1982

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Morrison, Robert Earl, "Eye guidance in extrafoveal choice reaction." (1982). *Masters Theses 1911 - February 2014*. 1814.
Retrieved from https://scholarworks.umass.edu/theses/1814

EYE GUIDANCE IN EXTRAFOVEAL CHOICE REACTION

A Thesis Presented

By

ROBERT EARL MORRISON

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

February 1982

Psychology

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Dedicated to my parents, Sherman and Liz, for teaching me to think and seek the truth.

ACKNOWLEDGEMENTS

The author sincerely wishes to thank the members of his Thesis Committee: Sandy Pollatsek, Arnie Well, and Kay Fite; and especially the Chairman of the Committee, Keith Rayner, in whose laboratory this research was conducted.

The assistance of Jim Bertera in computer programming is appreciated.

The patience of subjects Joe DiCecco, Albrecht Inhoff, and Keith Rayner is greatly appreciated.

This research was supported by grant HD12727 from the National Institute of Child Health and Human Development.

ABSTRACT

Eye Guidance in Extrafoveal Choice Reaction

February 1982

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Although it has been amply demonstrated that eye movements are influenced by the presence of complex information in visual displays, the nature of the control of this behavior remains unclear. Because of the brevity of the eye fixations, a major theoretical dispute has arisen over whether the eyes are guided to new fixation positions immediately, on the basis of information glimpsed during the immediately preceding fixation, or on a delayed basis, because new information is not available early enough in a fixation to influence the direction of the next eye movement.

The experiments reported here attempted to illuminate this issue by presenting non-foveal stimuli (letter pairs) for classification while monitoring eye position. The response times and the tendency to execute eye movements to stimuli were manipulated by varying the eccentricity of stimulus presentation or the type of classification required of the stimulus, either a physical identity or name identity judgment. Stimulus eccentricity was varied randomly and type of classification required was varied between blocks.

During name identity judgments it was found that the random presentation of redundant physical identity information (letters which are physically identical must also have the same name) allowed the classification to be made based on the physical information, yielding faster response times. Yet eye movement tendencies were not affected: They were the same as for those trials on which redundant information was not presented and the classification was made based upon the name information. Thus, response times appeared to be determined on a trial-by-trial basis by the type of stimulus information present, while eye movement tendencies seemed to be determined globally, in response to an instructional set, rather than the stimulus information present on individual trials.

This was taken as support for the theoretical position that eye movements may not be controlled through the immediate use of complex extrafoveal stimulus information, and that such control may only occur delayed by one fixation-saccade cycle.

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CHAPTER I

INTRODUCTION

It has been said that "The most frequent choice ever made is where to look next" (Mackworth, 1965, p. 67). Ubiquitous though they may be, we are usually unaware of our eye movements. Most often it is not a conscious decision which redirects the eye. However, our choice of fixations is not random or haphazard. There are numerous demonstrations that we selectively fixate only a portion of the visual array before us and that this selection process is influenced by cognitive factors. This has been shown in studies of visual search (Williams, 1966), picture viewing (Mackworth and Morandi, 1967; Yarbus, 1967), and reading (O'Regan, 1979, 1980; Rayner, 1978). The eye movement patterns reflect information gathering needs or cognitive processes of the observer. Mackworth and Morandi (1967) found that the areas of a picture receiving a high percentage of fixations were independently rated the most informative or recognizable by other subjects. These areas contained irregular, novel contours or intellectually interesting details. Yarbus (1967) showed that fixation choices on a complex picture were altered when the observer attempted to answer different questions about the depicted scene. He stated, "The distribution of the points of fixation on an object...are determined by the nature of the object and the problem facing the observer at the moment of perception"

(p. 196). In reading, not only do we fail to fixate every word, but those that are not fixated tend to be highly redundant function words, less informative than content words. This is found even when words of the same length are compared (O'Regan, 1979).

The oculomotor behavior patterns observed in search, scene analysis and text processing are all facets of a common type of "visual exploratory behavior characterized by directed fixation-saccade sequences" (Breitmeyer, 1981, p. 1). The saccadic control system is but one type of eye movement capability we possess (for instance there is smooth pursuit, vestibular, and vergence eye movement as well). Each system is driven by different kinds of stimulation, accomplishes different visual tasks, and is subject to its own individual limitations. For example, the smooth pursuit system which allows tracking (fixating) of moving objects, requires a moving stimulus in order to respond (Ditchburn, 1973; Robinson, 1965; Yarbus, 1967). The saccadic control system accomplishes rapid redirection of the eyes' direction of regard in order to fixate extrafoveal targets, and it needs a perceptible target or object in order to perform accurately (people are notoriously poor at making accurate saccades to an unmarked position in space, Ditchburn, 1973). The different oculomotor control systems have distinct operational characteristics in terms of such things as speed of movement and latency to begin a movement as well (Robinson, 1968; Yarbus, 1967). It's obvious that these differences are mainly due to different underlying neurophysiological substrates, and indeed the selective effects of various pathologies on the separate control systems are well known (Westheimer, 1973).

It would not seem unreasonable then to assume that the behavior of the saccadic control system would show a high degree of commonality across the different situations in which humans utilize it. Accomplished by the same neurophysiological mechanism and subject to its limitations, the saccadic eye movements in different situations should be explainable, at some level, by a single oculomotor model. This is not to deny that such a model would be extremely complex. The saccades themselves seem to be of more than one type, perhaps variations on a basic theme (Bahill & Stark, 1980). Recently much effort has been directed towards specifying oculomotor models to account for the behavior of the eyes in visual information processing tasks, especially during reading (see Levy-Schoen and O'Regan (1979) and Rayner (1978) for reviews).

Although reading is an ingenious and complex behavior, man has practiced it only recently within the period of time over which mammalian saccadic eye movement systems have evolved (Walls, 1962). Indeed if the saccadic eye movement system was not available to exploit, we would probably read quite differently. It seems reasonable then to expect a fully elaborated model of saccadic control to encompass the oculomotor aspects of all kinds of visual information processing activities, not just reading, say. Nor should there be separate models for picture viewing, reading, or looking for a pencil on a cluttered desk top. Granted, a fully elaborated model would have many parameters free to vary, thus producing quantitative differences in eye movement indices across different tasks (as opposed to qualitative changes in the phenomena).

But if saccadic responses to move the eyes in order to place fixation on a new target are constrained by neurological factors resulting from millions of years of evolution, how can they be of interest to psychologists? Simply because it is also true that the placement of fixations is influenced by factors which are not part of the neurophysiological hardware: i.e., the intent of the observer, as influenced by conceptual or semantic information, which changes both between and within individuals. The saccades found in visual exploratory behavior are considered voluntary eye movements (as opposed to the involuntary types like optokinetic nystagmus) because they do require effortful processing of the visual array, but this should not be confused with conscious control, which is not necessary. We attend not at all to the execution of the motor act influencing the eye but to our interpretation of the visual array. Yet as Yarbus (1967) noted, the oculomotor system's selection of a point in the visual array for fixation seems to result from an interaction between the cognitive state of the observer and the physical properties of the stimulus. The exact manner in which this fascinating behavior occurs has proven elusive for experimental psychologists.

Eye Guidance by Extrafoveal Cues

Mackworth and Morandi (1967) suggest viewers discriminate novel from redundant stimuli with eccentric vision and use such judgments to guide eye movements. They compared fixation locations from the first two seconds of a viewing period with those from the last two seconds of the ten-second exposure and reported no difference. From the start, subjects fixated on highly informative areas. They did not fixate these areas as a result of making this distinction with foveal vision during an initial systematic scanning of the array. Fixation choices were truly based on information processed only by extrafoveal vision.

A theoretical framework for such a process is provided by Neisser (1967). He hypothesized "preattentive processes" which select appropriate portions of the visual field for further "focal processing". Williams (1966) provided data which implies such a process operates in guiding fixations. He operationalized the tendency to alter the fixation pattern of an array to accommodate task demands which was demonstrated by Yarbus (1967) in picture viewing. In the Williams experiment, subjects searched for a two-digit number centered in one of one hundred forms of varying size, shape, and color. An economy of search was achieved by telling subjects the color, size, or shape of the target's form. Some cues proved more useful than others (color was superior to size; shape was least helpful), but subjects did complete search faster by tending to fixate only those forms of a correct color, for example, and eliminating incorrect forms from foveal processing, having made the discrimination with extrafoveal vision.

There are a number of factors potentially limiting how this process may operate. First, acuity, which declines linearly with increasing retinal eccentricity (Anstis, 1974) will limit the detail of the cues that can be used as a basis for directing eye movements. Second, because mental processes occur in real time and fixation durations are relatively brief there may be timing constraints. The transmission time from retina to cortex and the latent period at the end of each fixation during which the neural command to move the eyes has been irrevocably issued but not yet evidenced leaves little time to be devoted to processing of extrafoveal fixation candidates. Additionally, Arden & Weale (1954) found that the latency to perceive stimulus onset, hence, retina to cortex transmission time, was longer for eccentric stimuli than foveal stimuli. Third, since foveal processing is usually being done in any natural situation, it may be difficult to divide attention between two separate locations (Kolers & Lewis, 1972).

Unresolved Issues Concerning Oculomotor Control

During the past ten years these issues, especially that of timing constraints, have fueled much debate and have been a major point of disagreement among theories of eye control in reading. Levy-Schoen and O'Regan (1979) provide a review of the taxonomies offered by a number of authors (Haber, 1976; Hochberg, 1970; Rayner & McConkie, 1976; and Shebilske, 1975) all of which classify different eye control models on the basis of the question, "Can the eye react immediately to what it sees?" (Levy-Schoen & O'Regan, 1979, p. 25). (Their use of the term immediate does not mean instantaneous, just able to influence the saccade that terminates a given fixation.) Many authors (Bouma & de Voogd, 1974; Kolers & Lewis, 1972; Morton, 1964) have concluded, as Williams (1966) did, that immediate control does not occur because of the timing constraints involved--increased retina to cortex transmission times for extrafoveal regions, the latency of the ballistic saccadic movement, etc. Kolers and Lewis (1972) explicate, "The information processed during any particular fixation, $\underline{n}$, cannot be what is used to drive the eye to fixation $\underline{n}$ + 1, but can be used at the earliest only for fixation $\underline{n}$ + 2." Also at issue is what level of information (purely visual, linguistic, or conceptual) is used to guide the eyes and where does it come from (foveal vision, peripheral vision, or in short term memory via previous fixations). Rayner and McConkie (1976) distinguished between low level and high level models of eye guidance. Low level control is based only on physical aspects of the stimulus. The location and lengths of words, for example. High level control uses some semantic information derived from the words to guide fixations. A possibility is that immediate control on the basis of low level cues may occur in the absence of such control based upon high level information. Additionally, immediate control at either level could derive its input extrafoveally or only from the fovea.

Simple vs. Complex Eye Guidance

Since it was demonstrated long ago that a stationary eye can saccade directly to a stimulus appearing in a random location with a latency no longer than those found in usual visual processing situations (about 150-200 msec; Hackman, 1940) the current debate among reading theorists about immediate control may seem puzzling. This may be due to an unstated assumption that what is at issue is the ability of the eye movement system to make a complex choice reaction between different candidates for fixation, i.e., to exercise high level immediate control. Certainly the simple reaction of saccading to a source of luminous energy in a psychophysical experiment occurs under immediate (but low level) control. This cannot be disputed. Whether a complex choice reaction by the eye movement system is possible without a great delay (i.e., possible within the duration of the usual fixation) is the question.

In his 1966 article on instruction-aided visual search, Williams presented a very lucid analysis within a traditional framework, which unfortunately seems to have received little attention. He said:

> One hypothesis is that the selection of each new object to fixate is a choice reaction task for the S. At any moment in time he is likely to be looking at a given object or point in the field. After having decided that that object is not the target, the next object is selected from the many visible ones in the extrafoveal field. The objects in the field can be seen with diminishing clarity with increasing distance from the fixation point. The hypothesis is that S makes a choice of one such object on the basis of the target specifications in at most about 300 msec....(This) has a major weakness with respect to the time constraints. Although up to 300 msec may be available for the choice reaction task, it is likely that only a fraction of this interval can actually be used since time is required for object identification and for eye movements. Since the simple reaction time for visual stimuli is about 180 msec (Woodworth & Schlosberg, 1960), it appears that there may be insufficient time for the hypothesized complex choice reaction. (p. 317-318)

A traditional Donders type-a manual simple reaction task (to a visual stimulus) consists of making the very same motor response (triggering some kind of response switch) when the presence of a single target is detected. The position of the target in the visual field is arbitrary; no matter what location is used for presentation the manual response is the same. In contrast, what can be considered a simple motor reaction of the eye, to fixate a single target appearing in the visual field, requires that a somewhat different motor response be executed depending upon the position of the stimulus. The target must be fixated via a saccade of appropriate direction and extent. Of course this is the nature of the saccadic eye movement system. A spatial sensory-motor neural network is presumed to be the basis for the saccadic system (Robinson, 1973) so that the natural response to a target in the visual field is the saccade required to fixate it. A saccadic simple reaction will be referred to as a simple fixation response (SFR).

