878.78	18	159.93	4.55	0.00
Frequency (F)	2704.18	3	901.39	25.66	0.00
L	2580.83	1	2580.83	73.46	0.00
Q	121.48	1	121.48	3.46	0.07
C	1.87	1	1.87	0.05	0.81
Frequency x Groups (E x F)	222.06	3	74.02	2.11	0.11
L	19.88	1	19.88	0.57	0.45
Q	168.38	1	168.38	4.79	0.03
C	33.80	1	33.80	0.96	0.33
S between Groups (error)	1897.09	54	35.13		
TOTAL	8185.69	79	103.62		

vi) 200 msec stimulus duration

Table 8 presents the summary of the analysis of variance. Results were similar to those reported above for 150 msec, tending, however, to be less significant. There was no significant overall quadratic function ($F (1, 18) = 0.95, p > 0.05$) and the interaction of groups with quadratic component only approached significance ($F (3, 54) = 2.97, p = 0.09$).

A significant effect of spatial frequency was again found ($F (3, 54 = 18.71, p < 0.001$). At this duration and the preceding duration, because a quadratic function is emerging for controls, the effect of spatial frequency has changed. Sensitivity for controls is now tending to peak at 4 c/deg, while falling sharply at the higher spatial frequencies. The change in quadratic component between the two groups is reflected by the significant sensitivity difference at 4 c/deg ($T = 2.74, p < 0.01$).

vii) 300 msec stimulus duration

The analysis of variance may be seen on Table 9, following. The overall quadratic function was significant ($F (1, 18) = 8.25, p < .01$), indicating that for both groups, CSF is approximating the quadratic curve described by Legge (1978). There was, however, a difference in the shape of the function in respect of the quadratic component, which approached significance ($F (1, 54) = 3.49, p = 0.07$). The significant difference at 4 c/deg ($T = 2.6, p < 0.05$) underlies the difference in shape of function, as will be seen by examination of Fig. 7 . Again, there was a significant spatial frequency effect ($F (3, 54) = 22.08, p < 0.001$).

TABLE 8

Summary of analysis of variance at 200 msec

Source of Variation	SS	df	MS	F	P
Groups (E)	346.37	1	346.37	1.55	0.22
S within Groups	4017.50	18	223.19	2.95	0.00
Frequency (F)	4246.53	3	1415.51	18.71	0.00
L	4173.08	1	4173.08	55.17	0.00
Q	71.82	1	71.82	0.95	0.33
C	1.62	1	1.62	0.02	0.38
Frequency x Groups (E x F)	348.60	3	116.20	1.54	0.21
L	63.28	1	63.28	0.84	0.36
Q	224.81	1	224.81	2.97	0.09
C	60.51	1	60.51	0.80	0.37
S between Groups (error)	4084.49	54	75.64		
TOTAL	13043.49	79	165.11		

TABLE 9

Summary of analysis of variance at 300 msec

Source of Variation	SS	df	MS	F	P
Groups (E)	347.69	1	347.69	1.33	0.26
S within Groups	4723.27	18	262.40	3.71	0.00
Frequency (F)	4684.58	3	1561.53	22.08	0.00
L	3954.55	1	3954.55	55.92	0.00
Q	583.38	1	583.38	8.25	0.01
C	146.65	1	146.65	2.07	0.15
Frequency x Groups (E x F)	295.04	3	98.35	1.39	0.26
L	0.03	1	0.03	0.00	0.98
Q	247.26	1	247.26	3.49	0.07
C	47.75	1	47.75	0.68	0.41
S between Groups (error)	3818.85	54	70.72		
TOTAL	13869.44	79	175.56		

viii) 500 msec stimulus duration

Table 10 presents the summary of analysis of variance. There is a significant overall quadratic function ($F(1, 18) = 13.64$, $p < 0.001$), and a significant difference in the quadratic component of the two groups ($F(1, 54) = 5, 16$, $p < 0.05$). SRD's showed a more linear function, again with the significant difference at 4 c/deg ($T - 2.61$, $p < 0.001$) underlying this difference in shape of function. Controls are showing peak sensitivity at 4 c/deg, while SRD's are continuing to show linearly decreasing sensitivity with increasing spatial frequency. At this duration there was also a significant interaction between groups and frequency ($F(3, 54) = 3.88$, $p < 0.01$), indicating that spatial frequency overall was exerting significantly different effects on the sensitivity of SRD's when compared with controls.

ix) 1000 msec stimulus duration

The analysis of variance summary is presented in Table 11. A significant overall quadratic function was found ($F(1, 18) = 9.88$, $p < 0.01$), and this is the first duration at which the function for SRD's on the graph can be observed to be quadratic, with a slight tendency to peak at 4 c/deg. The peak, however, is not as marked as for controls, and this is clear from the fact that a significant difference persisted at 4 c/deg ($T = 2.61$, $p < 0.05$). The tendency for SRD's to approximate controls in terms of shape of function is reflected by the lack of a significant difference in the quadratic component ($F(1, 54) = 1.79$, $p > 0.05$).

TABLE 10

Summary of analysis of variance at 500 msec.

Source of Variation	SS	df	MS	F	P
Groups (E)	568.72	1	568.72	2.05	0.17
S within Groups	4989.37	18	277.19	3.77	0.00
Frequency (F)	3509.02	3	1169.67	15.91	0.00
L	2375.29	1	2375.29	32.32	0.00
Q	1002.18	1	1002.18	13.64	0.00
C	131.55	1	131.55	1.79	0.19
Frequency x Groups (E x F)	854.80	3	284.93	3.88	0.01
L	78.04	1	78.04	1.06	0.30
Q	379.60	1	379.60	5.16	0.03
C	397.15	1	397.15	5.40	0.02
S between Groups (error)	3963.85	54	73.50		
TOTAL	13890.75	79	175.83		

TABLE 11

Summary of analysis of variance at 1000 msec

Source of Variation	SS	df	MS	F	P
Groups (E)	847.38	1	847.38	1.58	0.22
S within Groups	9660.32	18	536.68	2.74	0.00
Frequency (F)	7476.23	3	2492.08	12.71	0.00
L	4305.86	1	4305.86	21.95	0.00
Q	1937.65	1	1937.65	9.88	0.00
C	1232.71	1	1232.71	6.29	0.01
Frequency x Groups (E x F)	693.91	3	231.30	1.18	0.33
L	103.89	1	103.89	0.53	0.47
Q	351.24	1	351.24	1.79	0.19
C	238.77	1	238.77	1.22	0.27
S between Groups	10590.75	54	196.12		
TOTAL	29268.59	79	370.49		

In the individual analyses at the nine durations, while a main effect of groups has not generally been found, examination of Fig. 7 reveals consistent trends towards differences, which were frequently significant.

Sensitivity was lower for SRD's at all spatial frequencies except 16 c/deg, and at all stimulus durations. Only 2 of the 72 data points (16 c/deg at 200 msec & 500 msec respectively) showed marginally greater sensitivity in SRD's when compared with controls. The trend towards lower sensitivity was not, however, equally marked in the remaining three spatial frequencies, and the differential effects of spatial frequency on contrast sensitivity can be seen in the different shapes of the functions provided by SRD and control data in Fig. 7.

It is clear that there was a spatial frequency selective difference. At 16 c/deg there was no difference at all. At 12 and 2 c/deg there were greater differences, and at each of these spatial frequencies, sensitivity was significantly lower at one of the nine stimulus durations. These results must be viewed with caution, because in a large number of comparisons, chance effects can not be ruled out.

However, at 4 c/deg the lower sensitivity of SRD's was clear and consistent, reaching significance at seven of the nine stimulus durations tested, and approaching significance at the remaining two.

