INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

University of Alberta

The Oculomotor Readiness Hypothesis: Revisited (Again!)

by

Tricia M. Ennis

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Division of Neuroscience

Edmonton, Alberta

Fall 1998

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

0-612-34358-8

University of Alberta

Library Release Form

Name of Author: Tricia M. Ennis

Title of Thesis: The Oculomotor Readiness Hypothesis: Revisited (Again!)

Degree: Master of Science

Year this Degree Granted: 1998

#605, 11307 - 99 avenue
Edmonton, Alberta
T5K 0H2

1 October 1998

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 of a thesis entitled The Oculomotor Readiness Hypothesis: Revisited (Again!) submitted by Tricia M. Ennis in partial fulfillment of the requirements for the degree of Master of Science.

Alan Kingstone, Ph.D.

Ivan Kiss, Ph.D., C. Psych

Romeo Chua, Ph.D.

28 September 1998

Date

Abstract

Does preparing an eye movement trigger covert orienting? And does covert orienting prepare an eye movement? According to the oculomotor readiness hypothesis (OMRH) there is a positive link between the oculomotor system and the covert orienting system, such that activation of one system produces activation of the other system. On two occasions Klein tested the OMRH (Klein, 1980; Klein & Pontefract, 1994), and on both occasions the data disconfirmed the OMRH. Klein used a dual-task design that required subjects to execute a speeded eye movement response (to measure oculomotor activation) and a speeded manual response (to measure covert orienting). One type of response was always far more likely than the other. Our concern with this design was that it may have encouraged participants to emphasize speed only for the primary response, effectively eliminating any response time effects in the secondary response. In the present study, we repeated Klein and Pontefract's (1994) design, with the exception that only the eye movement response was speeded. Manual responses were always unspeeded, with response accuracy providing evidence of covert orienting. The results of two experiments disconfirmed the OMRH -- and a similar proposal -- the Pre-motor Theory of attentional orienting (Rizzolatti, Riggio, Dascola & Umilta, 1987). Our data suggest that covert orienting and oculomotor activation can occur independently.

Acknowledgements

I would like to express my sincere thanks to:

Alan – not only for your brilliant supervision, direction, and enthusiasm – but also for the confidence you've shown in me.

Tony, Monica, Chris, Jan, Barry, and Geniva (the unnameable lab!) – the perfect medley of knowledge, jocularity, and friendship – for providing an exceptional atmosphere in which to learn, laugh, and succeed.

The Division of Neuroscience for its support and financial assistance.

Mom and Dad – for providing me with a true foundation of love, guidance, and encouragement.

Mark – my best friend and strongest supporter – for teaching me to believe in myself.

Table of Contents

Chapter 1

Chapter 2

Chapter 3

Chapter 4.

List of Tables

List of Figures

The Oculomotor Readiness Hypothesis: Revisited (Again!)

Introduction

James (1890) was perhaps the first to touch upon the multifaceted notion of attention when he stated, "*Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called 'distraction', and 'Zerstreutheit' in German.*"

This multifaceted nature of attention has resulted in its subdivision into various classifications. One division concerns how attention is shifted. When an eye movement has been executed and gaze direction is altered, overt orienting has occurred, and a new portion of the visual space is brought into view. Conversely, if focus remains unchanged at a given fixation, and hence, no eye movement has been executed, but attention has been directed to a parafoveal location, then covert (internal) orienting has occurred.

Endogenous and Exogenous Attention

Whether orienting is performed covertly or overtly, attentional shifts can be directed endogenously (i.e., volitionally) or exogenously (i.e., reflexively) to specific locations (or objects) in the visual field (Klein, Kingstone, & Pontefract, 1992). Endogenous orienting occurs internally, within an individual, whereby one 'pushes' attention towards some external event (i.e., a conscious decision is made to direct attention toward stimuli in the environment). Exogenous orienting occurs when an event in the environment 'grabs' one's attention and pulls it towards a particular event (e.g., the sound of a slamming door can grab one's attention reflexively). Both types of attentional shifts (exogenous and endogenous) and both types of orienting (overt and covert) typically benefit the acquisition of stimulus information at the attended location or object, with a cost of reduced processing efficiency for stimulus information at unattended locations or objects. Behaviorally, the result is that reaction time (RT) and/or response errors are smaller for attended locations/stimuli relative to unattended locations/stimuli.

A standard paradigm for studying shifts of covert (no eye movements allowed) spatial attention was developed by Posner (1980). In this paradigm, subjects typically view a screen with a central fixation cross flanked on the left and the right by two peripheral boxes. The first event in the sequence is the introduction of a spatial cue. This cue can occur centrally (e.g., an arrow pointing toward the left or right box), or peripherally (e.g., the illumination of one of the two peripheral boxes). While subjects remain fixated, their attention is shifted covertly in the direction indicated by the cue. When a central cue is utilized (e.g., an arrow), the cue predicts where a target is likely to occur, and thus attentional orienting to the cued location is controlled endogenously. On the other hand, when a peripheral cue is used (e.g., the brightening of a box), the cue does not predict at all where a target will appear, and thus attentional orienting to the cued location is controlled exogenously. Following the cue, a target (e.g., an asterisk) occurs in either the cued (valid) box or in the uncued (invalid) box, and subjects are required to respond as quickly and as accurately as possible to the target (Posner & Raichle, 1997). Regardless of whether attention is oriented endogenously or exogenously, RT and/or response accuracy is improved when a target appears at the cued location compared to when a target appears at an uncued location.

There are, however, some interesting behavioral differences between endogenous and exogenous orienting (see Klein, Kingstone & Pontefract, 1992; Rafal & Henik, 1994; Yantis, 1995). Compared to endogenous orienting, exogenous orienting is more rapid (Cheal & Lyon, 1991; Mueller & Findlay, 1988), difficult to inhibit (Mueller & Rabbitt, 1989), is unaffected by a concurrent task (Jonides, 1981), and is critical for the proper conjunction of stimulus features (Briand & Klein, 1987; but see Tsal, 1991). It also appears that both forms of orienting can be activated simultaneously but are subserved by different neural mechanisms with subcortical mechanisms crucial to exogenous orienting and cortical mechanisms crucial to endogenous orienting (Corbetta, Miezin, Shulman & Petersen, 1993; Kingstone, Grabowecky, Mangun, Valsangkar & Gazzaniga, 1997; Posner & Peterson, 1990; Rafal & Henik, 1994).

One other key difference is that covert exogenous orienting produces a biphasic RT performance pattern. When attention is drawn to a peripheral location by the abrupt onset of a luminance cue, RT to detect targets that appear at the cued location are initially shorter than RT to detect targets that appear at noncued (i.e., unattended) locations. However, unlike endogenous orienting, when the cue-target interval exceeds several hundred milliseconds, RT to detect targets that appear at the cued location becomes longer than RT to detect targets that appear at noncued locations. Posner and Cohen (1984) attributed this lengthening of RT to a mechanism that inhibits attention from returning to a cued location, and suitably called the effect "inhibition of return" (IOR).

In summary, there are at least four fundamental properties regarding shifts of attention: 1) shifts can be covert, that is, they need not require any change in eye or head position; 2) they can be linked tightly in time to the occurrence of a central or peripheral cue; 3) these shifts can be controlled either endogenously by an individual's decision to orient attention to one location or another, as in the case of central cues, or exogenously by the reflexive attraction to a cue, as in the case of peripheral cues; and 4) if attention is cued exogenously to a location, responses will be executed more slowly to a target at the cued location if the delay between the peripheral cue and the target exceeds approximately 500 msec.

Overt and Covert Attention

While it is true that people can attend to a location without moving their eyes (i.e., covert attention can be dissociated from overt orienting), it is also true that people typically look at what they are attending to (i.e., overt and covert attention appear to be closely linked). Examining the relationship between overt and covert attention has been the focus of considerable research. One line of research has examined the relationship between overt attention and exogenous covert orienting, the other has considered the relationship between overt attention and endogenous covert orienting. This thesis is concerned with the latter relationship, but let us first briefly consider the former.

Overt attention and exogenous covert orienting

The most fundamental and important relationship between overt orienting and exogenous covert attention is that when covert attention is captured reflexively by a peripheral cue it appears that the eye movement system is also activated. Thus activation of the overt (oculomotor) system appears to be intimately linked with covert exogenous orienting.

This point is perhaps best demonstrated by a study by Rafal, Posner, Friedman, Inhoff, and Bernstein (1988) in a study of patients with progressive supranuclear palsy (PSP). These patients suffer from a degenerative disease that affects the midbrain, including the superior colliculus, causing profound difficulties in making eye movements, particularly in the vertical plane. Rafal et al. (1988) discovered that these patients were also profoundly impaired at moving their covert attention reflexively to a peripheral cue, especially for covert shifts of attention in the vertical plane. Patients with Parkinson's disease, who suffer from a similar degenerative condition -- but one that does not involve the superior colliculus – did not show this pattern of results. That is, they did not show an impairment in orienting covert attention reflexively, nor did they exhibit any vertical-plane/horizontal-plane difference in covert orienting. Thus, the PSP data suggest that the superior colliculus is critical for moving covert attention reflexively to a peripheral event. Given that the colliculus is also fundamental to reflexive oculomotor (overt) shifts of attention (Kingstone, Fendrich, Wessinger, & Reuter-Lorenz, 1995) the strong implication is that covert and overt shifts of reflexive attention are intimately linked via their dependence on the colliculus.

Convergent evidence for this conclusion was provided by Rafal, Calabresi, Brennan, and Sciolto (1989). Recall that exogenous covert orienting, unlike endogenous covert orienting, results in a phenomenon called "inhibition of return" (IOR). Rafal et al. (1989) discovered the reason for this dissociation. When subjects were asked to execute an eye movement to a peripheral location, and then return their eyes to central fixation, IOR was observed at the moved-to peripheral location -- demonstrating that IOR can be produced by endogenous processes if the eye movement system is engaged. Indeed, IOR was observed even when subjects were asked to prepare an eye movement to a peripheral location and then to cancel that eye movement program. Thus, what is critical to the occurrence of IOR is whether the neural machinery of the eye movement system -- presumably the superior colliculus – is activated. Given that IOR occurs for covert exogenous orienting but not for covert endogenous orienting, the strong implication is that exogenous covert orienting results in activation of the oculomotor system but endogenous covert orienting does not.

