

EVIDENCE AGAINST THE PREMOTOR THEORY OF ATTENTION

by

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The premotor theory of attention postulates that attention allocation and saccadic programming are strictly linked. We conducted an eye-tracking study to test this theory. Participants were presented with a centrally-located cue arrow and were instructed to make a saccade to the corresponding peripheral dot while attending to the center, in order to report a briefly-displayed target letter. Using two separate temporal cutoff criteria from the arrow onset, we found both significant increases in performance accuracy with practice and decreases in performance accuracy with longer cue delays, but with accuracies being above chance across conditions. These results suggest that attention allocation and saccadic programming may be governed by separate mechanisms.

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1.0 INTRODUCTION

Humans perform rapid ocular movements called *saccades* that orient the fovea to areas of interest within the visual field (Findlay & Walker, 1999). These occur many times per day; according to Rayner (1998), saccades occur frequently due to visual acuity limitations in the areas outside the fovea—the parafovea and the periphery. During reading, saccades propel the fovea through lines of text and are punctuated by fixations, or periods of relative ocular motionlessness (Rayner, 1998), during which information is acquired (Reichle, Rayner, & Pollatsek, 2003). During active reading of English text, saccades typically propel the eyes from left to right, although 10-15% of saccades are regressions that result in refixations of previously fixated words (Rayner, 1998). In this article, we will consider attention as being allocated in a “spotlight,” typically to the right of the fixated word during reading of English text (Reichle, et al., 2003).

1.1 SUPPORT FOR THE PREMOTOR THEORY OF ATTENTION

The question of how attention functions in saccadic eye movements is one of considerable debate. Rizzolatti, Riggio, Dascola, and Umiltá (1987) postulated the premotor theory of attention, in which covert attention and ocular motor programs for moving the eyes are strictly linked (i.e., eye movements to a given location are obligatorily preceded by a shift of

attention to that location). They conducted a study in which participants were instructed to attend to a cued location. The target was presented 70% of the time in the cued location and 30% of the time in a non-cued location. In similar trials, participants were instructed to attend to all of the potential target locations, each having an equal probability of being stimulus locations. Participants manually responded to the stimulus as quickly as possible. Results showed that validly cued trials yielded a temporal performance benefit, and that invalidly cued trials resulted in temporal cost. They also found that temporal cost increased as a function of distance between the attended and stimulus locations. Finally, if attended and stimulus locations were on opposite sides of the horizontal or vertical meridian, additional costs ensued. These additional costs are (according to the central assumption of the premotor theory of attention) the result of reorienting the direction of the oculomotor program; in other words, reorienting covert attention.

Hoffman and Subramaniam (1995) support this claim. They conducted two experiments to determine whether attention is required for a saccade. In the dual-task block of the first experiment, participants were instructed to make a saccade to one of four specified locations. Within those four locations (located in the top, bottom, left, and right of the computer display), one of four different letters was briefly displayed immediately before the saccade was executed. One of these was the target letter, and participants had to report which letter appeared, after making the saccade. Although participants were told to make a saccade to a specific location, they were instructed to attend to all four locations equally. Results showed that detection accuracy was best when the target letter matched the saccade location. This showed that, although all stimulus locations were equally probable, participants chose to attend to the intended saccade location. In the second experiment, participants were instructed to make a saccade to a fixed location throughout. They were specifically instructed to attend to a specific location,

although most of the time the saccade did not coincide with this location. Results showed that detection accuracy was greatest when the saccade location and the attended location coincided. Hoffman and Subramaniam thus concluded that participants cannot attend to and move their eyes to separate locations.

Clark's (1999) computational model also follows the assumptions of the premotor theory of attention. In his model, the processes involved in shifting attention continuously define where the eyes move, thus cutting out the need for a separate saccadic programming mechanism. Clark specifically cites the premotor theory of attention (Rizzolatti, 1983) and the oculomotor readiness hypothesis (Klein, Kingstone, & Pontefract, 1992), in which attention and eye movements directed by exogenous cues are closely associated. As cited by Clark, however, Klein et al. (1992) did not find this same close association between attention and endogenously-cued saccades. The reason for this discrepancy remains unclear, but it may indicate that saccadic programming is not obligatorily coupled with attention shifts—a hypothesis that will be directly tested in this article.

1.2 ALTERNATIVE VIEWS

Other models of saccade generation do not assume that attention and saccadic programming are strictly linked. For example, Findlay and Walker (1999) postulate a system of competitive interaction involving “fixate” and “move” centers that determines when, where, and whether a saccade should be made. They reject Posner and Peterson's (1990) theory (described by Posner & Cohen, 1984, p. 1864) that postulates attention as being disengaged from the current location, then moved and engaged on a new target. Findlay and Walker argue that, in their

model, disengagement and attention allocation involve separate processes, and thus attention is not singularly moved from one locus to another.

In a similar manner, Reichle, Rayner, and Pollatsek (2003) also propose separate saccadic programming and attentional processes in their E-Z Reader model. In this processing model, the lower-level cognitive process of word identification determines both when and where the eyes move during reading. Higher-level (post-lexical language) processes only directly engage the attention and oculomotor systems when lower-level processes fail—then, they signal termination of forward progression and/or the initiation of a regression (Reichle, Warren, & McConnell, 2009). Core assumptions of this model include (1) that attention proceeds serially from one word to the next in a “spotlight” encompassing one word at a time, and (2) that a sub-stage of word identification signals a saccade. The first stage of the two-stage word identification system (i.e., the *familiarity check*) sends an eye-movement signal to the first stage of the oculomotor system, which is comprised of a labile stage, where the saccadic program can be cancelled, a non-labile stage, where the program cannot be cancelled, and a saccade generator. The second stage of the word identification system (i.e., the *completion of lexical access*) signals an attention shift (Reichle, et al., 2003, 2009).

