National Library
of Canada

Canadian Theses Service

Ottawa, Canada
K1A 0N4

Bibliothèque nationale
du Canada

Services des thèses canadiennes

CANADIAN THESES

THÈSES CANADIENNES

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30.

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30.

THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED

LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

Canada

NL-339 (r.86/06)

THE UNIVERSITY OF ALBERTA

Effects of Intensity and Proximity of Inducing Stimuli on Duration of Visible Persistence

by

© Brady D. Johnson

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF Master of Science

Department of Psychology

EDMONTON, ALBERTA
Spring, 1987

ISBN 0-315-37761-5

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR Brady D. Johnson

TITLE OF THESIS Effects of Intensity and Proximity of Inducing Stimuli on Duration of Visible Persistence

DEGREE FOR WHICH THESIS WAS PRESENTED Master of Science

YEAR THIS DEGREE GRANTED Spring, 1987

Permission is hereby granted to THE UNIVERSITY OF ALBERTA LIBRARY to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

(SIGNED) ....

PERMANENT ADDRESS:

#4 11420 100 Ave.
Edmonton, Alberta
Canada T5K 0J4

DATED ...December 12, 1986

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Effects of Intensity and Proximity of Inducing Stimuli on Duration of Visible Persistence submitted by Brady D. Johnson in partial fulfilment of the requirements for the degree of Master of Science.

Supervisor

Date... December 12, 1986...

Dedication

To my parents, Bob and Shirley

Abstract

The duration of visible persistence has been found to be both inversely and directly related to stimulus intensity. In this thesis, the effect of stimulus intensity on the duration of visible persistence was measured. It was hypothesized that a direct relation between stimulus intensity and duration of visible persistence might occur under certain experimental conditions, not because brighter stimuli produce longer total durations of visible persistence, but rather, because a longer portion of the visible persistence produced by a brighter display may be available in some situations. This hypothesis was tested in two experiments, both of which employed Di Lollo's (e.g., Di Lollo, 1980) variant of the temporal-integration-of-form procedure (Ericksen and Collins, 1967). In Experiment 1, five conditions, distinguished on the basis of the intensity of the first of two sequential displays (D1), were employed. Within conditions, the independent variable was the intensity of the second display (D2). It was found that the duration of visible persistence measured from D1 was determined by the intensity of D2. Under a fixed stimulus onset asynchrony (SOA), more errors were made within conditions as the intensity of the second display was increased. The differences in performance observed in this experiment suggest that the second display had an active role in determining the measurement of visible persistence that was obtained by the integration procedure. In the

second experiment, three displays (1, 2 and 3° visual angle) were combined with five SOAs. At a given SOA, the number of errors made by observers depended upon the size of the display. Specifically, for smaller interpoint distances, more errors were made in the integration task. This dependence of performance on interpoint distances, as opposed to SOA, again suggested that the second display had an active role in determining the measurement of visible persistence that was obtained in the experiment. The results of both experiments are discussed in the context of two closely related hypotheses. Notably, these hypotheses may provide a basis for explaining why opposing functional relations can be obtained when different procedures are used to examine the effects of stimulus intensity on the duration of visible persistence. In this respect, an alternative account of the relation between these variables is given in the General Discussion.

Acknowledgement

I would like to give special thanks to Dr. Charles Bourassa for his supervision from the initial to final stages in the development of this thesis. Thankyou also, Charles, for your generosity and guidance as my mentor.

Special thanks also to Dr. Vincent Di Lollo for his helpful discussions during the preparation of the thesis, and especially, for his comments on an earlier draft. I would like to note that Dr. Di Lollo suggested the principal manipulation used in Experiment 2. In general, I am most grateful for the time Dr. Di Lollo afforded me.

Finally, I would like to thank Dr. Andrew French for serving as External Examiner on my thesis committee, and Tanis Ferman for giving up much of her spare time to participate in the thesis experiments.

Table of Contents

List of Figures

I. Introduction

Visible persistence refers to the experience that a briefly presented photic stimulus continues to be visible after its termination. Visible persistence is elicited by increments in luminance (e.g., onsets of stimulation), and continues for a period of time that is inversely related to the duration of the inducing display (cf., Coltheart, 1980). On the basis of this relation, visible persistence can be distinguished from a retinal afterimage, the duration of which is directly related to the duration of the display from which it is produced (Alpern and Barr, 1962).

It has been suggested that visible persistence represents neural activity engaged in an early stage of visual processing (Di Lollo, 1980). On this view, the duration of visible persistence represents a period during which features of a visual display are actively being encoded. Therefore, measures of the duration of visible persistence are akin to measures of the time required by the visual system to complete a preliminary stage in the encoding process. By this same line of reasoning, then, an identification of the factors that modulate visible persistence might be considered as an identification of the factors that can control the temporal duration of early visual processing.

The suppression of visible persistence is considered in this thesis. In particular, an hypothesis based on inhibitory interactions between neural channels is developed, which is intended to account for the suppression of visible persistence as determined by intensity relations between inducing stimuli.

The focus on intensity relations between inducing stimuli distinguishes the present work from earlier investigations of factors that may influence the duration of visible persistence. For example, suppression of visible persistence has been investigated, but the major variable studied in earlier work was the spatial relationship between inducing stimuli (e.g., Di Lollo and Hogben, 1985, 1986). The present research, then, extends this line of research by examining another factor that may be important in causing the suppression of visible persistence.

An aim of the thesis was to develop a basis for explaining the perplexing observations that the duration of visible persistence is directly related to stimulus intensity in some cases (c.f., Long, 1980), and inversely related to stimulus intensity in others (c.f., Coltheart, 1980). The inhibition hypothesis developed in this thesis is intended to provide a basis for explaining how these two opposing relations may be found when, presumably, only a single perceptual phenomenon (i.e., visible persistence) is being studied.

A. Contents of the Thesis

In developing the inhibition hypothesis, the thesis takes the following form. First, a more detailed description of visible persistence is presented. In this section, visible persistence is identified as a product of processing activity in the visual system, and the major assumptions about visible persistence held in this thesis are delineated. Next, several paradigms used to measure the duration of visible persistence are discussed. The point of this discussion is to illustrate that, under comparable viewing conditions, estimates of the duration of visible persistence may vary quite significantly between methods. More importantly, it will be seen that the functional relation between the intensity of an inducing stimulus and the duration of visible persistence produced by that stimulus, appears to depend upon which method is employed in obtaining the measure.

The thesis continues with a review of several studies in which the duration of visible persistence was measured as a function of stimulus intensity. These studies were chosen because they all employed the integration-of-form method (discussed later) to measure visible persistence. Long (1985) recently suggested that the integration method may measure a different *type* of visible persistence than is measured by other experimental procedures. Long's (1985) argument stems largely from the observation that results from several studies employing the integration technique indicate that a direct relation exists between the intensity of the inducing stimulus and the duration of its visible persistence (Long, 1980). When other paradigms are used, an inverse relation between these variables is typically found (c.f., Coltheart, 1980).

The rationale for Long's (1980,1985) controversial suggestion (see Irwin and Yeomans, 1986), will be discussed, and the major criticims of the view that different types of visible persistence are measured under different experimental settings will be addressed. It may be noted that Long's (1985) arguments will be supported, but his conclusions will be rejected.

The Introduction concludes with a proposal of how inhibition of visible persistence explains why a direct relation between stimulus intensity and the duration of visible persistence appears to obtain when temporal integration procedures are used.

In the second chapter of this thesis, the inhibition hypothesis is developed. The hypothesis is based on a model of visual masking developed by Breitmeyer and Ganz (1976). Accordingly, the major tenets of Breitmeyer and Ganz's (1976) model will be discussed, and the additional assumptions that are necessary to adapt the interchannel-inhibition model (Breitmeyer and Ganz, 1976) to account for the suppression of visible persistence are presented. At the end of Chapter 2, some predictions about performance in an integration task, derived from the inhibition hypothesis, are presented.

Chapters 3 and 4 are reports of experiments that were conducted to test a prediction derived from the inhibition hypothesis. In Experiment 1, performance was measured as a function of intensity relations between test stimuli. In the second experiment (Chapter 4), performance was measured as a function of proximity relations between test stimuli. This latter manipulation had been employed previously (Di Lollo and Hogben, 1986). However, the spatial separations used in Experiment 2 were larger than the separations used in previous research.

In the General Discussion, the results of the experiments reported in this thesis are briefly reviewed. Following this, a discussion about the relation between stimulus intensity and duration of visible persistence is presented. In two independent reviews of the same literature, opposing conclusions have been reached concerning the functional relation between these variables (see Coltheart, 1980, and Long, 1980). For example Coltheart (1980) concluded that the duration of the visible persistence is inversely related to stimulus intensity, while Long (1980) concluded that a direct relation exists between stimulus intensity and duration of visible persistence. The thesis concludes with an alternative suggestion about the relation between these variables, that may account for how measurements of the duration of visible persistence can be directly related to stimulus intensity in some cases, and inversely related in others.

B. Visible Persistence

The following view of visible persistence is based on Di Lollo's conceptual developments, and much of what is stated below is adapted from Di Lollo's previous work (e.g., Di Lollo, 1980; Di Lollo and Bourassa, 1983; Di Lollo and Hogben, 1986).

In this thesis it is assumed that visible persistence represents neural activity engaged in an early phase of visual processing. It is believed that the role of this activity is to encode information about a novel visual event, and that visible persistence is a by-product of the encoding activity. Congruently, the onset of visible persistence is assumed to be time-locked to the onset of an inducing stimulus. Once initiated, it is assumed that visible persistence will continue for a relatively fixed duration. Provided that normal encoding is not impeded, the minimal duration of the processing phase has been estimated at 100-150 ms (Di Lollo and Hogben, 1986).

Coltheart (1980) has reviewed a large body of evidence that suggests that visible persistence can be regarded as the product of a neural response, but that visible persistence is not simply produced by retinal activity. For example, numerous investigations have demonstrated that the duration of visible persistence is inversely related to the duration of the inducing display (e.g., Bowen, Pola and

Matin, 1974; Efron, 1970; Di Lollo, 1980). Of course, this particular relation would be expected if visible persistence was a response of finite duration, and was initiated shortly after the onset of the inducing display (Di Lollo, 1980).

C. Measurement of Visible Persistence

Measurements of the duration of visible persistence may be made using a variety of experimental paridigms (for reviews of these methods, see Coltheart, 1980 and Long, 1980). Regardless of the paradigm employed, the inverse relation between the duration of the inducing display and the duration of the display's visible persistence is reliably obtained (e.g., Bowen et.al., 1974; Haber and Standing, 1970; Di Lollo, 1980). Where the effects of display intensity are investigated, however, the resultant effects upon the duration of visible persistence have been characterized by an inverse relation (Bowen et.al., 1974), by no relation (Di Lollo and Bourassa, 1983), and in some cases, by a direct relation (Kinnucan and Friden, 1981).

Importantly, the diversity of effects of display intensity are almost exclusively observed when the duration of visible persistence is measured using temporal integration techniques (Ericksen and Collins, 1967,1968). This technique involves the presentation of successive ~~displays~~, which, when viewed alone, contain no meaningful information. When the display halves are presented in close temporal succession, however, a unitary display containing information not evident within either display half may be perceived. From this unitary percept the observer may be asked to identify a nonsense syllable (e.g. Ericksen and Collins, 1967,1968), or perhaps, to identify the location of a missing display element (e.g. Hogben and Di Lollo, 1974).

It should be clear how this method can be used to measure the duration of visible persistence. Present the first display (D1) and after some interstimulus interval (ISI) present the second display (D2). If the duration of visible persistence from D1 is sufficiently long, it will bridge the otherwise blank ISI, creating some degree of perceived continuity between displays. If D1 persists so long as to overlap in appearance with D2, then the observer will see a composite display, and will be able to perform the integration task with relative ease. The duration of visible persistence as inferred by this technique is equal to the maxium stimulus onset asynchrony (SOA) under which performance will not fall below some arbitrary criterion level: Estimates obtained using this procedure may range from about 50 ms (Di Lollo and Hogben, 1986) to 200 ms (Di Lollo and Bourassa, 1983), depending on factors such as the distance between inducing stimuli.

These experimental conditions can be contrasted to those used in other paradigms intended to measure the duration of visible persistence. For example, in a "Choice Reaction-Time", or in a "Probe-Matching" task, only a single display is presented. In the former case, the observer is required to make some response (e.g., a key press) to indicate the phenomenal disappearance of the test display (Briggs and Kinsbourne, 1972). Duration of persistence is then inferred as the time from the physical offset of the display to the time of the observer's response, minus some constant duration to allow for response execution. In the probe-matching task, the observer adjusts the onset of a probe stimulus (such as a click) to coincide with the phenomenal appearance and disappearance of the display (Efron, 1970). The duration of persistence as measured using this technique is taken as the inter-click interval, which has been measured from 130 to 200 ms (Efron, 1970; Haber and Standing, 1970).

"Phenomenal Continuity" is another method used to measure the duration of visible persistence (e.g., Marx and May, 1983). This technique involves the repetitive presentation of a single display and blank interstimulus interval (ISI). The observer's task in this method is to adjust the duration of the ISI so that the display appears to be continuously present. Of course, the duration of the ISI at which the intermittent display appears to be continuously present is used as an indicator of the time for which the display visibly persists. By this procedure, the duration of visible persistence has been estimated to last 200 to 300 ms (Haber and Standing, 1969; Marx and May, 1983).