Overt attention and endogenous covert orienting

The conclusion that exogenous covert orienting involves activation of the overt (eye movement) attention system is readily accepted. However, the conclusion that endogenous covert orienting does not depend on activation of the oculomotor system is controversial -- and it is the question addressed by this research thesis.

There are effectively two positions on the question of how overt attention and endogenous covert orienting are related. One position is that endogenous covert orienting simply reflects "weak" activation of the eye movement system (Rizzolatti, Riggio, Dascola & Umilta, 1987; Shepherd, Findlay, & Hockey, 1986; Knowler, Anderson, Dosher, & Blasher, 1995; Hoffman & Subramaniam, 1995). The alternative position is that endogenous covert orienting does not depend on activation of the eye movement system (Remington, 1980; Rafal et al., 1989; Klein, 1980; Klein & Pontefract, 1994; Stelmach, Campsall, & Herdman, 1997). The former position is best illustrated by the work relating to the Pre-motor Theory of covert orienting; the latter position is best illustrated by the work relating to the Oculomotor Readiness Hypothesis. Each is discussed below.

Pre-Motor Theory

Rizzolatti, Riggio, Dascola & Umilta (1987) discovered that when covert endogenous attention is shifted across the horizontal or vertical midline, a meridian effect comes into play such that there is a significant increase in time to detect a target stimulus. A visual display was composed of a central fixation point and four peripheral boxes for stimulus presentation. The position of the peripheral boxes varied across different experimental conditions. In conditions 1 and 2, the stimulus boxes were arranged horizontally in the upper or lower hemifield, and in conditions 3 and 4, they were arranged vertically in the right or left hemifield. The cue for directing attention was a digit ranging from 0-4 which was presented in the fixation box. The response stimulus was a geometrical pattern which appeared in one of the peripheral boxes. When subjects detected the appearance of this stimulus they pressed a key as quickly as possible.

Each trial began with the fixation point being presented and a digit (1-4) placed in each of the peripheral boxes corresponding to its position. A digit was then presented in the fixation box indicating either that the target stimulus would be shown with high probability within the corresponding stimulus box (1-4) or that all four boxes were equiprobable (0). Subjects were to focus their gaze on the fixation box while producing an endogenous shift of covert attention to the cued box. If the boxes were equiprobable, subjects were to pay attention to all of the boxes equally. Subsequent to the attention cue at fixation the target stimulus was presented and subjects were to respond as quickly as possible. When a specific box was cued, the stimulus appeared in it 70% of the time (valid trial) and 30% of the time it appeared in one of the uncued boxes (invalid trial). Neutral trials occurred when all locations were equiprobable with a non-directional cue. Time to detect a target was measured from the onset of the target.

Results indicated that RT on a valid trial was faster than on a neutral trial (RT benefit) and RT on an invalid trial was slower than on a neutral trial (RT cost). While there existed benefits and costs for both vertical and horizontal arrangements, this cannot be taken to mean that responses to all uncued positions were slowed down equally (i.e., uncued responses occurring within the cued hemifield versus uncued responses occurring in the uncued/opposite hemifield). Thus, a further analysis was performed that compared RT to stimuli that appeared at an uncued location that shared the same hemifield as the cued location versus a different hemifield. Results confirmed that within the cued hemifield RT on a valid trial was faster than RT on an invalid trial. However, RT on an invalid trial in the cued hemified was faster than in the opposite hemifield, regardless of whether a vertical or horizontal meridian was crossed.

To account for these data Rizzolatti et al. (1987) put forward their "Pre-motor Theory" of endogenous covert orienting. The Pre-motor Theory argues that before an event can be detected at a certain location, attention must be directed to that location. Further, programming the saccadic system to foveate a location carries attention to that location. And lastly, saccadic programming modifications which include crossing the midline (either vertical or horizontal) require an increase in time than those that do not cross this midline. This is due to the fact that choosing different groups of muscles takes more time than changing the activation of already selected muscle groups. When the first and second assumptions are combined, it is suggested that invalid trials require a change in the eye movement program. When this is coupled with the third proposition, it implies that detection at invalid locations which are across the meridians (either vertical or horizontal) from the cued location will be delayed relative to otherwise equal locations that do not cross a meridian. The Pre-motor Theory proposes the existence of a definite connection between endogenous covert orienting and the programming of eye movements in the overt attention system. Covert attention is shifted to a certain location only when the saccadic program for moving the eyes to this location is ready to be executed. The attentional cost is the time which is needed to cancel one eye movement program and prepare the subsequent program. Rizzolatti et al. (1987) conclude, *"Attention and eyes are undoubtedly closely linked in everyday life; only when eye movements are voluntarily prevented does a covert orienting of attention take place. It would seem highly plausible therefore that overt and covert orienting of attention are controlled by common mechanisms and that the absence of eye movements in case of covert orienting is a consequence of a peripheral inhibition, which leaves unchanged the central programming. In other words, the program for orienting attention either overtly or covertly is the same, but in the latter case the eyes are blocked at a certain peripheral stage".*

The Oculomotor Readiness Hypothesis

In 1980, Klein put forward a hypothesis that was similar to the Pre-motor Theory. This Oculomotor Readiness Hypothesis (OMRH) proposes that, *"When attention to a particular location is desired, the observer prepares to make an eye movement to that location; the oculomotor readiness, via as yet unknown feedforward pathways, has the effect of enhancing processing in or from sensory pathways dealing with information from the target location"* (Klein, 1980, p. 262). More simply stated, this view asserts that preparing to move one's eyes (oculomotor readiness) is the mechanism by which visual attention is oriented endogenously prior to stimulation. The OMRH asserts that *"...a readiness to move the eyes to a certain locus produces an attentional bias toward that locus, and that attention to a location in space involves a readiness to move one's eye to that locus"* (Klein, 1980, p. 264).

It was assumed, through the OMRH, that if a subject was preparing to look to a particular location, then any stimuli presented at that location would be detected at a faster rate than stimuli presented anywhere else in the visual field. However, if the oculomotor system and attention are independent entities, then the time it takes to detect a target at a particular location should not be affected by whether or not the eye movement system is prepared for a particular location. Klein (1980) used a dual-task paradigm to differentiate which of these two proposals was correct.

In Klein's (1980) first experiment, subjects were instructed to make a saccadic eye movement as quickly as they could from a central fixation point to one of two peripheral target dots (positioned to the left and right of fixation) when an asterisk appeared at either of the left or right dot locations (saccadic task). For each block of trials *the direction for the saccadic eye movement response was pre-specified and was held constant for the entire block*. Hence, the location of the asterisk was insignificant with regard to the direction of an eye movement response, e.g., if the saccadic task was to look to the left dot, subjects executed this response as quickly as they could when an asterisk appeared at the left dot or the right dot. A different stimulus, the brief brightening of one of the peripheral dots, appeared on a small subset of trials. When a dot brightened subjects were to make a simple manual response as quickly as they could by pressing a key (detection task).

Klein (1980) tested subjects in blocks of three types: 1) a saccadic block that consisted entirely of saccadic (80% asterisk) and catch (no target presented) trials (20%), 2) a manual block which consisted only of manual (80% brightening) and catch trials (20%), and 3) a dual block which consisted of all three types of trials. In the dual block, the majority of trials required a saccadic response (60%) and a lesser proportion of trials required either a manual response (20%) or were catch trials (20%). Before the saccadic and dual blocks, subjects were told which of the peripheral dots (either the right or the left) would be the target for their saccadic response in that block. As asterisks appeared equally often at each of the two peripheral locations, and the direction of movement was held constant, the target occurred at the target location 50% of the time and at the nontarget location 50% of the time.

The OMRH predicts that subjects should be faster in making eye movements to the target if it occurs in the same location as the one they have already prepared to move their eyes to. The results showed that saccadic RTs were compatible for the saccadic and dual-task blocks, with subjects being faster at executing a saccade when the target appeared at the location that subjects were prepared to look. The same results were predicted by the OMRH for the manual task of the dual block. This did not occur. Instead, manual RTs in the dual block were not affected by the relationship between the location of the brightening and the direction of eye movement preparation. They were, in fact, almost equal to one another. Klein (1980) reported that these findings reveal that simply because one gets ready to move their eyes it does mean that a shift of covert visual attention has taken place.

Klein (1980) ran a second experiment in which he used the same two tasks from Experiment 1, and reversed the primary task components. Subjects were now to detect an increase in the brightening of one of the peripheral dots (manual task) the majority of the time, and infrequently, subjects were to make a saccadic response to the left or right dot when an asterisk appeared at the left or right dot. Shifts in the subject's covert attention were produced through the use of attentional cues. These cues could be either informative to the subject and indicate the location of the luminance increase (i.e., arrows pointing left or right), or the cues could supply no information to the subject (i.e., plus sign). It was hypothesized that if the shifts in attention were accomplished by preparation of a saccadic eye movement to the attended location, then on the small subset of trials that demanded an eye movement response, saccadic RT would be faster if the asterisk appeared at the attended location than at the unattended location.

In Experiment 2, Klein (1980) compared two eye movement conditions to adequately investigate the OMRH. He measured compatible eye movements (subjects are told to look at the dot where the asterisk has appeared) and incompatible eye movements (subjects are told to look at the dot opposite from where the asterisk had appeared). This measure was included in the paradigm due to the difficulties which arise with compatible eye movements, i.e., eye movements are typically faster when they are made toward a target stimulus than when they are made away from a target stimulus. This compatibility effect was confounded with the costs and benefits which should occur in stimulus perception if the OMRH is valid. The OMRH predicts that prime condition (neutral, valid, or invalid) will interact with eye movement compatibility. Given this premise, compatible eye movements should produce costs and benefits, while incompatible eye movements should produce a reversal of this effect. However, if the ocular motor system does not play a role in visual attention, then additive effects should be produced with compatibility and prime condition.

Klein (1980) again used three types of blocks, 1) manual detection block (manual and catch trials), 2) saccadic task block (saccadic and catch trials), and 3) dual task block (all three types of trial with the majority being manual response trials). Arrows (pointing right or left) were used as cues in the manual and dual task blocks, and indicated where the brightening dot was most likely to occur. A plus sign was a neutral cue. The saccadic block had a neutral cue only.