1.2.1 Testing the premotor theory of attention

This assumption of a dissociation between saccadic programming and attention shifting was explicitly tested by Belopolsky and Theeuwes (2009). In their first experiment, they presented participants with two figure-eight masks on the left and right sides of the upper hemifield. A central arrow cued participants to covertly attend to one of the masks. Segments of the figure-eights were then removed to reveal either the digits one or two, which directed

participants to make a saccade toward the upper left or right, respectively. Eighty-percent of the trials were validly cued, in which the target character was presented at the attended location. Twenty-percent were invalidly cued, in which the target and attended locations did not match. Experiment 1 results showed that reaction times were faster on the validly-cued trials; i.e., when the attended and target locations matched. Performance was also faster on the trials in which the target and saccade locations matched, indicating that attention reduced saccadic latencies. This is consistent with the premotor theory of attention (Rizzolatti, et al., 1987) and Hoffman and Subramaniam's (1995) results. In the Experiment 2, Belopolsky and Theeuwes added two additional target locations to the left and right sides of the lower hemifield. This reduced the probability of saccade and target congruence to 25%. Cues remained valid for 80% of trials. Performance was faster on validly-cued trials, but for these trials, performance was slower when the target location matched the saccade location than when these locations were incongruent. These results suggest that when the probability of making a saccade to an attended location is low (25%), saccades to that location are suppressed. Taken together, the results from both experiments are inconclusive because they fail to demonstrate a consistent dissociation of attention allocation and saccade preparation.

1.3 THE EXPERIMENT

In our study, we aimed to provide more conclusive evidence about the coupling (or lack thereof) between saccadic programming and the movement of attention. We designed our experiment to test the premotor theory of attention (Rizzolatti, et al., 1987) and the E-Z Reader model's (Reichle et al., 2003, 2009) disparate assumption that attention allocation and saccadic

programming diverge within the word identification process. Although in everyday life, attention and eye movements are undoubtedly closely associated (congruent with the premotor theory of attention; e.g., Rizzolatti, et al., 1987), we propose that attention shifts and eye movements may only be linked through association because we make saccades so frequently. In other words, it may appear as if attention and eye movements are tightly coupled because most of the time they are. However, although attention shifts often precede eye movements, this does not necessarily mean that they cannot be “teased apart” as separate processes.

In order to determine if attention and saccadic programming can be separated, we presented participants with an unusual situation in which they were forced to maintain attention on a central location while making a cued saccade to a peripheral location. The saccade direction was cued by an arrow pointing either left or right, that was displayed for 100 msec, 150 msec, or 200 msec. To ensure that participants were attending to the center of the display, they were required to report the briefly displayed letter. We predicted that, although this task would be difficult, participants’ performance would be above chance, indicating that they could simultaneously attend to one location while programming a saccade to another location. We had two other major hypotheses. First, we predicted that participants’ performance would improve with each of the three subsequent blocks of trials. This improvement would reflect practice as participants gained experience dissociating saccadic programming from attention. Second, we predicted that performance would decrease as a function of arrow lag. The reason for this prediction is that participants would have to separate saccadic programming from attention allocation for a longer period of time with each increase in arrow lag duration. This would increase the necessity of participants to separate the two processes, resulting in a performance

decrease in this highly unusual situation. However, as already indicated, we believed that performance would be above chance in all conditions.

2.0 METHOD

2.1 PARTICIPANTS

Twenty-two compensated university students participated in the study. The first four were considered pilot participants and their data was not used. Two additional participants failed eye-tracking calibration. We used the data from the remaining sixteen participants, which included 11 females and five males. All participants received the same stimuli. Participants signed an informed consent form that was approved by the University of Pittsburgh's Internal Review Board prior to beginning the experiment.

2.2 APPARATUS AND STIMULI

We utilized the EyeLink 1000 tower-based eye-tracking system from SR Research, with dimensions of $400 \times 750 \times 270$ mm, 1000 Hz sampling rate, noise (RMS) < 0.01 , and a gaze position accuracy of 0.15° , using version 4.21 of the host computer software. We designed the experiment using version 1.6.1 of the SR Research Experiment Builder software. Participants' right pupils were tracked.

The stimuli consisted of a white background with a central area of interest. Two equidistant grey circles (dots) were always present on the far left and right, each measuring from

the center at 13.87° visual angle. The central area initially consisted of an arrow, pointing either left or right. After the arrow disappeared, a letter (B, D, O, or P) appeared, followed by a pound sign mask (see Figure 1).