The overall difference in sensitivity, as well as being spatial frequency-specific, was more apparent at some durations. While functions in both groups clearly changed from linear to quadratic with increasing durations, this change occured at longer stimulus durations for SRD's than for controls. The quadratic function, apparent in controls at 150 msec, was not clearly seen in SRD's till 1000 msec. This is shown by the interaction of the quadratic component in the orthogonal analysis, which, at durations from 150-500 msec, is either at or near significance. These results reflect the tendency in controls towards a quadratic function with peak sensitivity at 4 c/deg, while SRD's showed a persisting linear function. Linear decrease of sensitivity with increasing spatial frequency in SRD's was evident at all durations except the longest.

3.8 Summary

The trend towards a significant interaction between CD as a function of spatial frequency and groups is supported by the significance reached by Duncan's, showing that CD for controls but not for SRD's increases with spatial frequency. The analysis of individual regression coefficients provides further support for the contention that spatial frequency is exerting a differential effect on controls and SRD's, although the failure of group tests to show significance means that these results are to be viewed with caution.

Marked differences have been shown in the CSF of SRD's when compared with controls. These take the form of differences in the shape of functions, especially at intermediate durations, the latter corresponding closely to reported estimates of the duration of a single fixation (Haber & Hershenson, 1973). For SRD's it is likely that fixation duration is longer than for normal readers (Griffin, Walton & Ives, 1974). The most consistent difference was at 4 c/deg; hence there is a clear conclusion of spatial frequency-selective loss in sensitivity.

CHAPTER 4.

DISCUSSION

This chapter begins with a discussion of the results in terms of similarity to other research; an integration of the present results, with the research on SRD and early visual information processing, is then presented. The concluding interpretation is offered. The implications for the reading process, and for the amelioration of SRD, are raised.

4.1 Control data and previous research

An important yardstick to the general validity of these results, in terms of accurate calibration of equipment, relative constancy of conditions, and consistency of testing, is the similarity of control data to previously found data on normal S's.

While there is a certain amount of noise in the data from controls, as has been mentioned, in general the findings agree well with earlier published research, in the following areas:

a) Critical duration increases linearly with spatial frequency. Legge's (1978) data on CD may be replotted in the manner described by Bowling, Lovegrove and Mapperson (1979). A linear function with a slope of 11.1 is obtained; in the present study, the straight line fitted to control data on mean CD as a function of spatial frequency has a similar slope at 10.3. The data points themselves correspond reasonably well; the only identical spatial frequency Legge has used is 12 c/deg., where a CD of 215 msec. is reported, and the present study finds a CD of 221 msec. Breitmeyer and Ganz's (1977) similar finding of an increase in CD with spatial frequency is replicated, though their specific numerical data points correspond only very approximately; they find a CD of 200 msec. at 16 c/deg., where the present study finds 276 msec. It should, however, be noted, that Breitmeyer and Ganz, and Legge, are not themselves in agreement over the CD values, but that their important common finding of a steeply linear increase in CD with spatial frequency, is replicated by the present study.

b) CSF data corresponds to Legge's. Spatial frequency-specific effects are evident. A quadratic function peaking at 4 c/deg. is clear for controls by 150 msec., and for SRD's at 1000 msec only. A comparison between Fig.7, and the figure presented in Chapter Two (p.22) of the present study, shows the similarity. Contrast sensitivity increases with increasing duration. Again Legge's figure demonstrates this effect, a prediction from Bloch's Law. The shift in CSF with duration will be seen by examination of the sub-sections of Fig.7, as well as the statistical analysis on Table 2, which shows this effect to be significant.

The above findings in the present study are consistent, then, with published research on all measures, for controls. The clear differences in SRD's are now to be considered.

4.2 SRD-control differences

Critical duration, a measure of integration time in the visual system, has been linked with other temporal measures, such as visual persistence (VP). The possibility that CD is a component of VP, so that VP = CD + k, where k is a constant, has been put forward by Bowling, Lovegrove and Mapperson (1979), and the following figure is obtained:

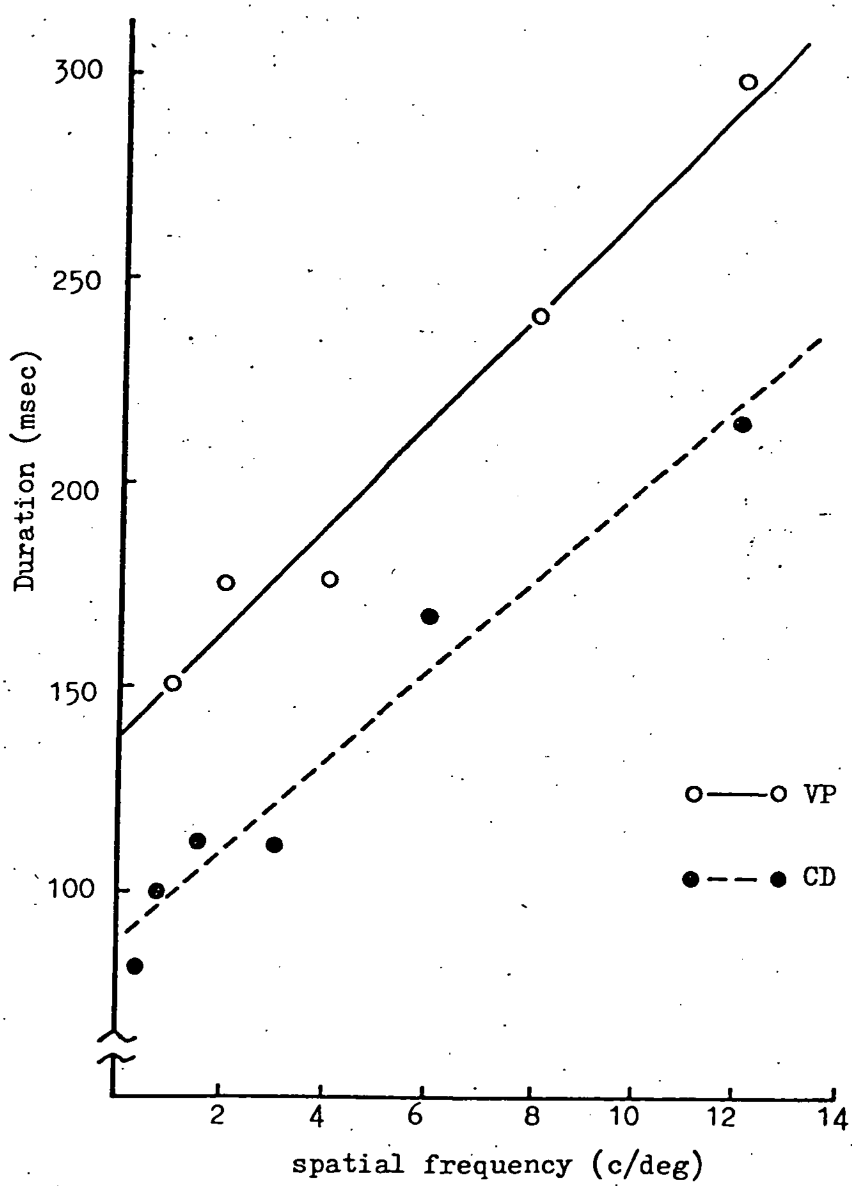


Fig.8: A comparison between the effects of spatial frequency on persistence (data from Experiment 1, Bowling, Lovegrove & Mapperson, 1979) and upon CD (Legge, 1978). (Bowling, Lovegrove & Mapperson, 1979)

If this is so, the present results can usefully be compared with those obtained by Lovegrove, Heddle and Slaghuis (1979, in press), who found that VP for SRD's differed from controls in the manner represented below.