Results indicated that for the manual task blocks, subjects were using the cues to allocate attention for detection of the luminance increase. RTs were significantly faster when a target appeared at the cued location, and significantly slower when a target appeared at an uncued location. RT data fell midway between these two extremes when the cue was neutral. Similar results were found for the manual task in the dual task block (increased RTs for invalid cuing/decreased RTs for valid cuing). However, no significant interaction was found for the saccadic trials in the dual task blocks. Regardless of where the arrow cue was directing attention, it did not affect subject's RTs on the saccadic trials of the dual task block. Further, data from the manual task of the dual task block indicated an additive effect between prime and compatibility. The incompatible trials had increased RTs compared to the compatible trials. Klein concluded from these data that visual attention shifts are not accompanied by a readiness to move one's eyes.

In sum, the results of two experiments led Klein to disconfirm the OMRH. The results of Experiment 1 indicated that the readiness to move one's eyes does not seem to induce a covert attentional shift toward the targeted location. And the results of Experiment 2 indicated that attentional shifts to a location in space are not accompanied by oculomotor readiness.

The Oculomotor Readiness Hypothesis: Revisited

Two theories, the Pre-motor Theory and the OMRH, have been proposed thus far, which are fairly homogenous in their claims. Tests of these two hypotheses, however, are extremely divergent in their results. Recall that after Klein's (1980) disconfirmation of the OMRH, Rizzolatti et al. (1987) presented data that supported the Pre-motor Theory of covert orienting.

With this revived interest in the relationship between oculomotor readiness and covert orienting, Klein and Pontefract (1994) re-investigated the possibility that there existed a direct relationship between the endogenous control of covert and overt orienting by asking whether the overt orienting system (in the form of oculomotor programming) plays a mediating role in covert endogenous orienting. This new investigation by Klein and Pontefract (1994) was designed to rectify potential problems with the design of Klein (1980).

One significant flaw with Klein's (1980) paradigm was that its design did not permit an independent assessment of whether eye movements were being prepared on each trial because the location of the eye movement was blocked. The Klein and Pontefract (1994) revised paradigm (Experiment 1), consisted of trial-by-trial cuing of the eye movement response most likely to be required (primary task), with occasional luminance increment probes (secondary task) presented at 1 of 2 possible target locations. The words *left* and *right* were presented auditorily and indicated the saccadic direction that was to be prepared. The signal for a saccadic response was also presented auditorily. Klein and Pontefract (1994) made these changes to their paradigm because the mere onset of a visual cue or target might exogenously activate the oculomotor system. Further, the auditory (saccadic cue or target)-visual (manual target) discrimination was thought to be simpler than the visual-visual one used by Klein in 1980. It was expected that because of this subjects would have a larger incentive to prepare eye movements than in Klein's (1980) initial study where all the signals were visual. This modified design also made it feasible to apply cost-benefit analysis to the oculomotor data to ascertain if saccades were actually prepared on any given trial. The purpose of Experiment 1 was the same as in Klein's (1980) initial study where in Experiment 1 it was to be determined whether detection is facilitated in the region the oculomotor system is prepared to fixate.

In the modified Experiment 1, the fixation display consisted of a horizontal row of 3 evenly spaced dots, with the middle one being placed in the screen's center. A computer-generated male voice ("Perfect Paul") gave an auditory cue (*left, right or ready).* Trials were of three types and were randomly intermixed: catch trials, in which the display remained unchanged for 2000 msec; eye movement trials, in which 1000 msec after the onset of the cue a computer-generated female target voice ("Beautiful Betty") said *"left"* or *"right"*; and detection trials, in which 1000 msec after cue onset, the left or right dot increased in luminance for 1000 msec.

Subjects were instructed to prepare an eye movement in the direction of the target dot indicated by the male auditory cue (Perfect Paul) without actually moving their eyes. They were told that the most likely direction for their actual eye movement would be the same as the direction indicated by the male auditory cue. On *ready* trials (neutral condition), subjects were told that a saccade was likely to be made but that it was equally likely to occur in either direction. Subjects were told that any time Perfect Paul was followed by Beautiful Betty directing them to move their eyes (primary eye movement task), they were to do so as quickly and accurately as possible. Conversely, if the cue was followed by an increase in luminance of the left or right dot, they were to press the response key as quickly as possible without moving their eyes from fixation (secondary detection task). On catch trials, the display remained unchanged and no response was to be made.

Recall that the purpose of the primary eye movement task in the Klein and Pontefract (1994) modified Experiment 1 was to encourage subjects to prepare an eye movement in the cued direction. Results indicated benefits (decreased RT) for the valid condition as compared to the neutral condition (V<N) and no costs (N=I). Subjects were in fact preparing to shift their gaze in the direction indicated by the auditory cue. Thus, subjects were executing saccades quicker when they were preparing to move their eyes in the

pre-specified direction, while preparing the incorrect response (i.e., preparing an eye movement in the wrong direction) was no worse than the nonspecific preparation in the neutral condition. If the OMRH is correct and preparation to make a saccade to a specified location draws attention covertly to that location, there should be a cuing effect for the detection trials. Results indicated that subjects were fastest at the manual detection task in the neutral condition when they were not preparing to move their eyes in a particular direction. When subjects were preparing to make an eye movement, it did not make a difference whether the target was presented at the valid or invalid location. Therefore, as in Klein (1980, Experiment 1) the results of Klein and Pontefract (1994, Experiment 1) lends no support for the OMRH. And as was the case in 1980, Klein & Pontefract (1994) concluded that eye movement preparation to a given region is not accompanied by a covert shift of endogenous attention to that region.

Recall that Klein's (1980) Experiment 2 tested the prediction that when attention is covertly shifted to a location under endogenous control, saccadic eye movements to that location should be facilitated. In the initial paradigm, arrow cues were utilized to direct the subject's attention and they responded with a key press to a luminance increment of the target (primary task). When instead an asterisk appeared (secondary task), subjects executed an eye movement. Attentional direction had no effect on saccadic RT and Klein (1980) concluded that covert orienting was not accompanied by oculomotor preparation. Klein and Pontefract (1994) find fault with the initial results by stating *"...it is possible that the appearance of a salient visual event such as an asterisk triggers the rapid and* *reflexive computation of a saccadic program to fixate the event. Such a program might "overwrite" a preprogrammed eye movement, thus destroying any evidence that a saccade had been prepared to produce the attentional shift."*

In the revised Experiment 2, Klein and Pontefract (1994) abolished this possibility of overwriting by using auditory stimuli for the saccadic responses (as was the case in Klein and Pontefract (1994) Experiment 1). At the start of each trial an attentional cue (an arrow pointing to the left or right) was presented signaling the likely location of an increase in luminance to which subjects would make a manual response (primary task). An auditory stimulus was used on 20% of trials and indicated that subjects must execute a saccade to the left or the right (secondary task). The attentional cues were 87% valid on the primary detection trials and provided no information about the direction of the saccade required on the secondary eye movement trials. Subjects were told that the likely location of the luminance increase would be the same as that indicated by the cue. They were instructed to prepare to detect a target brightening in the direction indicated by the attentional cue while maintaining fixation. On neutral trials, subjects were instructed that the two target locations were equally likely for the luminance increase. On primary detection trials, subjects were to press a response key as quickly as possible while maintaining fixation when the attentional cue was followed by a luminance increase of the left or right dot. On occasional trials, the cue was followed by a female voice saying "left" or "right" and subjects were to execute a saccade as quickly and accurately as possible to the left or right dot. On catch trial, the display remained unchanged and subjects made no response.

The purpose of the primary detection task was to give subjects incentive to direct their attention in the cued direction. Results showed a significant effect of cue condition upon mean detection RT, and benefits (V<N) and costs (I>N) were revealed. Thus, subjects were using the arrow cues to shift their attention endogenously to the predicted location. If the OMRH is correct (and covert endogenous shifts of visual attention are accomplished by preparing a saccadic program toward the attended location) then there should be a corresponding cuing effect for the saccadic trials, with RTs being faster at the valid as compared to the invalid condition. While results indicated a significant effect of cue condition, it was in the opposite direction to that predicted by the OMRH. Eye movements in the attended direction were slower than in the unattended direction. Klein and Pontefract (1994) interpreted this 'reverse' cuing of saccadic responses by stating that in shifting attention, the subject engages in some degree of suppression of the natural tendency to foveate the cued location.

In summary, Klein and Pontefract (1994), like Klein (1980), were unable to find evidence in support of the OMRH. In contrast to the OMRH their research indicates that endogenous covert orienting is accomplished independent of eye movement programming. In other words, *"the oculomotor readiness hypothesis (and Rizzolatti et al.'s pre-motor theory) may be aesthetically appealing, but it appears to be false."* (Klein and Pontefract, 1994).

The Oculomotor Readiness Hypothesis: Revisited (Again!)

Klein (1980) and Klein and Pontefract (1994) supposed the following logic: *"If eye movements are prepared when subjects attend covertly to a location, then probed oculomotor responses towards an attended location will be facilitated; and conversely, if covert attention is deployed to a location towards which subjects prepare an eye movement, then probed detection responses to targets appearing at this location will be facilitated"* (Klein, 1997, p.2). Experimental results from two dual task designs indicated that these predictions are false, leading Klein to conclude that, in conflict with the OMRH and Pre-motor Theory, endogenous covert orienting is accomplished independent of the oculomotor system.

There is, however, a potential fundamental flaw with the investigations of Klein (1980) and Klein and Pontefract (1994). In both studies, the primary task <u>and</u> the secondary task have demanded speeded responses. While the primary task has always shown the expected RT effects, the secondary task has never done so -- and it is this lack of a RT effect in the secondary task that has led Klein to reject the OMRH.

A fundamental problem with dual-task paradigms in which both responses are speeded, is that it poses subjects with the dilemma of being as fast as possible on two tasks. To solve this dilemma subjects may choose to give one task greater priority than the other, thereby masking any RT effects in the task that is given less priority. In Klein's studies the primary task occurred on most trials, therefore it is reasonable to assume that this task was given priority. Hence, it is possible that Klein's repeated failures to observe RT effects in the secondary tasks has to do with the fact that subjects were trading off speed on the secondary task for speed on the primary task.

The paradigm utilized in the present research controls for this fatal flaw. The basic paradigm of Klein and Pontefract (1994) was repeated but subjects were now required to execute only one speeded response. The other response was nonspeeded with response accuracy as the dependent variable. Specifically, subjects were required to execute saccadic eye movements as quickly as possible. The other task was a visual discrimination of a line's orientation. The question was whether evidence for, or against, the OMRH and the Pre-motor Theory would be obtained.