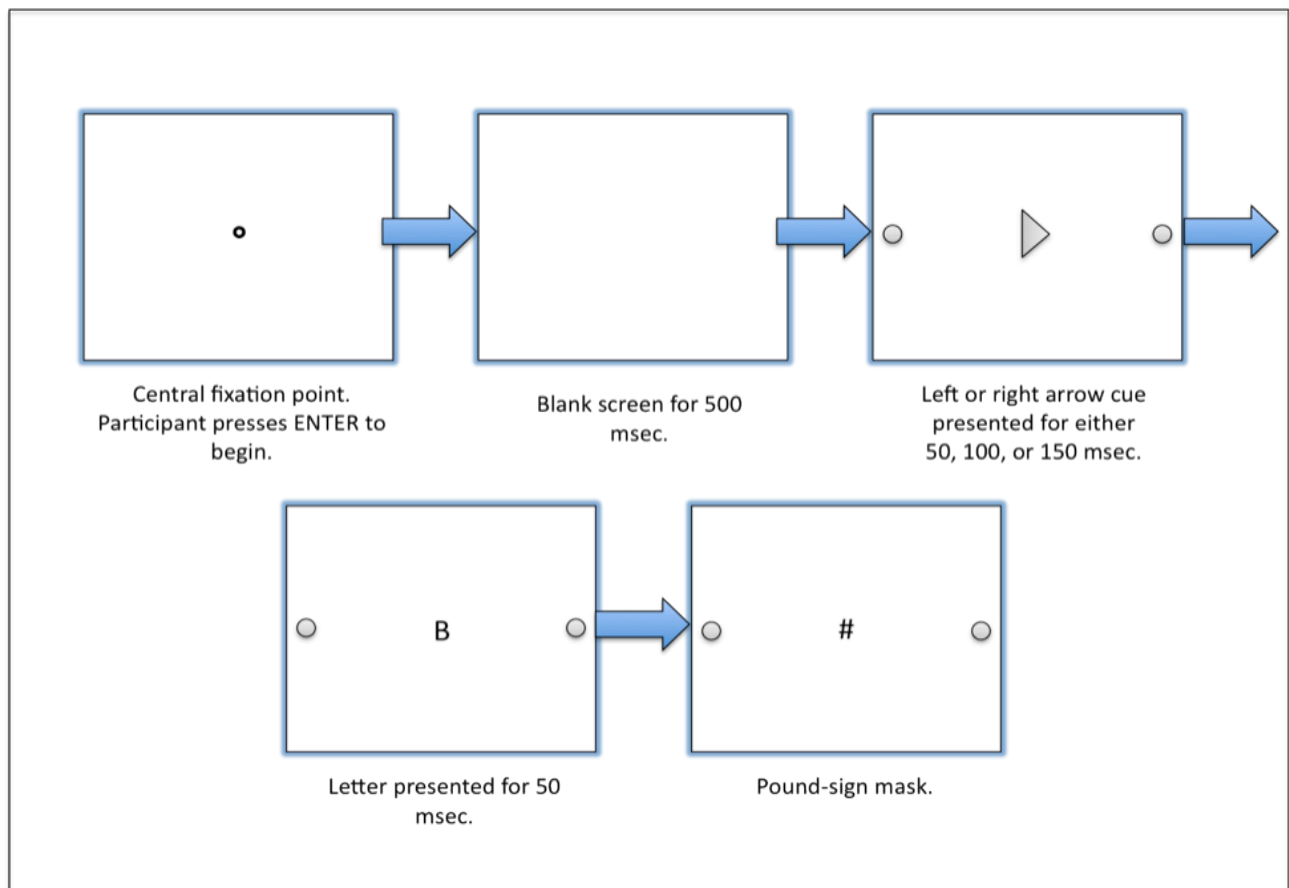


Figure 1. Order of stimuli presentation.

During the pilot experiments, we discovered a disproportionate number of incorrect left trials. We think that this was possibly due to right-eye-dominant participants, and that we only tracked the right pupil. Participants' right eyes, therefore, had to move slightly farther left in order to break the plane of the "interest area" of the left dot, and were failing to do so. (The interest areas were invisible to participants.) We therefore symmetrically expanded the interest

areas around both peripheral dots into oblong shapes, slightly off-center relative to the dots, and oriented toward the central area (Figure 2). The areas of interest thus extended approximately 6.8° horizontally and 4.03° vertically, with 8.91° from the central fixation point to the proximal border of each interest area.

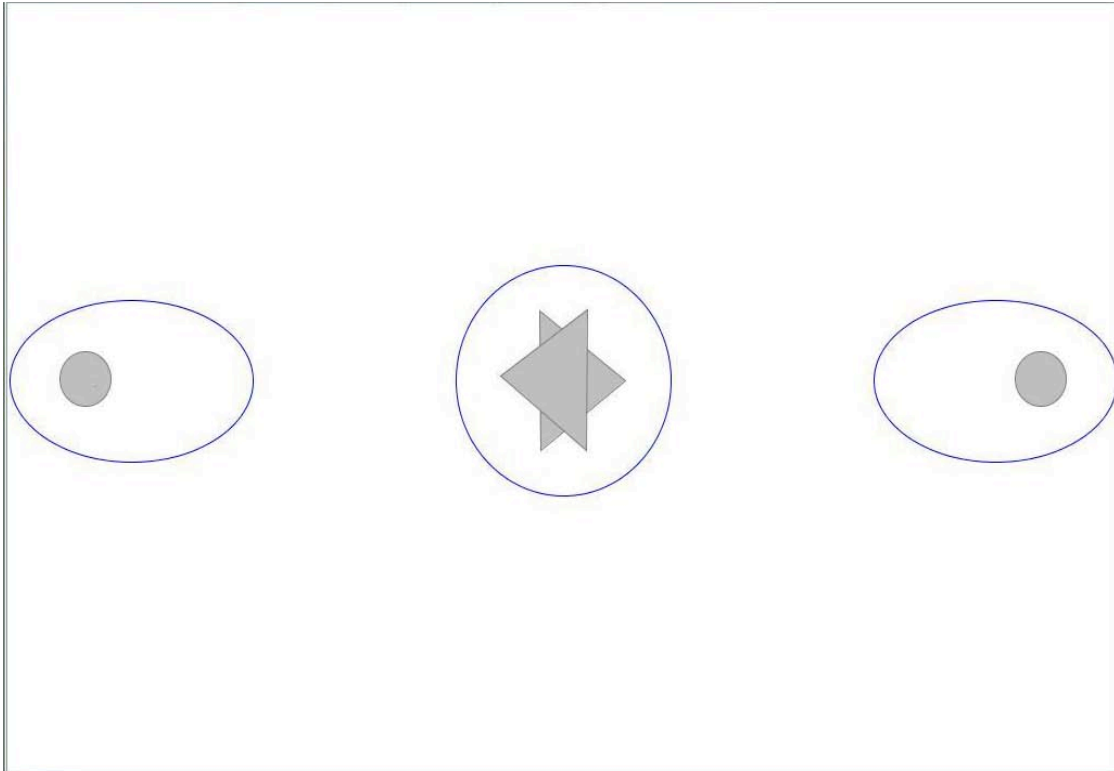


Figure 2. “Interest areas,” invisible to the participant. The participant must make a saccade out of the central interest area that lands within the interest area of the correct dot.