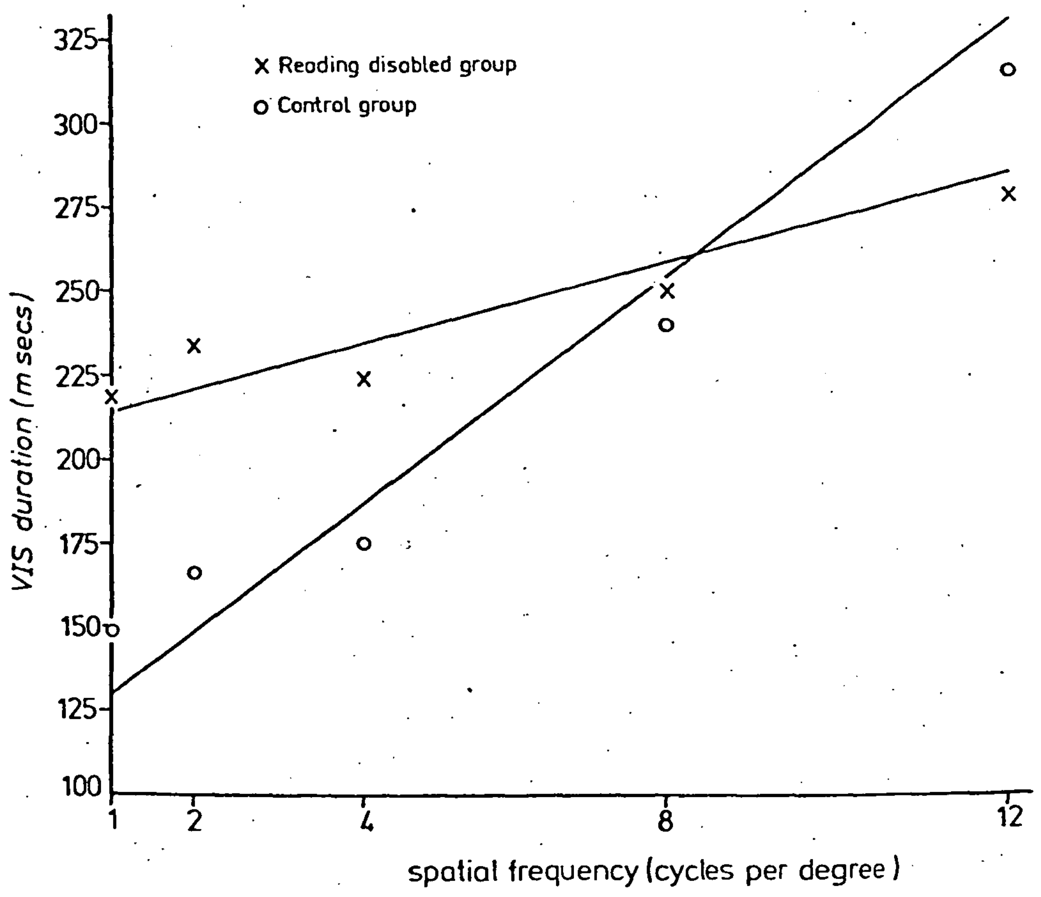


Fig. 9: Visual persistence as a function of spatial frequency (Lovegrove, Heddle & Slaghuis, 1979, in press).

The similarity between the slopes of these lines, and the slopes of the lines represented in Fig 6 of the present study, is evident, as shown on the following page.

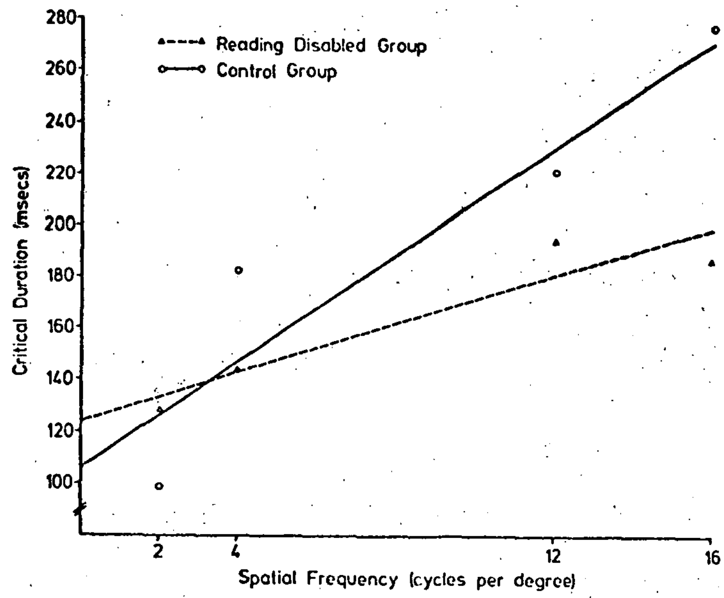


Fig. 10: Critical duration as a function of spatial frequency (the present study).

Regression coefficients for VP in controls and SRD's respectively in the figure on p.71 were 14.9 and 4.8; in the present study, the regression coefficients for CD were 10.5 and 4.6 respectively. There is also agreement in the relative values, so that CD in both groups is shorter than VP. It should be noted, however, that the crossover points of the two figures differ. VP for SRD's is similar to controls at the medium spatial frequency of 8 c/deg., whereas the present study shows CD at 4 c/deg. to be approximately similar. However, the high variance in the present study, suggests that the precise point of intersection cannot be confidently stated. The broad similarity is of interest at this stage. Entirely parallel results would be rather surprising, considering the differences of age of S's in the earlier study, as well as such factors as different equipment and test conditions.

It has been argued (Lovegrove, Heddle & Slaghuis, 1978) that the persistence data reflects abnormality in the visual information processing channels with respect to spatial frequency. The present results, in the light of the possible dependence of VP on CD, proposed by Bowling et al., suggests that these abnormalities may be produced by CD differences, as a more basic index of visual temporal processing, and that VP differences represent almost parallel findings to those of the present study, the latter being at a more fundamental level.

It would appear that SRD's integrate the low spatial frequency of 2 c/deg. more slowly than do controls, with no difference at slightly higher spatial frequency (4 c/deg.), and that integration time at the high spatial frequencies (12 and 16 c/deg.) is shorter. The absence of a significant group-frequency interaction, however, shows that these differences between SRD's and controls can only be regarded as trends.

If this similarity between the CD data and the VP data can be interpreted as showing some sort of parallel functioning, then the conclusion of the present study reiterates and strengthens the argument, put forward by Lovegrove, Heddle and Slaghuis (1979, in press) that there are "differences between the two groups, but, more importantly ... that these differences vary in a complex way with the spatial frequency of the stimuli involved". SRD's show different temporal patterns of spatial frequency processing, so that the expected inter-relationships do not apply. The effect such processing differences might have on reading will be considered in a later section of this chapter.

The properties of transient and sustained channels have been discussed in Chapter Two. The predictions arising from those properties, as outlined by Breitmeyer and Ganz (1977), and Legge (1978), are that lower spatial frequencies will produce shorter CD's, as a reflection of greater transient activity, with higher spatial frequencies, involving mainly sustained activity, producing longer CD's. The control data from the present study are consistent with these predictions. For SRD's, however, the increase in CD with spatial frequency is not significant, and this may reflect a different relative proportion of sustained and transient cells with respect to spatial frequency response. Overall, although the CD's are shorter, they are not significantly so, and an inference of greater transient activity throughout cannot be made; the pattern of CD with spatial frequency shows this. It would seem from examination of Fig. 6, that sustained and transient activity may be occurring in approximately similar proportions at all spatial frequencies, so that unusually high sustained or weak transient activity is raising the CD at low spatial frequencies, and the converse, with high transient activity or weak sustained, continuing to operate at high spatial frequencies. This possibility is offered with caution, as it is yet to be tested directly. The interpretation presented in the preceding section, which implies a difference in spatial frequency channels, may be made with some confidence.

It is noticeable that the shape of the CSF curve in SRD's differs from controls in terms of the quadratic component at intermediate durations (150 to 1000 msec.) The analysis of variance shows that these differences are either at ($p < 0.05$) or near ($p < 0.10$) significance. These stimulus durations are similar to fixation durations, and the specific implications for reading will be discussed in a later section of this chapter.