A manual type-b choice reaction task might require different responses (activating different response switches) to a stimulus occurring randomly in one of a number of locations. As noted above, since moving the eye to a single stimulus occurring randomly in a number of locations would only be an SFR, the simultaneous presentation of more than one target would be required to force the eye into a choice reaction situation. A saccadic choice reaction will be referred to as a choice fixation response (CFR). Note however, that the basis on which the target is chosen in a CFR could be either simple or complex, as Williams (1966) put it. If prior bias or instructions dictated which target to fixate, such as "saccade to the target to the right of fixation" or only to one occurring "in the seven o'clock position" the task would not be much different from the SFR - to make a location-specific saccade on the basis of the position of the stimulus only. Any kind of a pre-set strategy allowing a simple CFR on the basis of positional cues would allow immediate control, but only by the low level information of position in the visual field which is information the saccadic control system cannot avoid processing if a saccade is to occur.

Thus in ongoing visual information processing tasks with multiple target arrays such as search, picture viewing, or reading, immediate control of the simple (i.e., low level) CFR should also be quite possible given that the durations of fixations here are longer on the average than the minimal latency for saccades to peripheral targets found in the psychophysical paradigms. Obviously the only difference between the SFR and the simple CFR is that more than one target is present at once in the latter and the predetermined "correct" or preferred target location must be differentiated from the others. In fact, it does appear that at least some form of simple CFR operates on an immediate basis in normal viewing situations. Random control models of eye movements in reading (Haber, 1976; Rayner & McConkie, 1976) are largely straw men, since it has been shown that the eyes are directed to fixate the central region of a word and avoid blank areas (Rayner, 1979). To accomplish this the same processes of localization of the next fixation object with respect to the momentary line of sight, computation and execution of the saccade must occur; within one fixation-saccade cycle as in the psychophysical saccadic latency paradigms. This is immediate control. It may be only a simple CFR occurring within some kind of preset strategy such as "saccade to the nearest target" or to "the first word to the right of fixation". The former strategy has been reported to operate very strongly in visual search (Engel, 1978; Levy-Schoen, 1973). The latter would be a sensible reading strategy, especially for novices.

In contrast, a complex CFR would require a capacity to decide between different simultaneously present fixational candidates on the basis of some conceptual or high level information derived from them (for example, color, size, shape or identity). This is opposed to a simple CFR on the basis of some preset criteria of location.

The Problem of Inferring Immediate Complex Control

According to the present line of reasoning the only theory of immediate control of eye guidance in information processing (search, picture viewing, or reading) that can be controversial is one that predicts immediate control of complex CFRs. Support for such a theory would require unambiguous evidence that the eyes use high level information to eliminate from consideration the nearest target in visual search, for example, or skip over a word during reading, and that this is done on the basis of immediate control. That such skipping can occur is well documented, but the information could be coming in on previous fixations, which would not constitute immediate control as the term is used here.

Complex CFRs in reading are demonstrated by the fact that not every word is fixated and that this does not occur randomly. Nor is it due to a strategy driven only by visual information such as "skip all three letter words". The so-called THE-skipping phenomenon reported by O'Regan (1979) claims that fixation choices are based on linguistic information.

The abundant data showing selective fixation of only certain portions of the visual array in visual search (see Williams, 1966) and picture viewing (see Yarbus, 1967), and the flexibility of the process to cognitive demands are indisputable evidence of complex CFRs.

What is unclear, in reading or any visual information processing activity, is whether the complex CFR is guided on the basis of conceptual information received during the immediately preceding fixation--immediate control--or whether it can only come from earlier fixations, thus a delayed use of high level information.

Levy-Schoen and O'Regan (1979) explain how THE-skipping might occur on an immediate basis in an argument popularized by Hochberg (1970), "If, at the current fixation point, there is a little information about what is coming (say, for example, that the next word is short and begins with a T), then, with added cognitive predictions it might be possible to guess that the next word is THE, and the eye would be able to skip over it.... Note that Hochberg's model assumes that information, peripheral or cognitive, acts immediately on the next saccade" (Levy-Schoen & O'Regan, 1979, p. 23). O'Regan (1979) interprets his data as evidence for immediately controlled THE-skipping. However, he failed to rule out the possibility that this phenomenon occurs on an almost-immediate (yet delayed) basis. That is, a three letter word could be tentatively identified as THE from input received during a glimpse of text on the fixation prior to the fixation from which the word-skipping saccade was launched.

At any rate, a pure demonstration of immediate complex CFR control would necessitate some way of ruling out almost-immediate control, such as on-line contingent mutilation of the stimulus. Recently Rayner and Pollatsek (1981) have used such a technique and claim evidence for immediate control (or in their terms, direct control). They constrained readers within windows of 9, 17, and 33 characters with the text outside the window replaced with a homogenous square wave grating. Window size was varied either by blocks or randomly. Mean saccade length increased with window size equally for the two conditions. This was taken as evidence for immediate control. Indeed it is but perhaps only for simple CFRs. Subjects may have been using a simple fixation response strategy based on positional cues of the stimulus, such as saccading out to some location between the edge of the window (which was admittedly quite salient) and the first empty space to the right of fixation. This would approximate moving to the center of the first word to the right of fixation. Furthermore, in the random window size condition (and by inference in the fixed window size condition as well) the effect of the window size on the previous fixation (n-1) was just as large as the effect from the fixation (n) immediately preceding a saccade. Hence delayed control seems to operate to a large degree during reading. Rayner and Pollatsek (1981) were not looking for THE-skipping or any other effect that would support the notion of complex CFRs under immediate control.

Evidence for immediate control of the durations of fixations in reading in response to complex cognitive information is widespread (Just & Carpenter, 1976; O'Regan, 1979; Rayner, 1978). However since there exists no correlation between fixation duration and subsequent saccade size (Rayner & McConkie, 1976; Walker, 1938) it has been argued that these two variables are separately controlled in the oculomotor system (Rayner & Inhoff, 1981). If the decision of where to move the eye is independent of that of how long to stay then fixation duration could be under high level immediate control yet the location of the subsequent fixation would not necessarily be controlled immediately on any more than a simple CFR basis.

An Empirical Test of a Specific Prediction of Immediate Control of a Complex CFR

Evidence showing that fixation choices are correlated with conceptual information in the stimulus processed only during the fixation immediately preceding a saccade is necessary to support high level (i.e., complex CFR) immediate control models of eye guidance. An adequate test of the immediate complex CFR model must also eliminate the possibility of accomplishing complex CFRs on a delayed basis, i.e., by processing of stimulus information glimpsed on previous fixations. Since reading and picture viewing naturally involve multiple fixations and the opportunity to glimpse a peripheral target and make a complex CFR on a delayed basis, the model can only be adequately tested by introducing a degree of artificiality into the situation (as in the mutilated text paradigm). In addition, in natural situations like reading or picture viewing the cognitive state of the observer is in constant flux. This makes it difficult to determine what expectations or interpretations of the stimulus are being entertained during any one fixation and thus quite difficult to predict specific complex CFRs likely to occur. The hypothesized THE-skipping during reading seems to be the only detailed-enough prediction to be testable.

It would be desirable to create an experimental paradigm wherein the cognitive factors assumed to affect fixation behavior are more clearly specifiable so that specific predictions about complex CFRs can be made and a more confident test of the model provided. Additionally, almost-immediate control of fixation choices must be ruled out. The latter requirement is satisfied simply by a paradigm entailing flashing a stimulus in eccentric vision which subjects may either saccade to or not while classifying it. Whether a saccade to the peripheral target is executed is certainly under immediate control. Whether such behavior is limited merely to simple reactions dictating the likelihood of fixating the target depending upon its eccentricity or perceptual salience or alternatively, whether there can be complex choice fixation responses based on a perception of the conceptual aspects of the target is open to question. Since a CFR can just as easily be viewed as the elimination of one possible fixation choice (e.g., THE-skipping) as the selection of another, this paradigm can be viewed as a choice fixation situation between the current fixation position (thus remaining fixated) and the position of the stimulus (making a saccade). Information is perceived at either position. Although extrafoveal vision is of poorer acuity than foveal vision, a saccade would interrupt processing and might slow the response if extrafoveal acuity was adequate in this situation. Under instruction to respond quickly, the subject has the option of holding fixation and processing extrafoveally or changing fixation (saccading) to utilize the high acuity fovea. (Perhaps the option belongs to the oculomotor system - it is not intended to imply a conscious decision process.)

Sanders (1973) reported discrete changes in the fixational behavior necessary to respond to extrafoveal stimuli at different eccentricities. He differentiated three useful fields of view:

the stationary field, in which stimuli could be responded to on the basis of extrafoveal information alone; the eye field, in which eye movements to fixate the stimulus were necessary for accurate responding; and the head field, in which head movements as well as eye movements were necessary. Of course, the location of the boundaries of these three regions would differ between tasks and sets of stimuli depending upon the degree of detail necessary to discriminate in the stimulus in order to respond.

It is hypothesized that a paradigm necessitating different degrees of discrimination of identical sets of stimuli, by dictating responding on the basis of different types of information, could serve to test immediate complex CFR control models by presenting the stimuli in extrafoveal vision and determining the useful fields of view discussed by Sanders (1973). Such a paradigm has been extensively studied by Posner and his associates (Posner & Mitchell, 1967; Posner, 1978). In a same-different classification task, subjects sometimes used physical (visual) information about pairs of letters to make a decision, and sometimes used the letter names (conceptual information). Subjects responded "same" or "different" to upper and lower case letter pairs under two kinds of instructions: on the basis of physical identity (PI) or name identity (NI). Under PI instruction, subjects always responded on the basis of visual form. Identical pairs (AA, bb) were classified same, dissimilar ones (Aa, AB) were classified different. Interesting results were found when subjects responded under NI instructions. Because physically dissimilar items could have the same name (Aa, Bb) or different names (AB, Ab), subjects had to access and use the letter names as a basis for comparison and response. Response time was lengthened by 70 to 100 msec. (Posner & Mitchell, 1967).

Surprisingly, RT did not increase for physically identical forms (AA, bb), as long as proportion of response types was controlled (Posner & Mitchell, 1967). Since such pairs logically share the same name, subjects were able to base their decision on the physical form information and did not wait to compare the conceptual information (even though the instructions specified seeking similarity of names). Apparently subjects did not, under NI instructions, always respond on the basis of name information. Subjects were able to short cut the comparison of the names and respond on the basis of physical information if the letters matched physically, still quicker than the responses requiring name comparison and no slower than if the response had occurred under PI instructions. This paradigm has been meticulously studied since Posner and Mitchell's original paper and certainly must be one of the most robust phenomena in the information processing literature. The original conclusion that responses under NI instructions to physically matching and mismatching pairs are based upon different levels of information, namely visual codes and name codes, is still held today (Posner, 1980).

On the basis of the cognitive factors operant, employing this task with extrafoveal stimulus presentation allows specific predictions about eye behavior to follow from immediate and delayed models of complex CFR control.

When letters are seen with extrafoveal vision, whether they are uniquely identifiable will depend upon physical variables such as size, as well as luminance and contrast (Boynton & Boss, 1971) and adjacent contours (Mackworth, 1965). Because of the decrease in acuity with increasing retinal eccentricity (Anstis, 1974), for a given letter, at some eccentricity a subject will not be able to uniquely identify it and will need to make a saccade bringing it into foveal vision in order to encode the letter's name. Letter pairs so presented under NI instructions will generally necessitate saccades for accurate responding.

Although letters are unidentifiable at a given eccentricity, certain physical characteristics might still be discriminable. Attributes such as gross shape, size, or angularity versus roundness may be perceived and of use to subjects in making decisions based upon the physical characteristics of a pair, regardless of letter names. Mackworth (1965) proposed peripheral matching of items as the function of peripheral visual processing. Posner (1967) also interprets the physical identity judgment as a perceptual matching process, wherein the observer knows that the stimuli match (or mismatch) before knowing their names. Excepting certain letters which are physically quite similar but not exactly the same (e.g., Kk), many letter pairs might be perceived to not match (and the failure to detect a mismatch might be interpreted as a positive match) on the basis of gross physical differences that could be detected by poorer extrafoveal acuity at an eccentricity beyond which discrimination is good enough to allow perfect and confident identification of the letters.

By making physical match-mismatch judgments observers might be able to respond accurately under PI instructions on the basis of extrafoveal vision alone at greater eccentricities than are possible when NI judgments are required (for the very same stimuli). In Sanders' terminology (1973), the size of the stationary field for PI judgments would exceed that for NI judgments. The eye field for NI judgments would begin at an eccentricity nearer the fovea than that for PI judgments, and would include areas of the visual field still in the stationary field for PI responses. Stimuli presented there would elicit eye movements under an NI instructional set but not under a PI instructional set, according to this view. (Of course it does not have to be an all-or-none phenomenon. All that is required is a significantly higher probability of making a saccade for NI judgments than PI judgments at the eccentricity in question.)