Measures of visible persistence obtained using these procedures differ in important ways from measures obtained using the temporal integration paradigm. For example, the duration of visible persistence is inversely related to display intensity when measured using reaction-time, probe-matching or phenomenal continuity techniques (c.f., Coltheart, 1980). Using integration procedures, the duration of visible persistence has been found to bear no relation (e.g., Di Lollo and Bourassa, 1983), or to be directly related to stimulus intensity (Kinnucan and Friden, 1981). Also, under comparable viewing conditions, all three of the methods described ~~above~~ yield longer estimates of the duration of visible persistence than are obtained using temporal integration methods (Coltheart, 1980). Considering these findings, the effects of stimulus intensity observed under the integration paradigm deserve further study. It is not clear why the robust inverse intensity effect is not observed when integration procedures are used. Indeed, the absence of inverse intensity effects in studies employing temporal integration procedures has prompted Long (1985) to suggest that integration procedures may be measuring a different type of visible persistence. This is a somewhat controversial suggestion (see Irwin and Yeomans, 1986), that will be considered in more detail later.

Another matter that deserves consideration is that under certain spatio-temporal conditions, estimates of the duration of visible persistence obtained using temporal integration procedures are much shorter than estimates obtained using other experimental procedures (e.g., Di Lollo and Hogben, 1986). This finding may indicate that visible persistence is suppressed, possibly by mechanisms that are activated under the conditions used in the integration procedure. Of course, information leading to the identification of such mechanisms would be of value, since factors that may suppress visible persistence have only recently begun to be identified.

In the next section, a number of studies are reviewed. Temporal integration procedures were employed in each of these studies to measure the effects of stimulus intensity on the duration of visible persistence. In each case, a weak, but reliable effect of intensity was observed: Namely, performance in an integration task seemed to be enhanced if the intensity of the first display was greater than that of the second. The implications of this finding will be considered after the following review.

D. Effects of Display Luminance

In the original study using the temporal integration method, Ericksen and Collins (1967) investigated the effects of stimulus intensity on performance of the integration task. Intensity was manipulated in this experiment by presenting D1 or D2 for a longer period than its counterpart. Thus, by Bloch's law, the energy of the longer duration display would be greater, and would therefore constitute more intense stimulation. Ericksen and Collins found when D1 was the longer display, performance remained quite high, although a decreasing trend in performance was observed as the duration of the first display increased. On the other hand, as the duration of D2 increased, performance of the integration task declined rapidly.

On the basis of these results, Ericksen and Collins (1967) concluded that differences in the intensities of the two displays unequivocally interfere with the integration process. Performance declined (albeit gradually) as the intensity of D1 became progressively greater than that of D2, and performance declined rapidly as the intensity of D2 became increasingly greater than that of D1.

Some caution is in order when interpreting these results, however. As noted by Ericksen and Collins (1968), intensity differences in this experiment were confounded with differences in stimulus onset asynchrony (SOA). In fairness to Ericksen and Collins, ISI -- not SOA -- was of critical importance with respect to the hypothesis they were testing. Yet, in considering how the confounding of SOA and display intensity affects the interpretation of these data based on the involvement of visible persistence, the confounding becomes of critical importance.

The gradual decline in performance associated with the increasing durations of D1 should be considered first. In studies that followed the original experiment by Ericksen and Collins, it was established that performance in an integration task declines rapidly as the duration of the leading display increases (e.g., Di Lollo and Bourassa, 1983). Importantly, in these studies care was taken to match the brightness of the longer first display to that of the shorter second display. It is possible, then, that the gradual decline in performance observed by Ericksen and Collins (1967) was in part attributable to having a bright display precede a dim display. Presumably, if Ericksen and Collins had matched the brightnesses of the two displays, they may have observed a more rapid decline in performance as the duration of the first display was increased, like that observed in subsequent studies (e.g., Di Lollo and Bourassa, 1983). This suggests that contrary to disrupting performance of the integration task, the brighter leading display may have in fact facilitated performance in Ericksen and Collins's (1967) study.

Other evidence exists that indicates that performance in an integration task may be facilitated by having a brighter display precede a dimmer display. For example, Di Lollo and Bourassa (1983) conducted an experiment in which the intensity of the first display was greater than that of the second (Di Lollo and Bourassa, 1983, Experiment 2). The intensity difference in this experiment was introduced by an intensification of the elements in D1, which occurred 20 ms prior to the offset of this display. Under this manipulation, the decline in performance obtained as the duration of D1 increased was much more gradual than when a longer duration, but intensity-corrected display was presented first. For example, in the non-intensified condition, observers averaged about 50 percent correct performance of the task at an SOA of 200 ms. When the final 20 ms of D1 was intensified, observers were only incorrect on approximately 15 percent of the trials at an SOA of 200 ms.

The effect obtained by Di Lollo and Bourassa (1983) can largely be attributed to a new lease of persistence induced by the sudden intensification of dots in the leading display. However, the intensity difference created by this manipulation may have contributed to the maintenance of the high levels of performance that were observed. For example, while intensification of D1 certainly produced a new period of visible persistence, it is possible that the duration of this persistence was not solely determined by the size of the increment in the luminance of the display. In this respect, the new lease of persistence reported by Di Lollo and Bourassa might have been of shorter duration had the intensity of D2 been matched to the intensified portion of D1, rather than to the original intensity of the leading display. Consequently, the new lease of persistence that is generated by a luminance increment is probably of somewhat shorter duration than was reported by Di Lollo and Bourassa (1983).

Clearly, to isolate the effects of an intensity mismatch, it is necessary to unconfound differences in intensity and differences in SOA. Furthermore, it is necessary to produce intensity differences without producing increments in the intensity of an exisiting display.

These conditions were satisfied in two temporal integration studies. Having noted the confounding of SOA with intensity differences, Ericksen and Collins (1968) performed a second experiment to investigate the effects of presenting displays of different intensities on performance of their integration task. In this study, durations of the leading and trailing displays were both six ms. ISI varied from 0 to 100 ms in 25 ms steps, and three display intensities, equal to 1, 2 and 5 mL (roughly 3.5, 7.0, and 17.5 cd/m^2 respectively), were used. It was reported that the poorest levels of performance occurred when the difference between display intensities was greatest, and that an impairment was evident regardless of the order in which display intensities were paired. That is, across the range of SOAs tested, the worst levels of performance occurred when a 5 mL display was presented with a 1 mL display, regardless of the luminance order. However, it is possible that performance was poorer when a weak display was involved in the task owing simply to a difficulty in seeing that display. For example, if observers could not do the identification task when a complete display was presented, then perhaps they had some difficulty in seeing that display. If this were the case, then the low levels of performance that were observed when the 5 mL display was paired with the 1 mL display may not have been caused by the brightness difference, but, more simply, by the observer's inability to see the weakly illuminated part of the display. Another point to be made is that performance was always better in the mismatch conditions when the leading display was more intense than the trailing display. That is, performance in the 5-1 and 5-2 mL conditions was better than performance in the 1-5 and 2-5 mL conditions, except when the displays were presented simultaneously (i.e., SOA=0). This finding is not readily accounted for by postulating that brightness differences between displays impairs temporal integration, because the brightness difference does not change as a function of the order in which the displays are presented.

On the basis that performance of the integration task was lower overall in the mismatched conditions, Ericksen and Collins concluded that intensity differences between display halves act to disrupt the integration process.

More recently, Kinnucan and Friden (1981) re-examined the effects of presenting displays of different intensities on performance in an integration task, but concluded that brightness differences between display halves do not unequivocally interfere with integration processes. Kinnucan and Friden (1981) employed Di Lollo's variant of the integration of form method (e.g., Hogben and Di Lollo, 1974). Briefly described, this method involves the presentation of two displays, each containing 12 elements.

The elements are randomly distributed within a square viewing region. As a whole, the two displays form a regular (square) 5X5 matrix from which 1 element is missing. The observer's task is to specify the coordinates of the matrix location that did not contain a dot on a given trial. Of course, the location of the empty cell is randomly assigned from one trial to the next.

Using this procedure, Kinnucan and Friden (1981) measured performance under four intensity-pair conditions. In the bright-dim (BD) condition, a 40.9 mL (130.1 cd/m^2) leading display was paired with a 2.8 mL (8.9 cd/m^2) trailing display. The second intensity condition (dim-bright or DB) involved the same luminance differences as the first, but the weak display preceded the more intense display. In the remaining conditions, both displays were presented at the higher (BB) or lower (DD) intensity level. Durations of the displays were 30 ms each. SOA was varied within intensity conditions and ranged from 50 to 80 ms in 10 ms steps. Kinnucan and Friden (1981) reported that the lowest levels of performance occurred when the weak display preceded the more intense one. Contrary to the results obtained by Ericksen and Collins (1968), the best overall performance in Kinnucan and Friden's (1981) study occurred when the intense display preceded the weaker display. Performance in the BB and DD conditions was much the same accross the entire range of SOA's tested, with the level of performance under these conditions falling between levels obtained under the two intensity-mismatch conditions. At the two longer SOAs, however, Kinnucan and Friden reported that the difference between the BB and DD conditions was significant: Specifically, performance in the BB condition was superior to performance in the DD condition.

Kinnucan and Friden (1981) concluded that differences in display intensities did not unequivocally interfere with integration processes in their study. In fact, these investigators demonstrated a facilitation of performance when a brighter display preceded a dimmer display, and a impairment of performance when this luminance order was reversed.

E. A Summary and Discussion

In summary, evidence from several integration studies indicates that better performance may be obtained when the first display is more intense than the second. This was apparent in the results reported by Ericksen and Collins (1967,1968), and by Di Lollo and Bourassa (1983), and was clearly evident in the study by Kinnucan and Friden (1981).

Importantly, an interpretation of this result might be that visible persistence elicited by brighter displays is of longer duration. Stated otherwise, this result might be interpreted as evidence that the duration of visible persistence is directly related to stimulus intensity. This interpretation has been adopted by Long (1980,1985), who additionally contends that the type of visible persistence measured using integration techniques is different from the type measured using other experimental procedures.

The rationale for Long's (1985) contention is quite simple. Assuming that longer durations of visible persistence underlie better performance, then results from studies like those cited above suggest, that more intense displays generate longer periods of visible persistence. Further, if intensification of the stimulus increases the duration of its visible persistence, then the duration of this type of persistence is directly related to stimulus intensity. As noted earlier, when other paradigms are used to measure visible persistence, an inverse relation between the duration of visible persistence and the intensity of the inducing stimulus is obtained. Consequently, because different functional relations obtain between stimulus intensity and the duration of visible persistence, Long (1985) suggests different types of visible persistence are being measured in the different experimental settings.

Of course, the important assumption in Long's (1985) proposal is that better performance in an integration task requires that a longer duration of visible persistence is elicited by the leading display. However, as pointed out by Bowling and Lovegrove (1982), and reiterated by Irwin and Yeomans (1986), this assumption may be unwarranted.

For example, Bowling and Lovegrove (1982) suggested that brighter leading displays may facilitate performance on the basis of improved visiblity rather than by generating longer periods of visible persistence. According to these investigators, the improved visiblity of the display might act to enhance "other cues" that would facilitate performance in the integration task (Bowling and Lovegrove, 1982).

One problem with this argument is that it is unclear what the "other cues" might be. More importantly, however, if one assumes that the duration of visible persistence is inversely related to stimulus intensity, then enhancing the visibility of D1 by increasing its intensity should lead to declines - not gains - in performance of the integration task.

The reasoning for this expectation is as follows. If it is assumed that longer periods of perceptual integration produce better performance in the integration task, then any manipulation that would reduce or eliminate the period of integration should impair performance. For example, when SOA is increased in an integration task, performance declines (e.g., Di Lollo and Bourassa, 1983; Kinnucan and Friden, 1981). Of course, as SOA increases, there is a decline in the time for which perceptual integration can take place, because the temporal overlap of the responses mediating visible persistence produced by D1 and D2 declines with increases in SOA. In this respect, there is a clear relation between performance and the amount of time for which D1 and D2 are perceptually integrated.

Now, if the duration of visible persistence is inversely related to stimulus intensity, an intensification of D1 should serve to reduce the duration of the integration period, because the absolute duration of visible persistence elicited by D1 will be reduced as a function of the intensification. In this respect, it would seem that if "improved visibility" of D1 facilitated performance in the integration task, it would do so only if the more visible display visibly persisted for a longer duration. Of course, this is what Long (1985) suggests.

Although Long's (1985) reasoning seems to be valid, his conclusion that brighter displays produce longer durations of visible persistence is probably overstated. More specifically, it is agreed that, at a given SOA, longer durations of visible persistence will facilitate performance of the integration task by providing longer periods of perceptual integration. However, one must make a distinction between the conclusion that brighter displays produce longer absolute durations of visible persistence, and the alternative option, that a longer portion of the visible persistence elicited by brighter displays may be available to the observer under certain test conditions.

In other words, there are two ways in which intensification of D1 could increase the period for which D1 and D2 are perceptually integrated. As Long (1985) suggests, intensification of D1 may simply increase the length of time for which D1 visibly persists. This means the total (i.e., unimpeded) duration of visible persistence elicited by bright displays would be longer than that produced by dim displays. Thus, if we presented a bright stimulus and a dim stimulus at the same time and for the same duration, we would expect the dim stimulus to disappear from view sooner, because it visibly persisted for a shorter total duration. Of course, an immediate difficulty for Long's (1980, 1985) proposal is that when procedures yielding a measure of the total duration of visible persistence are used (e.g., when observers must respond to the onset and disappearance of the test stimulus), a robust inverse relation is observed between stimulus intensity and the duration of visible persistence.

Alternatively, intensification of D1 may increase the period of perceptual integration because a longer portion of the visible persistence elicited by the intensified leading display may be available for integration with D2. This option introduces the importance of the second display in determining the duration of visible persistence elicited by D1 that is measured by integration procedures.

To illustrate this, consider the results reported by Kinnucan and Friden (1981). Kinnucan and Friden (1981) observed that the best performance in their study occurred in a condition in which D1 was brighter than D2 (the BD condition). Importantly, performance in this condition could be compared to performance in another condition that had an identical leading display (the BB condition). But, compared at each SOA tested, Kinnucan and Friden (1981) found that performance in the BD condition was significantly better than performance in the BB condition.