2.3 DESIGN

We conducted a $2 \times 3 \times 3$ mixed factorial experiment. All variables were within-subjects. There were 20 practice trials and 540 experimental trials, which were divided into three blocks of 180 trials each. The independent variables of interest were Arrow Direction (left or right), Lag (100, 150, or 200 msec), and Block (1, 2, or 3). Lag was defined as the duration of the cue arrow (50, 100, or 150 msec) plus the duration of the target letter, which remained a constant 50 msec on all trials. Both Arrow Direction and duration, and letter displayed were randomized through the Experiment Builder run-time randomization feature on each trial. Correct trials were defined as trials in which participants both made a saccade (within 300 msec of the arrow onset) from the central interest area to the interest area of the correct dot, and reported the correct letter. Incorrect trials were defined as trials in which participants broke the plane of the central interest area with a saccade within 300 msec of the arrow onset, but fixated on any location other than within the interest area of the correct dot, or reported the incorrect letter after fixating the correct dot. Trials in which participants dwelled in the central interest area for longer than 300 msec after the arrow onset were discarded. Participants earned \$.05 for each correct trial as an incentive to put effort into this difficult task. They were not penalized for incorrect trials.

2.4 PROCEDURE

After the instruction screen, participants were calibrated for accurate tracking and were given further explanation of the task. They were told that only the first ten trials were practice

and the rest were experimental, but we discarded the first 20 trials. At the beginning of each trial, a central fixation dot appeared. After participants pressed enter to begin the trial, a blank screen was displayed for 500 msec, followed by an arrow pointing either left or right, which was displayed for either 50, 100, or 150 msec. (The blank screen before the arrow onset was displayed for 500-msec on every trial.) Participants were instructed to make a saccade to the peripheral dot corresponding to the arrow direction as quickly as possible after the arrow onset. After the arrow offset, a letter immediately appeared in the center for 50 msec, followed by a mask. During each trial, participants had to make a saccade to the correct dot corresponding to the arrow direction, while simultaneously maintaining attention on the center, in order to verbally report the correct letter at the prompt. Participants were only prompted after fixating on the correct dot. If participants did not make a saccade within 300 msec of the arrow onset in all conditions, they were warned, “You did not move your eyes quickly enough.” If they did not fixate within the interest area of the correct dot, they were warned, “You did not look at the correct dot.” The reason for verbal as opposed to manual entry of each letter was that this was a difficult task and manual entry would have added unnecessary burden. Consequently, participants only had to press enter to begin each trial; the experimenter entered the letters.

2.5 DATA ANALYSIS

We analyzed the proportion of trials with qualifying saccadic latencies to the total number of trials in each condition using two separate temporal cutoff criteria, starting from the arrow onset. We then analyzed performance accuracy proportional to the number of qualifying

trials using each of two temporal cutoff criteria. All analyses were conducted using repeated-measures ANOVAs, and all results reported in the text reflect estimated marginal means.

3.0 RESULTS

First, we analyzed the proportion of trials with qualifying saccadic latencies to total trials in each condition ($n = 30$), within two separate temporal cutoff criteria from the arrow onset—250 msec and 300 msec. For example, when applying the 300-msec cutoff criterion, all trials in which participants did not make a saccade within 300 msec of the arrow onset were excluded.

3.1 QUALIFYING TRIALS: 300-MSEC CUTOFF

Using the 300-msec cutoff, we found a significant main effect of Block, $F(2, 30) = 17.25$, $p = .000$, and Lag, $F(2, 30) = 15.59$, $p = .000$. We found no significant main effect of Arrow Direction ($p > .5$) and no interactions (all $ps > .3$). The proportion of qualifying trials increased as a function of Block—the lowest proportion of trials came from block 1 ($M = .64$, $SE = .04$). A greater proportion resulted in block 2 ($M = .75$, $SE = .04$), and block 3 yielded the highest proportion of qualifying trials ($M = .82$, $SE = .03$). The proportion of qualifying trials decreased as a function of Lag, with the greatest proportion in the 100-msec condition ($M = .82$, $SE = .04$). The 150-msec condition yielded a lower proportion ($M = .71$, $SE = .04$), and the lowest proportion was in the 200-msec condition ($M = .67$, $SE = .04$). (See Table 1 for qualifying means within the 300-msec cutoff.)

Table 1. Proportional means of qualifying to total trials, applying the 300-msec cutoff criterion.

| Block | Condition | | Proportion of qualifying trials | |
|-------|------------|-----------------|---------------------------------|-----------|
| | Lag (msec) | Arrow Direction | <i>M</i> | <i>SD</i> |
| 1 | 100 | Left | .76 | .22 |
| 1 | 100 | Right | .72 | .22 |
| 1 | 150 | Left | .62 | .18 |
| 1 | 150 | Right | .58 | .24 |
| 1 | 200 | Left | .59 | .22 |
| 1 | 200 | Right | .56 | .21 |
| 2 | 100 | Left | .82 | .22 |
| 2 | 100 | Right | .84 | .21 |
| 2 | 150 | Left | .74 | .21 |
| 2 | 150 | Right | .74 | .26 |
| 2 | 200 | Left | .69 | .18 |
| 2 | 200 | Right | .66 | .23 |
| 3 | 100 | Left | .90 | .14 |
| 3 | 100 | Right | .88 | .13 |
| 3 | 150 | Left | .85 | .12 |
| 3 | 150 | Right | .78 | .19 |
| 3 | 200 | Left | .77 | .15 |
| 3 | 200 | Right | .75 | .22 |