A short pilot study utilizing extrafoveal presentation of letter pairs in the Posner same-different classification task appeared to confirm the above hypothesis. The probability of spontaneously saccading to fixate the stimulus in order to respond increased with the eccentricity of the stimulus location for responses made under NI instructions as well as PI instructions, but was greater at each eccentricity for the NI judgments. Furthermore, the typical foveal-presentation reaction time trends were evidenced for extrafoveal presentation. Namely, NI judgments increased reaction time for physically mismatched stimuli but not for physical match pairs which apparently are still responded to on the basis of visual codes.

Assuming this effect on spontaneous fixation tendencies is robust, the relevant data for differentiating models of eye guidance will be obtained when subjects respond to physical match pairs (AA) while under instructions to base decisions upon name identity. Will the probability of making a saccade to fixate the stimulus be equal to that obtained when subjects are mentally set to base decisions on physical match or mismatch judgments--the PI trials, or will the probability increase to that found when subjects are mentally set to access name codes in order to respond correctly to the stimuli--the NI trials? The former would be interpreted as support for immediate control of complex CFRs. It would be concluded that subjects can avoid making superfluous eye movements on randomly occurring trials which do not require discrimination finer than that of extrafoveal vision. This could only occur as a result of the immediate perception of a visual match or mismatch of the letter pair in extrafoveal vision. On the other hand, the latter alternative would be interpreted as evidence against the immediate complex CFR control position. It would suggest that in this task subjects do not control saccades contingent upon a conceptual analysis of the information received in the immediately preceding fixation. The conclusion would follow that this cannot be done in this task, at least not without greatly inflating saccadic latencies. Thus the best strategy to pursue in the NI condition would be to saccade to the location of the stimulus on each trial as if a name code comparison would be necessary, without first attempting to eliminate those which physically match. This view holds that the different eye movement tendencies between the PI and NI pilot data sets are due to global task-induced effects and are not mediated trial-by-trial via immediate control of complex CFRs.

It was predicted that under the NI instructions the probability of making a spontaneous eye movement to a physical match stimulus would not increase significantly from the level found in the PI condition because, even within the roughly one-sixth to one-quarter of a second fixation period before a saccade occurs, the oculomotor control system would be interfacing information from the stimulus with the prevailing cognitive demands in order to optimize the eye movement behavior.

CHAPTER II

GENERAL METHOD AND EXPERIMENTS

Subjects. Three adult males from the University of Massachusetts community (ages 24, 28, 37) with normal uncorrected vision served as subjects. Two of them were naive about the hypotheses to be tested in the study although the other was not. The former two subjects received forty dollars for participating while the third took part voluntarily. (These factors were unrelated, however.) All subjects were right-hand dominant and were experienced eyetracking subjects.

Apparatus. Eye movements were monitored (from the right eye, viewing was binocular) by a Stanford Research Institute Dual-Purkinge-Image Eyetracker (Clark, 1975; Cornsweet & Crane, 1973). The eyetracker was interfaced with a Hewlett-Packard 2100A Computer which in turn was on line to a Hewlett-Packard 1300A X-Y Display (CRT) and received signals from two telegraph keys operated by the subject and a number of push buttons available to the experimenter.

The initial calibration of subjects with the eyetracker required fixation of a target (a small 5 x 5 cross of luminous dots approximately .33° of visual angle square) successively displayed for a duration of one second 1° above, below, left, and right of the location of a central fixation cross which then appeared indefinitely, while the computer sampled a signal from the eyetracker for each of these four predetermined points in space. Based on the sampled values an additional cross was then displayed on the CRT at the calculated position of the subject's fixation for the currently received signal. This cross appeared to "follow the subject's eye." The experimenter instructed the subject to fixate the stationary central fixation cross, causing the eye-following cross to superimpose over it if the calibration was precise. If it did not the calibration routine was repeated.

When satisfied with the accuracy of the calibration the experimenter pressed a button to begin the trial block. The eye-following cross was no longer displayed but its hypothetical position was still computed by the computer program. If the condition in which it superimposed with the position of fixation cross existed for 30 msec the fixation cross disappeared and the stimulus appeared. The computer then recorded and stored data about the eye movements of the subject during response to the stimulus as well as the subject's reaction time to classify the stimulus on one of the two telegraph keys. Immediately following the response a homogenous brightness mask was displayed for 100 msec in the position the stimulus had occupied on the CRT.

At the end of a trial the experimenter pressed a button which displayed the central fixation cross again. As soon as the criterion fixation was demonstrated for 30 msec the next stimulus appeared. Thus, once the fixation cross was provided by the experimenter the trial ran off automatically as soon as the subject was properly fixated. This insured that the stimuli did occur at the specified eccentricities in the visual field. Since the time required by this process was variable the intertrial interval was also, but usually lasted no more than ten seconds (including the time for the computer to print out partial data and the prompting of the fixation cross by the experimenter). If the subject believed he was fixating properly, but the trial would not begin, a new calibration was performed. The subject's head was held steady by means of a bite bar molded from Kerr dental impression compound. Subjects responded via the two telegraph keys using the thumb and index finger of the right hand.

Stimuli. The stimuli were single pairs of letters aligned vertically. Five letters: a, b, d, e, and g were employed in both upper and lower case, resulting in 55 possible stimulus pairs. The letters were composed of luminous dots from a 15 by 23 matrix on the face of the CRT which subtended approximately 1° x 1½° of visual angle at the viewing distance of 50 cm. The matrices encompassing the letters were separated vertically by .33° of visual angle.

Procedure. Subjects were instructed to fixate a central cross after which a letter pair would appear randomly to the left or right of the cross. They were to classify the pair-mates same or different as quickly and accurately as possible on the basis of either physical identity (PI) or name identity (NI) according to the well known paradigm developed by Posner and his associates (Posner, 1978; Posner & Mitchell, 1967).

Thus, some stimuli (e.g., $\begin{matrix}E & B \\ E & g\end{matrix}$) required but one response whether encountered under a PI or NI instructional set. But same-letter, mixed-case stimuli (e.g., $\begin{matrix}A \\ a\end{matrix}$) could elicit either response depending upon the prevailing instructional set. Response type was equated across instructional sets, that is under either instructional set half the stimuli required "same" responses and half were to be classified "different." This necessitated two different sources of stimuli, one for PI trial blocks composed of 50% same-letter, same-case pairs, 25% same-letter, different-case pairs, and 25% different-letter pairs; the other composed of 25, 25, and 50% of these three classes of stimuli, respectively, for NI trial blocks.

The stimuli were presented at one of 13 positions in the visual field: ½, 1, 1½, 2, 3, or 5° left or right of the fixation cross (measured from the center of the fixation cross to the nearest edge of the letter pair), or simply centered around the fixation cross--the "foveal presentation" condition. Pilot experimentation showed that the letters were large enough to be perceived and classified in parafoveal vision.

Stimuli were presented in blocks of 40 trials, with up to eight blocks in any one experimental session. Each session was performed under one instructional set only.

Experiment 1

Method. In Experiment 1 subjects made PI judgments for six consecutive experimental sessions, usually on successive days, and then performed NI judgments for six sessions also. Two sessions of practice on two consecutive days preceded the PI condition while one session preceded the NI condition. The extra initial practice allowed the subject to get accustomed to and improve performance on the precise fixational task he needed to perform in order to prompt the stimulus from the computer.

Subjects were aware that their eye movements were being monitored during the task. They were instructed to view the display freely--to direct their eyes in any manner they chose--in order to make the quickest responses possible while still maintaining a high degree of accuracy.

Results. Under instructions to view the display freely, subjects spontaneously made saccadic eye movements while responding to the stimuli only part of the time. Often they did not move their eyes, responding to the stimulus on the basis of extrafoveal information alone, with no loss of accuracy even when the stimulus appeared 5° eccentric to the point of fixation. Averaged across subjects, error rates for moving and non-moving responses were 12.8 and 8.8 percent, respectively (overall error rates for individual subjects ranged from 2.1 to 12.1 percent).

Throughout the experiments reported here the latencies and durations of saccadic eye movements were within expected distributions with means of approximately 150-300 msec for the latencies and 15-50 msec for the durations. Since the occurrence of a saccadic eye movement while responding to the stimulus was not a factor manipulated by the experimenter but was controlled in some manner by the subjects the reaction time data from movement and no-movement responses were analyzed separately.

Mean reaction times for the three subjects from trials during which an eye movement occurred are shown in Figure 1. The stereotypical increase in reaction time found when name code comparison is necessary was evidenced not only for letter pairs presented foveally but for extrafoveal stimuli as well (up to 5° left or right of fixation). A practice effect or increase in response speed from the first half of the experiment (PI trials) to the second (NI trials) seems to be present also, accounting for the lower reaction times to physically matching stimuli during the NI task and the less pronounced NI-PI difference on physically mismatching stimuli. The relevant piece of data to examine is the difference between reaction times to the two stimulus types, which increases when an NI task is performed (the filled symbols in Figure 1 are spaced farther apart than the open symbols). Mean reaction times (when eye movements occurred) for individual subjects are plotted in Figure 2.

The reaction times were tested with a 2 x 2 x 13 repeated

Figure 1. Group mean response times (msec) in Experiment 1 for trials on which a spontaneous eye movement to fixate the stimulus occurred, as a function of stimulus eccentricity. Data for zero eccentricity ("foveal condition") is taken from no-movement responses and presented to provide continuity of the plot and baseline information. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

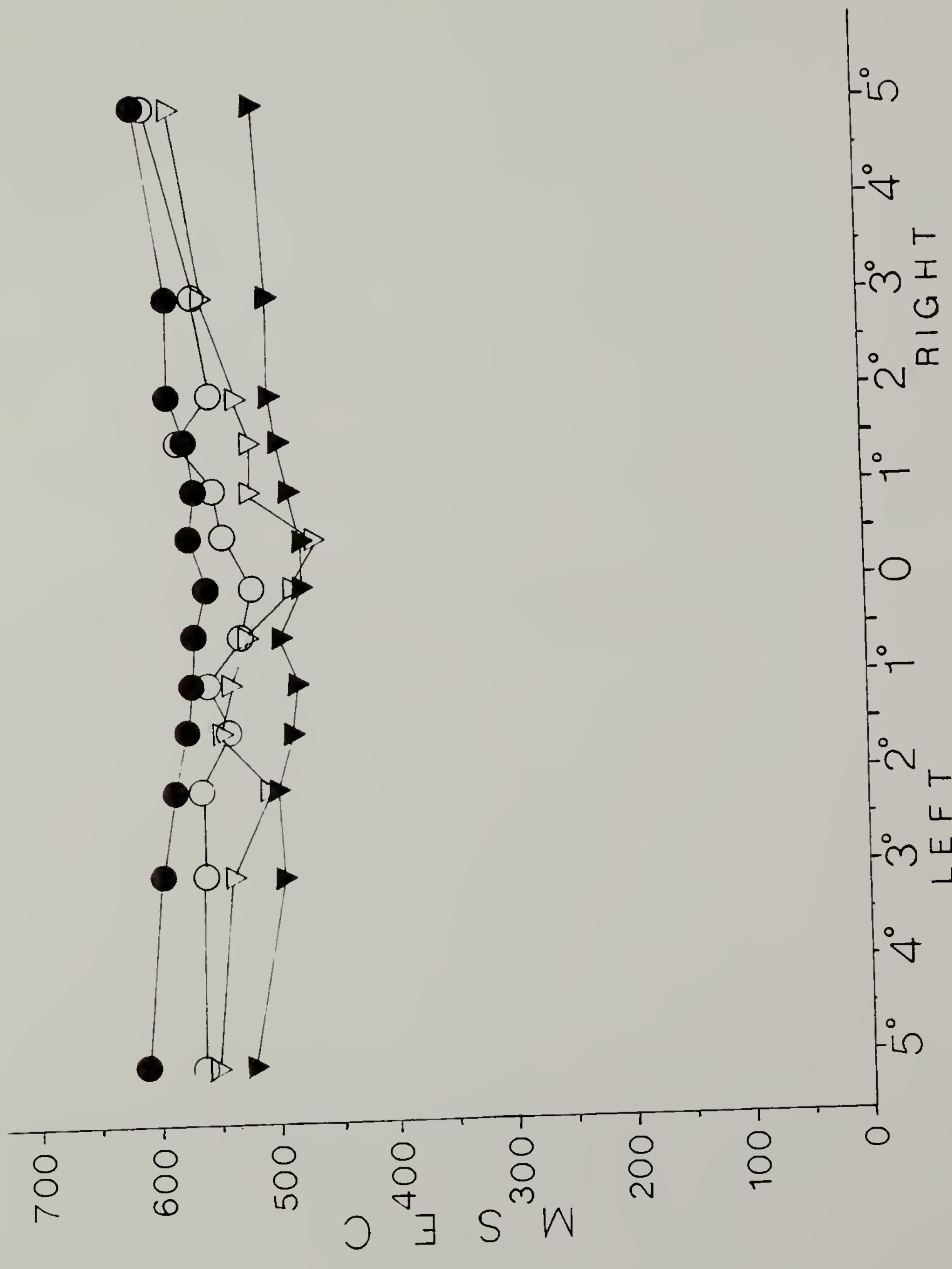

Figure 1

Figure 2. Individual mean response times (msec) for three subjects in Experiment 1 for trials on which a spontaneous eye movement to fixate the stimulus occurred, as a function of stimulus eccentricity. Data for zero eccentricity ("foveal condition") is taken from no-movement responses and presented to provide continuity of the plot and baseline information. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