As identical leading displays were used in these conditions, the difference in performance between conditions could not be attributable to differences in the duration of visible persistence *elicited* by the leading displays. Rather, it seems that what Kinnucan and Friden (1981) measured were different portions of the visible persistence that was elicited by the identical leading displays. In this sense, a longer portion of the response was available in the BD condition, and a shorter portion of the response was available in the BB condition, as indicated by the differences in performance observed in the two cases.

This dependence of performance on the intensity of D2 suggests two things. First, D2 appears to modulate visible persistence elicited by D1 under certain conditions. Specifically, it appears that intense D2s may suppress visible persistence elicited by D1 more so than less intense D2s (e.g., Kinnucan and Friden, 1981). Second, the influence of D2 indicates that some caution is required when making conclusions about the functional relation between stimulus intensity and duration of visible persistence when integration procedures are used to obtain the measure of the response. Clearly, one cannot conclude what the nature of this relation is when identical test displays produce different measures of visible persistence.

Importantly, inhibitory interactions between D1 and D2 may provide a basis for explaining how a direct relation between stimulus intensity and the duration of visible persistence may appear to exist when the duration of visible persistence is measured using temporal integration procedures. Of course, the modulation of the leading display's visible persistence relies upon the assumption that the second display in the integration procedure can inhibit neural responses mediating visible persistence of the first display. In the next chapter, a basis for the suppression of visible persistence that may occur in a temporal integration task is proposed. In the final chapter of the thesis, the functional relation between stimulus intensity and the duration of visible persistence will be given further consideration.

II. An Inhibition-based Account for the Suppression of Visible Persistence

In the preceding chapter, it has been suggested that visible persistence elicted by a leading display (D1) may be suppressed by mechanisms activated upon the presentation of a second display (D2). It is suggested here that neural responses elicited by the presentation of the second display may actively inhibit a neural response that is assumed to be mediating the visible persistence of the first display. It was noted in the last chapter that the degree of this inhibition might vary as a function of the intensity of the second display. In this chapter, an inhibition-based account is developed to state how the suppression of visible persistence might occur, and how the degree of this inhibition may be determined by intensity relations between D1 and D2.

A model for this inhibition has been developed by Breitmeyer and Ganz (1976). In this respect, the present hypothesis, although based on psychophysical evidence reviewed in the preceding chapter, is discussed in terms of inhibitory neural interactions occurring between the processing channels that, according to Breitmeyer and Ganz (1976), underlie visual masking. Thus, in developing my hypothesis, this chapter will continue in the following order. First, a discussion of "transient" and "sustained" channels (Breitmeyer and Ganz, 1976) is presented. The point of this discussion is to illustrate the basic distinctions between these processing channels, and to suggest their possible relation to visible persistence. Given this background, an overview of Breitmeyer and Ganz's (1976) interchannel-inhibition model is provided. The point of this discussion is to illustrate how inhibitory interactions between transient and sustained systems are characterized by Breitmeyer and Ganz (1976). Following this, some additional assumptions about the interactions that may occur between transient and sustained channels are outlined. These additional assumptions are required in order to adapt the interchannel inhibition theory (Brietmeyer and Ganz, 1976) to account for the suppression of visible persistence. Finally, some predictions about performance in a temporal integration task, derived from the inhibition hypothesis developed in this chapter, are presented.

A. Transient and Sustained Channels

Two classes of cells have been identified in the visual systems of a number of species of mammals by single unit recording techniques. According to Breitmeyer and Ganz (1976), the cells in these classes can be distinguished on both anatomical and neurophysiological grounds. In Breitmeyer and Ganz's classification, "transient" cells are characterized as having large receptive fields, fast conduction velocities, and short response latencies to photic stimulation. In these respects, transient cells exhibit properties very similar to "Y" cells, as described by Enroth-Cugell and Robson (1966). By comparison, "sustained" cells are characterized as having smaller receptive fields, slower conduction velocities and longer response latencies. These characteristics resemble those of "X" cells in Enroth-Cugell and Robson's classification scheme.

Owing to these basic differences, it has been suggested that transient and sustained cells underlie different types of analyses performed by the visual system. Transient cells are thought to be involved in the processing of low spatial frequency information, and to signal abrupt changes (e.g. appearances and disappearances) in the visual scene. Sustained cells are believed to process the higher spatial frequency information about a stimulus, and are thus implicated in the processing of attributes such as stimulus detail (Breitmeyer and Ganz, 1976).

It has been suggested by some investigators (e.g., Coltheart, 1980) that visible persistence may be mediated by activity in sustained channels. This view is consistent with the observation that transient and sustained cells appear to be involved in different aspects of early visual processing. However, processing within transient and sustained channels is not independent: Activity in transient channels may inhibit activity in sustained channels and vice versa (Breitmeyer and Ganz, 1976).

B. Interchannel Inhibition Theory: An Overview

Breitmeyer and Ganz (1976) have developed a model of visual masking based on inhibitory interactions between transient and sustained channels. An assumption of this theory is that upon the presentation of a novel visual event, activity in both transient and sustained processing channels is initiated. An important tenet of the interchannel-inhibition model is that backward masking may be caused by transient-on-sustained inhibition. In backward masking, perception of the first of two briefly presented displays is impaired by the presentation of the second (c.f., Weisstein, 1972). The hypothetical basis for this impairment is that sustained activity produced by the first stimulus may be inhibited by transient responses elicited by the second stimulus (Breitmeyer and Ganz, 1976). On the assumption that form information is carried in sustained channels, then, the disruption of sustained activity would account for why perception of the leading stimulus is impaired.

According to Breitmeyer and Ganz (1976), several factors will determine whether masking by transient-on-sustained inhibition will be produced. First, the transient response elicited by the second stimulus must occur during the period in which the sustained response produced by the first stimulus is active. In other words, if the transient response of the second stimulus is not temporally contingent with some portion of the sustained response produced by the first, then no masking by transient-on-sustained inhibition will occur. A large body of psychopysical evidence supports this assumption. For example, the critical temporal variable in backward masking is SOA, rather than ISI (c.f., Kahneman, 1968).

A second factor that will determine whether masking will occur is the spatial relation between inducing stimuli. According to Breitmeyer and Ganz (1976), masking will occur if the channels involved in the inhibitory interaction are close enough together in cortical space. Further, Breitmeyer (1984) suggests that the degree of masking will increase as the cortical distance between interacting channels decreases.

It should be noted that it is not entirely clear if the visual cortex is the locus for the interactions presumed to underlie masking effects. However, there is evidence indicating that cells with transient and sustained temporal properties do exist within the cortex (Ikeda and Wright, 1975; Duysens, Orban, Cremieux and Maes, 1985). Additionally, there is abundant evidence that the spatial relations between points of stimulation are preserved as one progresses from the retina, through the lateral geniculate nucleus, and to visual cortex. This retinotopic organization through the visual system, then, would allow for lateral inhibitory interactions between systems to occur at the cortex. On the other hand, such interactions might occur at any or perhaps all of these levels.

Importantly, differences in stimulus intensity will affect response magnitudes in both transient and sustained channels. As intensity of a display increases, response magnitudes in both transient and sustained channels increases (Ikeda and Wright, 1972). In consideration of the effects that stimulus intensity has on these response magnitudes, the interchannel inhibition model developed by Breitmeyer and Ganz (1976) might be modified to account for the suppression of visible persistence, as determined by differences in the intensities of the inducing stimuli. Such a modification requires some additional assumptions about the interactions between transient and sustained channels. These additional assumptions are outlined below.

C. The Inhibition Hypothesis

It is suggested here that visible persistence elicited by D1 can be suppressed by the presentation of D2. Given some additional assumptions, the manner in which D2 suppresses visible persistence produced by D1 can be discussed in terms of interactions between transient and sustained processing channels, as characterized by Brietmeyer and Ganz (1976). The first few assumptions presented below have been adopted from Brietmeyer and Ganz (1976). Following these, an new assumption is added so that inhibition produced by intensity differences between inducing stimuli can be explained within framework provided by Brietmeyer and Ganz (1976).

It is assumed that the presentation of D1 and D2 will elicit activity in both transient and sustained processing channels, and that a transient response elicited by D2 may, under certain temporal and spatial constraints, inhibit activity in a sustained channel, that was elicited by the presentation of D1 (Brietmeyer and Ganz, 1976). Importantly, visible persistence is assumed to be mediated by sustained responses produced by the individual displays. A comprehensive account of the psychophysical evidence in support of these assumptions has been given by Breitmeyer and Ganz (1976). For example, the visibility of a leading stimulus will be reduced by a subsequent stimulus under certain spatio-temporal conditions (Breitmeyer and Ganz, 1976; Weisstein, 1972). Also, Kahneman (1968) has indicated that the reduced visibility of the first display occurs whether or not the display is physically in view. That is, suppression by the second stimulus may terminate perception of the first whether the first display is actually present, or is visibly persisting, when the second stimulus is presented.

A new assumption is that the extent of transient-on-sustained inhibition may be determined by the relation between response magnitudes in the interacting channels. That is, it is assumed that a sustained response produced by the first stimulus may be inhibited to varying degrees, as determined by the magnitude of the inhibitory transient produced by the second display. Specifically, it is assumed that more inhibition will be produced by transient responses of larger magnitudes than is produced by transient responses of lesser magnitudes.

On the basis of these assumptions, it is explicitly suggested that the effect of inhibition is to reduce the duration of visible persistence produced by D1. In this respect, stronger inhibition is presumed to forshorten the leading display's visible persistence to a greater extent than would weaker inhibition.

As noted earlier, Ikeda and Wright (1972) demonstrated that response magnitudes in transient and sustained channels vary directly with stimulus intensity. Additionally, a more intense second display is known to produce more suppression of the visibility of a preceding display in backward masking experiments (e.g., see Weisstein, 1972 for a review).

To illustrate the major assumptions of the inhibition hypothesis, the relationship between stimulus intensity, and transient and sustained channel response characteristics is schematized in Figure 1 (patterned after Breitmeyer and Ganz, 1976). The y-axis in Figure 1 shows the magnitudes of transient and sustained responses produced by stimulus presentation. Differences in the heights of these responses are intended to indicate differences in their magnitudes. Namely, taller symbols are intended to represent stronger responses in the respective channels. A further note is that the shapes of the responses illustrated in Figure 1 were selected merely to ease the identification of transient

All Figures are inserted at the end of the thesis,beginning with p. 73.

Tous les Figures sont inserées à la fin de la thèses, (Commencant avec p. 73).

responses on the one hand, and sustained responses on the other. Therefore, the symbols do not represent actual forms of the responses recorded in the two channels.

----

insert figure 1 about here

The abscissa in Figure 1 represents time. Along this axis, the distance from the start to finish of a response provides an illustration of its duration. In this figure, the durations of transient and sustained responses were not shown to vary as a function of stimulus intensity, because the relation between stimulus intensity and response duration is not entirely clear. Although Ikeda and Wright (1972) measured the effects of stimulus intensity on response magnitudes in transient and sustained channels, they did not report whether durations of the responses were also affected by the intensity manipulation. In the absence of this information, I have chosen to illustrate responses that do not change in duration as a function of stimulus intensity.

On the other hand, it has been demonstrated that onset latency of transient and sustained channel activity is affected by differences in stimulus intensity. Response latencies in both channels decrease as stimulus intensity increases. The rate of decrease in response latency is, however, faster for transient responses (Ikeda and Wright, 1972), and this has been indicated in the illustrations in

Figure 1 (see panel A).

In panel B, transient and sustained responses are drawn for two equally intense displays presented in synchrony. Under this condition, the transient responses of the first (D1) and second (D2) displays occur together. Thus, no overlap of transient activity produced by presentation of D2 coincides with sustained activity produced by presentation of D1, and no transient-on-sustained inhibition would occur (Breitmeyer and Ganz, 1976).

Panels C-E illustrate the temporal overlap of responses in the two channels that may be produced by presenting displays of different intensities. Note that SOA is identical in each of the conditions shown.

Panel C shows the interchannel interactions that may be expected when presenting two displays of equal intensity at an idealized SOA. The transient response of D2 in this panel occurs during the sustained response of D1. Considering that response magnitudes in both channels are similar, an intermediate level of inhibition might occur under this condition. For example, if it is assumed that the degree of inhibition is affected by response magnitudes in the interacting channels, then more or less inhibition of the sustained response produced by D1 could conceivably occur, because the transient response of D2 could be of greater or lesser magnitude.

Panel D illustrates a case in which inhibition might be severe. In this panel, a strong transient response produced by an intense D2 is inhibiting a weak sustained response. Under such conditions, the inhibition may be strong enough to completely obliterate activity in the sustained channel. Finally, panel E illustrates a case in which inhibition of the sustained response produced by D1 might be minimal. In this panel, a relatively strong sustained response is being inhibited by a transient response of much lesser magnitude. Although activity in the sustained channel would be expected to decline to some degree by this inhibition, it would be inhibited to a much lesser extent than in the other cases illustrated.

Of course, Panels C-E illustrate some testable predictions arising from the inhibition hypothesis. Namely, under appropriate temporal conditions, one might expect performance in an integration task to vary with changes in the intensity of the second display. For example, given a D1 of constant intensity, performance in an integration task might decline as the intensity of the second display was increased. The proposed basis for the decline would be that as the intensity of D2 increased, so would the magnitude of the transient response that D2 elicited. As a consequence, the sustained response (i.e., the visible persistence) elicited by D1 would be increasingly suppressed as the intensity of D2 was increased.

This prediction was tested in the experiment reported in the next chapter. In line with the inhibition hypothesis, it was found that performance in the integration task varied as a function of the intensity of the second display.