Findings on the CSF in patients with cerebral lesions in the visual pathways have been reported by Bodis-Wollner (1972). The following findings are of interest to the present results for SRD's, seen in Fig. 7. Bodis-Wollner reports :

i) A generally reduced CSF in those patients when compared to normals.

ii) Selective spatial frequency loss; some patients showed greater mid-frequency loss, and others more marked high-frequency loss.

iii) Failure to "peak" at 4 c/deg. This failure to peak was more marked in the early stages of recovery, and gradually ameliorated, though failing to reach normal contrast sensitivity even after 6 weeks.

The figure may be seen on the following page. Patient 1 represents the preponderance of patients tested.

The similarity with the present findings may be noted in all three of the above respects, at intermediate durations, which correspond to fixation durations. In SRD's it is likely that these are longer than in normal readers, (Griffin, Walton & Ives, 1974). This accommodates the present findings, which persist to 500 msec.

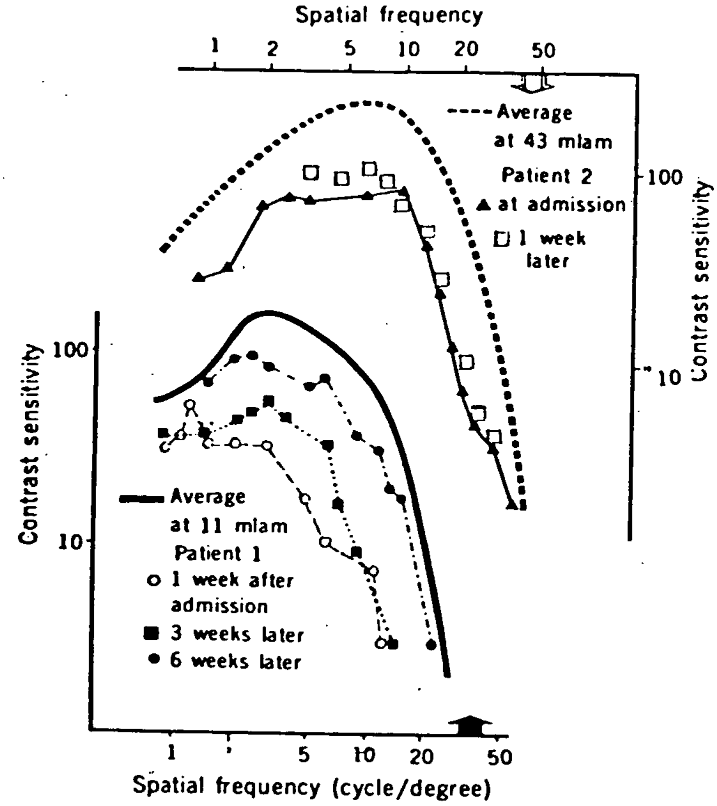


Fig. 11: Spatial contrast sensitivity curves at a mean luminance of 11 mlam (A) and 43 mlam (B). The right eye was used throughout. Sensitivity is plotted against the spatial frequency of the grating pattern on a log-log scale. The arrows represent the extrapolated cutoff frequencies (visual acuity) at 11 and 43 mlam for the normal (average of four individuals) observer. In (A), curves with interrupted lines were obtained from a patient with an infectious lesion of the left parieto-occipital area (patient 1). In (B) data points are from a patient with a meningioma pressing on the left occipital pole (patient 2). (Bodis-Wollner, 1972)

There is no argument presented here that SRD's may be considered to have sub-clinical cerebral lesions. Rather, the contention is that Bodis-Wollner's work supports the concept of spatial frequency-specific channels in human vision, which may be differentially affected; in the case of his patients, by a known cause. He states, most importantly for the present study, that "a non-uniformly altered contrast sensitivity would pose a greater difficulty in pattern recognition than a simple drop in visual acuity" (p. 770), because, he argues, in supra-threshold conditions, an invariate neural representation of the retinal image depends on the proper balance of signals. It is apparent from the CSF data in the present study that SRD's have non-uniformly different CSF, in similar directions to those reported by Bodis-Wollner, and his prediction of difficulty in pattern recognition may be regarded as symptomatic of this finding. In SRD's, such difficulties, less gross than those of Bodis-Wollner's patients, may be represented by reading disability as the most accessible measure. This will be considered in more detail later.

The CSF data leads clearly to the conclusion that the spatial frequency-specific channels in the visual pathways of SRD's, given normal acuity, differ significantly from controls.

Theories accounting for perceptual deficit in SRD's have been considered in detail in Chapter One. It is proposed now to examine briefly the present results in the light of some of these theories.

The present study adds evidence to the proposition that visual perceptual deficits are present, on very basic measures, in SRD children. As such, it is entirely in disagreement with Vellutino (1977), who claims that frank visual perceptual deficits do not exist, and that any deficit derives primarily from verbal deficit.

Of the studies supporting a perceptual deficit, those supporting the notion of a developmental lag (Satz, Rardin & Ross, 1971; Lyle & Goyen, 1975) have argued that visual perceptual deficit is present only in younger children, and that these deficits disappear with age. The present results are not consistent with such an interpretation, for two main reasons:

i) The children tested had an average age of 14.1 years. It seems unlikely that a developmental lag hypothesis can accommodate such relatively mature children, although it remains possible that the "lag" persists into adolescence.

ii) More importantly, the CSF results, and to a lesser extent, the CD results, suggest qualitative, rather than quantitative, differences. The CSF data would suggest that "maturing" would need to occur differentially across spatial frequency channels, so that the normal peak at 4 c/deg. would be acquired. Such a proposition seems implausible. In the present data on CD, a developmental lag hypothesis would demand the prediction that maturing would occur in two ways: a decrease in integration time, at low spatial frequencies, and an increase in integration time, at high spatial frequency. This would bring SRD and control data into line. Again, this seems an unlikely eventuality.

The work of Stanley and Hall (1973a; 1973b), indicating a memory deficit, has links with the present study, in view of recently published research (Tieger & Ganz, 1979) which suggests that visual memory itself may also be spatial frequency-specific. It is not inconceivable that parallel findings to the present results could occur at the level of memory, and this would bear investigation. This remains speculative, and the consistency of the present study.

with the work of Stanley and Hall cannot really be assessed, because that research examined sequential processing, and the present results rely on single stimulus presentation only. Although different functions are clearly being measured, spatio-temporal abilities underlie both areas of research, and differences are found between SRD's and controls.

4.3 Implications for reading

There are a number of ways in which the present results may contribute to reading disability, particularly when considered in conjunction with VP data. A recent model suggests that low spatial frequency channels rapidly transmit general information to the visual cortex. Detail is considered to be added later by the slower transmitting high spatial frequency channels (Breitmeyer & Ganz, 1976).

In these terms the longer periods of temporal integration with increasing spatial frequency permit processing to occur as a series of successive approximations with detailed discriminations (based on high frequency information) requiring more time than general discriminations (based on low frequency information). Such a view implies that perception proceeds in a global-to-local manner. Recent evidence suggests that this, indeed, is the case (Navon, 1977). The control data reported here indicate that integration of increasing spatial frequencies does occur sequentially in normal readers. The lack of increase in critical duration with increasing spatial frequency in disabled readers would tend to decrease the extent to which information is integrated sequentially, possibly creating difficulties in word recognition.

A related way in which the differences in increase of integration times between normals and SRD's may contribute to reading disability concerns visual information processing in central and peripheral vision. It is suggested that in normal readers the shorter integration times of the low frequency channels which predominate in peripheral vision (Enroth-Cugell & Robson, 1966; Campbell, Cooper & Enroth-Cugell, 1969) would facilitate rapid processing of peripheral information and serve a role in visual guidance (Breitmeyer & Ganz, 1976).

In disabled readers, however, this would not occur to the same extent, as their integration times for low spatial frequencies do not differ significantly from their integration times for medium spatial frequencies. Such a problem is suggested by studies where interference with or removal of peripheral information disrupts the normal reading process (McConkie, 1976).

Bodis-Wollner's (1972) findings lead to further confidence in the claim that selective spatial frequency sensitivity loss can be expected to produce pattern perception and reading difficulties. The similarity with SRD's at intermediate durations has already been discussed.