3.2 QUALIFYING TRIALS: 250-MSEC CUTOFF

After applying the more stringent 250-msec cutoff criterion, we again found a significant main effect of Block, $F(2, 30) = 21.29, p = .000$, and Lag, $F(2, 30) = 12.18, p = .000$. We found no significant main effect of Arrow Direction ($p > .9$) and no interactions (all $ps > .3$). Again, the proportion of qualifying trials increased with each block. Slightly less than half of the trials in block 1 met the criteria ($M = .49, SE = .04$). Block 2 yielded a greater proportion ($M = .63, SE = .05$), and block 3 yielded the greatest ($M = .72, SE = .04$). The proportion of qualifying trials

decreased as a function of Lag. The 100-msec condition yielded the highest proportion ($M = .71$, $SE = .05$), with the 150-msec condition yielding a smaller proportion ($M = .57$, $SE = .04$) and the 200-msec condition yielding the smallest proportion of trials with qualifying latencies ($M = .55$, $SE = .04$). (See Table 2 for qualifying means within the 250-msec cutoff.)

Table 2. Proportional means of qualifying to total trials, applying the 250-msec cutoff criterion.

| Block | Condition | | Proportion of qualifying trials | |
|-------|------------|-----------------|---------------------------------|-----------|
| | Lag (msec) | Arrow Direction | <i>M</i> | <i>SD</i> |
| 1 | 100 | Left | .57 | .23 |
| 1 | 100 | Right | .60 | .23 |
| 1 | 150 | Left | .44 | .22 |
| 1 | 150 | Right | .42 | .25 |
| 1 | 200 | Left | .45 | .20 |
| 1 | 200 | Right | .46 | .17 |
| 2 | 100 | Left | .71 | .26 |
| 2 | 100 | Right | .75 | .26 |
| 2 | 150 | Left | .58 | .26 |
| 2 | 150 | Right | .60 | .25 |
| 2 | 200 | Left | .54 | .25 |
| 2 | 200 | Right | .58 | .23 |
| 3 | 100 | Left | .84 | .19 |
| 3 | 100 | Right | .80 | .16 |
| 3 | 150 | Left | .71 | .21 |
| 3 | 150 | Right | .68 | .21 |
| 3 | 200 | Left | .66 | .20 |
| 3 | 200 | Right | .64 | .23 |

3.3 ACCURACIES: 300-MSEC CUTOFF

We then analyzed the proportion of correct trials to qualifying trials using both 250-msec and 300-msec criteria. Applying the 300-msec cutoff criterion, we found a significant main effect of Block, $F(2, 30) = 10.17, p = .000$, and Lag, $F(2, 30) = 5.4, p < .05$, and a marginal main effect of Arrow Direction, $F(1, 15) = 3.79, p = .071$. We found no interactions (all $ps > .26$). Chance performance was considered to be 50%. Proportional accuracies increased as a function of Block. Performance was lowest in block 1 ($M = .56, SE = .05$). Proportional accuracy was higher in block 2 ($M = .65, SE = .04$), and highest in block 3 ($M = .70, SE = .03$). Accuracy decreased as a function of Lag. Performance was highest in the 100-msec condition ($M = .69, SE = .05$), lower in the 150-msec condition ($M = .62, SE = .04$), and lowest in the 200-msec lag condition ($M = .60, SE = .04$) (Figure 3). Considering the marginal effect of Arrow Direction, accuracies were higher in the right arrow condition ($M = .69, SE = .04$) than in the left arrow condition ($M = .58, SE = .05$). (See Table 3 for mean accuracies within the 300-msec cutoff.)