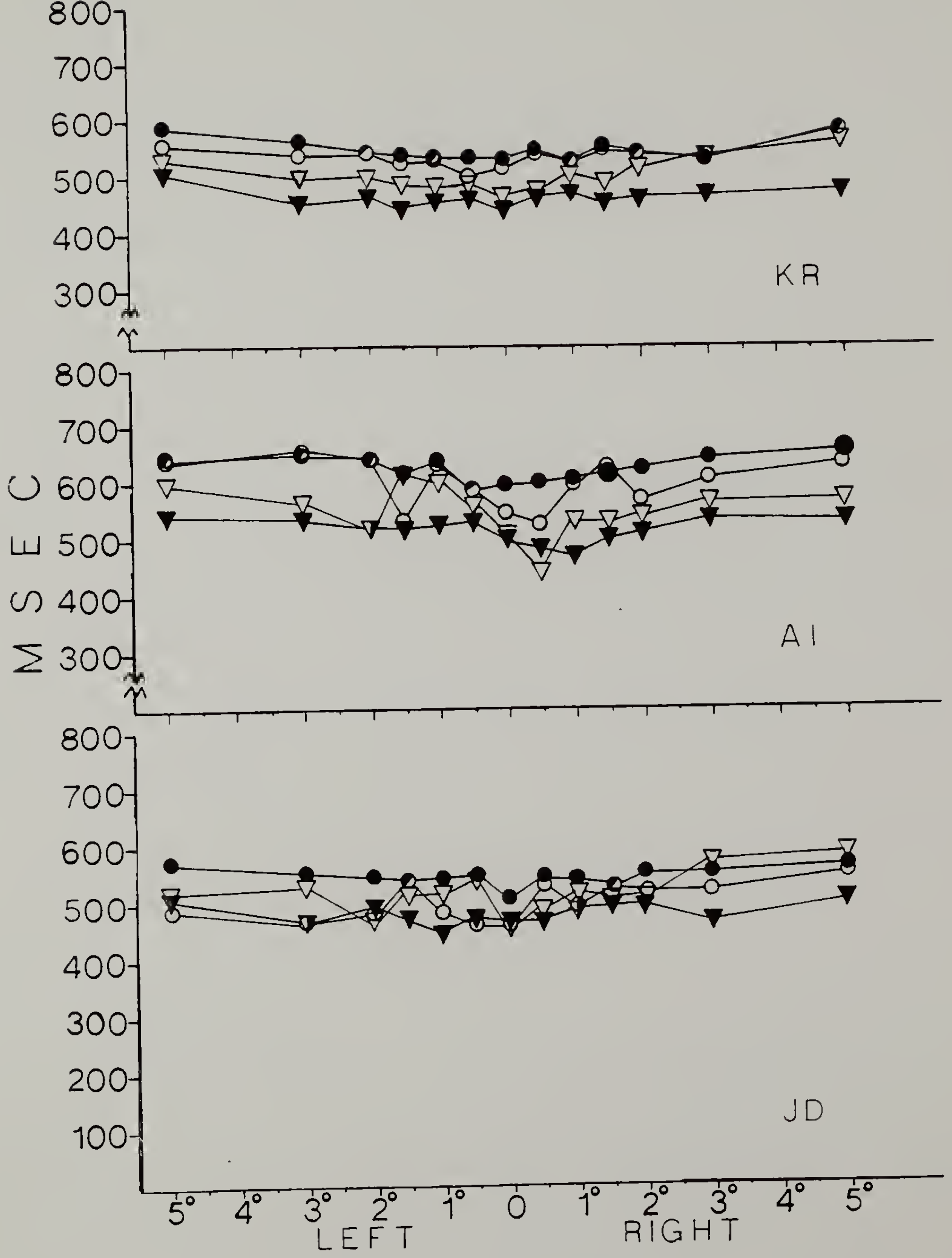
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Figure 2

measures design ANOVA (Task (PI vs. NI) x Stimulus type (physically identical vs. nonidentical) x Position in visual field (5° left to 5° right)). Since the critical NI-PI difference in reaction time occurs only for some stimuli (those that do not physically match) the effect is indexed by a significant Task x Stimulus interaction ($F(1,2) = 43.38$, $p < .025$). Although the increase in reaction time with increasing eccentricity was not steep, a main effect of Position was obtained ($F(12,22) = 3.07$, $p < .011$). These were the only effects reaching significance at the .05 level. When averaged over tasks, the main effect of Stimulus type was marginally significant ($F(1,2) = 16.15$, $p < .06$) as was a Stimulus x Position interaction ($F(12,22) = 2.02$, $p < .075$).

Reaction times for trials responded to by remaining fixated about the position of the central fixation cross are plotted in Figure 3. Again, the slight increase in reaction time as eccentricity increases and the increase for name code comparison trials is robust across the eccentricities employed. Since one subject had quite a high proportion of spontaneous eye movements, leaving many empty cells in the data matrix for non-moving responses, Figure 3 represents only the data from the other two subjects (plotted individually in Figure 4), which was analyzed with a 2 x 2 x 13 ANOVA. The interaction effect of Task x Stimulus was still highly significant ($F(1,1) = 180.3$, $p < .05$). The main effect of position reached marginal levels of

Figure 3. Group mean response times (msec) in Experiment 1 for trails which were responded to without making an eye movement, as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli; circles = physical mismatch stimuli.)

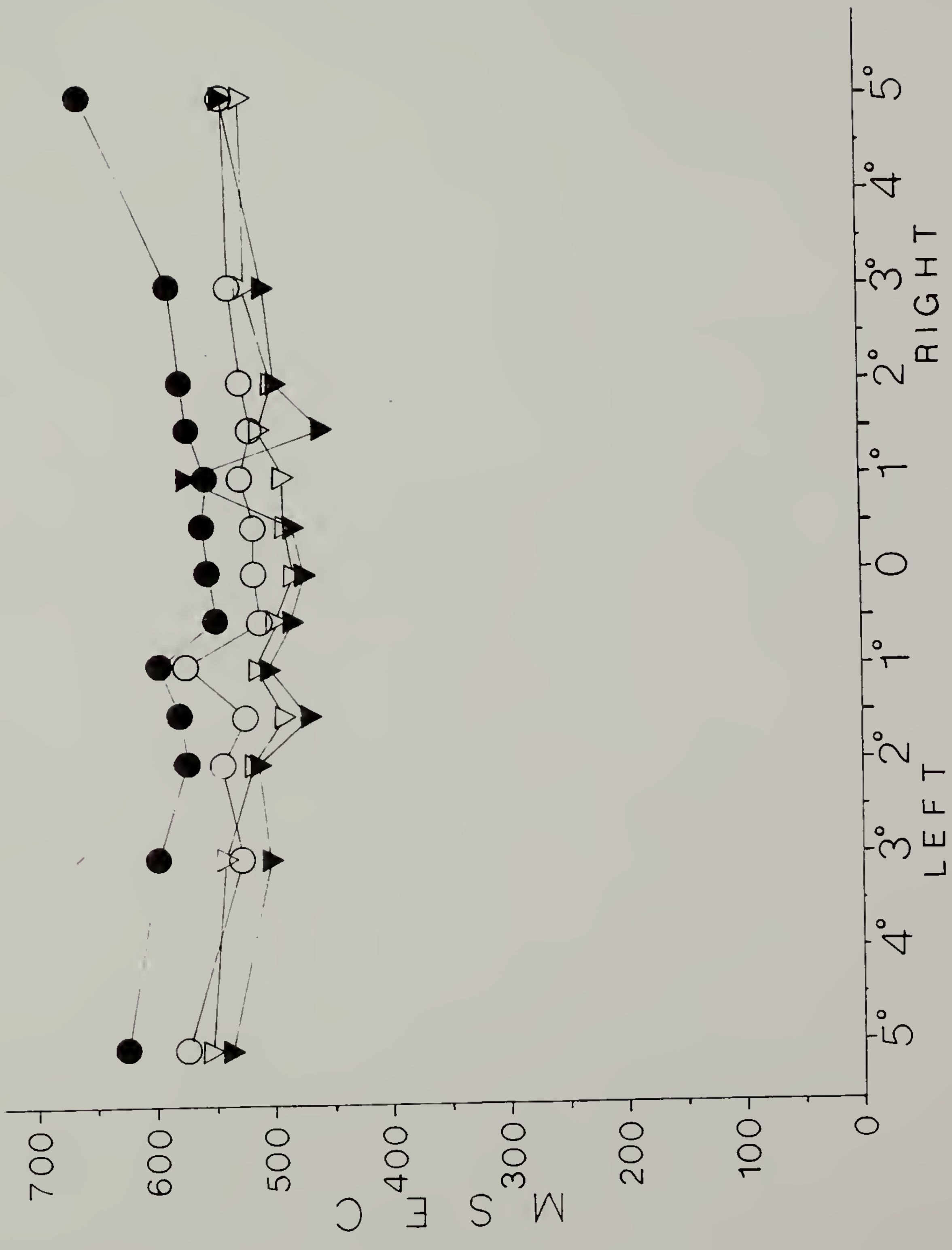

Figure 3

Figure 4. Individual mean response times (msec) for two subjects in Experiment 1 for trails which were responded to without making an eye movement, as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli; circles = physical mismatch stimuli.)

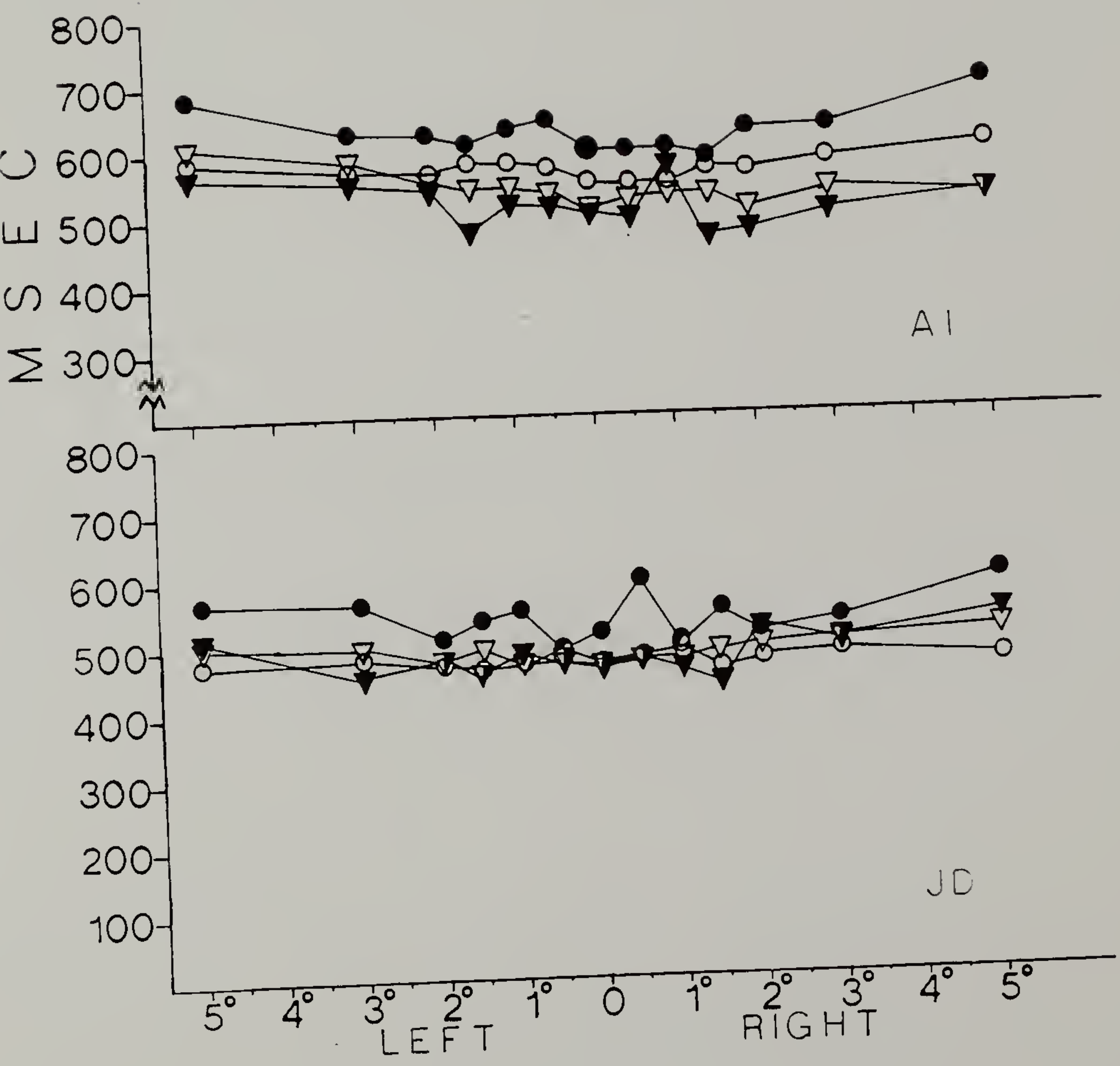
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Figure 4

significance ($\underline{F}(12,10) = 2.83$, $\underline{p} < .06$).