The analysis presented here would indicate that disabled readers should experience a general visual deficit on many tasks requiring temporal integration. Reading should only be one manifestation of the problem, albeit the most often measured one. Such a conclusion is strongly supported by a recent study (Rosewarne, 1978, unpub.), requiring subjects to identify pictorial and verbal material moved behind a stationary slit in the manner initially used by Parks (1965). Disabled readers had more difficulty than controls with all sorts of stimuli indicating a general deficit in spatio-temporal integration. It is possible that the differences reported here underlie such difficulties.

Finally the analysis presented here suggests that the differences between disabled readers and controls would produce relatively few problems on tasks involving only central viewing and single fixations, which have often been studied (Vellutino, 1977) in reading disability. Problems would arise primarily with tasks requiring integration of successive fixations, involving central and peripheral visual information processing. Reading, of course, is such a task.

4.4 Possibilities for treatment

The concept of spatial frequency-specific deficits has only recently been established, and for that reason treatment possibilities are in the very early stages. Bodis-Wollner's (1972) findings, for example, act as evidence for spatial frequency-specific deficit, without suggesting treatment implications; his patients improved through medical intervention, such as drugs. However, the plasticity of the mammalian visual cortex, and the reversible effects of selective deprivation of various stimuli (Dews & Wiesel, 1970; Mitchell, Millidot, & Heagstrom, 1973) would suggest that deficits in CSF may be remediated. Such a finding is reported by Banks, Campbell, Hess and Watson (1978), who treated amblyopia by using high contrast square-wave rotating discs. The children treated over short periods of time on a regular basis with this method, showed improved visual acuity, and, more importantly for the present study, improved contrast sensitivity function. The present results indicate that at 4 c/deg. SRD children show the most striking deficit; it would seem worth-while to investigate the effect of exposure to the method of Banks et al, using high contrast gratings at that spatial frequency. However, this possibility must be qualified by the fact that whereas the visual perceptual origins of amblyopia are known to be lack of stimulation, the basis of spatial frequency-specific processing differences in SRD is far less clearly understood. The earlier suggestion in this chapter, that a deficit in the processing of peripheral stimuli may be involved in SRD, leads also to treatment possibilities; improved performance as a result of practice and feed-back with motion discrimination (Johnson & Leibowitz, 1974), and acuity discrimination (Saugstad & Lie, 1964) in peripheral vision, have been reported.

Such methods have the advantage of being unconnected with the reading task, and use general stimuli with no educational overtones. The reading task itself represents a source of frustration, and of experience of failure, for children with specific reading disability.

REFERENCES

Banks, R.V., Campbell, F.W., Hess, R., and Watson, P.G. "A New Treatment for Amblyopia", British Orthoptical Journal, 1978, 35, 1.

Birch, Herbert and Belmont, Lillian, "Auditory-visual Integration in Normal and Retarded Readers", American Journal of Orthopsychiatry, 1964, 34, 852-861.

Blank, M., and Bridger, W.H., "Deficiencies in Verbal Labelling in Retarded Readers", American Journal of Orthopsychiatry, 1966, 36, 840-847.

Bodis-Wollner, Ivan, "Visual Acuity and Contrast Sensitivity in Patients with Cerebral Lesions", Science, 17 Nov. 1972, 769-771.

Bowling, A., Lovegrove, W., and Mapperson, B., "The Effect of Spatial Frequency and Contrast on Visual Persistence", Perception, 1979, 8, 529-539.

Breitmeyer, Bruno G., "Simple Reaction Time as a measure of the Temporal Response Properties of Transient and Sustained Channels", Vision Research, 1975, 15, 1411-1412.

Breitmeyer, Bruno G., and Ganz, Leo, "Implications of Sustained and Transient Channels for Theories of Visual Pattern Masking, Saccadic Suppression, and Information Processing", Psychological Review, Jan. 1976, 83, 1, 1-35.

Breitmeyer, Bruno G., and Ganz, Leo, "Temporal Studies with Masked Gratings: Inferences about Human Transient and Sustained Channels", Vision Research, 1977, 17, 861-865.

Bryden, M.P., "Auditory-Visual and Sequential-Spatial Matching in Relation to Reading Ability", Child Development, 1972, 43, 824-832.

Butters, N., and Brody, B.A., "The Role of the Left Parietal Lobe in the Mediation of Intra and Cross-modal Associations", Cortex, 1968, 4, 328-343.

Campbell, Fergus, "The Transmission of Spatial Information Through the Visual System", in Schmitt, F.O., and Worden, F.G. (eds.) MIT, The Neurosciences, Cambridge, 1974.

Campbell, F.W., Cooper, G.F. and Enroth-Cugell, C., "The Spatial Selectivity of the Visual Cells of the Cat". Journal of Physiology, 1969, 203, 223-235.

Campbell, F.W., Cooper G.F., Robson, J.G. and Bachs, M.B., "The Spatial Selectivity of Visual Cells of the Cat and the Squirrel Monkey", Journal of Physiology (Lond.), 1969, 204, 120-121.

Campbell, F.W., and Kulikowski, J.J., "Orientational Selectivity of the Human Visual System", Journal of Physiology (Lond.), 1966, 187, 437-445.

Cleland, B.G., Dubin, M.W. and Levick, W.R., "Sustained and Transient Neurones in the Cat's Retina and LGN", Journal of Physiology, 1971, 217, 473-496.

Clifton-Everest, I.M., "The Immediate Recognition of Tachistoscopically Presented Visual Patterns by Backward Readers", Genetic Psychology Monographs, 1977, 89, 221-239.

Clifton-Everest, I.M., "Dyslexia: Is there a Disorder of Visual Perception?" Neuropsychologia, 1976, 14, 491-494.

Congalton, A.A., "Occupational Status in Australia", Studies in Sociology, 3, University of N.S.W., Kensington N.S.W., 1963.

Cornsweet, Tom N., Visual Perception, Academic Press, N.Y., 1970.

Critchley, McDonald, The Dyslexic Child, Thomas Springfield, Illinois, 1970.

Critchley, McDonald, Developmental Dyslexia, William Heinemann Medical Books Ltd., London 1964.

Dechant, Emerald, Detection and Correction of Reading Difficulties, Meredith, N.Y., 1971.

Deutsch, D., and Deutsch, J.A., Short Term Memory, Academic Press, 1975.

Dews, P.B. and Wiesel, T.N. "Consequences of Monocular Deprivation on Visual Behaviour in Kittens". Journal of Physiology, 1970, 206, 437-455.

Enroth-Cugell, C., and Robson, J.G., "The Contrast Sensitivity of Retinal Ganglion Cells of the Cat", Journal of Physiology (Lond.), 1966, 187, 517-552.

Esson, T.H., "The Reaction of Parents to Reading Failure", Proceedings, Dyslexia Symposium, Melbourne 1967.

Fletcher, J.M., and Satz, Paul, "Unitary Deficit Hypotheses of Reading Disability: has Vellutino led us astray?" Journal of Learning Disabilities, 1979, Vol. 12, 3.

Frostig, M., The Marianne Frostig Developmental Test of Visual Perception, Palo Alto, California, Psychological Press, 1961.

Gardner, Howard, "Developmental Dyslexia: the Forgotten Lesson of Monsieur C.", Psychology Today, Aug. 1973, 63-67.

Griffin, D.C., Walton, H.N. and Ives, V., "Saccades as Related to Reading Disorders", Journal of Learning Disabilities, 1974, 7, 5, 310-316.

Haber, R.N. and Hershenson, M., The Psychology of Visual Perception, Holt, Rinehart and Winston, N.Y., 1973.

Hepworth, T.S., Dyslexia: The Problems of Reading Retardation, Angus and Robertson, Sydney, 1971.