III. Experiment 1

A. Introduction

Earlier, it was hypothesized that visible persistence elicited by a leading display (D1) may be suppressed when a second display (D2) is presented within an appropriate time interval. In the preceding section of the thesis, a basis for this suppression was developed. In review, it was suggested that a neural response presumed to be mediating the visible persistence of D1 might be inhibited by a neural response elicited by the presentation of D2. It was also suggested that the degree of this inhibition might vary as a function of the intensity relation between D1 and D2. Namely, it was hypothesized that as the intensity of D2 increased, a greater inhibition of the response elicited by D1 would be produced.

In the present experiment, five conditions, distinguished on the basis of the intensity of the leading display, were tested. The independent variable within conditions was the intensity of the trailing display. On any given trial, the intensity of D2 was presented at one of the five intensities selected for the leading display. In total, 25 unique intensity pairings were created by this design.

The major reason for conducting the experiment was to test a prediction derived from the inhibition hypothesis. Namely, Experiment 1 was designed to examine whether performance in the integration task would vary as a function of the intensity of D2.

By design, Experiment 1 resembles experiments previously conducted by Ericksen and Collins (1968) and Kinnucan and Friden (1981). However, there are some differences in the details of the present study that represent an improvement over previous experiments.

For example, Ericksen and Collins (1968) reported performance in seven out of a possible nine intensity conditions. Specifically, they did not measure performance in conditions in which there was only a minimal difference between the intensities of D1 and D2. This sort of information would have been useful in determining whether the effects of intensity differences were all-or-none, or whether graded effects would be produced as determined by the value and sign of the intensity difference.

Kinnucan and Friden (1981) tested and reported performance under all possible intensity conditions in their experiment. However, these investigators used only two intensities. Consequently, they could not evaluate effects over a range in which the intensity of the second display was less intense, equally intense, and more intense, than the leading display. Hence, only a partial evaluation could be made of the effects that the second display may have on visible persistence elicited by the first display.

The present experiment, although comparatively more limited in the absolute range of intensities tested, employs a greater number of intensity pairings than has previously been used. In total, 25 intensity pairings were tested. Also, in three conditions, the intensity of the second display ranged from less intense to more intense than the leading display. These conditions permit an analysis of how variations in the intensity of the second display systematically affect the duration of visible persistence produced by the first display, as inferred by performance in the integration task.

It was found in Experiment 1 that fewer errors were made in the integration task when D1 was brighter than D2. Conversely, more errors were made when D2 was the brighter of the two displays.

B. Methods

Observers

The author and one other observer (a female undergraduate student) served in the experiments reported below. Corrected acuity of the observers was 20/30 or better.

Visual Display

The display consisted of 24 of the 25 dots defining a 5 X 5 square matrix plotted on a Hewlett-Packard 1332A oscilloscopic point plotter equipped with fast P-15 phosphor. The 24 dots were presented in two displays containing 12 dots each. Dot positions within displays were randomly assigned on each trial, and the presentations of the displays was separated by a fixed interstimulus interval in all conditions.

Viewing distance was 57 cm as set by a viewing hood. The surface of the oscilloscope was illuminated by two 10-watt lamps, built into the sides the viewing hood. Background luminance was controlled by crossed polaroid filters mounted between the lamps and the viewing surface of the oscilloscope. The filters were adjusted daily to provide a moderate photopic background luminance of 0.9 cd/m^2: (Bartley, 1951, p.945). Individual dots in the display were separated by 0.5° of visual angle, and the entire matrix subtended 2° of visual angle as seen from the viewing position.

Selection of Display Intensities

The five intensities used in Experiment 1 were based upon detection thresholds obtained independently for the two observers. Testing for threshold was conducted using the same viewing conditions that were used in the actual experiments. Therefore, target duration, background luminance and viewing distance were of the same value during threshold testing and in Experiments 1 and 2.

PEST (Parameter Estimation by Sequential Testing; Taylor and Creelman, 1967), was used in conjunction with a two-alternative forced-choice procedure to obtain 10 estimates of threshold for each observer. The threshold task involved detection of a single dot, which could appear 1 degree to the right or left of a centrally located, non-luminous fixation point. Criterion for threshold was taken as 75 per cent correct reporting of the target's location. Based on the averaged threshold estimate, five display intensities corresponding to 0.25, 0.50, 0.75, 1.00 and 1.25 log units above threshold were computed for use in Experiment 1. Corresponding dot intensities for these levels were 0.32, 0.55, 0.97, 2.65 and 10.7 cd/m^2 for observer BDJ, and 0.41, 0.70, 1.22, 3.4, and 13.5 cd/m^2 for observer TJF. The luminances were obtained by specifying different values on the oscilloscope's Z-axis (luminance axis).

Selection of SOA

After display intensities had been determined the observers participated in pre-testing for the purpose of selecting an appropriate stimulus onset asynchrony (SOA) for use in Experiment 1. Using the intermediate target intensity (0.75 log units) preliminary trials were run to choose values of ISI that yielded approximately 50% correct responses. This medium level of performance was chosen so as to permit both increasing and decreasing trends to develop in response to changes in stimulus intensity. From the pre-testing trials, the chosen ISI's were 70 ms for observer BDJ, and 50 ms for observer TJF.

Procedure

The observer sat in a dimly lit room facing the display surface of the oscilloscope. This surface was enclosed by the viewing hood described earlier. Four fixation dots defined a square viewing region in which test displays were centered. Observers initiated all trials by pressing the return key on a computer keyboard. After a key press, 24 of the 25 matrix elements were presented in two successive flashes of 12 dots, separated by an ISI. Taken together, the dots in the flashes formed a 5 X 5 matrix from which one element was missing. The location of the missing dot was randomly assigned by the controlling software on every trial. The observer's task was to provide the row and column coordinates of the missing dot. Responses were entered into an IBM PC, which produced the randomly designed displays in addition to recording the observers responses. Presentation of displays was controlled by a high-speed point-plotter buffer (Finley, 1985). Durations of the leading and trailing flashes were held constant at 40 ms. SOA was also constant, although it was different for the two observers, owing to differences in the optimal ISI selected for each observer in the pre-test procedures described above. Five intensity conditions, defined by the intensity of the leading flash, were used. On any single trial, the intensity of the trailing flash was set at one of the five intensities selected for the leading displays.

A complete condition consisted of 500 trials comprised of 100 observations for each intensity level of D2 paired with a fixed intensity of D1. Within a session (125 trials), the five intensities of D2 were randomly paired with a fixed intensity of D1 five times each. Approximately 20 minutes was required to complete a single session.

During testing, a new condition was tried after two sessions were run in any given intensity condition. Participation was limited to a maximum of six sessions on any one day of testing, with a mandatory 30 minute rest period imposed after completion of four consecutive sessions (500 trials). Upon completion of a session, a printed summary of the observer's performance was made. Observers were given the option to examine their performance at that time. Otherwise, no feedback was given.

In total, four sessions were completed for each of the five intensity conditions, yielding 100 observations for each display-intensity pair involved in the experiment.

C. Results

The results for observers BDJ and TJF are given in Figure 2(a) and Figure 2(b), respectively. In these figures, the percentage of correct responses are shown at each combination of intensity for D1 and D2. A clear effect of intensity can be observed, which can be summarized as follows. Performance of the integration task reaches the highest and lowest levels when the difference between the intensities of D1 and D2 is greatest. Specifically, the best performance occurred when the most intense leading display was paired with the weakest trailing display. On the other hand, when the weakest display preceded the strongest display, performance was poor.

---

insert figure 2 about here

These results replicate findings reported by Kinnucan and Friden (1981), but provide additional information about the effects the second display may have in determining the duration of visible persistence elicited by the first display. Namely, the results in Figure 2 indicate that the duration of visible persistence elicited by a D1 of a given intensity will be systematically reduced owing to increases in the intensity of D2, as inferred by the declining performance observed as the intensity of D2 increased.

Figure 3 illustrates performance for both observers under the conditions in which D1 and D2 were of equal intensity. The data for this figure are taken from Figure 2. There may be a tendency for performance to decline as the intensities of the displays increase. A decline in performance occurs for observer BDJ, but much less so, if at all, for observer TJF. If the differences in performance illustrated in this figure are real, it might be argued they are due to an inverse intensity effect. This option, and others, are considered below.

---

insert figure 3 about here

D. Discussion

The results illustrated in Figure 2 confirm a prediction derived from the inhibition hypothesis. Namely, performance in the integration task varies as a function of the intensity of D2. For the moment, consider the intensities of D1 and D2 as a ratio (i.e., intensity of D1/intensity of D2). Within conditions then, more errors occurred when the ratio was less than one, and fewer errors occurred when the ratio was greater than one, as compared to the case in which the ratio was equal to one.

Before discussing the results of the present experiment in the context of the inhibition hypothesis, an alternative hypothesis may be considered and discounted. It may be suggested that fewer errors were made when the first display was brighter solely because the brighter first display generated a longer period of visible persistence (c.f., Long, 1980). This hypothesis is contradicted by the data in Figure 2, which show that, within all conditions, the number of correct responses ranged from relatively high to low, depending on the intensity of the second display. This dependence on a variable other than the intensity of the first display suggests that the duration of visible persistence, as inferred by performance in the integration task, was determined jointly by the intensities of both displays. Further, the dependence of performance on the intensity of D2 rather than on SOA strongly suggests that an active suppression of the leading display's visible persistence produced the results observed within conditions.

An inhibition-based account of the effect of the intensity of the second display can be illustrated by direct reference to the data. For both observers, an increasing suppression of the visible persistence produced by D1 is evident as the intensity of D2 increases. That is, performance declines as the intensity of D2 increases, because the sustained response produced by D1 is being suppressed by transient responses of increasing magnitudes, produced by the more intense D2s. Of course, it is assumed that the better levels of performance within conditions may be attributed to longer periods of perceptual integration. In this respect, the brighter D2 mimics the effect of a longer SOA: More intense trailing displays produce more errors in the task because they reduce the time for which the two displays are perceptually integrated. It is suggested that the reduction in the period of integration may be attributed to the forshortening of the visible persistence elicited by the first display.

Although it cannot be proven, it appears that a systematic suppression of the sustained response of the first display is produced by increases in the intensity of the second. With only two exceptions (Figure 2a), a monotonic decline in the percentage of correct responses was produced by increments in the intensity of D2.

Assuming that inhibitory interactions between processing channels produced the present results, it might also be argued that the differences in performance could be accounted for by differences in the time at which inhibition began. Recall that Ikeda and Wright (1972) demonstrated response latencies in both transient and sustained channels are inversely related to stimulus intensity. Importantly, response latencies in transient channels decline more rapidly with increases in stimulus intensity than do latencies in sustained channels (Ikeda and Wright, 1972). With respect to the present experiment, it might be argued that earlier, as opposed to stronger, inhibition produced by brighter trailing displays could account for the poorer performance that was observed when more intense trailing displays were presented in a condition.

Although a time-of-inhibition explanation cannot be completely ruled out, it seems to be an unlikely explanation for logical reasons. For example, one could, in theory, construct conditions in which inhibitory transient responses produced by D2s of different intensities occurred at the same point in the sustained response produced by a D1 of fixed intensity. To illustrate this, consider two conditions that differ only in respect to the intensity of the second display. In condition A, D2 is intense, and its inhibitory response occurs early in the response mediating the visible persistence of D1. In condition B, D2 is weak, and at the same SOA, its inhibitory response occurs somewhat later in the sustained response elicited by D1. Of course, under such conditions, performance would be expected to be better in condition B, perhaps because the inhibitory response began later in this condition (see Figure 2).

Now, to test the time-of-inhibition hypothesis, one would have to match the time at which the inhibitory response occurred in both conditions. This could be done by *decreasing* the SOA in condition B. However, performance is already superior in this condition, and it seems likely that a reduction in SOA would produce even better, not worse, performance. Consequently, time-of-inhibition would appear to be of less importance than the magnitude of the inhibitory response produced by the trailing display, at least under the present conditions.

An alternative explanation could be offered to account for the results illustrated in Figure 3. This figure shows the percentage of correct responses for both observers in the five cases where the intensities of both D1 and D2 were the same. Under these conditions, there might be a tendency for more errors to be made as the intensities of the displays increase. At the very least, there does appear to be a difference between the extreme intensity conditions. That is, for both observers, performance appears to be better when both displays are very dim compared to the case in which both displays are very bright.

If the decline in performance seen in Figure 3 is real, then this decline might be attributed to an inverse intensity effect. For example, perhaps the brighter leading displays generated shorter durations of visible persistence, which in turn reduced the period of time for which D1 and D2 were perceptually integrated. This option seems unlikely for two reasons. First, the data in Figure 2 show that the duration of visible persistence measured from D1 is clearly influenced by the second display. To suggest that the data in Figure 3 can be attributed to an inverse intensity effect, then, would be tantamount to ignoring effects produced by the second display.

More importantly, a passive account for the results in Figure 3 is totally inconsistent with the finding that the least number of errors in any of the conditions occurred in the condition in which the most intense leading display was presented (see Figure 2). This strongly suggests that the declining performance illustrated in Figure 3 is also due to some sort of active suppression of the leading display's visible persistence. Specifically, performance declines with increases in the intensities of both displays because the more intense D2s produce greater inhibition of the sustained response elicited by D1.

A general conclusion from the results obtained in Experiment 1 can be stated as follows: When the duration of visible persistence is inferred on the basis of performance in a temporal integration task, it can be concluded that visible persistence produced by more intense leading displays may last for longer periods than visible persistence elicited by dim leading displays. This inference can be made because, under fixed temporal conditions, performance was better when the first display was brighter than the second. Further, the more intense D1 was relative to D2, the better was performance in the integration task.

In general, these results support the inhibition hypothesis outlined in the preceding chapter. Namely, performance was better when D1 was more intense than ~~D2~~ because the weaker transient response elicited by the dimmer D2 produced less inhibition of the sustained response mediating the visible persistence of D1.