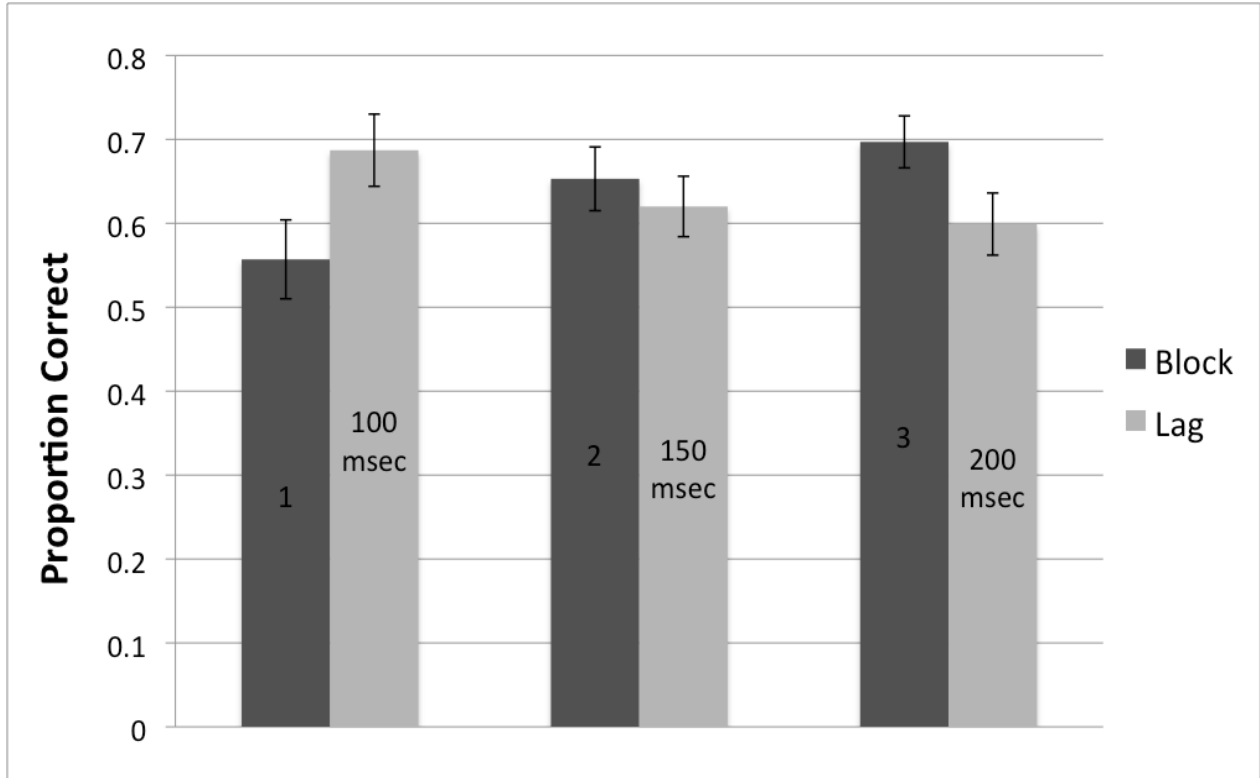


Figure 3. Mean accuracy with the 300-msec cutoff applied, as a function of Block and Lag.

Table 3. Proportional means of correct to qualifying trials, applying the 300-msec cutoff criterion.

| Block | Condition | | Proportion of correct trials | |
|-------|------------|-----------------|------------------------------|-----------|
| | Lag (msec) | Arrow Direction | <i>M</i> | <i>SD</i> |
| 1 | 100 | Left | .56 | .27 |
| 1 | 100 | Right | .65 | .26 |
| 1 | 150 | Left | .49 | .26 |
| 1 | 150 | Right | .58 | .27 |
| 1 | 200 | Left | .51 | .25 |
| 1 | 200 | Right | .55 | .22 |
| 2 | 100 | Left | .63 | .27 |
| 2 | 100 | Right | .78 | .20 |
| 2 | 150 | Left | .58 | .24 |
| 2 | 150 | Right | .68 | .19 |
| 2 | 200 | Left | .54 | .27 |
| 2 | 200 | Right | .71 | .17 |
| 3 | 100 | Left | .70 | .26 |
| 3 | 100 | Right | .80 | .19 |
| 3 | 150 | Left | .62 | .23 |
| 3 | 150 | Right | .78 | .14 |
| 3 | 200 | Left | .59 | .20 |
| 3 | 200 | Right | .69 | .16 |

3.4 ACCURACIES: 250-MSEC CUTOFF

We then applied the 250-msec criterion and found a significant main effect of Block, $F(2, 30) = 11.46$, $p = .000$, and Lag, $F(2, 30) = 5.94$, $p = .007$. We found no main effect of Arrow Direction ($p > .15$) and no interactions (all $ps > .2$). Performance increased as a function of Block, with the smallest proportional accuracy in block 1 ($M = .54$, $SE = .05$), a slightly larger

proportion in block 2 ($M = .66, SE = .04$), and the highest proportional accuracy in block 3 ($M = .70, SE = .03$). The Lag accuracies followed a slightly different pattern in this cutoff criterion, with the highest proportional accuracy in the 100-msec condition ($M = .70, SE = .04$), a lower accuracy in the 150-msec condition ($M = .59, SE = .04$), and a slightly higher accuracy in the 200-msec lag condition ($M = .61, SE = .04$) (Figure 4; see Table 4 for mean accuracies within the 250-msec cutoff.)