Houlihan, K., and Sekuler, R., "Contour Interactions in Visual Masking, Journal of Experimental Psychology, 1968, 77, 281-285

Hurvish, Leo M., and Jameson, Dorothea, The Perception of Brightness and Darkness, Allyn and Bacon Inc., Boston, 1966.

Johnson, C.A. and Leibowitz, H.W. "Practice, refractive error, and feedback as factors influencing peripheral motion thresholds." Perception and Psychophysics, 1974, 15, 276-280.

Kirk, S.A. and McCarthy, J.J., The Illinois Test of Psycholinguistic Abilities, Urbana, University of Illinois Press, 1968.

Kolers, Paul A., "Pattern Analysing Disability in Poor Readers", Developmental Psychology, 1975, 11, 3, 282-290.

Kulikowski, J.J. and Tolhurst, D.J. "Psychophysical Evidence for Sustained and Transient Detectors in Human Vision", Journal of Physiology (Lond.), 1973, 232, 149-162.

Legge, Gordon E., "Sustained and Transient Mechanisms in Human Vision: Temporal and Spatial Properties", Vision Research, 1978, 18, 69-81,

Lovegrove, W.J. "Spatial Frequency Sensitivity and Reading Disability", (unpub.) 1978, University of Tasmania.

Lovegrove, W., Billing G. and Slaghuis, W., "Processing of Visual Contour Orientation Information in Normal and Disabled Reading Children", Cortex, xiv, 1978, 208-278.

Lovegrove, William and Brown, Christina, "Development of Information Processing in Normal and Disabled Readers", Perceptual and Motor Skills, 1978, 46, 1047-1054.

Lovegrove, W., Heddle, M., and Slaghuis, W. "Reading Disability: Spatial Frequency Specific Deficits in Visual Information Store", Cortex, in press, 1979.

Lupp, U., Hauske, G. and Wolff, W. "Perceptual Latencies to Sinusoidal Gratings", Vision Research, 1976, 16, 969-972.

Lyle, J.G. and Goyen, Judith, "Effect of Speed of Exposure and difficulty of Discrimination on Visual Recognition of Retarded Readers", Journal of Abnormal Psychology, 84, 6, 673-676.

Malmquist, E., Reading Disabilities, Amqvist and Wiksell, Stockholm. 1958.

McConkie, G.W. "The use of Eye Movement Data in Determining the Perceptual Span in Reading". In R.A. Monty and J.W. Senders (Eds.), Eye Movements and Psychological Processes, 1976, Hillsdale, N.J., Erlbaum.

Meyer, Glenn and Maguire, William, "Spatial Frequency and the Mediation of short-term Visual Storage", Science, Nov. 1977, 198.

Mitchell, D.E., Freeman, R. and Millidot, M. and Haegstrom G., "Meridional Amblyopia: Evidence for Modification of the Human Visual System by Early Visual Experience". Vision Research, 1973, 13, 535-558.

Navon, David, "Forest Before Trees: The Precedence of Global Features in Visual Perception", Cognitive Psychology, 1977, 9, 353-383.

Neale, Marie, The Neale Analysis of Reading Ability, 1966, London, MacMillan.

Pantle, A. and Seknler, R. "Size Detecting Mechanisms in Human Vision", Science, 1968, 162, 1146-1148.

Parks, T.E. "Post-retinal Visual Storage", American Journal of Psychology, 1965, 78, 145-147.

Preston, Malcolm S., Guthrie, John T., and Childs, Barton. "Visual Evoked Responses (VER's) in Normal and Disabled Readers". Psychophysiology, 1974, 11, 4, 452-247.

Rachman, S., "Learning Theory and Child Psychology: Therapeutic Possibilities", Journal of Child Psychology and Psychiatry, 1962, 3, 149-163.

Rosewarne, Pamela. "Spatio-Temporal Integration of Pictorial and Symbolic Material in Average and Problem Readers". (Unpublished thesis) 1978, Monash University, Melbourne.

Rutter, Michael and Yule, William. "The Concept of Specific Reading Retardation", Journal of Child Psychology and Psychiatry, 1975, 16, 181-197.

Sachs, M.B., Nachmias, J., and Robson, J.G., "Spatial Frequency Channels in Human Vision", Journal of the Optical Society of America, 1971, 61, 9.

Sapir, S.G., and Nitzburg, A.C., Children with Learning Problems: Readings in a Development-Interaction Approach, 1973 Brunner-Mazel, N.Y.

Satz, Paul, Rardin, Donald and Ross, John. "An Evaluation of a Theory of Specific Developmental Dyslexia", Child Development, 1971, 42, 2009-2021.

Saugstad, P., and Lie, I., "Training of Peripheral Visual Acuity", Scandinavian Journal of Psychology, 1964, 5, 218-224.

Schonell, F.T., The Psychology and Teaching of Reading, Oliver and Boyd, London, 1945.

Sekuler, Robert, "Spatial Vision", Annual Review of Psychology, 1974, 25, 195-232.

Siegel, Sidney, Non-parametric Statistics for the Behavioural Sciences, McGraw-Hill, Tokyo, 1956.

Staats, A.W., Learning, Language and Cognition, 1968, Holt, Rhinehart and Winston, N.Y.

Staats, A.W., Brewer, B.A., and Gross, M.C., "Learning and Cognitive Development: Representative Samples, Cumulative Hierarchical Learning, and Experimental Longitudinal Methods", Society for Research in Child Development Monograph, 1970, 35, 8.

Staats, A.W., and Butterfield, W.H., "Treatment of Non-reading in a Culturally Deprived Juvenile Delinquent: An Application of Reinforcement Principles", Child Development, 1965, 4, 925-942.

Staats, A.W., Minke, K., Finley, J.R., Wolf, M., and Brooks, L.O., "A Reinforcer System and Experimental Procedure for the Laboratory Study of Reading Acquisition", Child Development, 1964, 35, 209=231.

Stanley, G. and Hall, R. "Short Term Visual Information Processing in Dyslexics", Child Development, 1973 a, 44, 841-844.

Stanley, G., and Hall, R. "A Comparison of Dyslexics and Normals in Recalling Letter Arrays after Brief Presentation". British Journal of Educational Psychology, 1973 b, 43, 301-304.

Tieger, Todd and Ganz, Leo. "Recognition of Faces in the Presence of Two-Dimensional Sinusoidal Masks", Perception and Psychophysics, 1979, 26, 2, 163-167.

Umansky, John A., and Umansky, Shashanna F., "Parents as Behaviour Therapy-technicians in Treating Reading Deficits", Australian Psychologist, 1976, 11, 3, 305-311.

Vassilev, A., and Mitov, D., "Perception Time and Spatial Frequency", Vision Research, 1976, 16, 89-92.

Vellutino, F.R., "Has the Perceptual Deficit Hypothesis Led us Astray?" Journal of Learning Disabilities, 1977 a, 10, 6.

Vellutino, F.R., "Alternative Conceptualizations of Dyslexia: Evidence in Support of a Verbal-deficit Hypothesis", Harvard Educational Review, 1977 b, 47, 3.

Vellutino, F.R., "The Validity of Perceptual-deficit Explanations of Reading Disability: A reply to Fletcher and Satz", Journal of Learning Disabilities, 1979, 12, 3.

Vellutino, F.R., Pruzek, R.M., Steger, J.A. and Meshoulam, U., "Immediate Visual Recall in Poor and Normal Readers as a Function of Orthographic-linguistic Familiarity", Cortex, 1973, 9.

Vellutino, F.R., Smith, H., Steger, J.A. and Kaman, M., "Reading Disability: Age differences and the Perceptual Deficit Hypothesis", Child Development, 1975, 46, 487-493.

Vellutino, F.R., Steger, J.A. and Kandel, G. "Reading Disability: An Investigation of the Perceptual Deficit Hypothesis", Cortex, 1975 b, 8, 106-118.

Vernon, M.D., Backwardness in Reading: A Study of its Nature and Origin, Cambridge, Cambridge University Press, 1957.