Presumably, reduced inhibition made a greater portion of the visible persistence elicited by D1 available for integration with the second display. In other terms, less inhibition by the weaker D2s may have increased the effective duration of visible persistence produced by D1. Of course, whether visible persistence produced by the brighter displays would have outlasted that produced by dimmer displays could not be determined in the present experiment. Consequently, although better performance of the integration task occurred when more intense leading stimuli were used, it cannot be concluded that the visible persistence produced by more intense displays is of longer total duration than persistence produced by less intense displays. Clearly, only partial measures of the response were obtained in this experiment, due to the inhibitory influence produced by D2. To obtain a clear measure of the effect of stimulus intensity on the duration of visible persistence produced by D1, it would be necessary to use test conditions that would eliminate inhibitory effects produced by the second display. To this end, the distance over which inhibitory effects could be measured was considered in Experiment 2.

IV. Experiment 2

A. Introduction

It was noted earlier that a major factor involved in the attenuation of visible persistence is the spatial proximity between inducing stimuli. Specifically, the more closely spaced the inducing stimuli are, the greater is the suppression of visible persistence elicited by a leading stimulus (e.g., Di Lollo and Hogben, 1985, 1986).

Recently, Di Lollo and Hogben (1986) outlined an inhibition-based hypothesis to account for the suppression of visible persistence in a two-flash stimulus sequence. Di Lollo and Hogben (1986) demonstrated increasing suppression of visible persistence in a temporal integration task as the average separation between adjacent points in D1 and D2 decreased. The explanation offered for this finding was based on inhibitory interactions occurring between the same hypothetical neural systems that form the basis of the inhibition hypothesis developed in the present thesis. In this regard, the framework for both hypotheses was provided by Breitmeyer and Ganz's (1976) interchannel inhibition model.

The salient difference between the hypothesis presented by Di Lollo and Hogben (1986) and the present hypothesis is that, in the present case, the magnitude of the inhibitory response is considered as the critical determinant of the suppression of visible persistence. Di Lollo and Hogben

(1986) noted that response magnitudes may be important in determining the suppression of visible persistence. However, the inhibiton hypothesis proposed by these investigators was developed to account for the suppression of visible persistence as determined by spatio-temporal relations between inducing stimuli.

In this experiment, the suppression of visible persistence as determined by proximity relations between inducing stimuli was studied. In this respect, the present experiment might be considered as an extension of the work already conducted by Di Lollo and Hogben (1986). However, separations between points in the present study extended over a much greater distance than was previously tested. For example, the largest interpoint separation investigated by Di Lollo and Hogben was 18 minutes of arc. In the present study, the smallest interpoint separation tested was 15 min, and the largest was 45 min. Consequently, the present experiment extends the study of proximity effects over larger interpoint distances.

Given that Di Lollo and Hogben's (1986) hypothesis postulates interactions between the same neural mechanisms that are implicated in the present hypothesis, another reason for conducting Experiment 2 was to determine whether the proximity effects demonstrated by Di Lollo and Hogben (1986) could be observed over the spatial separations used in Experiment 1. Clearly, if the effects of inhibition do not extend over this range, then it becomes difficult to explain how differences in response magnitudes between non-interacting neural systems could account for the results of the first experiment.

In Experiment 2, three interpoint separations were tested. The separations measured 15, 30 and 45 minutes of arc between adjacent elements, corresponding to matrices subtending 1, 2 and 3 degrees of visual angle. It was found that differences in interpoint separation did affect performance: Performance improved as interpoint separation increased.

B. Methods

Aside from the exceptions noted below, observers, the experimental task, and procedures were the same as those used in Experiment 1.

The major deviation from Experiment 1 was in the size of the visual display. In Experiment 2, three interpoint separations defined three matrix-size conditions. The separations measured 15', 30' and 45' of arc between adjacent points in the array. In total, the corresponding matrices subtended 1, 2 and 3 degrees of visual angle as seen from the viewing position. SOA was varied as the independent variable within size conditions. This manipulation was included so that the effects produced by proximity manipulations could be considered at more than just one temporal onset asychrony. SOA ranged from 90 to 130 ms, and 70 to 110 ms for observers BDJ and TJF, respectively, in 10 ms steps.

Durations of D1 and D2 were the same as used in Experiment 1. In Experiment 2 however, the intensities of the displays were kept constant at 0.75 log units above threshold in each of the experimental conditions. As in the first experiment, exactly two sessions were conducted under a given condition before a new condition was tested. Prior to collection of experimental data, observers received 50 practice trials using the 1 and 3 degree matrices. Results from the practice sessions were not included as experimental data.

C. Results

The results of Experiment 2 are given in Figures 4(a) and 4(b) for observers BDJ and TJF, respectively. These figures show the percentage of correct responses made by the two observers at each combination of SOA and interpoint separation. A clear effect of interpoint separation and SOA is evident in these results. At every SOA, the best performance is obtained where the interpoint separation is maximal, and the worst performance occurs where the separation is minimal. As SOA increased, the number of errors made in each condition also increased.

insert figure 4 about here

It is worth considering the performance of the two observers under the intermediate SOA, as this was the same SOA used in Experiment 1. Figure 5 illustrates the effect of interpoint separation on performance in the integration task at this SOA. It is evident in this figure that interpoint separation significantly affects the number of errors made, and under the same temporal constraints that were used in Experiment 1. This outcome is important for the interpretation of the results of Experiment 1, because the same processing channels that were hypothesized to account for those results provide the explanatory framework for the results of the present experiment. Of course, if the spatial range of these channels were less than the range used in Experiment 1, then the results of that experiment could not be attributed to interactions between these channels.

---

insert figure 5 about here

D. Discussion

As illustrated in Figure 4, performance declined as SOA increased and as interpoint separation decreased. Results very similar to these have been reported by Di Lollo and Hogben (1986). Further, these investigators have proposed an inhibition-based theory to account for the negative effects of both increasing SOA and decreasing interpoint separation. The results of the present experiment will be discussed within the context of this theory at a later point.

First, however, an alternative explanation that may partly account for the present results should be considered. Namely, it is possible that the positive effects of the larger interpoint separations could be attributed to the involvement of rod photoreceptors.

More generally, a potential criticism of the present conditions is that due to the range in size of matrices tested, the results obtained might have been produced because different ret[illegible]al regions were involved in each condition. It has been demonstrated by several investigators that visible persistence elicited in peripheral receptors is of longer duration than persistence elicited by foveal stimulation (e.g., Di Lollo and Hogben, 1985).

In the present experiment, although each matrix was primarily stimulating foveal regions, the three-degree matrix was also stimulating parafoveal regions (Dowling and Boycott, 1966). Consequently, when tested under the 45' interpoint separations, rod photoreceptors would have been involved in the task. Considering that rods generate longer durations of visible persistence than cones (e.g., Adelson, 1978), then it might reasonbly be argued that the better performance observed in the three-degree matrix condition could be attributable to rod involvement.

This explanation is, however, clearly limited. For example, although the better performance obtained with the large matrix may have been due to the involvement of rods, a different factor would need to be invoked to account for the differences in performance observed between the one- and two-degree matrix conditions. The fovea, which contains no rods, subtends approximately two degrees of visual angle (Dowling and Boycott, 1966). Thus, while rod persistence may have contributed somewhat to the better performance observed under the largest interpoint separation, it cannot account for the differences in performance observed in the smaller matrix conditions.

On these observations, it is suggested that an explanation based on the involvement of rods is not sufficient to account for the effects of proximity observed in this experiment. However, beyond interpoint separations of 30', the involvement of rods may have contributed somewhat to the better performance that was observed.

A more parsimonious account for the present results has been outlined by Di Lollo and Hogben (1986). These investigators proposed an inhibition-based theory for the suppression of visible persistence that can account for the negative effects of both increasing SOA and decreasing interpoint separation. The framework for Di Lollo and Hogben's theory was provided by Breitmeyer and Ganz (1976). In fact, the inhibitory processes postulated by Di Lollo and Hogben are the same as those described in the inhibition theory proposed earlier in this thesis.

Di Lollo and Hogben's theory accounts for the negative effects of small interpoint separations on the grounds that the magnitude of inhibitory interactions between transient and sustained channels increases as the distance between the interacting channels decreases. A number of studies have produced psychophysical evidence that supports this notion. For example, it has been demonstrated in a number of experimental settings that visible persistence is increasingly suppressed as the distance between inducing stimuli is reduced (Di Lollo and Hogben, 1985, 1986).

Clearly, the results of the present experiment are amenable to the same explanation. As interpoint separation increased, the strength of the transient-on-sustained inhibition would be expected to decrease, and performance would be expected to be better at the larger interpoint distances. Of course, it cannot be determined from the present results whether the better performance obtained under the 45' separations should be attributed to the decreased inhibition expected over these distances (Breitmeyer, Rudd and Dunn, 1981), or alternatively, to longer durations of visible persistence generated by rods. In this respect, a reasonable conclusion would be that the better performance at the larger interpoint separations was due to a combination of longer duration rod persistence and a reduced amount of transient-on-sustained inhibition. It was noted that performance in the present experiment also declined as a function of increasing SOA. Before considering the inhibition-based account for this effect, an alternative account, noted by Di Lollo and Hogben (1986), can be evaluated. Namely, it might be suggested that the negative effect of increasing SOA occurs because visible persistence has spontaneously decayed as a function of the time elapsed from stimulus onset (Di Lollo and Hogben, 1986). This hypothesis can be abandoned on the observation that at a given SOA, the number of correct responses made by an observer depended upon interpoint separation. As noted by Di Lollo and Hogben (1986), the dependence of performance on a variable other than SOA suggests an active process of suppression, and is inconsistent with the option that the impairment in performance at a particular SOA reflects the passive decay of visible persistence produced by the first display.

Di Lollo and Hogben (1986) account for the negative effects of increasing SOA in terms of differences in the temporal overlap of transient and sustained activity. For example, Di Lollo and Hogben suggest that the higher levels of performance obtained at shorter SOAs may occur because the short-latency transient response of D2 begins and subsides before the long-latency sustained response from D1 begins. In these cases, the sustained response elicited by D1 would not be impeded, and could continue over an interval in which it would be temporally integrated with sustained activity produced by the second display. On the other hand, as SOA increases, the brisk transient produced by D2 would occur later in time, and, for some range of SOAs, occur during the sustained response elicited by D1. In these cases, sustained activity produced by D1 would be shortened or terminated by the inhibitory transient. In the extreme case, no sustained activity produced by D1 would be available for integration with sustained activity produced by D2, and no perceptual integration of the flashes would occur.

This explanation may also be used to account for the results of the present experiment. For example, the decline in performance as SOA increased might be attributed to a progressive increase in the temporal overlap of an inhibitory transient produced by D2 on a sustained response produced by D1.

In support of this, it might be noted that the best performance reported by Di Lollo and Hogben (1986) was obtained under interpoint separations similar to those that produced the worst performance in the present experiment. However, it is likely that differences in the temporal conditions used in the two studies (and therefore differences in transient-on-sustained interactions) would account for the different levels of performance observed.

For instance, in a 15' interpoint distance condition, Di Lollo and Hogben (1986) reported the longest SOA at which near-perfect performance was obtained was about 40 ms (for observer RDB). For this same observer, performance had dropped by approximately 10% at an SOA of 48 ms. In the present experiment, the minimum SOA tested was 70 ms for observer TJF and 90 ms for observer BDJ. For both observers, performance was about 40% correct at these SOAs. It seems likely that more errors were made in the present study under the same spatial conditions because observers were tested at longer SOAs. Presumably, over these SOAs there was a greater temporal overlap of the inhibitory transient response on the sustained response of D1. In this respect, more suppression of the visible persistence produced by D1 would occur, and a lower level of performance would be expected in the integration task.

In summary, the results of the present experiment support results reported earlier by Di Lollo and Hogben (1986), but, in addition, indicate that a suppression of visible persistence may extend over interpoint separations of 30', and possibly up to 45'. The establishment of this range is of value in itself. However, the demonstration of the suppression of visible persistence over the separations used in this experiment provides empirical support for the hypothesis outlined earlier in the thesis. Namely, the spatial reach of the mechanisms postulated in that hypothesis goes as far, and possibly beyond, the interpoint separations used in Experiment 1.

V. General Discussion

In two experiments reported here it was found that visible persistence produced by the leading display (D1) in a temporal integration task can be modulated by the second display (D2). The results of Experiment 1 indicated that the degree of this modulation may vary as a function of the intensity of D2. For example, more intense D2s reduced visible persistence produced by D1 more so than less intense D2s. This was inferred on the basis that, under fixed temporal conditions, more errors were made when a brighter D2 was presented than were made when D2 was relatively dim.

In Experiment 2, it was found that the distance between elements in the test displays also affected performance. Specifically, more errors were made under smaller interpoint separations than were made under larger interpoint distances. The positive effects of the larger interpoint distances were observed across a range of stimulus onset asynchronies (SOAs), indicating that, at a given SOA, the number of errors made by the observer was determined by the spatial relationship between elements in the inducing displays (Di Lollo and Hogben, 1986).

The results of both experiments were discussed in the context of two closely related inhibition hypotheses. Both hypotheses account for the suppression of visible persistence elicited by D1 in terms of an inhibitory neural response produced by the presentation of D2. In both cases, it is believed that the effect of inhibition is to impede or terminate the response mediating visible persistence produced by the first display. With respect to the present hypothesis, it was postulated that the stronger the inhibitory response elicited by D2, the greater would be the inhibition of the response that was mediating the visible persistence of D1.

Di Lollo and Hogben's (1986) inhibition-based theory provided the explanatory framework for the results obtained in Experiment 2. This hypothesis accounts for negative effects of both increasing SOA and decreasing interpoint separations in terms of interactions between the same hypothetical neural channels that were postulated to underlie inhibition in the present studies (see Chapter 2).