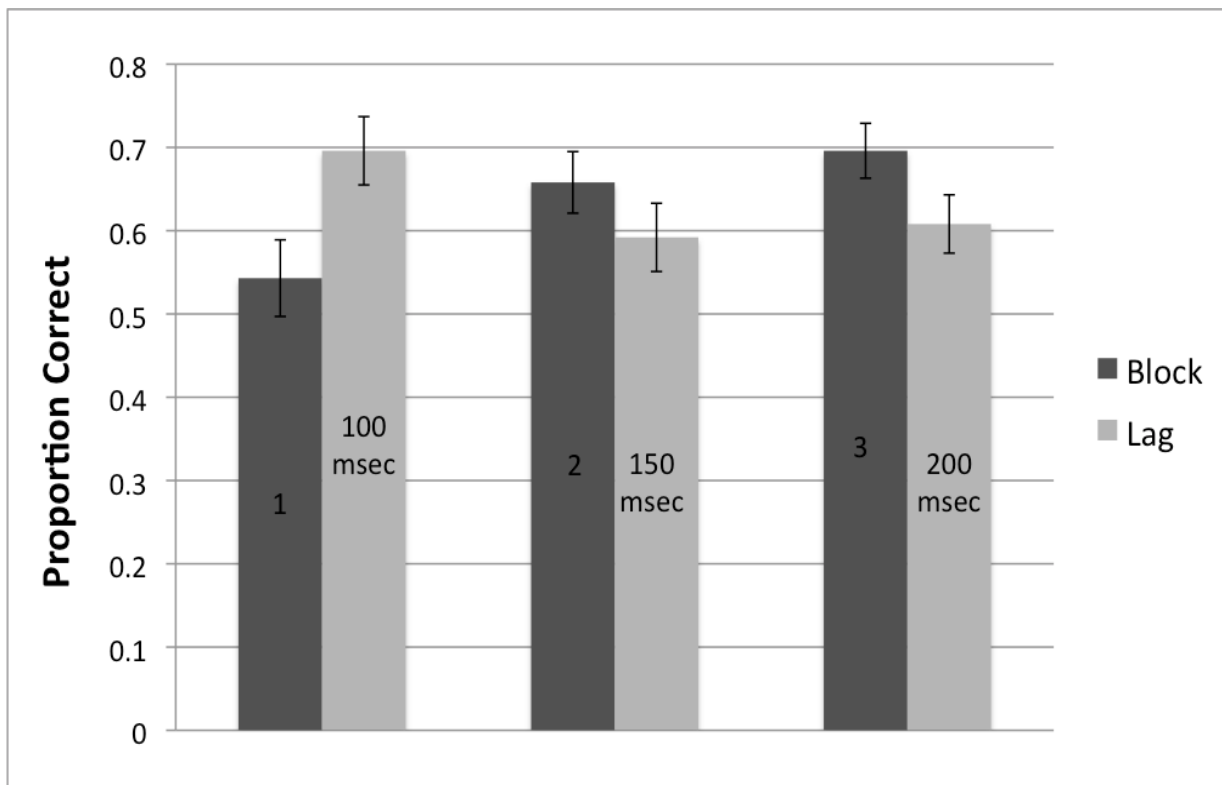


Figure 4. Mean accuracy with the 250-msec cutoff applied, as a function of Block and Lag.

Table 4. Proportional means of correct to qualifying trials, applying the 250-msec cutoff criterion.

| Block | Condition | | Proportion of correct trials | |
|-------|------------|-----------------|------------------------------|-----------|
| | Lag (msec) | Arrow Direction | <i>M</i> | <i>SD</i> |
| 1 | 100 | Left | .56 | .28 |
| 1 | 100 | Right | .66 | .27 |
| 1 | 150 | Left | .48 | .28 |
| 1 | 150 | Right | .48 | .27 |
| 1 | 200 | Left | .53 | .27 |
| 1 | 200 | Right | .54 | .22 |
| 2 | 100 | Left | .66 | .28 |
| 2 | 100 | Right | .80 | .20 |
| 2 | 150 | Left | .59 | .24 |
| 2 | 150 | Right | .63 | .28 |
| 2 | 200 | Left | .54 | .28 |
| 2 | 200 | Right | .72 | .20 |
| 3 | 100 | Left | .69 | .27 |
| 3 | 100 | Right | .80 | .20 |
| 3 | 150 | Left | .62 | .24 |
| 3 | 150 | Right | .75 | .16 |
| 3 | 200 | Left | .61 | .21 |
| 3 | 200 | Right | .70 | .17 |

3.5 HYPOTHESES SUPPORTED

The above results support our prediction that performance would increase with each successive block, within both 250-msec and 300-msec latency cutoffs. Results from the 300-msec cutoff support our prediction that performance would decrease as a function of Lag, and the results are similar in the 250-msec cutoff, with highest performance in the shortest lag condition and decreased performance in the longer lag conditions. Given that this was a learning

experiment, our finding that slightly less than half of the trials in block 1 met the latency criteria for a 250-msec cutoff is not surprising. This was the only condition in which less than half of the trials qualified. Mean accuracies were above chance within the Block (1, 2, and 3) and Lag (100, 150, and 200 msec) conditions, within both cutoff criteria.

4.0 DISCUSSION

The results of this study provide evidence against a strong premotor theory of attention (Rizzolatti, et al., 1987) and support the E-Z Reader (Reichle, et al., 2003, 2009) assumption of divergent mechanisms for attention allocation and saccadic programming. We defined the two cutoff criteria in order to thoroughly examine whether participants were actually dissociating attention from saccadic programming, or simply fixating on the center well into the letter onset, overtly detecting the letter, then making a saccade to the peripheral dot; or detecting the arrow, covertly attending to the corresponding peripheral dot, making a saccade to the dot, then allocating covert attention back to the center. If these scenarios were the case, the results would have had a bimodal distribution, with the highest accuracies in the shortest (100 msec) and the longest (200 msec) lag conditions, and lowest accuracies in the medium lag condition (150 msec). The 300-msec-cutoff results do not show this trend. While accuracies were slightly higher in the 200-msec lag condition than in the 150-msec lag condition within the 250-msec cutoff, these results are not strongly bimodal. Also, given the brief duration of stimuli presentation and the counterbalancing of Arrow Direction and Lag, it is implausible that participants would be have been able to use these alternative strategies. We defined the arrow onset as the starting time for participants to begin programming an eye movement in all the trials. Therefore, the 300-msec cutoff criterion represents a 300-msec maximum saccadic latency. This is slightly longer than approximate saccadic latencies found in other studies, but

the 250-msec cutoff constrains saccadic latencies to a 250-msec maximum, which is within the 180-250-msec range (see Becker & Jürgens, 1979; and Rayner, Slowiaczek, Clifton, & Bertera, 1983, as cited in Reichle, et al., 2003). (See Figure 5).