Wilson, J.B. "Teddy Bear: Statistical Program", Technical Report T5, Edition 2, Botany Department, University of Otago, N.Z., May 1976.

Witelson, S.F., "Developmental Dyslexia: Two Right Hemispheres and None Left", Science, 1977, 195, 309-311.

Young, F.A., and Lindsley, D.B. (eds.) Early Experience and Visual Information Processing in Perceptual and Reading Disorders. National Academy of Sciences, Washington, 1970.

APPENDICES

APPENDIX 1

Details of subjects: IQ, reading age, chronological age and socio-economic status (n = 20)

Group	Experimental					Control			
Subject No.	d.o.b.	IQ	R.A.	C.A.	SES (Congalton)	d.o.b.	IQ	C.A.	SES (Congalton)
1	19/ 5/65	100	9.6	14.4	Design Engineer 1.92	9/ 2/65	92-112	14.7	Design Engineer 1.92
2	19/12/64	115	11.6	14.9	Ganger 6.57	16/ 2/65	111	14.7	Warehouse man 6.57
3	15/ 6/67	113	8.7	12.3	s.e. bricklayer 4.91	5/ 7/67	111	12.2	Undertaker 5.53
4	4/11/65	88	9.0	13.10	Mail Officer 5.52	22/ 4/65	88	14.5	Police Officer 5.07
5	8/10/64	72-88	9.4	14.11	Pensioner	14/ 8/64	83-95	15.1	Foreman
6	1/ 4/64	88	7.9	15.5	Motor Mechanic 5.97	17/ 4/64	80-86	15.5	Plasterer 6.22
7	23/ 4/65	114	11.2	14.5	Painter 6.21	3/ 6/65	106	14.3	Builder 4.83
8	22/ 2/67	100	8.9	12.7	Motor Mechanic 5.97	30/ 1/67	99	12.8	Logging Contractor 6.56
9	2/11/64	93	8.1	14.10	Plant Operator 6.66	15/ 9/64	108	15.0	Bricklayer 6.38
10	7/ 2/66	99	9.5	13.7	Toolroom Turner	29/ 8/66	100-107	13.1	Home duties
$\bar{x}$		99	9.4	14.1			100	14.0	
Min			7.9	12.3				12.2	
Max			11.6	15.5				15.5	

APPENDIX 2

Cross randomising of presentation order of spatial frequency and duration

	Experimental				Control				
	2	4	12	16	2	4	12	16	Sf
S 1	1d	3d	4i	2i	2i	1i	3d	4d	Order of presentation (1, 2, 3 or 4) and direction of testing at each sf (i = increasing duration order; d = decreasing)
2	4i	1d	3d	2i	1i	2i	3d	4d	
3	2d	4d	2i	1i	3d	1i	2i	4d	
4	2d	3i	4d	1i	2d	4d	1i	3i	
5	2i	1i	4d	3d	4i	1d	2d	3d	
6	3i	2d	4d	1i	2d	3d	4i	1i	
7	2d	4i	1i	3d	4d	3i	1i	2d	
8	1d	2i	3i	4d	3d	2d	4i	1i	
9	4i	2d	1i	3d	3d	4i	1d	2i	
10	1i	3i	2d	4d	1i	2d	3d	4i	

APPENDIX 3

INSTRUCTIONS

When you press this button, just about straight away what we call a "grating" will come on the screen. A grating has lines and spaces, like this (demonstration). But it will be sometimes quite hard to see, like this (low contrast).

And sometimes it will not be there at all, even for someone with the best eyes in the world (blank). Every time I want you to press the button, I will fiddle with a dial, then say "Now", and I want you to press the button, and then to say "Yes" or "No" if you can or cannot see the grating.

So each time you press the button, there might be a grating, or there might not. You are to say "Yes" if there is, and "No" if there's not. Is that clear?

Sometimes it will be very hard to decide. I only want you to say "Yes" if you can actually see lines, not if there is just a flicker or a change in the screen but you can't really see lines.

It does not matter at all if you are right or wrong, because for every person there is a place where you just can't tell the difference. I want to find exactly where that place is for you.

APPENDIX 4 : RAW SCORES

Contrast thresholds in voltage readings for the two groups at 2 c/deg (n = 20)																		
	Experimental									Control								
msec.	40	60	80	100	150	200	300	500	1000	40	60	80	100	150	200	300	500	1000
S 1	.048	.025	.034	.028	.029	.033	.025	.019	.0296	.054	.048	.037	.033	.035	.0267	.025	.037	.0315
2	.079	.065	.060	.05	.048	.044	.037	.039	.037	.051	.042	.042	.031	.031	.031	.031	.025	.0335
3	.2125	.176	.093	.086	.0848	.0868	.082	.122	.048	.06	.0515	.0395	.037	.036	.0325	.028	.0275	.0338
4	.115	.0983	.0791	.0622	.051	.041	.0405	.040	.040	.048	.047	.031	.04	.035	.019	.029	.031	.017
5	.039	.028	.025	.025	.0263	.013	.015	.019	.012	.054	.042	.041	.047	.041	.035	.037	.037	.042
6	0.65	.065	.054	.048	.046	.041	.037	.042	.035	.084	.071	.051	.054	.051	.037	.041	.040	.03
7	.068	.047	.051	.039	.039	.0395	.037	.038	.037	.065	.054	.045	.048	.051	.054	.05	.046	.033
8	.06	.039	.039	.044	.045	.037	.04	.038	.038	.062	.054	.048	.042	.039	.038	.037	.025	.019
9	.079	.062	.048	.0505	.046	.042	.048	.037	.034	.062	.042	.046	.042	.045	.042	.047	.039	.031
10	.065	.065	.056	.048	.055	.041	.042	.055	.044	.0465	.039	.037	.029	.03	.027	.031	.037	.025

APPENDIX 4 : RAW SCORES

Contrast thresholds in voltage readings for the two groups at 4 c/deg (n = 20)																		
	Experimental									Control								
msec.	40	60	80	100	150	200	300	500	1000	40	60	80	100	150	200	300	500	1000
S 1	.059	.078	.073	.073	.054	.047	.039	.035	.032	.054	.058	.047	.051	.039	.030	.019	.016	.011
2	.115	.086	.078	.062	.078	.058	.062	.054	.094	.058	.056	.034	.033	.024	.024	.022	.017	.016
3	. 24	.188	.159	.142	.113	.113	.101	.078	.039	.047	.042	.037	.033	.03	.025	.023	.022	.015
4	.149	.106	.104	.078	.066	.062	.039	.054	.025	.074	.059	.035	.034	.028	.027	.026	.020	.022
5	.064	.058	.025	.022	.03	.025	.014	.018	.009	.121	.113	.12	.074	.059	.047	.047	.035	.030
6	.153	.107	.091	.092	.082	.06	.06	.043	.039	.082	.062	.07	.07	.074	.054	.047	.050	.033
7	.115	.094	.083	.074	.07	.064	.057	.054	.044	.084	.054	.057	.047	.039	.042	.03	.022	.034
8	.094	.081	.0455	.039	.047	.039	.03	.03	.022	.11	.089	.086	.062	.039	.049	.037	.040	.034
9	.113	.104	.083	.078	.059	.058	.047	.0425	.042	.104	.078	.083	.062	.051	.047	.039	.033	.025
10	.097	.0965	.083	.059	.047	.045	.043	.0425	.0355	.04	.049	.039	.03	.027	.02	.02	.018	.01

APPENDIX 4 : RAW SCORES

Contrast thresholds in voltage readings for the two groups at 12 c/deg (n = 20)