The interpoint distances tested in Experiment 2 were larger than those that have previously been tested. In this respect, the results of Experiment 2 extend earlier work (e.g., Di Lollo and Hogben, 1986) by confirming that suppression of visible persistence is affected by spatial relations between inducing stimuli, and further, that the range of suppressive effects may extend over interpoint distances of up to 45'.

A conclusion made in Experiment 1 was that bright leading displays may facilitate performance in the integration task because, under some conditions, longer portions of the visible persistence elicited by brighter displays may be available for integration with D2. This conclusion was distinguished from the stronger statement that brighter displays actually produce a longer total duration of visible persistence (e.g., Long, 1985), which implies a direct relation exists between stimulus intensity and duration of visible persistence.

Some indirect arguments were raised in opposition to this view, but not for the purpose of supporting the alternative option that visible persistence is inversely related to stimululs intensity (e.g., Coltheart, 1980). In fact, it will be suggested below that while *measures* of the duration of visible persistence may be affected by changes in stimulus intensity, it is quite possible that the duration of the response, per se, is not.

A. Effects of Stimulus Intensity on Duration of Visible Persistence

Recall that Ikeda and Wright (1972) demonstrated that response latencies in transient and sustained channels are inversely related to stimulus intensity. If it is assumed that visible persistence is mediated in sustained channels, and that the duration of the sustained response does not vary with stimulus intensity, then the inconsistent effects of stimulus intensity on the duration of visible persistence can be explained on the basis of response latency changes in sustained channels.

For example, consider the conditions in which the inverse intensity effect is reliably observed. In many cases, the observer's task is to indicate the phenomenal disappearance of a test stimulus (e.g. probe-matching tasks or reaction time methods). Under these conditions, increments in the intensity of the stimulus shorten the interval over which the observer sees the test stimulus. That is, brighter displays tend to disappear sooner than dim displays (e.g., Efron, 1970). Importantly, this does not necessarily mean that the observer sees brighter displays for shorter periods, as would be the case if the visible persistence of the more intense displays was of shorter duration. Instead, the observer responds to the disappearance of the test stimulus, which may occur earlier for more intense stimuli, because the sustained response produced by brighter stimuli begins and *ends* earlier. In other words, the measured effect of stimulus intensity in these situations may provide an index of how much earlier the visible persistence of brighter stimuli started, as opposed to how much shorter the duration of the response is.

If the sustained response produced by brighter stimuli occurs earlier in time, then it might be possible to obtain a measure of the latency shift by using reaction time methods. This approach has been taken recently by Harwerth and Levi (1978). These investigators found that for contrast levels above 10%, an increase in contrast of about 0.75 log units reduced reaction time to the onset of a test stimulus by about 60 ms. Efron (1970) found that when stimulus intensity was increased by about 1.0 log unit, the duration of visible persistence of the test stimulus was reduced by roughly 45 ms. Importantly, Harwerth and Levi (1978) suggested that the differences in reaction times for their high contrast test conditions were providing measures of the change in response latency in sustained channels. If this were indeed the case, then the changes in response latency that were produced by increases in stimulus intensity correspond quite well with the change in the duration of visible persistence as measured by Efron (1970).

With respect to studies demonstrating a positive effect of stimulus intensity, it was noted that the duration of visible persistence measured in these studies varied as a function of the intensity of the second display (e.g., Kinnucan and Friden, 1981). In other words, there was no basis for concluding that brighter stimuli produce longer durations of visible persistence, because only a portion of the total duration of the leading display's visible persistence could be measured. Of course, to determine the functional relation between stimulus intensity and the duration of visible persistence, one must measure the effect of intensity under conditions in which the response is allowed to terminate spontaneously.

It might be noted that, aside from a few studies in which dark-adapted observers were used, the only procedure that produces the so-called positive energy persistence (Long, 1985) effect is the integration paradigm. As noted above, measures of visible persistence obtained in this paradigm are subject to effects produced by the second display. On the other hand, when conditions are arranged such that it is unlikely that the second display can affect visible persistence produced by the first, a very different view of the effects of stimulus intensity on the duration of visible persistence emerges.

For example, Di Lollo and Bourassa (1983) reported an experiment in which the intensities of both displays were covaried over a range of about 1.2 log units. SOA was constant between conditions, and therefore, effects on performance could be evaluated in terms of the intensities of the displays. Importantly, the interpoint separation used in this study was 60', which appears to be outside the range over which inhibitory interactions between transient and sustained channels may occur (Breitmeyer, Rudd and Dunn, 1981). If it is assumed that inhibitory interactions between responses did not extend over this range, then the results reported by Di Lollo and Bourassa (1983, Experiment 3) can be explained on the basis of changes in response latencies in sustained channels.

Across the range of intensities studied by Di Lollo and Bourassa (1983), performance in the integration task remained constant. Note that if the duration of visible persistence was inversely related to stimulus intensity, one could reasonably expect performance to decline with increases in stimulus intensity. For example, an inverse duration effect would shorten the sustained responses produced by both D1 and D2. Consequently, the period for which the two responses were temporally integrated would be reduced, and performance would be expected to be impaired, much as though a longer SOA had been used. On the other hand, if the duration of visible persistence was directly related to stimulus intensity, better performance would be expected under the higher intensity conditions. In this respect, responses of longer duration would temporally overlap for longer periods, so bright stimuli would be expected to facilitate performance, if, indeed, they produced sustained responses of longer duration.

It is worth noting that under intensity ranges similar to those used by Di Lollo and Bourassa (1983), Efron (1970) observed an inverse effect of intensity in a probe-matching task. On the other hand, over an intensity range of 2 log units, Long and Sakitt (1980) reported a direct effect of stimulus intensity on duration of persistence using a temporal integration task. Clearly, the functional relation between stimulus intensity and duration of visible persistence should not vary as a function of the procedure used. However, measurements of the duration of visible persistence may be largely affected by the type of procedure employed, and by the experimental conditions used within a given procedure. In this sense, measurements of the duration of visible persistence could be both directly and inversely related to stimulus intensity. An alternative explanation that can account for the effects of stimulus intensity on duration of visible persistence is that response latency in sustained channels, as opposed to response duration, is affected by intensity manipulations. As noted, this account provides an explanatory framework for inverse intensity effects, which are observed in several paradigms. This account may also explain why intensity effects are not observed under certain spatial conditions in the integration paradigm. For example, consider the absence of an intensity effect reported by Di Lollo and Bourassa (1983). Recall that intensities of the displays were covaried between conditions in this study, and that the interpoint distances used were likely greater than the distance over which inhibitory transient responses would reach (Brietmeyer et.al., 1981). An effect of covarying display intensities, then, would be to produce a constant shift in the latencies of sustained responses produced by D1 and D2 within each of the intensity conditions. The value of the shift would be equal to the change in response latencies as produced by a given change in display intensity. That is, in comparison to an intermediate intensity condition, sustained responses for brighter stimuli would begin earlier in time, whereas onsets of sustained responses for dimmer stimuli would occur at a later point.

If the intensities of D1 and D2 are covaried, then response latencies within a condition would change by the same amount. Consequently, the effect of stimulus intensification would be to change the time at which, but not the time for which, the sustained responses were temporally integrated. Of course, given equal durations of temporal integration across conditions, one would not expect to observe differences in the level of performance achieved between the different intensity conditions. As noted, Di Lollo and Bourassa (1983) reported no effect of intensity on performance in this experiment.

In summary, it may be that the opposing functional relations described for stimulus intensity on the duration of visible persistence could be explained on the basis that the duration of visible persistence is not affected by changes in stimulus intensity. In this respect, measurements of the duration of visible persistence may be affected by changes in stimulus intensity, and by the procedure used to estimate the duration of the response. For example, if the observer must respond to the disappearance of a test stimulus, brighter test stimuli might disappear sooner than dim test stimuli. However, this does not necessarily mean that the duration of the response mediating visible persistence of the stimulus became shorter due to the intensification. Rather, visible persistence may subside earlier for brighter stimuli, because the response mediating the persistence of the display begins and ends earlier. In this sense, relations between stimulus intensity and duration of visible persistence might alternatively be considered in terms of the relation between stimulus intensity and the latency of the response that mediates visible persistence.

B. Concluding Remarks

The effects of stimulus intensity on response latency in sustained channels should be investigated in future research. Changes in response latency may provide a reasonable account for the effects that stimulus intensity is believed to have on the duration of visible persistence, and in this respect, may offer a basis for developing a common forum in which the effects of stimulus intensity can be considered. The nature and role of visible persistence is currently being debated (e.g., see Coltheart (1980) and Long (1980)), largely because of the evidence that suggests the duration of the response is inversely related to stimulus intensity in some cases, and directly related in others. On the basis of the foregoing discussion, it may be that these views can, to some extent, be considered to be related rather than opposing.

Since it is clear that visible persistence can be impeded, another direction for future research would be to investigate the possible role of visible persistence as a stage in the processing of visual information. For example, one may be able to measure the effects of an impedence of visible persistence on higher processes such as recognition or identification of the inducing stimulus. In this regard, visible persistence might be studied under the confines of a backward visual masking paradigm.

Figure 1: Schematic representation of stimulus and transient (Λ) and sustained (∩) response magnitudes. Panel A shows response magnitudes as a function of stimulus intensity. Panel B shows transient and sustained responses for two displays (D1 and D2) presented simultaneously. The transient response elicited by D2 does not coincide with the sustained response from D1, so no masking by transient-on-sustained inhibition would occur in this condition. Panels C-E illustrate transient-on-sustained interactions for flashes of various intensities, all presented under fixed temporal conditions. Based on the magnitudes of the transient responses, inhibition of the sustained responses would be predicted to be moderate in Panel C, maximal in Panel D, and minimal in Panel E.

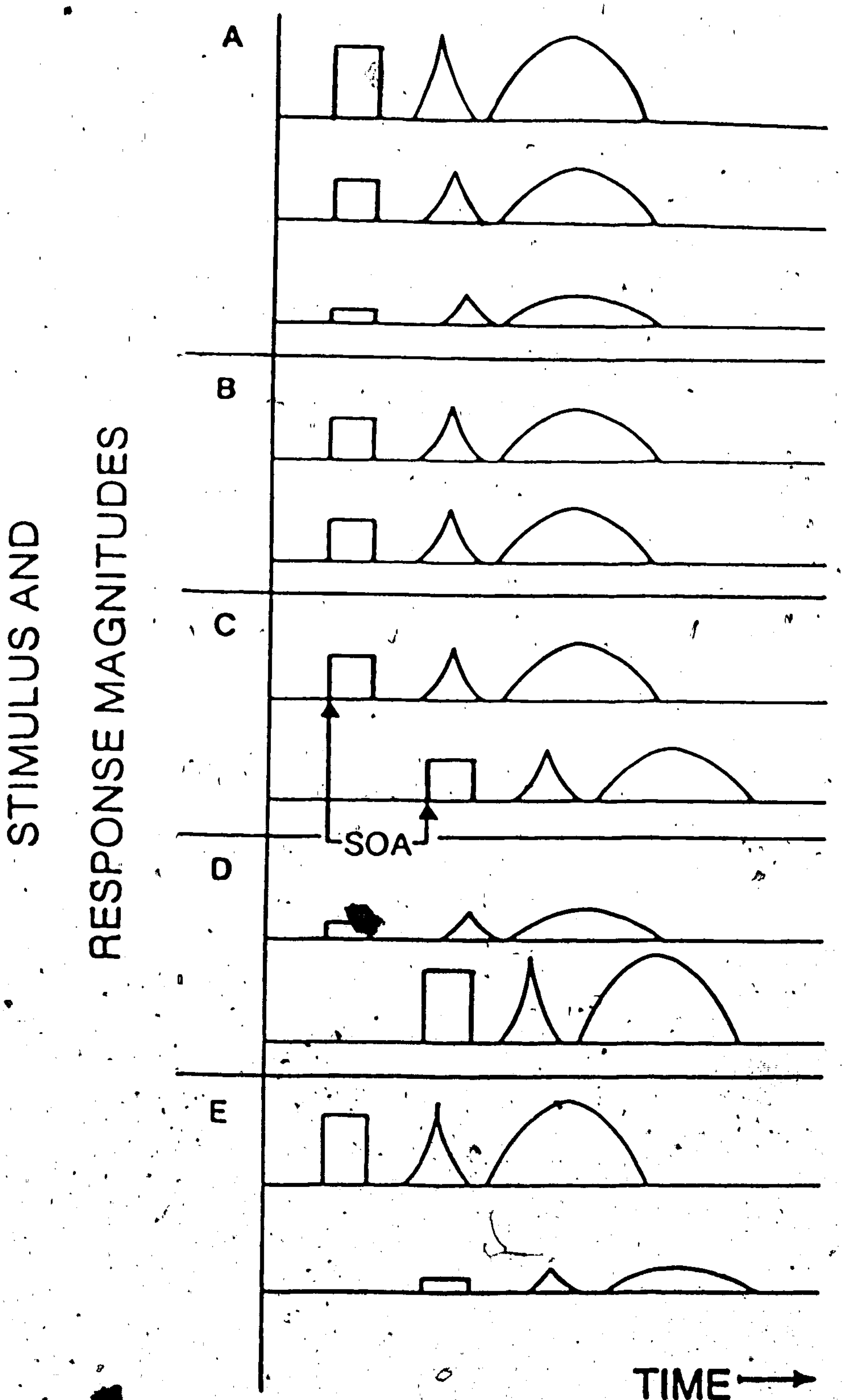

FIGURE 1

Figure 2: Performance as a function of stimulus intensity. Each datum represents performance obtained under a unique intensity pairing. The intensity of the first flash is given along the right side of the figure. The intensity of the second flash can be read along the bottom of the figure. Data in Figure 2(a) is for observer BDJ. Data in Figure 2(b) is for observer TJF.