Experiment 1

A dual task paradigm (primary saccadic task and secondary manual task) was utilized in order to investigate the OMRH prediction that readiness to move the eyes to a particular location would produce covert orienting of attention to that location. Saccadic reaction time (RT) was used to assess overt orienting, while level of accuracy on a visual discrimination task was used as a measure of covert attention.

Methods

Subjects

Twenty-five undergraduate students from the University of Alberta (13 males, 12 females) took part in the experiment and received credit for their participation. Average age of the subjects was 20.24 years and the range was 18 to 28 years of age. All had normal or corrected-to-normal vision. Each was tested in two sessions of approximately one hour each. Sessions were conducted on two separate days (with one day between test sessions).

Apparatus

Visual stimuli were presented at eye level on a Tektronix 604 oscilloscope in a darkened room. Subjects sat at a table in the testing room positioned in front of the oscilloscope. Their heads were supported in a table-mounted chin rest and the distance from the chin rest to the oscilloscope screen was 40 cm for all subjects. All subjects were dark adapted prior to the experiment commencing. For calibration purposes, a thumb press button was utilized at the start of each block of trials and then discarded. A dual-button, hand-held button-box was used for responses in the manual (visual discrimination) task. An Eye-Trac eye-movement monitor (model 210) was utilized to sample the horizontal position of subject's left eye once every 1 msec (i.e., at a rate of 1000Hz). Auditory stimuli were presented over speakers positioned directly in front of subjects in the testing room. The oscilloscope, the thumb press button, the button-box, the eye-movement monitor, and the audio speakers were interfaced with an IBM compatible 486DX/80 computer that controlled and recorded the events and responses of each experiment. The computer was positioned outside of the testing room, in an adjacent room, to enable the experimenter to view a graphic display of subjects eye movements, as well as monitor performance.

Stimuli

Subjects were presented with a visual display on the oscilloscope consisting of a central plus sign with adjacent circles to the right and left of fixation. Each circle measured 150 mm in diameter. The center-point of each circle was four degrees from fixation. Subjects were instructed to fixate the plus sign of this display. An auditory cue was presented 500 msec after trial initiation and lasted 300 msec. This auditory cue was a recording of a human male voice saying "left" or "right". Two types of trials (saccadic and discrimination) were randomly integrated. On saccadic (eye movement) trials, 1000 msec after the offset of the male voice cue, a recording of a human female voice said "left" or "right". On manual (visual discrimination) trials, 1000 msec after the offset of the male voice cue, either a horizontal or a vertical line appeared in one of the circles of the visual display. This target line measured 3 mm in length. Subsequent to the first block of trials, the SOA from the target to the mask (which was initially set at 100 msec) was varied by either increments of 10 msec or decrements of 10 msec based on individual subject performance. The target line was presented for 100 msec and was covered by a random-line mask (7 mm X 7 mm) for 300 msec. Once the mask had been displayed for 300 msec, a response interval of 1000 msec began during subjects were to generate a response prior to an intertrial interval of 2000 msec.

Design and Procedure

Subjects participated in two days of testing. In the first session subjects were exposed to saccadic (with left and right cues) trials and manual (neutral only) trials in separate practice blocks. The two tasks were then combined in a dual-task practice block (80% saccadic task and 20% manual task) which was repeated until an acceptable level of accuracy was attained. For the second session, subjects participated in a dual-task practice block which consisted of 120 trials. They subsequently continued with four dual-task test blocks of 120 trials each, for a total of 480 test trials (table 1).

Table 1. Number of trials in each experimental block.

Task		Experiment 1		Experiment 2	
		Cue		Cue	
		Left	Right	Left	Right
Discrimination	Left	6	6	42	6
	Right	6	6	6	42
Eye movement	Left	42	6	6	6
	Right	6	42	6	6

The experimenter started each block of trials from an adjacent room. Prior to commencing each block of trials, subjects underwent a calibration procedure. With their heads supported in the chin rest mechanism, subjects were given a central fixation plus sign upon which to rest their gaze. To begin the calibration, subjects were to press the thumb button once and a sequence of three plus signs, appearing one at a time, were produced on the horizontal midline of the screen. The first plus sign appeared to the left of fixation and disappeared after a thumb press was executed. The second plus sign appeared in the center (at fixation) and the third appeared to the right of fixation. As each plus sign emerged, subjects fixated it and made a thumb press when they felt that their gaze was steady.

Two types of trials were randomly integrated within each block: a primary saccadic (eye movement) task (80% of trials) and a secondary manual (visual discrimination) task (20% of trials). The start of each trial was the same for each of the two tasks. Approximately 500 msec after trial initiation, the auditory male voice cue said "left" or "right" and lasted for 300 msec. Subjects were instructed to maintain fixation and to "get ready" to move their eyes or to prepare an eye movement in the direction specified by the male auditory cue. The male voice cue was a valid predictor of the target stimulus in the primary task (87.5% valid) and non-predictive of the target stimulus in the secondary task (50% valid). Subjects were informed of this prior to each block of trials commencing.

On the primary saccadic (eye movement) trials, 1000 msec after the male voice cue, a second auditory voice was heard. This target voice was a recording of a human female saying "left" or "right". Subjects responded by generating a saccade as quickly and accurately as possible in the direction commanded by the female target voice. They were instructed to aim for the center of the circle on the target side. Once a saccade was executed, subjects were to return their gaze to the central fixation point and await the subsequent trial, which occurred 2000 msec later. The male voice cue was 87.5% valid, such that the male voice cue was a correct indicator of which direction the female target voice would command 87.5% of the time (e.g., the male voice cue said "right" and the female target voice said "right"). Subject's eye movement RT was recorded and was calculated as the time from the start of the female voice to the start of the saccadic response (Figure 1a shows an example of a valid trial on the saccadic task.).

On the secondary manual (visual discrimination) trials, 1000 msec after the auditory cue (male voice), a target was presented. This target was either a horizontal or a vertical line, each appearing 50% of the time. It was randomly presented for 100 msec to the right or left of fixation (within the circles of the visual display) and was then covered by a random line mask, which appeared for 300 msec. Subjects were to determine the orientation of the target line by making a forced-choice button press using a 2-pronged button box (2AFC). The left button was used to signal the presence of a horizontal target and the right button for a vertical target. Subjects were instructed to remain fixated on the central plus sign during the visual discrimination trials and to respond as accurately as possible once the target appeared. It is of importance to note that subjects were told that speed was not important on this task. Once a button press was executed, a delay of 2000 msec occurred prior to the subsequent trial beginning. Accuracy was the dependent measure for the visual discrimination trials (Figure 1b shows an example of a valid trial on the visual discrimination task.).

The target-mask SOA for manual response trials was varied according to individual subject performance. The experimenter attempted to keep subject's performance at 70-80% correct on visual discrimination trials when no eye movement errors had occurred in order to maintain an attentional component. Subject's performance was monitored for each block (120 trials) and the SOA was adjusted depending on subject's level of accuracy for the discrimination trials. Criteria was as follows: if subjects had a score of <70% on the visual discrimination trials when no eye movement errors were occurring, then the target-mask SOA was increased by 10 msec; if subjects had a score of >80%, then the target-mask SOA was decreased by 10 msec; and if subjects were scoring between 70-80%, then the target-mask SOA remained unchanged for the subsequent block of trials.

Data Analysis

The results were attained once distinct exclusion criteria had been applied to the data prior to the analysis being performed. To begin, for every subject, the first block of trials completed on the second day of testing was excluded from the analysis as practice. Thus, out of the 600 trials that subjects participated in during the test session, only the final 480 trials were included in the analysis.

After the initial calibration for each test block, saccades were detected on line with a velocity criterion of >50°/sec. Specifically, a saccadic response was recorded when the left eye moved in the same direction by more than 0.1° on each of five consecutive 2 msec eye samples. The end of a saccade was recorded when the left eye failed to shift in the same direction by more than 0.1° on five consecutive samples. Saccadic amplitude was based on the initial calibration of each test block. Saccadic RT was defined as the latency required to initiate a saccade following target onset.

Exclusion criteria was applied to saccadic (eye movement) trials as follows: If saccade amplitude was less than 2 degrees or greater than 6 degrees, these trials were excluded from the analysis because they reflected either blinks or failures to hit the target based on the calibration. Incorrect saccades were identified in four ways: no eye movement was executed; an eye movement was made in the wrong direction as specified by the female target voice; a premature eye movement was generated (<80 ms); or if a button press occurred on a saccadic trial.

Exclusion criteria was applied to manual (visual discrimination) trials as well. Three types of errors were monitored. The first error being an incorrect button press response (e.g., the target line had a horizontal orientation and the subject chose vertical). A second type of error on visual discrimination trials was a premature button press (if subjects responded prior to the target line appearing on the screen). The last type of error was as an eye movement error (recall that subjects were to maintain fixation on visual discrimination trials). These errors were classified into 4 groups: no eye movement/incorrect button press response; no eye movement/correct button press response; eye movement error/correct button press response; eye movement error/incorrect button press response). However, due to the difficulty of maintaining fixation on the visual discrimination trials of this dual task experiment, a second factor was applied. The analysis excluded only those discrimination trials where eye movement errors occurred based on the following criteria: if the saccade RT was greater than or equal to the target-mask SOA for that particular trial, then those trials were included in the analysis, whether the button press response was correct or incorrect (so a number of the trials which were initially excluded as errors were actually included in the analysis). The reasoning for such a decision was that if subjects did happen to move their eyes away from fixation, and it was *after* the target had been masked, then they would not have any advantage in detecting the orientation of the target line (they would not have seen the target anyhow, even though an eye movement had occurred).

Results and Discussion

Mean RT as a function of cue condition (valid; invalid) for the primary saccadic (eye movement) task and mean accuracy as a function of cue condition for the secondary manual (visual discrimination) task are shown in Figure 2. Recall that the goal of the primary saccadic task was to motivate subjects to prepare an eye movement in the direction commanded by the male voice cue. An ANOVA indicated a highly significant effect of cue condition upon correct saccadic RT for the primary saccadic task ($F(1, 24) =$

39.546, $p<.0001$). Mean RT of subject's eye movements was 338.9 for valid trials and 471.4 for invalid trials. This reveals that subjects were utilizing the cues and preparing to make an eye movement in the direction specified by the male voice. Hence, in sum, RTs were faster at the valid location (when subjects were preparing an eye movement for the correct direction in which they were to execute a saccade) than at the invalid location (when subjects were preparing an eye movement in the opposite direction to which they were to execute a saccade).