Given that subjects are responding to extrafoveal letter pairs by comparing visual or name codes, and are not always making spontaneous eye movements to fixate the stimulus, an examination of the relation between spontaneous eye movement behavior and the type of information one extracts from the stimulus on each trial may yield evidence bearing on the issue of immediate complex CFR control. Figure 5 shows the group means for proportions of spontaneous saccades occurring to fixate the stimulus.

As predicted (replicating the pilot study), there is an observable difference in the eye behavior induced by the different instructional sets. More spontaneous saccades are made to the stimulus in the NI task. However, the increase imposed by the NI task occurs for the trials of physically matched letter pairs in addition to the mismatched pairs, unlike the RT data. This pattern of data is not coincident with that predicted by immediate complex CFR models. The probability of making a spontaneous eye movement seems to be determined globally and not on a trial-by-trial basis via extrafoveal processing of the stimulus dictating whether a saccade is necessary or not. While the data may not completely rule out immediate complex CFR control in other situations, it is interesting to note that the physical match pairs are saccaded to differently under the NI and PI instructions, even though their RTs don't change.

A 6 x 2 x 2 x 13 ANOVA (Day x Task x Stimulus x Position) was

Figure 5. Group mean proportions of spontaneous eye movements in Experiment 1 as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

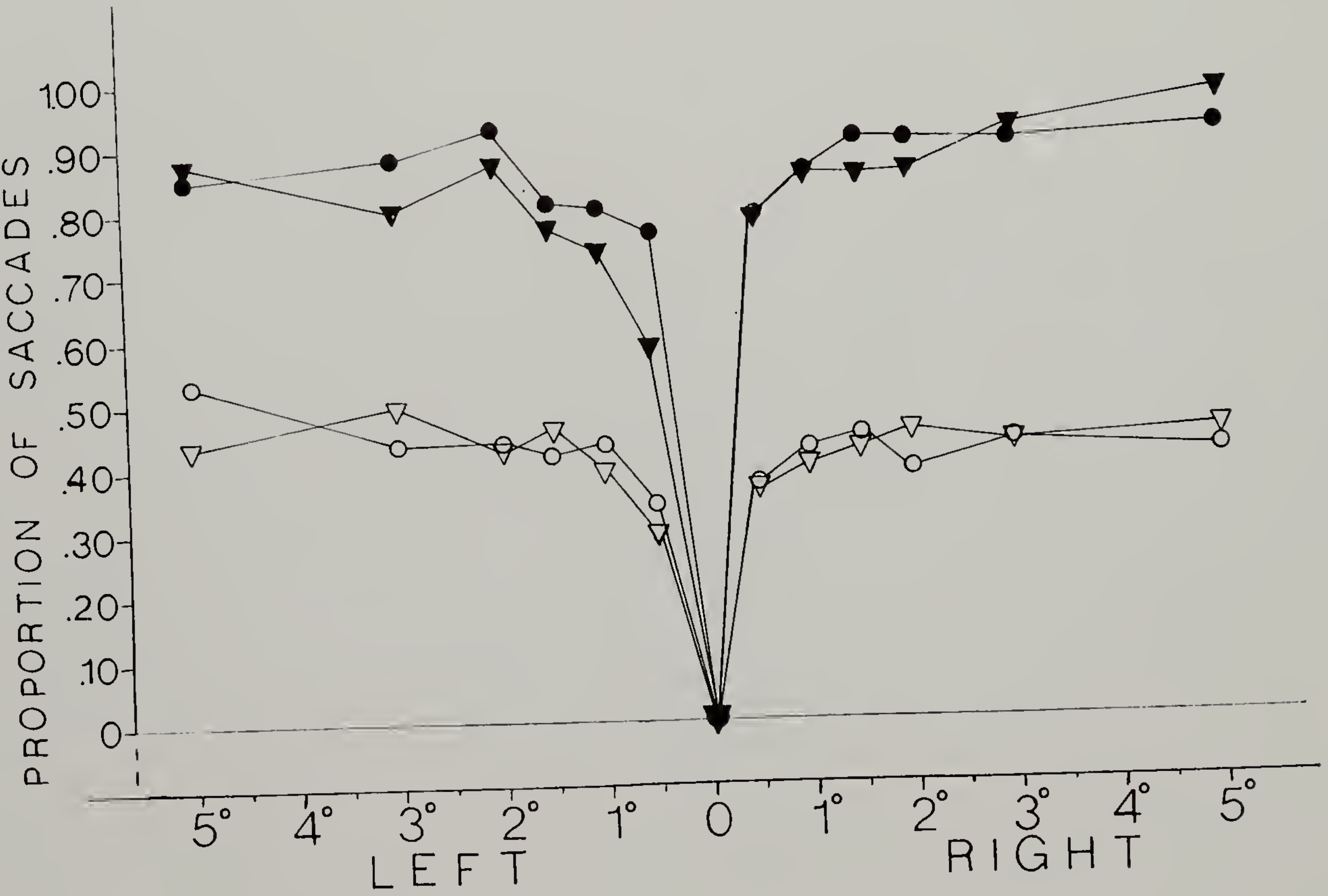
PROPORTION OF SACCADES
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Figure 5

used to analyze the data on proportion of spontaneous saccades. The data examined were from each of the six days of performance in each task in order to see if there was any adaptation or change of eye movement behavior with practice in a task. There was no main effect of the Day variable ($F(5,10) = 0.74$, $p > .6$). Surprisingly, the main effect of Task did not reach significance ($F(1,2) = 4.38$, $p > .174$), although the Task x Position interaction did ($F(12,24) = 2.35$, $p < .05$). The Position main effect was significant ($F(12,24) = 9.29$, $p < .00005$). The Day x Task x Stimulus x Position interaction reached marginal levels of significance ($F(60,117) = 1.35$, $p < .09$) but probably reflects unreliable noise in the data.

The significant Task x Position interaction does indicate that significantly more eye movements to the stimulus occurred in the NI task at some eccentricities (the exception was the foveal position). However, a strong main effect of Task had been desired as a prerequisite for discriminating immediate and delayed complex CFR models by inspection of the Task x Stimulus interaction. Note that the individual data for proportion of spontaneous saccadic responses (Figure 6), shows that the difference in eye behavior between NI and PI trials was largely due to two subjects. The third subject (KR) spontaneously saccaded on almost every trial although he too demonstrated a slight tendency to move less often under PI instructions (at eccentricities of ½°). Why this subject did not show a stationary field within which targets are responded

Figure 6. Individual proportions of spontaneous eye movements in Experiment 1 as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

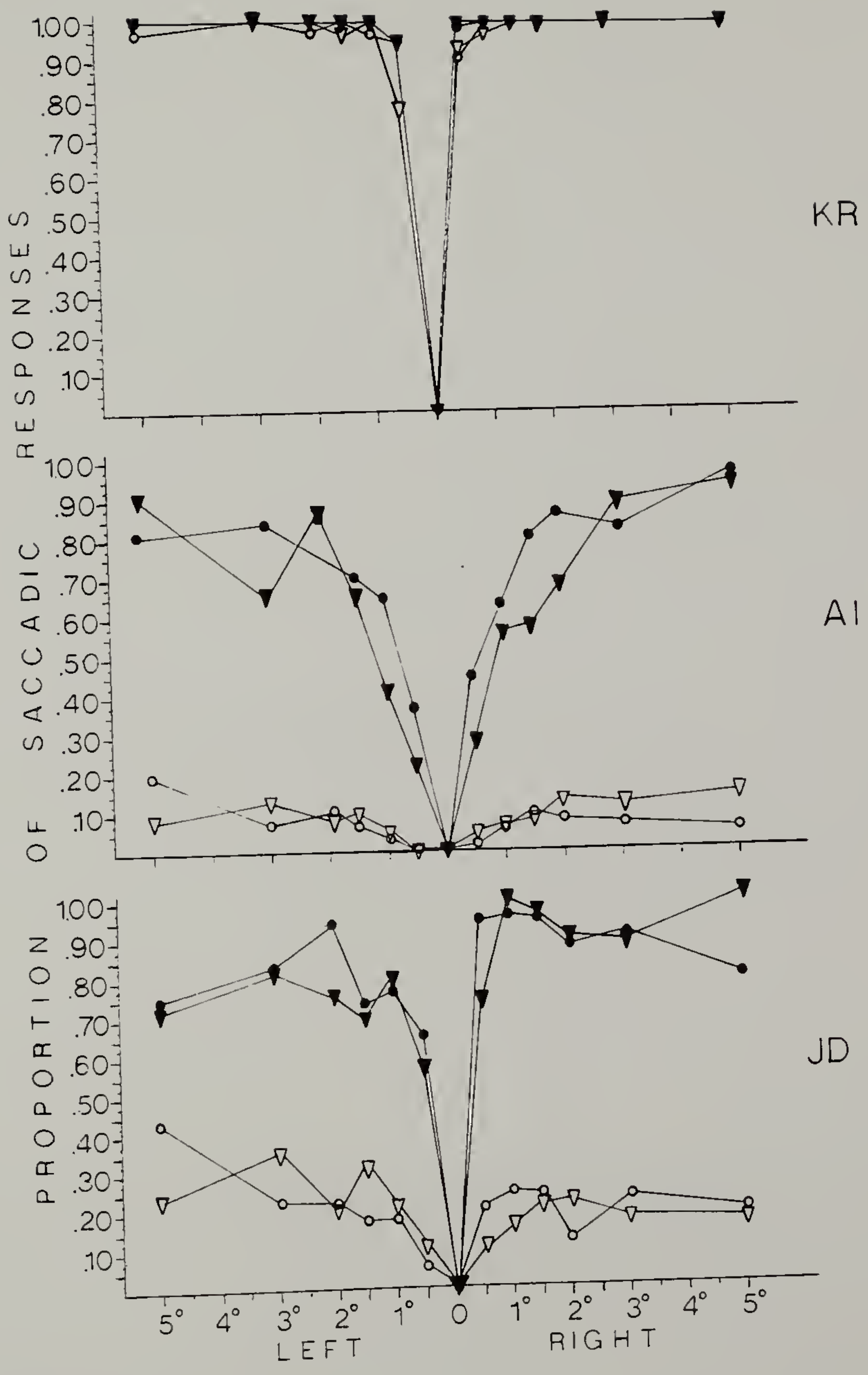
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Figure 6

to without making eye movements a majority of the time, at least for the PI task, is not clear. It should be noted that this subject was not naive about the purpose of the experiment which may have had something to do with his dissimilarity from the other subjects.

A 2 x 2 x 13 ANOVA (Task x Stimulus x Position; collapsed over days) on the data of the other two subjects did reveal a highly significant main effect of Task, i.e., a higher proportion of eye movements under the NI task ($F(1,1) = 2705.8$, $p < .02$). If this trend occurred only for physically mismatching stimuli while matching letter pairs elicited the same performance as in a PI task then immediate complex CFR models would be supported. However, such was not the case. Since the increase in proportion of spontaneous saccades occurred equally for both types of stimuli (physically matching and mismatching) the interaction effect of Task x Stimulus was not significant ($F(1,1) = .72$, $p > .5$). This is in stark contrast to the reaction time data.

Since the proportion of eye movements occurring when the stimulus appeared foveally was zero and generally rose with increasing eccentricity, the position main effect tested significantly ($F(12,12) = 9.53$, $p < .001$). Also, since the difference in PI and NI spontaneous eye movement tendencies that are found extrafoveally disappear with foveal presentation (because all proportions naturally drop to zero), the interaction of Task x Position was also significant ($F(12,12) = 4.49$,

$p < .01$).

The failure to obtain a significant Task x Stimulus interaction for proportions of spontaneous saccades, which would have supported immediate complex CFR models of eye guidance was considered surprising. An attempt to reveal such an effect was made in Experiment 2 by explicitly instructing subjects to control their eye movements in various ways and to see also if there were speed trade-offs between saccading or holding fixation which might help explain the results of Experiment 1.