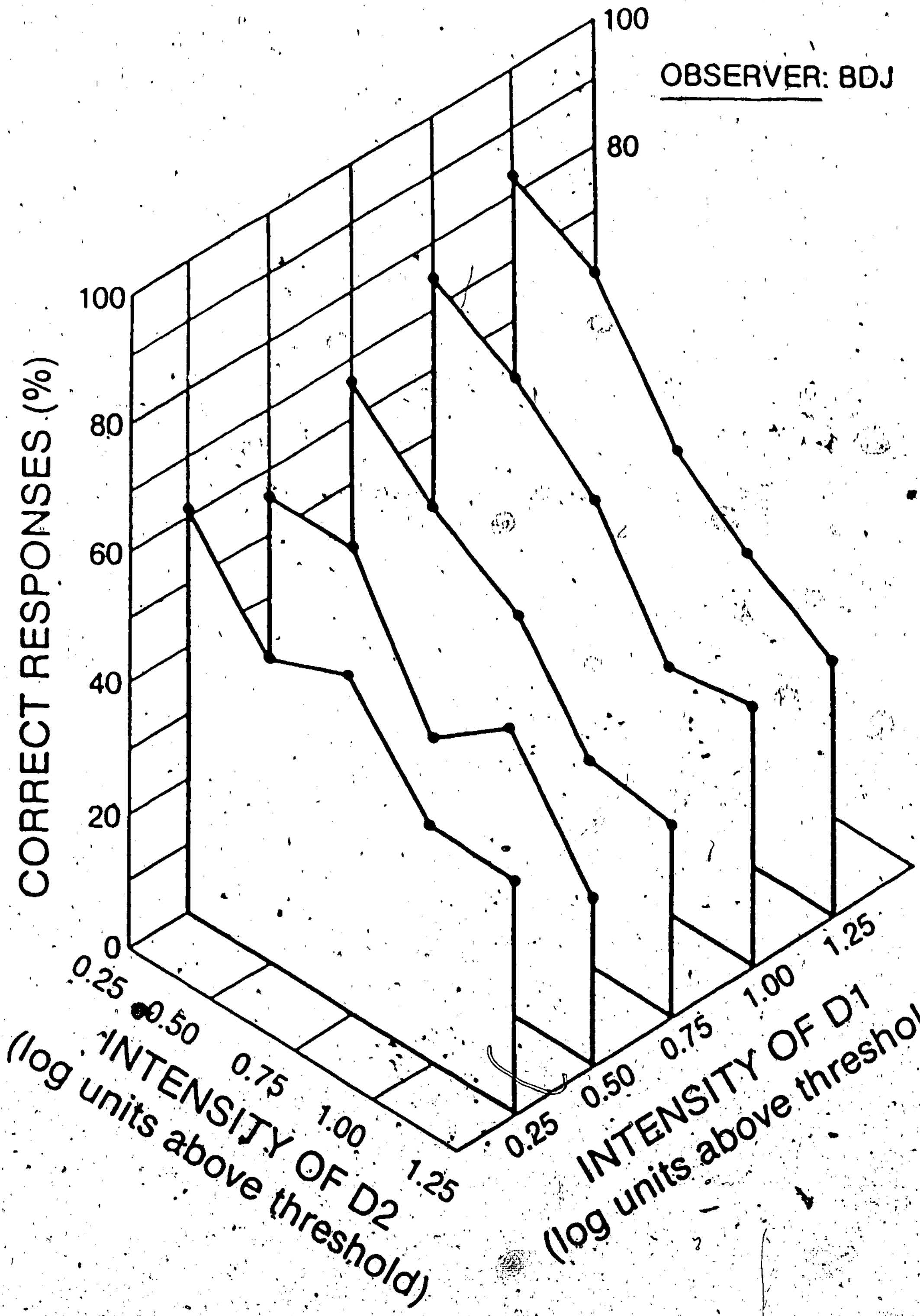
100
OBSERVER: BDJ
80
100
80
60
40
20
0
CORRECT RESPONSES (%)
0.25
0.50
0.75
1.00
1.25
INTENSITY OF D2
(log units above threshold)
0.25
0.50
0.75
1.00
1.25
INTENSITY OF D1
(log units above threshold)

FIGURE 2a

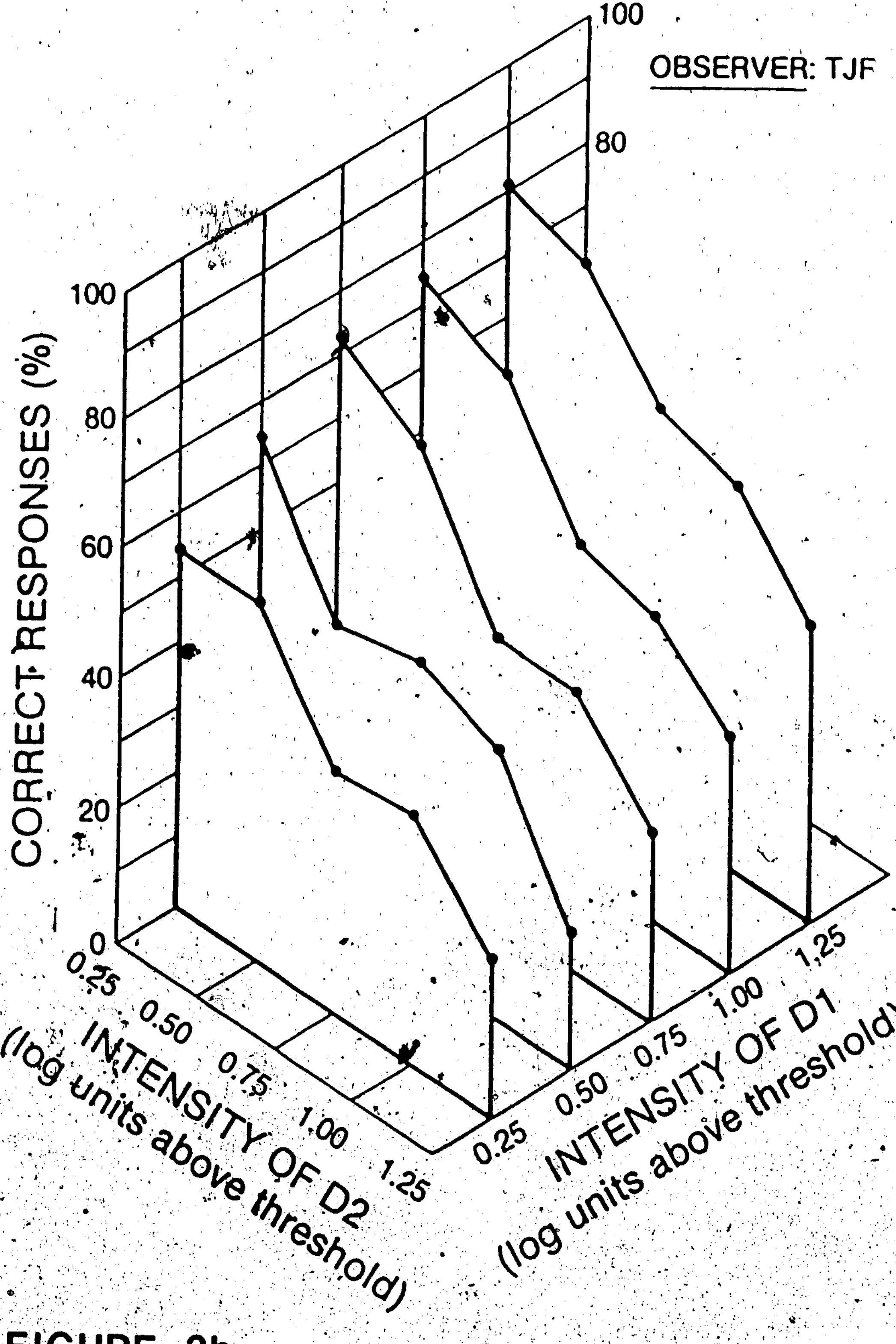
100
OBSERVER: TJF
80
100
80
60
40
20
0
CORRECT RESPONSES (%)
0.25
0.50
0.75
1.00
1.25
INTENSITY OF D2
(log units above threshold)
0.25
0.50
0.75
1.00
1.25
INTENSITY OF D1
(log units above threshold)

FIGURE 2b

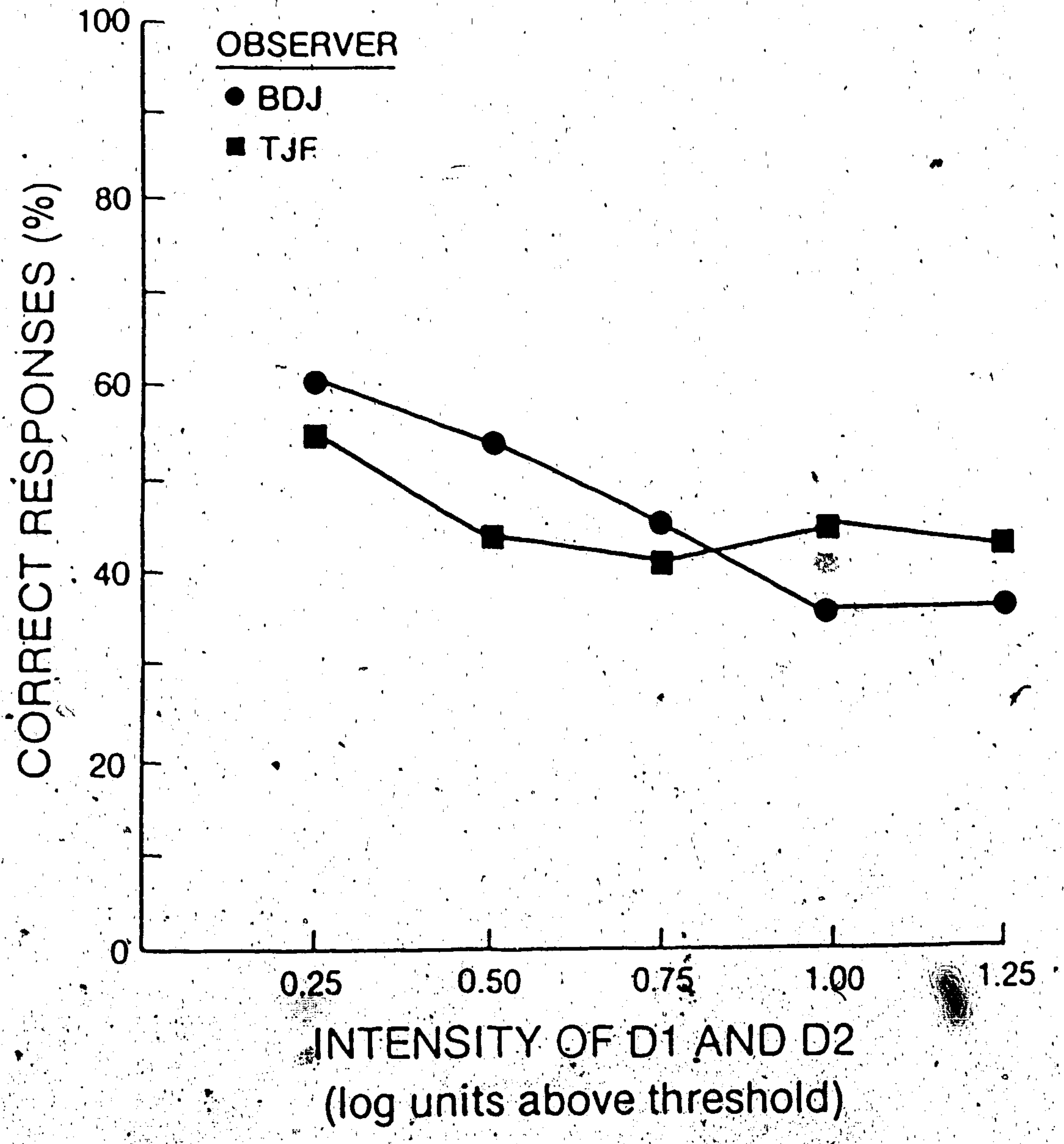

Figure 3: Performance as a function of stimulus intensity for conditions in which the intensities of D1 and D2 are matched.