If the OMRH is correct and "getting ready" to make an eye movement to a specific locale elicits covert attention to said locale, then one would expect to attain a similar cuing effect for the manual (visual discrimination) trials. An ANOVA indicated that significance was not reached for the visual discrimination trials ($F(1,24) = 3.193$, $p=0.0866$). Mean accuracy values of subject's responses on the visual discrimination trials were 0.716 for valid trials and 0.817 for invalid trials, indicating that subject's performance is actually improved at the uncued location. This effect is the *opposite* of what the OMRH would predict. While a significant effect is almost reached, it is in the wrong direction: subjects achieved a higher level of accuracy when detecting targets appearing at the invalid location than at the valid location.

This is reminiscent of the Klein and Pontefract (1994) finding in Experiment 2, whereby RT on the primary manual task was the reverse to what one would have predicted on the basis of the OMRH – i.e, saccadic RTs were faster for invalid location trials than valid location trials. Klein and Pontefract (1994) interpreted this 'reverse' cuing of saccadic responses by stating that in shifting attention, the subject engages in some degree of suppression of the natural tendency to foveate the cued location. A similar type of interpretation might apply here, such that in preparing to move the eyes to a particular location, the subject engages in some degree of suppression of the natural tendency to covertly attend to the saccadic location. Introspectively, it felt as if it was very difficult to maintain fixation and withhold a premature eye movement response by covertly attending to the location that a saccadic response was prepared for. An alternative account is that because the likely location for the saccadic target did not predict the location of the manual target, subjects inhibited their covert attention from shifting to the saccadic target location, thereby producing lower response accuracy at the valid location compared to the invalid location. In either case, the data indicate that subjects can prepare to move their eyes to a particular location without directing the covert attention to that location as well.

The error rates for Experiment 1 are shown in Table 2. These data show that subjects were definitely preparing an eye movement response as indicated by the tendency to make an eye movement in the prepared direction on invalid saccadic trials (i.e., wrong direction eye movement errors were 21% on invalid trials and 7% on valid trials). The fact that subjects were preparing an eye movement is further demonstrated by the tendency to make an eye movement to the valid location on visual discrimination trials (27% on valid trials and 21% on invalid trials).

Experiment 2

Similar to Experiment 1, a dual task paradigm was utilized. Now the primary task was visual discrimination of a line's orientation at an attended or unattended location (response accuracy being the dependent variable) and the secondary task was a saccadic response (RT being the dependent variable). The goal was to test the OMRH prediction that when covert attention is endogenously shifted to a location saccadic eye movements to that location will be facilitated.

Methods

Due to similarities existing between Experiments 1 and 2, only the differences will be reported below.

Subjects

Twenty-five undergraduate students from the University of Alberta (4 males, 21 females) took part in the experiment and received credit for their participation. None of these subjects had participated in Experiment 1. Average age of the subjects was 20.16 years and the range was 18 to 28 years of age. Each was tested in two sessions of approximately one hour each. Sessions were conducted on two separate days (with one day between test sessions). Three subjects (2 males; 1 female) were excluded from the analysis due to a failure to follow task instruction.

Apparatus

The apparatus was unaltered from Experiment 1 and so will not be discussed further.

Stimuli

Subjects were presented with the identical visual display used in Experiment 1. Again, subjects were instructed to fixate the plus sign of this display. The same male voice cue saying "left" or "right" was presented 500 msec after trial initiation and lasted approximately 300 msec. Identical trial types (manual and saccadic) as those used in Experiment 1 were randomly integrated.

Design and Procedure

Subjects participated in two days of testing. In the first session subjects were exposed to saccadic (with left and right cues) trials and manual (neutral only) trials in separate practice blocks. The two tasks were then combined in a dual-task practice block (80% visual discrimination task and 20% eye movement task) which was repeated until an acceptable level of accuracy was attained. For the second session, subjects participated in a dual-task practice block which consisted of 120 trials. They subsequently continued with four dual-task test blocks of 120 trials each, for a total of 480 test trials.

The experimenter started each block of trials from an adjacent room. Prior to commencing each block of trials, subjects underwent the same calibration procedure as in Experiment 1, using the same acceptance values.

Two types of trials were randomly integrated within each block: a primary manual (visual discrimination) task (80% of trials) and a secondary saccadic (eye movement) task (20% of trials). The start of each trial was the same for each of the two tasks. Approximately 500 msec after trial initiation, the auditory male voice cue said "left" or "right" and lasted for 300 msec. Subjects were instructed to maintain fixation and to covertly orient their attention in the direction specified by the auditory cue. The male voice cue was a valid predictor of the target stimulus in the primary task (87.5% valid) and non-predictive of the target stimulus in the secondary task (50% valid). Subjects were informed of this prior to the each block of trials commencing.

The primary manual (visual discrimination) task used in Experiment 2 is identical to that used as the secondary task in Experiment 1 and will not be discussed further. Recall that subjects were instructed to remain fixated on the central plus sign during the visual discrimination trials and to respond as accurately as possible once the target appeared. It is of importance to note that subjects were told that speed was not important on this task. Once a button press was executed, a delay of 2000 msec occurred prior to the subsequent trial beginning. Subject's accuracy was measured for the visual discrimination trials (RT was unimportant). Identical criteria to that of Experiment 1 regarding the target-mask SOA adjustment was used. The male voice cue was 87.5% valid, such that the male voice cue was a correct indicator of where the target line (either vertical or horizontal) would appear 87.5% of the time (i.e., the male voice cue said "right" and the target line emerged on the right).

The secondary saccadic (eye movement) task used in Experiment 2 is identical to that used as the primary task in Experiment 1 and will not be discussed further except to note that response speed was emphasized in this task, as it had been in Experiment 1.

Data Analysis

The data analysis in Experiment 2 was identical to that used in Experiment 1.

Results and Discussion

Mean accuracy rates as a function of cue condition (valid; invalid) for the primary manual (visual discrimination) task and mean RT as a function of cue condition for the secondary saccadic (eye movement) task is shown in Figure 3. Recall that the goal of the primary manual task was to motivate subjects to direct their attention in the cued direction. An ANOVA indicated a significant effect of cue condition upon mean discrimination accuracy rates ($F(1,21) = 10.320$, $p<0.005$). Mean accuracy rates for subject's visual discrimination responses were 0.784 for valid trials and 0.700 for invalid trials. This provides evidence that subjects were utilizing the male voice cues to orient their attention endogenously. Higher accuracy rates were found at the valid location (when subjects were endogenously orienting their attention in the direction in which they were cued to attend) than at the invalid location (when subjects were endogenously orienting their attention in the opposite direction to the cue).

As Klein and Pontefract (1994) stated, *"If the OMRH is correct and covert endogenous* *shifts of visual attention are accomplished by preparing a saccadic program toward the attended location, then there should be a corresponding cuing effect for the saccadic trials."* An ANOVA indicated that a significant effect was not produced for the saccadic trials ($\underline{F}(1,21) = 2.660$, $\underline{p} = 0.1178$). Mean saccadic RTs were 482.3 for valid trials and 493.8 for invalid trials, indicating that subjects were not significantly faster in executing a saccade when their attention was shifted covertly to the pre-specified (cued) location. This effect is not what the OMRH predicts.

The error rates for Experiment 2 are shown in Table 2. These data converge with the conclusion suggested by the RT data -- that covert orienting to the cued location did not result in subjects preparing an eye movement to the attended location. In contrast to the error data in Experiment 1, eye movement errors did not vary as a function of cue validity.

General Discussion

The present experiments sought to examine the relationship that exists between overt attention and endogenous covert orienting by testing the oculomotor readiness hypothesis (OMRH) of Klein (1980). The OMRH proposes that there is a reciprocal relationship between the overt and covert attention systems such that: a) preparing to move the eyes to a peripheral location activates a covert shift of attention to the targeted location, and b) shifting one's endogenous covert attention to a peripheral location is accompanied by the preparation to move one's eyes to the attended location. This latter prediction of the OMRH is also produced by the Pre-motor Theory of attentional orienting (Rizzolatti et al., 1987).

Two previous tests of the OMRH produced negative results (Klein, 1980; Klein & Pontefract, 1994). These tests used a dual task design in which there was a primary task and a secondary task. Both tasks were speeded. According to the OMRH, oculomotor preparation or covert orienting in the primary task should produce covert attentional orienting or oculomotor preparation in the secondary task, respectively. Results always produced evidence of oculomotor preparation or covert orienting in the primary task. However, there was never any evidence of covert orienting or oculomotor preparation in the secondary task. Based on these data, Klein concluded that readiness to move one's eyes does not seem to induce an attentional shift toward the targeted location, and conversely, covert shifts of endogenous attention to a location in space are not accompanied by oculomotor readiness.

The working hypothesis in the present thesis was that Klein's tests of the OMRH were fundamentally flawed because these investigations used response speed as a measure of performance in both the primary task and the secondary task. By placing priority on the primary speeded task it is not surprising to discover that there was no response speed effects in the secondary task. In other words, if subjects were not placing priority on responding as quickly as they could in the secondary task then one would not expect to find response speed effects in the secondary task. It is therefore for this reason -- and not because the OMRH is incorrect -- that Klein has failed repeatedly to obtain any evidence on the secondary task to support the OMRH.

The present research was conducted to address this potential shortcoming of Klein's previous research regarding the OMRH. In the current paradigm, only the saccadic task was speeded. For the manual task, response accuracy rather than response speed, was used to measure the allocation of covert attention. Therefore, the opportunity for a tradeoff between different speeded responses did not exist in the present research.

Nevertheless, the results from the current experiments again found no evidence to support the OMRH. In Experiment 1, the primary task was to prepare a speeded saccadic response in the direction indicated by a voice cue. The results indicated that subjects did, in fact, prepare eye movements indicated by the cue, with saccadic RTs faster when a target occurred at the cued location compared to the uncued location. If the OMRH is valid, then preparing to make a saccade to a certain location should also trigger an endogenous shift of attention to the targeted location. This, in turn, should produce an improvement in response accuracy when a visual target appears at the cued (saccadic target) location compared to the uncued location. Results revealed that there was no improvement in response accuracy at the cued location. In fact, the opposite effect was observed, with response accuracy lower at the cued saccadic target location than the uncued saccadic target location. This accuracy effect, which is the reverse of what the OMRH would predict, while not reaching significance, was indeed unexpected. As noted previously, this drop in accuracy might reflect the fact that in preparing to move the eyes to a particular location, the subject engages in some degree of suppression of the natural tendency to covertly attend to the saccadic location. An alternative possibility is that because the targeted location for a saccadic response did not predict the location of the manual target, subjects might have inhibited their covert attention from being shifting to the targeted location. In either case, the main finding in Experiment 1 was clear-cut: saccade preparation to a specific location is not accompanied by a covert attentional shift to that location. This finding is inconsistent with the OMRH.