Experiment 2

Method. Subjects made three sessions of PI judgments following one session of practice and then four sessions of NI judgments following one session of practice. Subjects were instructed to control their oculomotor behavior in a variety of ways. In one condition the subjects were to make a saccade to fixate the region of the stimulus on every trial, whether it was necessary or not.

In another condition the subject was instructed to maintain fixation of the area of the fixation cross and never make eye movements to the stimulus. These two conditions were counterbalanced in an A-B-B-A fashion over the first two sessions of both the PI and NI judgments. Thus, half of each session was performed under each condition of movement-on-every-trial or no-movement. These two conditions were counterbalanced over the practice session in a like manner.

The third sessions were performed under instructions to move the eyes only if it was necessary in order to respond correctly (while maintaining reaction times as quick as before). Thus, if they could respond just as quickly (and correctly) without executing a saccade then that was what the subjects should do on any given trial.

An additional session was included for NI judgments. In this condition, subjects were told about the purpose of the experiment and were asked to control their eyes so as to give data strongly supporting the immediate complex CFR hypothesis, in other words, to move their eyes on all trials except those for physically identical pairs, in which case they were to not make an eye movement. Experiment 2 was conducted three months after Experiment 1.

<u>Results</u>. Mean reaction times for responses made in the forced movement condition are shown for the three subjects as a group and individually in Figures 7 and 8, respectively. The forced no-movement group data and individual data are shown in Figures 9 and 10, respectively. It should be noted that the subjects did not have perfect success in obeying the instructions to move their eyes every time or conversely, not at all. Up to 13% of the trials in some conditions were eliminated from the analysis because the subjects' oculomotor behavior was inappropriate. Subjects were surprised when informed of these responses as they

Figure 7. Group mean response times (msec) in Experiment 2 in the forced eye movement condition as a function of stimulus eccentricity. Data for zero eccentricity represent no-movement responses of course, because these stimuli were centered in the fovea. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

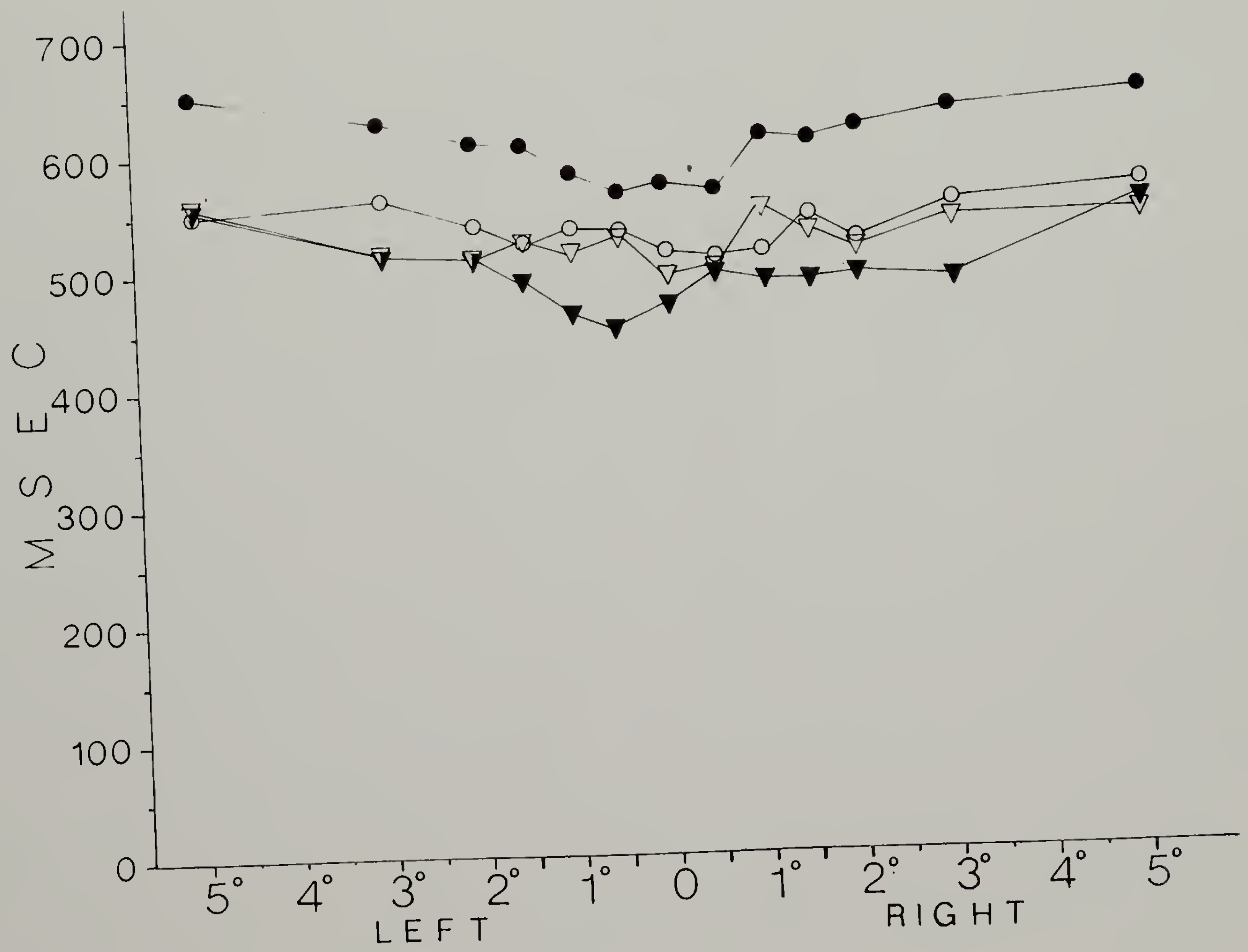

Figure 7

Figure 8. Individual mean response times (msec) for three subjects in Experiment 2 in the forced eye movement condition as a function of stimulus eccentricity. Data for zero eccentricity represent no-movement responses of course, because these stimuli were centered in the fovea. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

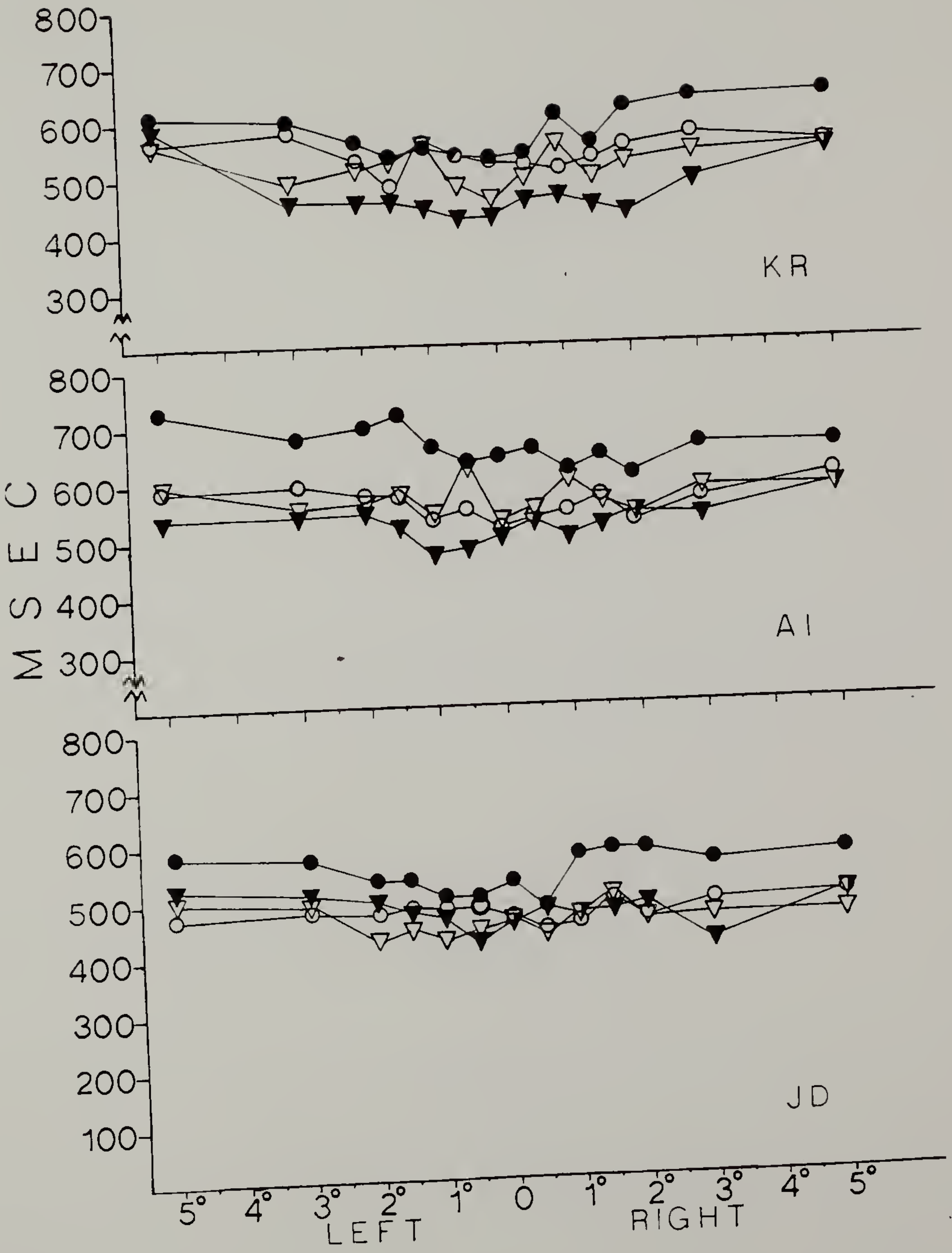
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Figure 8

Figure 9. Group mean response times (msec) in Experiment 2 in the forced no-movement condition as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

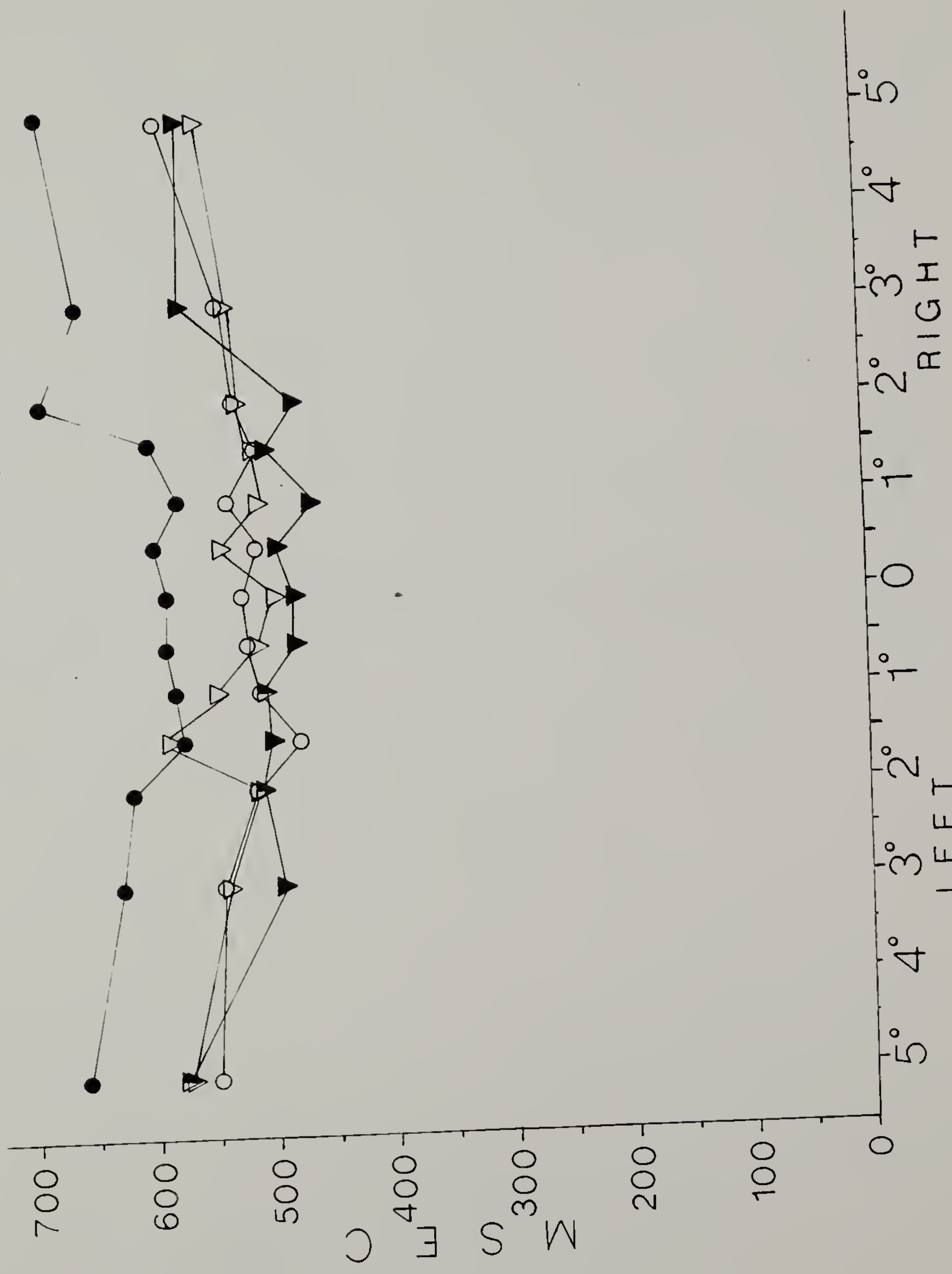

Figure 9

Figure 10. Individual mean response times (msec) for three subjects in Experiment 2 in the forced no-movement condition as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