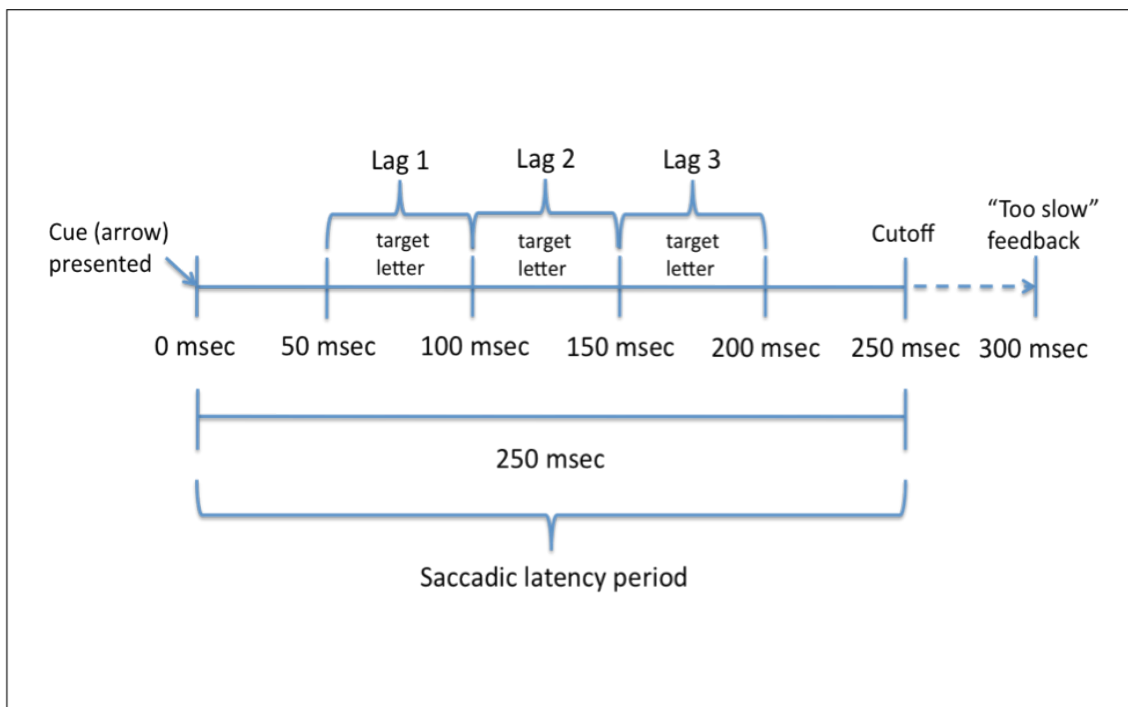


Figure 5. Diagram of the experiment outlining the 250-msec cutoff. The saccadic latency period extends to 300 msec in the 300-msec cutoff.

4.1 EVIDENCE AGAINST A STRICT PREMOTOR THEORY

This provides evidence against the position of Rizzolatti, et al. (1987). The 250-msec cutoff criterion condition did not allot adequate time, given saccadic latency, for participants to simply fixate on the center until the letter appeared, detect the letter with overt attention, then

shift attention to the periphery and make a saccade (if attention and saccadic programming are strictly linked). Thus, our findings support our claim that the oculomotor system can program a saccade to the periphery utilizing a process separate from that of attention allocation.

We also found that performance accuracy decreased as a function of Lag, and increased as function of Block. The Lag results show that with progressively longer time lags between arrow presentation and letter onset, participants had to increase the time during which attention and saccadic programming were dissociated. This prolonged separation of the two mechanisms is an unusual task that people do not commonly perform in everyday life. The Block performance improvement shows that although this task is unusual, participants could learn to perform the task and improve with practice. The marginal main effect of Arrow Direction within the 300-msec cutoff criterion suggests that participants performed slightly better on right-arrow trials. We postulate that this may have been due to both tracking participants' right pupils and possibly right-eye dominance, as previously mentioned. Better performance on right trials also made sense given that all participants were fluent in English, since the perceptual span extends asymmetrically from left to right for English readers (Rayner, 1998). Participants were used to making saccades from left to right, especially in the context of looking at a computer screen, where text is common. Given that the perceptual span in readers of Hebrew extends to the left of fixation because they read from left to right (Rayner, 1998), it would be interesting to see the effect of Arrow Direction on participants whose native language is Hebrew.

4.2 FUTURE RESEARCH

Additional future research relevant to our findings would include further investigation of our learning hypothesis. Accuracy increased with each successive block in our study, and it would be interesting to see the results of testing fewer participants over a longer period of time. We believe that performance would greatly improve in participants who did the task several times over multiple days, since this task situation is highly unusual. This would provide additional evidence against a strict premotor theory of attention.

Furthermore, our experiment used an endogenous cue (the arrow). Incorporating an exogenous, attention-capturing cue to this task may provide additional evidence for our findings; i.e., displaying the target dot after the arrow onset may render detection of the target letter extremely difficult or impossible. If this turns out to be the case, these results will further support our finding that participants were attending to the center in order to detect the target letter, in the original study. This would also lend support to Clark's (1999) suggestion that saccades and endogenous attention are not as closely associated as saccades and exogenous attention.

REFERENCES

- Becker, W., & Jürgens, R. (1979). An analysis of the saccadic system by means of double step stimuli. *Vision Research*, *19*(9), 1967-1983.
- Belopolsky, A. V., & Theeuwes, J. (2009). When are attention and saccade preparation dissociated? *Psychological Science*, *20*(11), 1340-1347.
- Clark, J. J. (1999). Spatial attention and latencies of saccadic eye movements. *Vision Research*, *39*, 585-602.
- Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *Behavioral and Brain Sciences*, *22*, 661-721.
- Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics*, *57*(6), 787-795.
- Klein, R., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition* (pp. 46-65), New York: Springer-Verlag.
- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bowhuis (Eds.), *Attention and performance X* (pp. 531-556). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25-42.
- Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372-422.
- Rayner, K., Slowiaczek, M. L., Clifton, C., & Bertera, J. H. (1983). Latency of sequential eye movements: Implications for reading. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 912-922.
- Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: comparisons to other models. *Behavioral and Brain Sciences*, *26*, 445-526.

- Reichle, E. D., Warren, T., & McConnell, K. (2009). Using E-Z Reader to model the effects of higher level language processing on eye movements during reading. *Psychonomic Bulletin & Review*, *16*(1), 1-21.
- Rizzolatti, G. (1983). Mechanisms of selective attention in mammals. In J. P. Ewart, R. R. Capranica, & D. J. Ingle (Eds.), *Advances in vertebrate neuroethology* (pp. 261-297). New York: Plenum.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltá, C. (1987). Reorienting attention across the horizontal and vertical meridians: evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*(1A), 31-40.