The OMRH also predicts that covert endogenous orienting to a specific location is accompanied by activation of the oculomotor system to that location. A similar prediction is made by the Pre-motor Theory of covert orienting. Experiment 2 tested this prediction. The primary task was to orient covert attention to the location indicated by a voice cue. On most trials subjects received a target demanding a visual discrimination and an unspeeded manual response. Response accuracy was the dependent variable on this primary task. On the secondary task subjects received an auditory target that signaled subjects to make a speeded saccadic response to the cued or uncued location. If covert orienting to a location activates the oculomotor system for responses to that location, then saccadic responses to the cued/attended location should be faster than saccadic responses to the uncued/unattended location.

The results indicated that subjects were orienting their covert attention endogenously to the cued location, with discrimination accuracy higher for targets that appeared at the cued location than the uncued location. If the OMRH is accurate, and covert endogenous shifts of visual attention are accomplished by preparing a saccadic program toward the attended location, then saccadic RT to the attended location should be faster than to the unattended location. Results showed that this was not the case. Saccadic RTs to the attended and unattended location were about equal. Thus, the results of Experiment 2 failed to support the OMRH, or the Pre-motor Theory of covert attention. Covert endogenous shifts of attention do not appear to be accompanied by activation of the oculomotor system.

In summary, the data from the present set of experiments are inconsistent with the predictions of the OMRH and the Pre-motor Theory of attention. The data indicate that preparing to move one's eyes to a peripheral location is not accompanied by a covert shift of attention to the targeted location. And shifting one's endogenous covert attention to a peripheral location is not accompanied by the preparation to move one's eyes to the attended location. These data are in full agreement with the conclusions of Klein (1980) and Klein and Pontefract (1994).

Reuter-Lorenz & Fendrich (1992) also examined recently the relationship between oculomotor and attentional orienting. The paradigm employed by Reuter-Lorenz et al. (1992) consisted of two experiments that compared the effects of spatial cues on simple manual responses and saccadic eye movements in the same subjects. Their reasoning was as follows: the costs that are generated when an invalid attentional cue is used depend on the spatial relationship between the location of the cue and the location of the target. If it is the case that eye movement programs mediate shifts of attention, then varying the spatial relation between the cue and the target should be equivalent for covert (manual responses) and overt (saccadic responses) orienting.

Because central and peripheral cues may involve different attentional mechanisms (e.g., Klein, Kingstone, & Pontefract, 1992), their first experiment used peripheral cues and the second used central ones. In Experiment 1, the display consisted of four outline boxes (two boxes 2 degrees to the left and right of fixation, and two boxes 6 degrees to the left and right of fixation). The cue consisted of a second outline box which flashed briefly around one of the target locations. The target was presented within one of the four boxes. For different trial blocks, subjects responded to the target onset either by making a manual response, or by making a saccade response, to the target location. The target appeared in the cued location 75% of the time (valid) and the cue and target appeared in different locations 25% of the time (invalid).

Results from Experiment 1 revealed that both saccadic and manual responses were faster on valid than on invalid trials. However, there was no difference between the manual and saccadic response conditions and RT costs were identical for both conditions. Reuter-Lorenz et al. (1992) evaluated the effect of the spatial relationship between the cue and target for each response condition by comparing the costs for four cue-target pairs: those separated by 4 degrees and falling in the same hemifield (e.g., both the cued box and the target box appeared left of fixation), those separated by 4 degrees and falling on opposite sides of the vertical meridian, those separated by 8 degrees and falling on opposite sides of the vertical meridian, and those separated by 12 degrees and falling on opposite sides of the vertical meridian. Analysis indicated that regardless of response condition (manual or saccadic), costs were reliably influenced by the spatial relation of the cue and target. To evaluate the meridian effect, the 4 degree same and 4 degree opposite pairs were compared as the retinal separation between cue and target is equivalent for these pairs. This comparison was not significant. In fact, only the 12 degree cue-target pair differed significantly from the other three pairs.

It was revealed through further analyses that the relative eccentricity of the cue and target generated notably different effects for the manual and saccadic conditions. Costs associated with pairs where the cued location is eccentric to the target were compared to costs from pairs where the target is eccentric to the cued location. Reuter-Lorenz et al. (1992) found a dissociation between response conditions. For manual responses, when the target was eccentric to the cue, costs were greater than when the cue was eccentric to the target. With saccadic responses the reverse pattern was obtained and costs were greater when the cue was eccentric to the target.

Thus, Reuter-Lorenz et al. (1992) found a significant divergence in the pattern of saccadic and manual costs when exogenous cues were used. This result is inconsistent with the Pre-motor Theory of attention which predicts that the costs observed for manual responses should be analogous to those obtained for saccadic responses. Further, and perhaps most troublesome to the Pre-motor Theory, is that no meridian effect was found: invalid cue-target pairs on the same side of the vertical meridian produced costs equal to or greater than pairs on opposite sides of the meridian.

Recall that Rizzolatti et al. (1987) used central cues in their paradigm while Reuter-Lorenz et al. (1992) used peripheral cues in their Experiment 1. This prompted a second experiment where central cues were utilized to further examine the possibility of a meridian effect. The stimulus display was identical to that used in Experiment 1 but instead of the peripheral cue, a single or double arrow was positioned directly above the fixation point indicating the likely location of the target. Subjects were told that the double arrows pointed to the outer-most box and that single arrow cues pointed to the inner box. Results again indicated that RTs were faster at valid as compared to invalid locations for both the manual and saccadic response conditions. In contrast to Experiment 1 however, results of Experiment 2 indicated that costs were significantly greater when the cue and target occurred on opposite sides of the vertical meridian than when they occurred on the same side. This was true for both manual and saccadic responses. Further contrasting results to those found in Experiment 1 were that relative cue-target eccentricity had no effect on the degree of costs for either the manual or saccadic responses. Thus, the findings of Experiment 2 are in agreement with those predicted by the Pre-motor Theory.

Taken together, Reuter-Lorenz et al. (1992) found evidence supporting Pre-motor Theory with endogenous orienting, and evidence against Pre-motor Theory with exogenous orienting. Because Pre-motor Theory depends on activation of the eye movement system, and because exogenous cues are known to activate the eye movement system (e.g., Rafal et al., 1989), Pre-motor Theory cannot provide a plausible account of why a meridian effect would be observed with endogenous cues but not exogenous cues. As a result, Reuter-Lorenz et al. (1992) rejected the Pre-motor Theory, and the OMRH. They proposed instead that endogenous shifts of attention and the eye movement system require access to a common cognitive representation of visual space -- one which contains a meridian effect. Programming a saccade response and programming an attentional movement occur independently and in parallel.

Conclusions

Two experiments were conducted that tested the oculomotor readiness hypothesis and the Pre-motor Theory of covert orienting. The results of both studies were inconsistent with these proposals, indicating that covert orienting can be engaged without activating the oculomotor system, and oculomotor preparation can be engaged without activation of covert orienting. Thus, in agreement with Reuter-Lorenz et al. (1992) our data point to the following conclusion: That covert orienting and oculomotor activation can occur independently.

References

Briand, K. A. & Klein, R. M. (1987). Is Posner's "Beam" the same as Treisman's "Glue"?: On the relation between visual orienting and feature integration theory. Journal of Experimental Psychology: Human Perception and Performance, 13(2), 228-241.

Cheal, M. & Lyon, D. R. (1991). Central and peripheral precuing of forced-choice discrimination. The Quarterly Journal of Experimental Psychology, 43A(4), 859-880.

Corbetta, M., Miezin, F. M., Shulman, G. L., & Peterson, S. E. (1993). A PET study of visuospatial attention. The Journal of Neuroscience, 13(3), 1202-1226.

Hoffman, J. E. & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. Perception and Psychophysics, 57, 787-795.

James, W. (1890). The principles of psychology, Volumes 1 & 2. New York: Holt.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In Long, J. & Baddeley, A. (Eds.), Attention and Performance, IX (187-203). Hillsdale, N.J.: Erlbaum.

Kingstone, A., Fendrich, R., Wessinger, M., & Reuter-Lorenz, P. (1995). Are microsaccades responsible for the gap effect? Perception and Psychophysics, 57(6), 796-810.

Kingstone, A., Grabowecky, M., Mangun, G. R., Valsangkar, M., & Gazzaniga, M. S. (1997). Paying attention to the brain: The study of selective visual attention in cognitive neuroscience. [Chapter] Burack, J. A. (Ed), Enns, J. T. (Ed), et al. Attention, development, and psychopathology. (pp. 263-287). New York, NY, USA: The Guilford Press.

Klein, R. M. (1997). Is endogenous covert orienting accomplished by endogenous preparation of overt orienting? Submitted to Journal of Experimental Psychology: Human Perception & Performance.

Klein, R. M. (1980) Does oculomotor readiness mediate cognitive control of visual attention? In R. Nickerson (Ed.), Attention and Performance VIII, (259-276). Hillsdale, N.J. : Erlbaum.

Klein, R. M., Kingstone, A. & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), Eye movements and visual cognition: Scene perception and reading, 46-65. New York: Springer-Verlag.

Klein, R. M. & Pontefract, A. (1994) Does oculomotor readiness mediate cognitive control of visual attention? Revisited! In C. Umilta & M. Moscovitch (Eds.), Attention and Performance XV, (333-350). Cambridge, MA: MIT Press.

Knowler, E., Anderson, E., Dosher, B., & Blasher, B. (1995). The role of attention in the programming of saccades. Vision Research, 35, 1897-1916.

Muller, H. J. & Findlay, J. M. (1988). The effect of visual attention on peripheral discrimination thresholds in single and multiple element displays. Acta Psychologica, 69, 129-155.

Muller, H. J. & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Perception and Performance, 15, 315-330.

Posner, M. I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3-25.