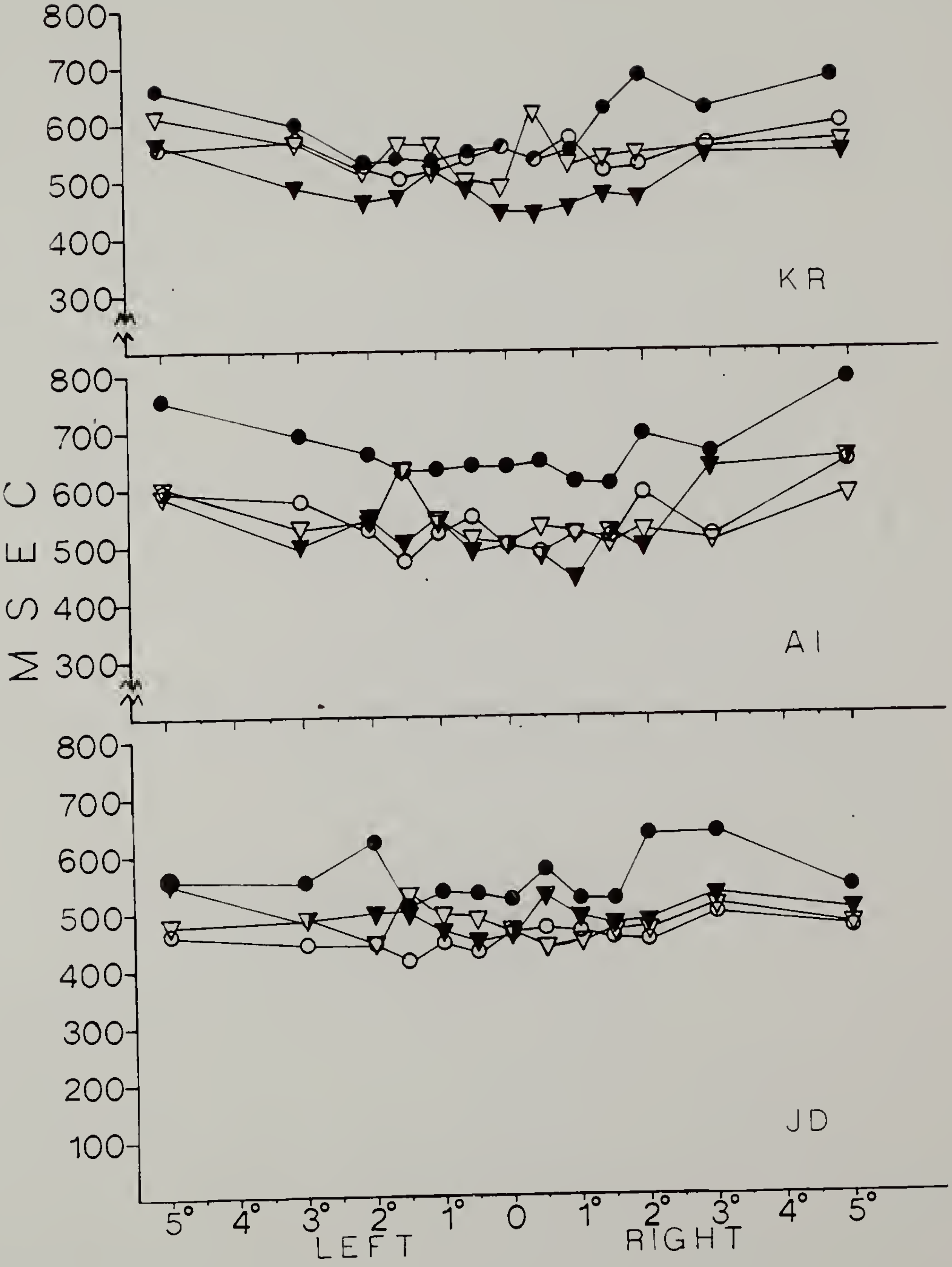
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Figure 10

thought they had been conforming with the instructions on each and every trial.

A comparison of Figures 7 or 8 with Figures 9 or 10 fails to reveal any strong influence on reaction time depending upon whether an eye movement was made or not. A 2 x 2 x 2 x 13 repeated measures ANOVA (Eye control (movement vs. no-movement) x Task x Stimulus x Position) confirmed the lack of a significant main effect due to Eye control ($\underline{F}(1,2) = 0.11$, $\underline{p} > .75$). On the average, saccading to the stimulus apparently did not allow significantly quicker responding than when no eye movement occurred and the stimulus was only seen with extrafoveal vision.

The effect of Position in the visual field, an overall rise in reaction time with increasing eccentricity, tested significantly ($\underline{F}(12,21) = 7.60$, $\underline{p} < .0001$). Again the typical NI-PI Task x Stimulus interaction effect obtained ($\underline{F}(1,2) = 27.11$, $\underline{p} < .05$), reflecting an increase in reaction time on physical mismatch stimuli under NI instructions without any increase for physical match stimuli. The NI-PI increase for those nonidentical stimuli requiring comparison of name codes was large enough to cause a significant main effect of Stimulus type on the average as well ($\underline{F}(1,2) = 31.7$, $\underline{p} < .05$).

It is not really surprising that there wasn't a great cost due to not making saccades. After all, the stimuli were arrived at through pilot experimentation to be highly perceptible in extrafoveal vision so as to allow subjects to demonstrate Sanders' "stationary field" (1973)--a region in the visual field from which subjects can respond to stimuli without making eye movements. However, since the size of the stationary field was smaller for NI responses in Experiment 1, in other words the proportion of saccades on NI trials was greater than on PI trials at each eccentricity, it was expected that not being able to make eye movements would adversely affect performance on those trials that require name code comparison, especially at greater eccentricities from the fovea. In fact the Eye control x Stimulus x Position interaction did reach the 6% significance level ($F(12,21) = 2.16$, $p < .06$). One reason this effect wasn't more evident may have been a trade-off between speed and accuracy. Error rates in the no-movement condition were higher than in the movement condition (13.8 versus 9.7%) although this difference was not significant ($F(1,2) = 1.69$, $p > .3$). Even though there is not a huge RT cost (or change in errors) due to not making an eye movement, it appears that slight changes in the processing efficacy of extrafoveal stimuli under different task demands cause large changes in eye behavior.

An increase in the difference between the RTs for the different stimulus types (averaged over Task and Eye control) with increasing eccentricity probably accounts for the first order Stimulus x Position interaction ($F(12,21) = 2.40$, $p < .04$). The Task x Position interaction (averaged over Stimulus type and Eye control) also reflected these effects and tested significantly

(F(12,21) = 2.59, $p < .03$). The only other effect approaching significance was for the Eye control x Task x Position interaction (F(12,21) = 1.93, $p < .091$) and probably is not reliable.

In sum there are two conclusions to be drawn from the forced eye movement or no-eye movement conditions. First, that although responding only on the basis of extrafoveal information in this experiment does not drastically affect most responses, it appears to slow down those for physically non-identical pairs in an NI task at the wider eccentricities; possibly this change in processing ease causes subjects to make more spontaneous eye movements in this situation during free viewing than they do in the PI task. Secondly, subjects have less than perfect control over and rather poor conscious awareness about the actual occurrence of saccades within 5° of visual angle around the fovea. The errors in conforming to the eye control instructions (6% on the average) and the introspective belief that such errors were practically nonexistent seem to indicate that subjects are more cognizant of shifts of attention than shifts of the visual axis per se, and these don't always coincide. This point has been made before by Kaufman and Richards (1969).

In light of the last point, the data from the condition wherein subjects were asked to saccade to the stimulus only when necessary to maintain fast, accurate responding is not surprising. The proportion of saccades occurring in each condition is plotted in Figure 11, combined across two subjects. Data from the third

Figure 11. Group mean proportions of spontaneous eye movements in Experiment 2 in the "move only if necessary" condition as a function of stimulus eccentricity. (Open symbols = PI task, filled symbols = NI task; triangles = physical match stimuli, circles = physical mismatch stimuli.)

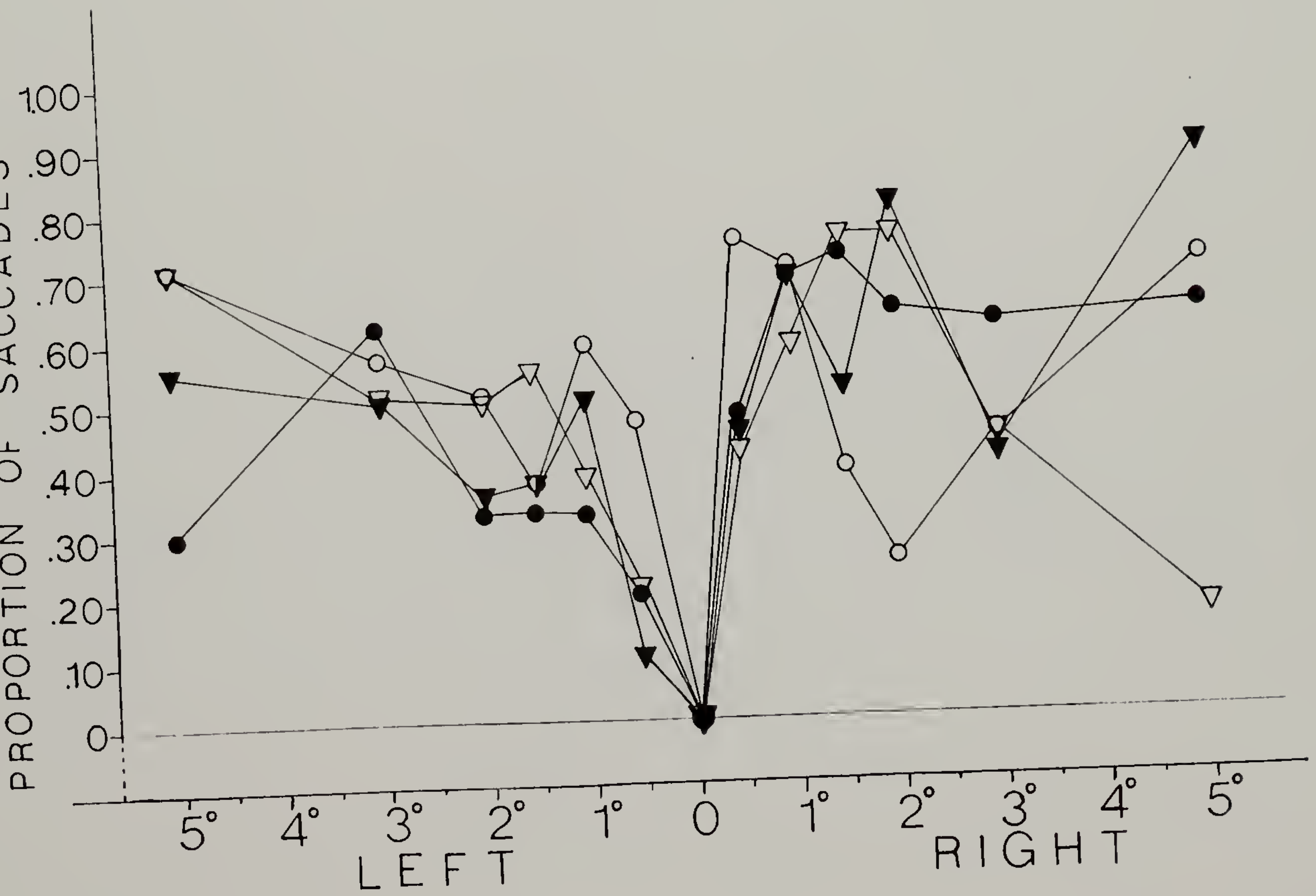
PROPORTION OF SACCADES
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Figure 11

subject was eliminated because he had not understood the instructions. There were no obvious patterns to the data from the different conditions, except to saccade more often to extrafoveal stimuli than to foveal stimuli (which logically have zero proportion of saccades). Thus only the main effect of position was significant ($F(12,11) = 3.14$, $p < .04$), all other effects were nonsignificant. Subjects seemed to just pick one strategy, perhaps of saccading about half of the time (slightly increasing with eccentricity) and changed this little depending upon the different tasks and stimuli encountered. The subjects seemed unable to consciously control their eye movements in the complex mode these instructions required.