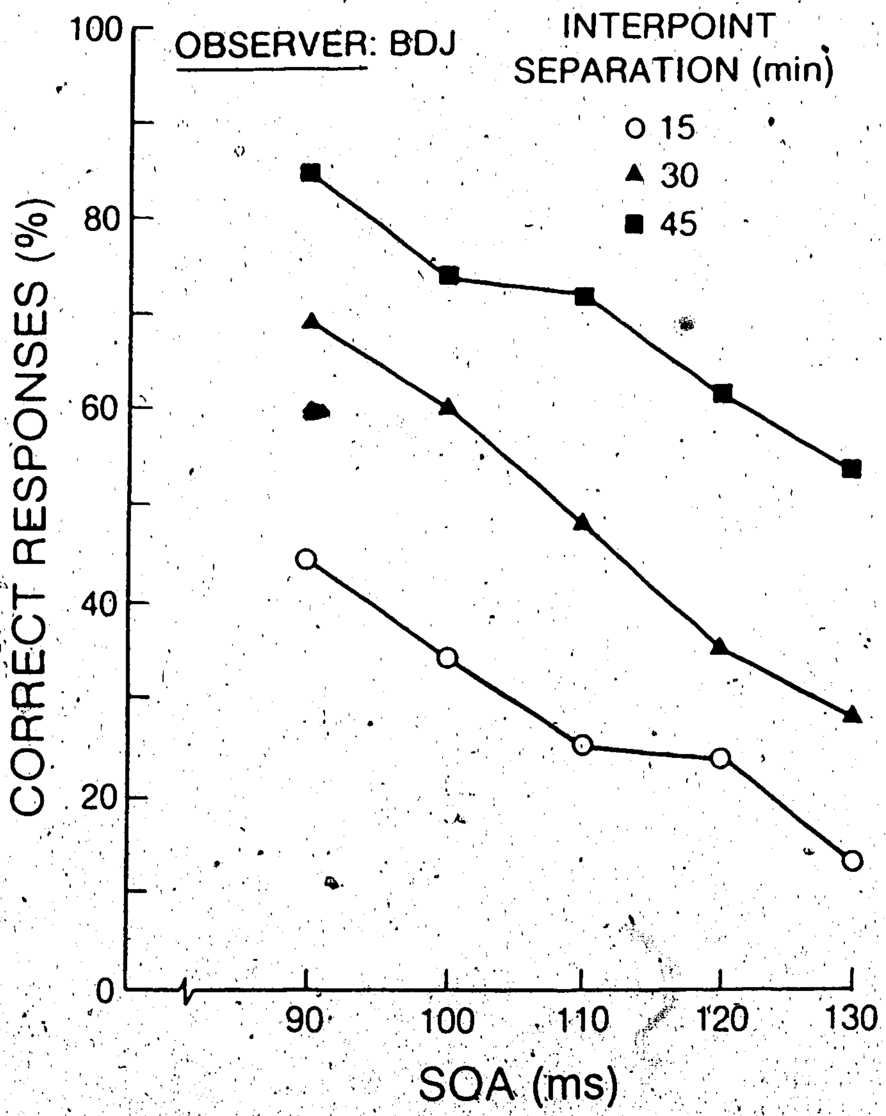

Figure 4(a): Performance as a function of the distance between adjacent elements in the test display.

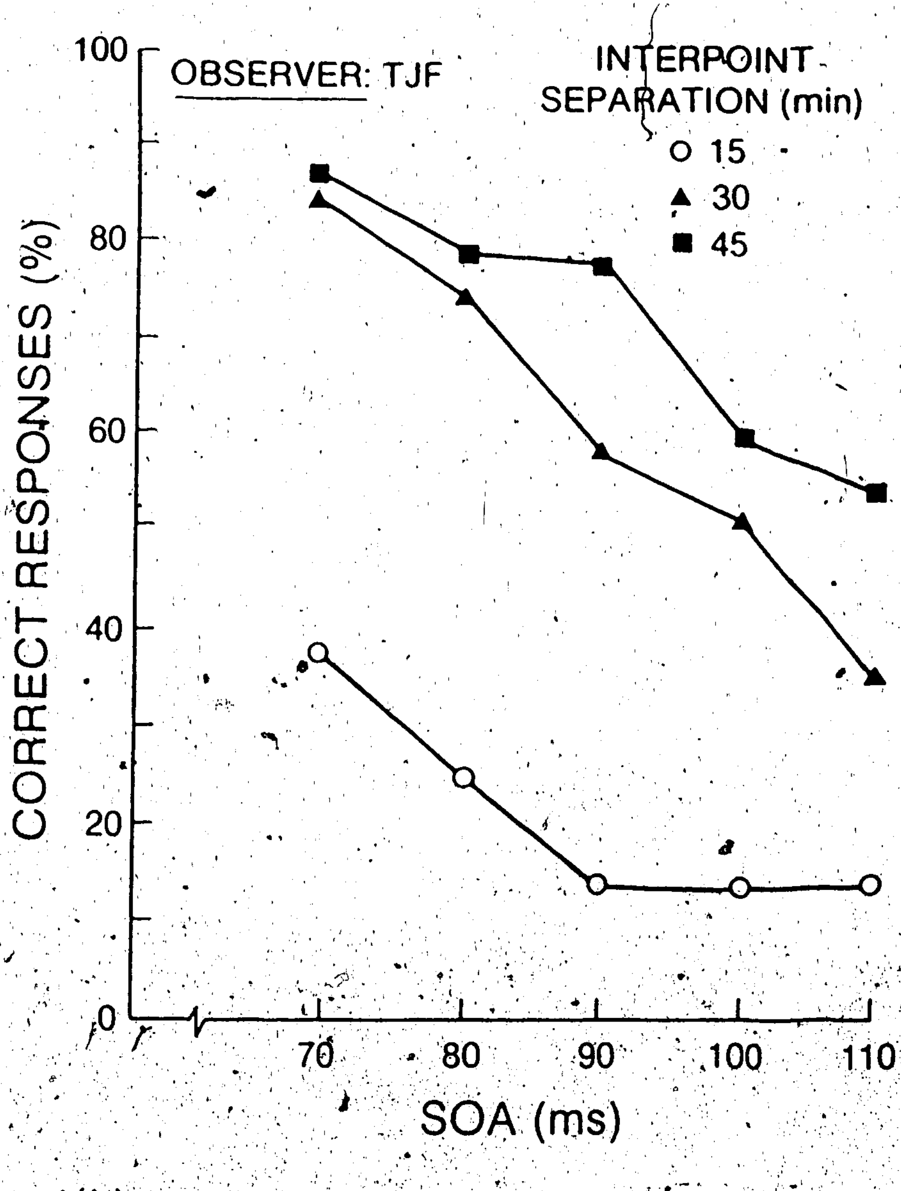

Figure 4(b): Performance as a function of the distance between adjacent elements in the test display.

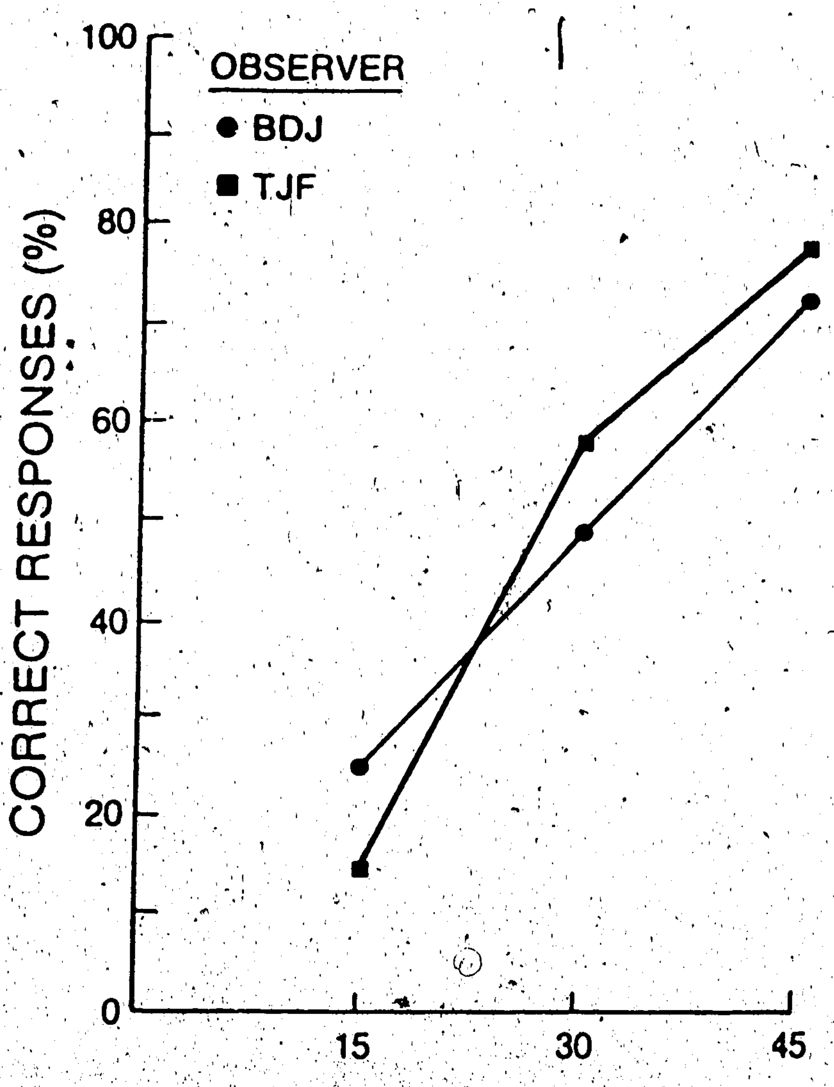

Figure 5: Performance as a function of interpoint separation under the same temporal constraints as used in Experiment 1.

References

Adelson, E.H. (1978). Iconic storage: The role of the rods. Science, 210, 544-546.

Alpern, M. and Barr, L. (1962). Durations of the afterimages of brief light flashes and the theory of the Broca and Sulzer phenomenon. Journal of the Optical Society of America, 52, 219-221.

Bartley, S.H. (1951). The psychophysiology of vision. In S.S. Stevens (Ed.), Handbook of Experimental Psychology (pp.811-867). New York: Wiley.

Bowen, R.W., Pola, J. and Matin, L. (1974). Visual persistence: Effects of flash luminance, duration and energy. Vision Research, 44, 295-303.

Bowling, A. and Lovegrove, W. (1982). Iconic memory: Fallacies persist (?). Perception and Psychophysics, 31 (2), 194-198.

Breitmeyer, B.G. (1984). Visual Masking: an Integrative Approach. Oxford Psychology Series (No.4), New York: Oxford University Press.

Breitmeyer, B.G. and Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. Psychological Review, 83 (1), 1-36.

Breitmeyer, B., Rudd, M. and Dunn, K. (1981). Spatial and temporal parameters of metacontrast disinhibition. Journal of Experimental Psychology: Human Perception and Performance, 7, 770-779.

Briggs, G. and Kinsbourne, M. (1972). Visual persistence as measured by reaction time. Quarterly Journal of Experimental Psychology, 24, 318-325.

Coltheart, M. (1980). Iconic memory and visible persistence. Perception and Psychophysics, 22, 183-228.

Di Lollo, V. (1980). Temporal integration in visual memory. Journal of Experimental Psychology: General, 109 (1), 75-97.

Di Lollo, V. and Bourassa, C. (1983). Temporal integration following intensification of long-lasting visual displays. Vision Research, 23 (7), 677-687.

Di Lollo, V. and Hogben, J. (1985). Suppression of Visible Persistence. Journal of Experimental Psychology: Human Perception and Performance, 11 (3), 304-316.

Di Lollo, V. and Hogben, J. (1986). Suppression of visible persistence as a function of spatial separation between inducing stimuli. Manuscript in review.

Dowling, J.E. and Boycott, B.B. (1966). Organization of the primate retina: Electronmicroscopy. Proceedings of the Royal Society (London), Ser. B., 166, 80-111.

Duysens, J., Orban, G.A., Cremieux, J., and Maes, H. (1985). Visual cortical correlates of visible persistence. Vision Research, 25, 171-178.

Efron, R. (1970). Effects of stimulus duration on perceptual onset and offset latencies. Perception and Psychophysics, 8, 231-234.

Enroth-Cugell, C. and Robson, J.G. (1966). The contrast sensitivity of retinal ganglion cells of the cat. Journal of Physiology (London), 187, 517-552.

Ericksen, C.W. and Collins, J.F. (1967). Some temporal characteristics of visual pattern perception. Journal of Experimental Psychology, 74, (4), 476-484.

Ericksen, C.W. and Collins, J.F. (1968). Sensort traces versus the psychological moment in the temporal organization of form. Journal of Experimental Psychology, 77, (3), 376-382.

Finley, G. (1985). A high-speed point plotter for vision research. Vision Research, 25 (2), 1993-1997.

Haber, R.N. and Standing, L.G. (1970). Direct estimates of the apparent duration of a flash. Canadian Journal of Psychology, 24 (4), 216-229.

Haber, R.N. and Standing, L.G. (1969). Direct measures of short-term visual storage. Quarterly Journal of Experimental Psychology, 21, 43-54.

Harwerth, R.S. and Levi, D.M. (1978). Reaction time as a measure of suprathreshold grating detection. Vision Research, 18, 1579-1586.

Hogben, J. and Di Lollo, V. (1974). Perceptual integration and perceptual segregation of brief visual stimuli. Vision Research, 14, 1059-1069.

Ikeda, H. and Wright, M.J. (1972). Receptive field organization of "sustained" and "transient" retinal ganglion cells which subserve different functional roles. Journal of Physiology, London, 227, 769-800.

Ikeda, H. and Wright, M.J. (1975). Spatial and temporal properties of "sustained" and "transient" neurones in area 17 of the cat's visual cortex. Experimental Brain Research, 22, 363-383.

Irwin, D.E. and Yeomans, J.M. (1986). Persisting arguements about visual persistence: Reply to Long. Perception and Psychophysics, 39 (3), 225-230.

Kahneman, D. (1968). Methods, findings, and theory in studies of visual masking. Psychological Bulletin, 70, 404-425

Kinnucan, M.T. and Friden, T.P. (1981). Visual form integration and discontinuity detection. Journal of Experimental Psychology: Human Perception and Performance, 7 (5), 948-953.

Long, G.M. (1980). Iconic memory: A review and critique of the study of short-term visual storage. Psychological Bulletin, 88 (3), 785-820.

Long, G.M. (1985). The varieties of visual persistence: Comments on Yeomans and Irwin. Perception and Psychophysics, 38 (4), 381-385.

Long, G.M. and Sakitt, B. (1980). The retinal basis of iconic memory: Ericksen and Collins revisited. American Journal of Psychology, 93 (2), 195-206.

Marx, M.S. and May, J.G. (1983). The relation between temporal integration and persistence. Vision Research, 23 (10), 1101-1106.

Taylor, M.M. and Creelman, C.D. (1967). PEST: Efficient estimates on probability functions. Journal of the Acoustical Society of America, 41 (4, part 1), 782-787.

Weisstein, N. (1972). Metacontrast. In D. Jameson and L.M. Hurvitch (Eds.), Handbook of sensory physiology (233-272). New York: Springer Verlag.