Posner, M. I. & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bowhuis (Eds.), Attention and Performance X, (531-556). Hillsdale, N.J. : Erlbaum.

Posner, M. I. & Peterson, S. E. (1990). The attention system of the human. Annual Review of Neuroscience, 13, 25-42.

Posner, M. I. & Raichle, M. E. (1997). Images of mind. Scientific American Library. New York, NY. : W. H. Freeman and Company.

Rafal, R. & Henik, A. (1994). The neurology of inhibition: Integrating controlled and automatic processes. [Chapter] Dagenbach, D. (Ed), Carr, T. H. (Ed), et al. Inhibitory processes in attention, memory, and language, 1-51. San Diego, CA, USA: Academic Press, Inc.

Rafal, R. D., Calabresi, P. A., Brennan, C. W., & Sciolto, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. Journal of Experimental Psychology: Human Perception and Performance, 15(4), 673-685.

Rafal, R. D., Posner, M. I., Friedman, J. H., Inhoff, A. W., & Bernstein, E. (1988). Orienting of visual attention in progressive supranuclear palsy. Brain, III, 267-280.

Remington, R. W. (1980). Attention and saccadic eye movements. Journal of Experimental Psychology: Human Perception and Performance, 6(4), 726-744.

Reuter-Lorenz, P. A. & Fendrich, R. (1992). Oculomotor readiness and covert orienting: Differences between central and peripheral precues. Perception and Psychophysics, 52(3), 336-344.

Rizzolatti, G., Riggio, L., Dascola, I., & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. Neuropsychologia, 25(1A), 31-40.

Shepherd, M., Findlay, J. M., & Hockey, R. J. (1986). The relationship between eye movements and spatial attention. Quarterly Journal of Experimental Psychology, 38A, 475-491.

Stelmach, L. B., Campsall, J. M., & Herdman, C. M. (1997). Attentional and ocular movements. Journal of Experimental Psychology: Human Perception and Performance, 23, 823-844.

Tsal, Y. (1989). Further comments on feature integration: A reply to Briand and Klein. Journal of Experimental Psychology: Human Perception & Performance, 15(2), 407-410.

Yantis, S. (1995). Perceived continuity of occluded visual objects. Psychological Science, 6(3), 182-186.

Appendix

Task	Error Type	Experiment 1		Experiment 2	
		Valid	Invalid	Valid	Invalid
Saccadic	No eye movement response	0	0	0	0
	Wrong direction	7	20	8	10
	Anticipatory response	8	8	7	7
	Button press response	0	0	0	0
Manual	Wrong button press	28	17	22	30
	Anticipatory response	0	0	0	0
	Eye movement occurred	27	21	20	18

Table 2. Error analysis for Experiment 1 (primary saccadic task) and Experiment 2 (primary manual task). Shown are the percent of errors as a function of error type and task.

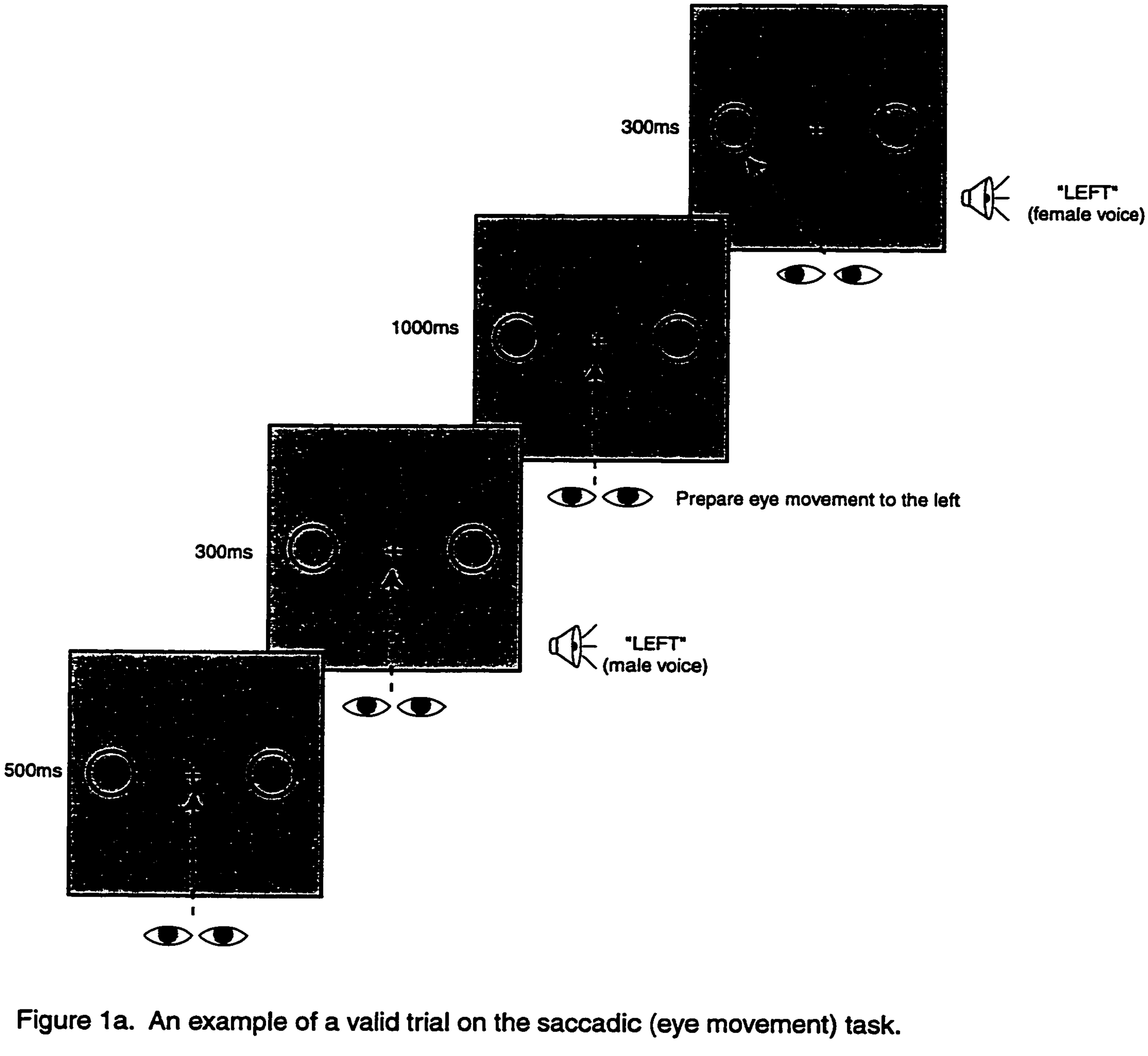


Figure 1a. An example of a valid trial on the saccadic (eye movement) task.

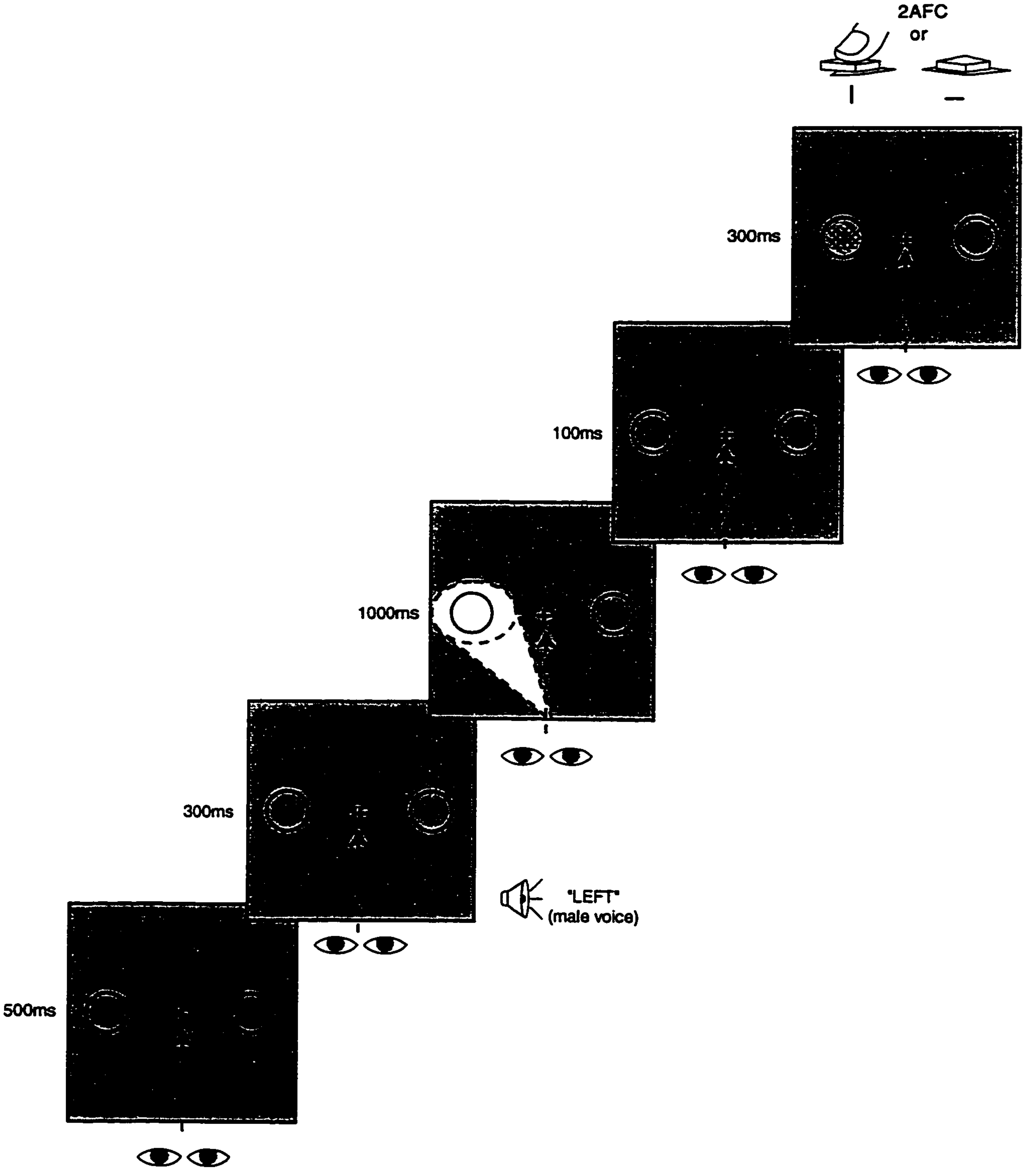


Figure 1b. An example of a valid trial on the manual (visual discrimination) task.