As a last attempt to find evidence for immediate control of complex choice fixation responses subjects were told the purpose of the study and asked to control their eyes so as to give the pattern that was predicted by the immediate complex CFR hypothesis. They could not. They generally showed similar proportions of saccades for each task and stimulus condition across the different eccentricities, similar to the behavior illustrated in Figure 11. Apparently a lack of motivation cannot be causing the failure to obtain evidence for immediate complex CFR control in Experiment 1. Subjects seem to be able to consciously influence their oculomotor behavior with a preset, global strategy only, not in a trial-by-trial manner based upon some conceptual evaluation of the extrafoveal stimulus array.

CHAPTER III

GENERAL DISCUSSION

The eye movement behavior examined in the two experiments reported here gives no demonstration of immediate control of complex choice fixation responses. Two key effects were obtained during the tasks employed in this study, namely the familiar NI-PI reaction time effect and a difference in the proportion of spontaneous saccades occurring on NI and PI trials. As a result, the eye movement behavior on a certain subset of the experimental trials was expected to match one of two opposing predictions made on the basis of two general views of oculomotor control of complex choice fixation responses, one which claims that such control is immediate, the other that it may only occur on a delayed basis.

The term, "complex choice fixation response", means selection of some part of the visual array for fixation on the basis of some extrafoveally processed conceptual information, as opposed to cues such as location and extent of targets (which after all must be processed when making a saccade, by definition). Given that such complex, "intelligent" fixation choices are made, the issue is whether they can be guided by the processing during the fixation preceding the saccade leading to the new fixation location, or, if the use of high level information lags by at least one saccade-fixation cycle and can show an effect only downstream one fixation or more. Immediate control (of complex choice fixation responses) posits an influence on any fixation-selection decision by information picked up in the immediately preceding fixation, while delayed control holds that the influence of high level information is delayed by one saccade-fixation cycle and the only immediate control of fixation responses possible is for simple choices based on low level information about location. This view would maintain that if different eye movement strategies are found in a task wherein only immediate control is possible, such as the experiments reported here, they are simply global effects. Thus, the likelihood of fixating targets is influenced only by their location in the visual field and does not result from dynamic, trial-by-trial interactions between the cognitive influences present and extrafoveally perceived high level information.

The two effects deemed necessary prerequisites for testing the immediate complex CFR control model were both obtained. First, the data showed a robust NI-PI reaction time effect. In the NI task, there was a significant difference between reaction times to physical match and mismatch stimuli, yet no difference on the PI task. This interaction between task and stimulus was found throughout the entire study. Secondly, since the increase in reaction time to physical mismatch stimuli in an NI task occurs because the name codes must be compared (identical letter pairs are still responded to on the basis of physical codes in the NI task, thus shortcutting the increase in RT) it was expected that this would tend to require foveal inspection for fast and accurate responding and thus more spontaneous saccades would occur than for PI matches. In fact, this was the case. During free viewing there were more spontaneous eye movements during the NI responses than the PI responses. Thus the proportions of saccades to extrafoveal stimuli did vary systematically with conceptual aspects of the overall task. The very same stimuli at the very same eccentricities elicited different fixation response behavior depending upon the cognitive operations subjects were required to perform in the different tasks. At issue is whether this occurs as a dynamic process tapping cognitive variables and complex stimulus attributes on each fixation, or as the result of a preset tendency not involving complex stimulus attributes on each trial.

The critical data for discriminating these opposing possibilities was the proportion of spontaneous saccades to physical match stimuli during the NI task. Since the reaction times for these trials are not increased it is concluded that they are still responded to on the basis of physical codes, as in the PI task. Are they only fixated then as often as was necessary when encountered in a PI task, or does the proportion of spontaneous saccades increase to the level found for trials requiring name-code comparison (physical mismatch stimuli in an NI task)? The former pattern was predicted on the basis of complex immediate CFR control, the latter pattern was predicted if complex CFR control is not possible on an immediate basis, but only on an almost-immediate (delayed) basis.

The data unambiguously supported the latter view. The proportion of saccades to physical match stimuli was greater in the NI task than in the PI task and was in fact the same as for the physical mismatch stimuli in the NI task. It appears that the likelihood of a saccade occurring on any trial is determined by a global tendency adopted by the subject in response to the task he's required to perform without regard to any extrafoveal processing of the stimulus in the initial phase of the trial (except for processing its location if there is to be a saccade).

Although Experiment 2 showed that it is possible to respond to the physical mismatch stimuli without moving the eyes and not suffer a catastrophic drop in performance, there was a hint that this slowed responses somewhat and perhaps increased erors. Thus, even small difficulties encountered when processing a stimulus with extrafoveal vision alone may have induced changes of eye movement behavior during free viewing in Experiment 1. Alternatively, an exaggerated subjective impression of the difficulty of the processing required may increase a subject's tendency to execute saccades in the NI task.

That subjects do not simply fail to bother exercising immediate complex CFR control was determined in Experiment 2. Here subjects were unable to show eye movement behavior supporting the immediate complex CFR hypothesis even when told about the experiment and asked to produce the exact pattern of data that was desired.

The lack of immediate complex CFR control is quite clear in the paradigm that has been employed here. Whether the findings represent general aspects of oculomotor function applicable in other visual processing tasks such as reading and picture viewing, or merely an isolated oculomotor quirk found only in the particular paradigm used here is open to question. However, considering that the saccadic control system is but one kind of distinct oculomotor capability, subject to certain limitations (Westheimer, 1973), and lacking evidence of fundamental changes of the saccadic eye movement parameters in different situations in which saccades occur (though quantitative variation does occur), it is felt that reasonable questions about the generality of the findings must be made on the grounds that different visuomotor phenomena are occurring in other tasks, not simply because other situations are "different."

The generalizability to other saccadic eye movement situations can be questioned on two major points: 1) usually the eyes are involved in a continual, cyclic fixation-saccade pattern, not holding fixation steady waiting for a stimulus to suddenly appear; and 2) normally the eyes are processing foveal information during the fixation period preceding a saccade. These points will be dealt with in turn.

First, it is indeed the case that the eyes are usually making multiple fixations on a stimulus, integrating the successive glimpses into a single percept. Although this does not occur in an experimental paradigm limiting the view of the stimulus to one fixation-saccade cycle, the oculomotor act of executing a saccade may be no different in the two situations. (Except of course for the fact that delayed complex CFRs based on previously processed information cannot occur in the situation lacking prior fixations of the stimulus, but could operate in the continual viewing situation.) The possibility of utilizing purely immediate complex CFR control should be equally feasible in continual viewing or single fixation situations. Recently Rayner, McConkie, and Zola (1980) showed that it is abstract information that is integrated over fixations (at least for textual stimuli). This would be expected if masking phenomena wipe out all traces of the previous fixation's input (see Breitmeyer, 1981). There is not any iconic "glue" binding together the sequence of fixations. They are separate visual acts. It appears that the phenomena involved in perceptual integration across fixations occur above the level at which they would be expected to have any effect on the oculomotor programming.

Also, while maintaining fixation and waiting for a stimulus to appear, the eye is not really held still at all (if it were, retinal image fading would occur). The eyes are making regular, conjugate microsaccades which might be considered a normal sequence of multiple fixation-saccade cycles all being of small amplitude and sharing a common fixation target (Westheimer, 1973).

Arnold and Tinker (1939) have also shown that when a subject fixates a row of dots in turn, the latency to move the eye to an extrafoveal dot in the middle of a series of such saccades is not very different from the latency found when a resting eye responds to fixate a suddenly occurring target. Thus, the use of a paradigm involving a single fixation-saccade sequence may not a priori limit the findings from being generalized to multiple fixation situations.

The second issue is far more serious. In most naturally occurring situations of visual information processing, certainly in reading and scene analysis, a foveal stimulus is being processed during each fixation at the same time that the next fixation location is being chosen. The necessity to complete foveal inspection makes fixation durations significantly longer than the mere saccadic latency found in tasks like the present one. The increased duration of the fixation preceeding the saccade may allow extrafoveal processing of high level information to be completed in time to influence the next saccade. This assumes that the full fixation duration would be used to process the extrafoveal array and program the next saccade, in parallel with the foveal processing. On the other hand, if the foveal processing is just dead time as far as the extrafoveal fixation location processing is concerned, if the latter awaits the completion of foveal processing and then commences with the usual saccadic latency, there would be little difference between the eye control capabilities involved in normal viewing situations and artificial experimental tasks lacking foveal processing. How portions of the fixation period are allocated to the various processing activities that must be accomplished is presently an open question.

Another question raised by the presence of foveal processing during the pre-saccadic fixation period is whether processing of high level information can occur simultaneously at separate locations in the visual field. Kolers and Lewis (1972) make a very strong claim that this cannot be done at all (for independent, unrelated units of information). At any rate, there is a long tradition of research showing that when more attention is allocated for foveal processing, extrafoveal processing seems to suffer (Kahneman, 1973; Mackworth, 1965). On these grounds the present experiments, by not requiring foveal processing, would allow full attention to the extrafoveal array which should provide an optimal situation for the demonstration of immediate complex CFR control.

At present there seems to be no overwhelming evidence either for or against generalizing from these experiments to natural viewing situations. If we believe that the saccadic control system is so constrained that there should be some degree of invariance across different situations, then in the absence of any evidence to the contrary, tentative general conclusions and speculations are warranted.

Certainly if immediate complex CFR control were operable in reading as a main component driving the saccadic eye movement system as some models would have us believe (Hochberg, 1970; O'Regan, 1979) then one would expect to be able to tap this behavior rather easily in other tasks. The present paradigm would be a good candidate. The NI-PI effect is robust across all eccentricities, indicating that responses are based upon different sources of information. Subjects make saccades often in the NI task where they are required to match some stimuli on the basis of names, not physical similarity. When expecting to perform only physical matching judgments (the PI task), subjects make fewer saccades. Why then would the proportion of spontaneous saccades to physical match stimuli increase in NI tasks if immediate complex CFR control were possible?

In actuality, the evidence for immediate complex CFR control during reading may be suspect. The only testable prediction of immediate complex CFR control has been the hypothesized "THE-skipping" (see introduction). But Shebilske (1975) found no difference between the conditional probability of fixating THE as opposed to other three letter words. O'Regan (1979) interprets data showing longer saccade lengths into THE than a three letter verb (preceding sentence context to this point was identical) as evidence for immediately controlled THE-skipping. However, he has failed to rule out the possibility that this might have occurred via delayed (almost-immediate) control. In normal reading, the words are glimpsed many times, in different extrafoveal eccentricities as the fixations proceed along a line. It is possible that a three letter word could be tentatively identified as THE from input received during a fixation prior to the fixation from which the saccade skipping over the word was launched (in other words, the next-to-last fixation). If only such delayed control of complex CFRs is possible, and if the perceptual span in reading limits the perception of words two fixations away, about 12-18 characters on the average, to length information mainly, then true THE-skipping might be hard to demonstrate. This is what the record seems to show (Shebilske, 1975). It may be that the immediate control of saccades in reading is limited to simple control on the basis of location cues (e.g., saccade to next word to the right with a certain probability which might vary as a function of word length) and that complex control (skipping words on the basis of extrafoveally processed high level information) occurs only on a delayed basis. (The duration of one typical fixation-saccade cycle is not very long, usually less than a third of a second, so this type of control could just as well be viewed as "almost-immediate" instead of delayed, as Levy-Schoen and O'Regan (1979) suggest.) The findings of Rayner and Pollatsek (1981) are not discordant with this type of model. They did not investigate whether the immediate control they found was made on the basis of anything more than low level cues (like the position of interword spaces visible in the window area) and they found a large delayed control phenomenon--the size of the window on the next to last fixation was a determinant of saccade size leaving the last fixation.

In conclusion, the results reported here cast doubt on the viability of immediate control of the choice fixation response based upon high level information processed in extrafoveal vision (at least out to five degrees eccentric from the fovea). The presence of immediate control via low level information such as location in the visual field is certainly not disputed; such control is the fundamental nature of saccadic eye movements.

At issue is whether saccades can be guided by new information at a semantic level which is acquired only during the immediately preceding fixation, as some models of oculomotor control in information processing activities claim (Hochberg, 1970).

The present results suggest not. The well known NI-PI difference produced robust RT effects and the tasks produced different eye movement behaviors as well. That the NI task does not increase RT for physical match pairs (compared with the PI task) but does increase spontaneous saccades to these stimuli over the proportion found in a PI task indicates that subjects altered their fixation response behavior globally and could not modulate the fixation response tendencies on a trial-by-trial basis in response to extrafoveally processed high level information. This lack of immediate complex CFR control is tentatively inferred to be an inherent aspect of the saccadic eye movement system. It is suggested that saccadic eye movements may be controlled immediately only as simple choice fixation responses, based on target location information, and that complex choice fixation responses (those based on extrafoveally acquired high level information) may be limited to almost-immediate control.

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