	Experimental									Control								
msec.	40	60	80	100	150	200	300	500	1000	40	60	80	100	150	200	300	500	1000
S 1	.22	.14	.105	.08	.064	.051	.038	<.03	<.03	.134	.10	.092	.085	.04	.042	.036	.032	.03
2	.352	.19	.176	.151	.099	<.03	.04	.03	<.03	.123	.095	.076	.034	.04	.054	.03	.03	.036
3	.30	.268	.175	.140	.123	.123	.123	.105	.057	.152	.116	.105	.075	.097	.064	.056	.036	.03
4	.094	.052	.03	.03	.03	.03	<.03	<.03	<.03	.098	.123	.105	.044	.03	<.03	<.03	<.03	<.03
5	.11	.056	.064	.057	.04	.032	.048	.03	.03	.11	.105	.105	.094	.094	.052	.036	.07	.032
6	.312	.330	.326	.326	.206	.166	.157	.123	.127	.17	.152	.148	.136	.109	.07	.05	<.03	.03
7	.318	.2478	.227	.172	.123	.117	.079	.075	.074	.32	.236	.184	.178	.03	.03	.05	.036	<.03
8	.202	.19	.085	.094	.056	.076	.05	.03	<.03	.164	.117	.085	.064	.054	.041	.052	.034	<.03
9	.195	.147	.113	.105	.092	.11	.052	<.03	<.03	.509	.405	.315	.314	.206	.202	.172	.165	.123
10	.29	.253	.19	.172	.129	.112	.094	.094	.09	.094	.075	.064	.064	.036	.036	<.03	<.03	<.03

APPENDIX 4 : RAW SCORES

Contrast thresholds in voltage readings for the two groups at 16 c/deg (n = 20)																		
	Experimental									Control								
msec.	40	60	80	100	150	200	300	500	1000	40	60	80	100	150	200	300	500	1000
S 1	.348	.244	.038	.055	.098	.04	.064	.039	<.038	.203	.142	.148	.084	.104	.077	.081	.039	.039
2	.403	.34	.273	.22	.174	.189	.185	.153	.04	.203	.192	.157	.19	.137	.088	.12	.12	.104
3	.385	.385	.385	.385	.371	.163	.12	.092	.12	.388	.344	.255	.203	.28	.21	.112	.102	.092
4	.396	.325	.228	.22	.132	.142	.104	.12	.088	.133	.11	.077	.07	<.038	.082	<.038	<.038	<.038
5	.136	.106	.132	.13	.077	.104	.08	.055	.038	.411	.324	.307	.282	.203	.185	.163	.134	.152
6	.369	.354	.391	.413	.34	.246	.163	.22	.211	.23	.214	.163	.152	.159	.138	.145	.12	.048
7	.444	.347	.22	.195	.142	.12	.12	.038	.056	.133	.12	.085	.10	<.038	<.038	<.038	<.038	<.038
8	.192	.216	.144	.12	<.038	<.038	<.038	.038	<.038	.466	.311	.211	.211	.211	.081	.081	.055	<.038
9	.29	.216	.172	.144	.144	.10	.10	.056	.055	.58	.549	.46	.394	.373	.28	.241	.246	.150
10	.275	.214	.22	.155	.12	.106	.11	.077	.077	.22	.142	.092	.142	.086	.142	.08	.038	<.038

APPENDIX 5

Average miss and False Alarm Rates for the control group and the SRD's

	Miss Rate	False Alarm Rate
Controls	.176	.079
SRD's	.164	.061

APPENDIX 6

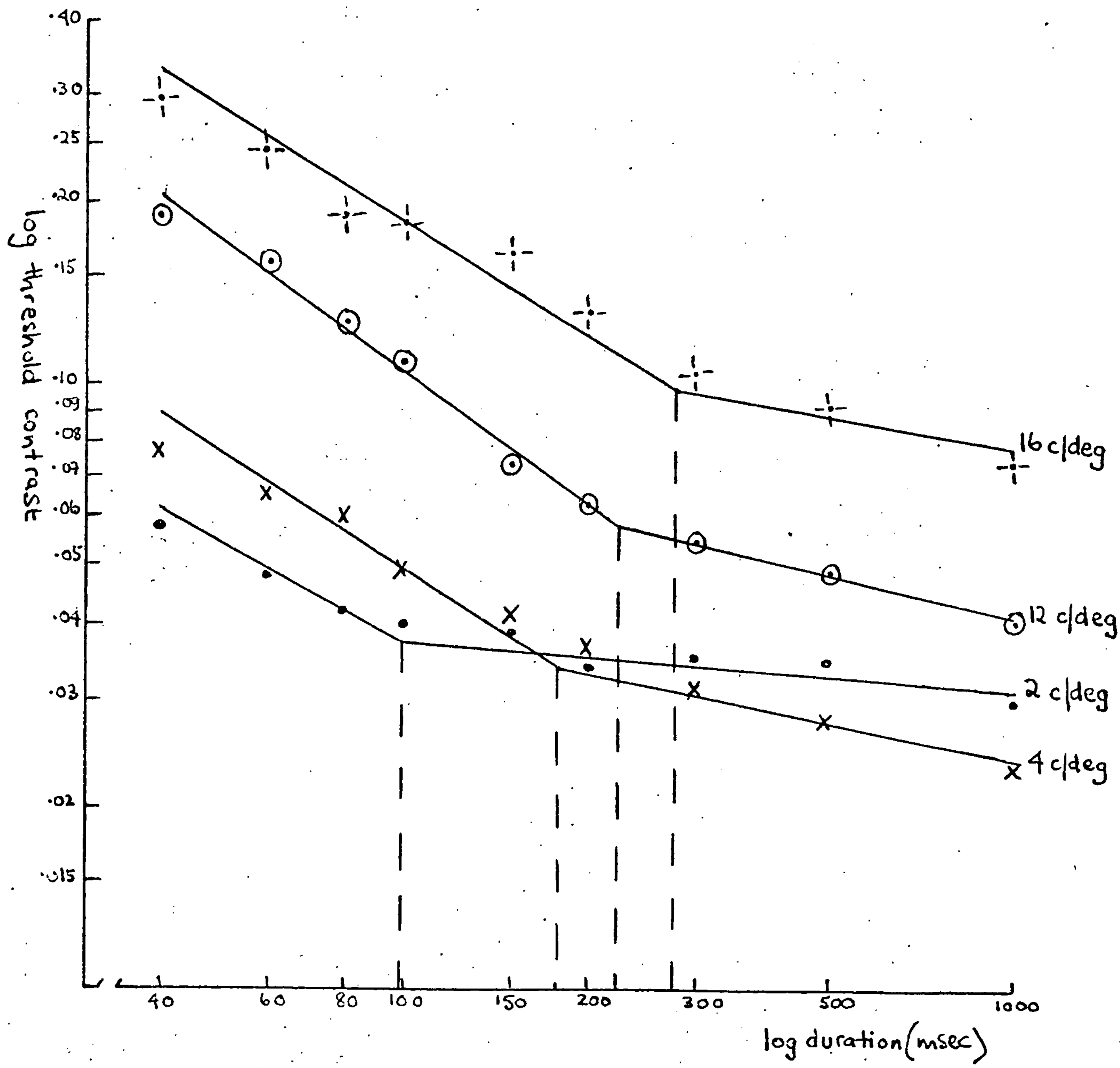
Critical durations (msec) at given spatial frequencies for all S's. (n = 20).

	Experimental				Control			
Sf (c/deg)	2	4	12	16	2	4	12	16
Subject No. 1	100	330	120	150	110	*(182)	200	(660)
2	118	120	240	120	120	140	115	180
3	86	120	86	*(187)	112	260	64	230
4	205	175	90	220	145	130	180	330
5	275	78	150	*(187)	62	220	300	245
6	135	70	410	310	98	*(183)	(660)	96
7	105	94	320	235	58	180	195	200
8	57	88	105	210	120	160	115	360
9	86	190	*(194)	72	54	160	160	185
10	115	170	225	180	110	210	220	*(276)
$\bar{x}$	128.2	143.5	194	187	98.9	182.49	220.9	276.22

* = missing data points.

APPENDIX 7

Mean log contrast thresholds as a function of log duration at the four spatial frequencies, for controls (n = 10).



APPENDIX 7

Mean log contrast thresholds as a function of log duration at the four spatial frequencies, for SRD's (n = 10).