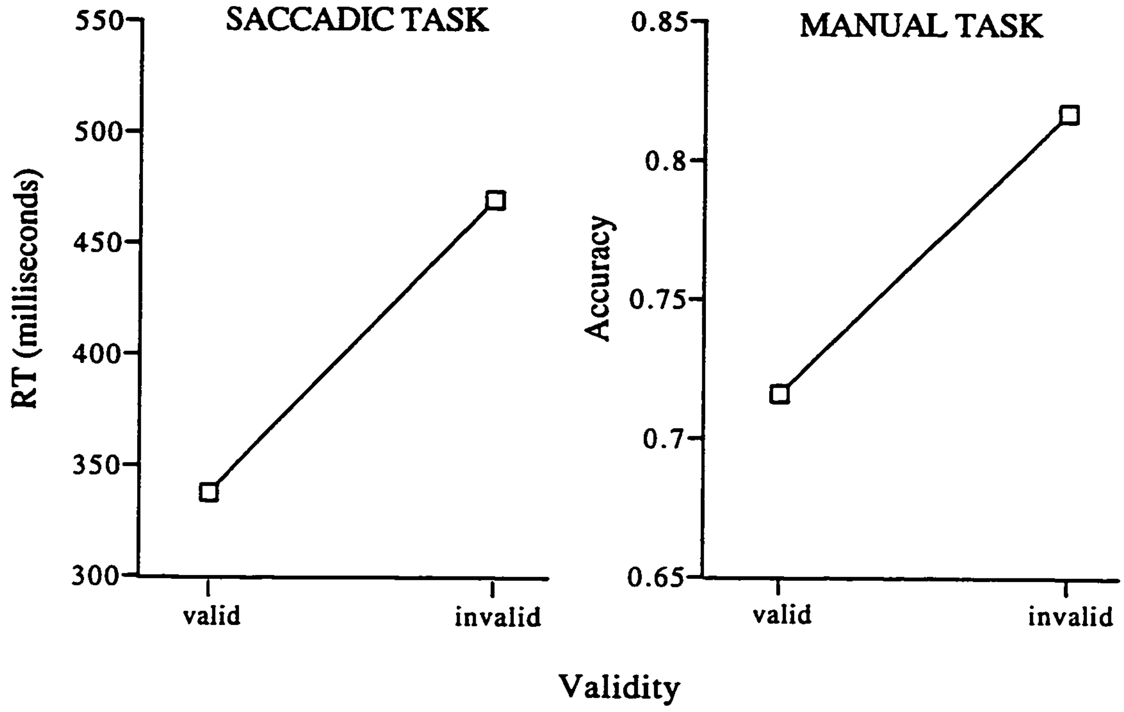


Figure 2. Mean RT (primary saccadic task) and accuracy levels (secondary manual task) in Experiment 1 as a funtion of cue condition and task. The first graph shows data from the primary eye movement task, while the second graph shows data from the secondary visual discrimination task.

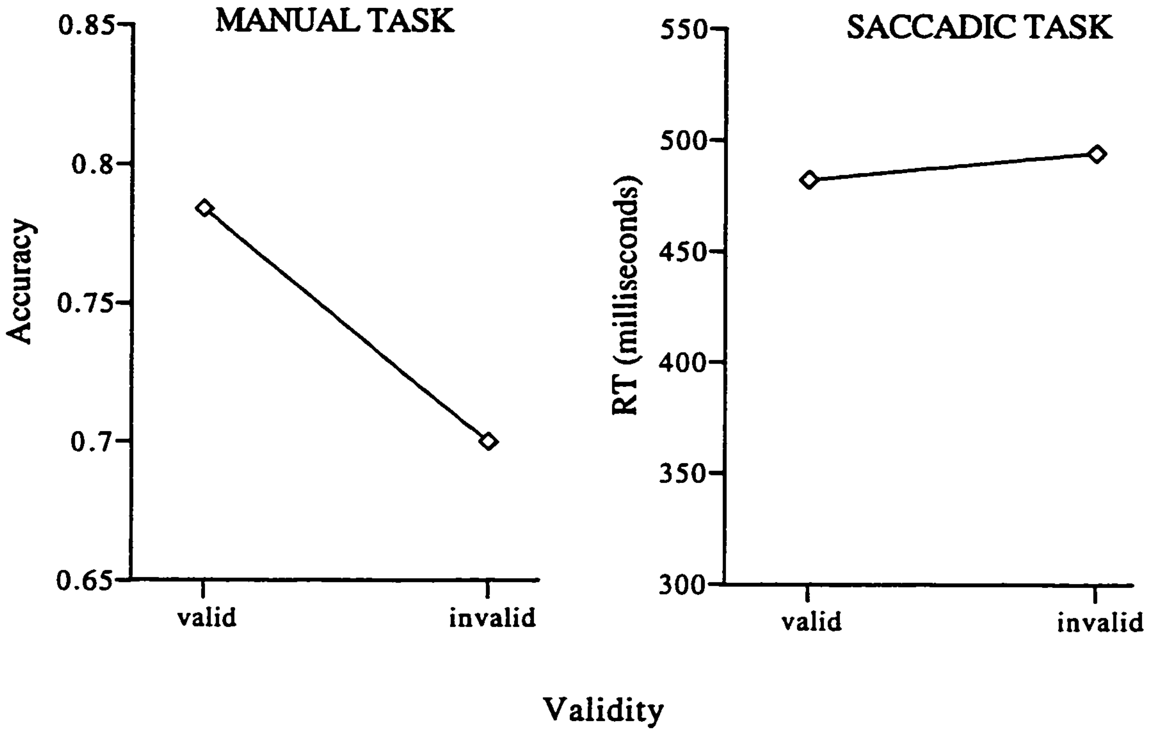
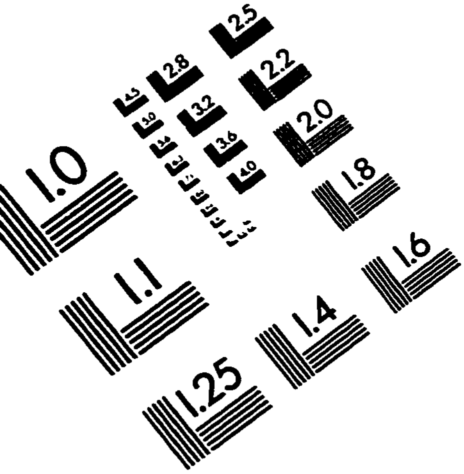
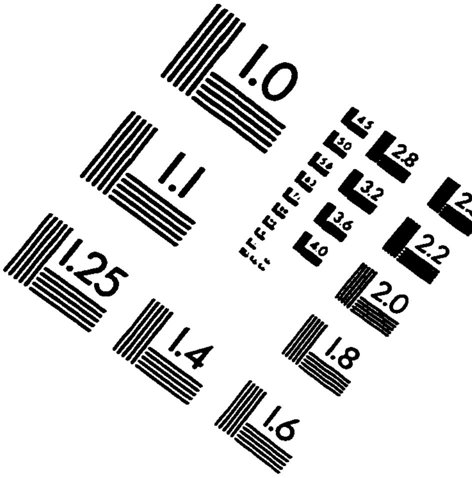
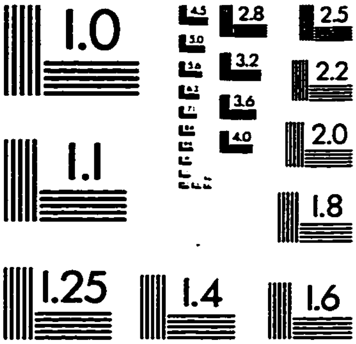


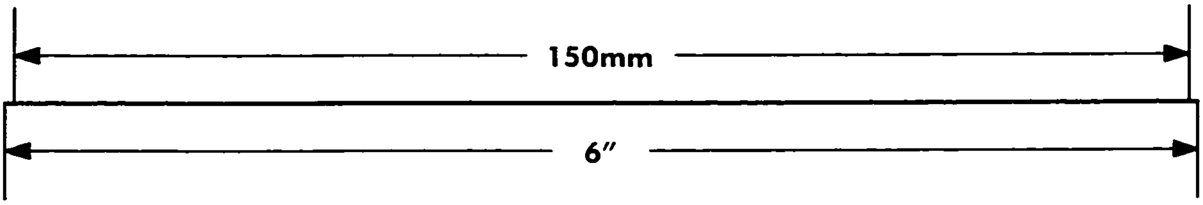
Figure 3. Mean accuracy levels (primary manual task) and RT (secondary saccadic task) in Experiment 2 as a function of cue condition and task. The first graph shows data from the primary visual discrimination task, while the second graph shows data from the secondary eye movement task.

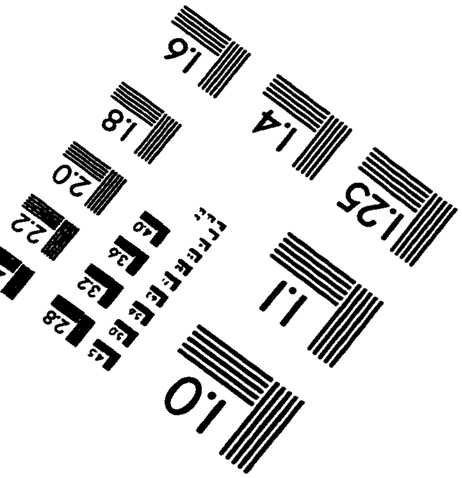
IMAGE EVALUATION
TEST TARGET (QA-3)

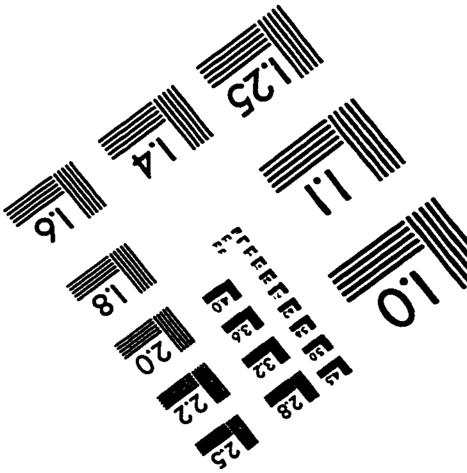












APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989