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Reading Direction and the Central Perceptual Span:

Evidence from Arabic and English

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Abstract

In English and other alphabetic languages read from left to right, useful information acquired during each fixational pause is generally reported to extend much further to the right of each fixation than to the left. However, the asymmetry of the perceptual span for alphabetic languages read in the opposite direction (i.e., from right to left) has received very little attention. Accordingly, we investigated the perceptual span for Arabic, which is one of the world's most widely read languages and is read from right to left, using a gaze-contingent window paradigm in which a region of normal text was displayed around each point of fixation while information outside this region was obscured. Skilled Arabic readers who were bilingual in Arabic and English read Arabic and English sentences while a window of normal text extended symmetrically 0.5° to the left and right of fixation, or asymmetrically by increasing the size of each window to 1.5° or 2.5° to either the left or right. When reading English, performance across these window conditions was superior when windows extended rightwards. However, when reading Arabic, performance was superior when windows extended leftwards, and was essentially the reverse of that observed for English. These findings provide a novel indication that the perceptual span is modified by the language being read to produce an asymmetry in the direction of reading, and shows for the first time that such an asymmetry occurs for reading Arabic.

Key Words: Reading, eye-movements, perceptual span

Normal reading relies on making saccadic eye-movements along lines of text and ending each movement with a brief fixational pause during which information is acquired. However, the extent of the area at each fixational pause within which information influences reading (the *perceptual span*) is limited. In particular, estimates of the perceptual span have often been reported using an eye-tracking technique in which an area of text extending outwards from each fixation is displayed normally during reading but text beyond this area is obscured (e.g., by replacing the original letters with *x*s). Using this technique, several studies have shown that skilled readers of English, and other alphabetic systems read from left to right, obtain useful information from an asymmetric area that extends 14-15 character spaces to the right of fixation but no more than 3-4 character spaces to the left, and certainly no further than the beginning of the fixated word (e.g., McConkie & Rayner, 1975, 1976; Rayner, Well, & Pollatsek, 1980; Rayner, Well, Pollatsek, & Bertera, 1982; Underwood & McConkie, 1985). Consequently, it is generally accepted that, when reading from left to right, the perceptual span extends much further to the right of fixation than to the left.

The nature of the perceptual span is viewed widely as reflecting the written characteristics of the language being read (e.g., Ikeda & Saida, 1978; Inhoff & Lui, 1998) and, in particular, that asymmetry in the perceptual span in alphabetic languages corresponds to the overall direction of reading. However, while the parameters of the perceptual span in English and other alphabetic languages read from left to right have been reported widely (for a review, see Rayner, 2009), the nature of the perceptual span for languages read from right to left has received very little attention. Indeed, only one study has specifically addressed the perceptual span in an alphabetic language read from right to left (Hebrew) and here the focus was the change in direction of the span's overall extent (Pollatsek, Bolozky, Well, & Rayner, 1981). Specifically, in this study, native Israeli readers who were bilingual in Hebrew and English read sentences in which a window of normal text extended asymmetrically either 14 characters to the left of fixation and 4 characters to the right, or 4 characters to the left of fixation and 14 characters to the right. The findings showed that reading

performance for Hebrew was superior when windows extended more to the left whereas performance for English was superior when windows extended more to the right. Thus, as Pollatsek et al. (1981) concluded, the overall direction of reading appears to modify the asymmetry of the perceptual span. However, this seminal study stands alone in its investigation of the perceptual span in languages read from right to left. Consequently, given the importance of the perceptual span for reading, and for guiding the implementation of computational models of reading (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Rayner, & Pollatsek, 2003), examining the nature of the perceptual span in other languages read from right to left is crucial for developing a full understanding of human reading ability.

Arabic has a global written usage second only to writing systems using the Latinate alphabet and so represents an ideal language for helping to develop a full understanding of the perceptual span that exists for languages read from right to left. However, an examination of the literature shows that no information about the perceptual span for readers of Arabic has ever been published. Accordingly, and following the approach of Pollatsek et al. (1981), we investigated the perceptual span of bilingual readers of Arabic and English using the window technique to control the amount of information that was available to the left and right of fixation during each fixational pause when Arabic and English text was read.

Rather than investigating the overall extent of the perceptual span, the focus of the present study was the influence of information within an area extending 2.5° either side of fixation. The reason for this approach is that the perceptual span encompasses a range of different types of information (e.g., interword spaces, word shape, letter identities; for a review, see Rayner, 2009), broadly reflecting retinal eccentricity. Indeed, previous research using English suggests that letter identification during reading extends to only 8 or 9 characters to the right of fixation (equal to approximately 2.5° of visual angle under normal reading conditions) and just 4 characters (equal to approximately 1°) to the left (e.g., Häikiö, Bertram, Hyönä, & Niemi, 2009; Underwood & McConkie, 1985). But asymmetry in this area (which we shall call here the *central perceptual*

span) appears to be particularly influential for reading because it provides information required to identify the fixated word and, crucially, important information about the next word along which aids parafoveal pre-processing. Consequently, given its importance, the central perceptual span is well-suited to reveal contrasting directional asymmetries when reading Arabic and English and so the present study investigated the influence of this area, extending 2.5° either side of fixation.

If asymmetry in the central perceptual span is determined primarily by reading direction, Arabic should show a directional asymmetry that is essentially the opposite to that for English. However, the situation for Arabic may be more complex than this. In particular, like English words, Arabic words presented to the left and right sides of central vision project directly to each contralateral hemisphere and, like English words, right-sided presentations produce perceptual superiority due to the left hemisphere dominance for language that is typical for humans (e.g., Almabruk, Paterson, McGowan, & Jordan, 2011; Ibrahim & Eviatar, 2009, 2012). Consequently, while an asymmetrical perceptual span to the right of fixation when reading English may facilitate reading because of greater use of information projected to the dominant left hemisphere, a reversal of this asymmetry when reading Arabic would involve greater use of information projected to the right (non-dominant) hemisphere, and this may be highly disadvantageous (for discussions, see Almabruk et al., 2011). This possibility is strengthened by studies of hemispheric asymmetry that suggest that the visual and linguistic characteristics of Arabic make it highly unsuited to right hemisphere processing, and even that the right hemisphere plays no part in Arabic word recognition (Eviatar, Ibrahim, & Ganayim, 2004; Ibrahim & Eviatar, 2009, 2012; see also Jordan, Paterson, & Almabruk, 2010). Moreover, several researchers have argued that the processing of words falling within central vision during reading is influenced greatly by hemispheric asymmetries (for a critique, see Jordan & Paterson, 2009) and, indeed, that this influence is closely related to reading direction because of disruptive right-hemispheric projections (e.g., Brysbaert & Nazir, 2005; Brysbaert, Vitu, & Schroyens, 1996). Consequently, as the perceptual span in Arabic has yet to be investigated, it may be the case that reading Arabic text is especially disadvantaged by leftward

asymmetry in the central perceptual span and so a leftward asymmetry may be entirely absent for this language.

As a result, the influence of hemispheric dominance and reading environment provide different predictions for the asymmetry of the central perceptual span in Arabic. Specifically, if the central perceptual span is determined primarily by hemispheric projections, both Arabic and English should produce a rightward asymmetry. In contrast, if the central perceptual span is determined primarily by reading environment, the central perceptual span should show a rightward asymmetry when reading English but a leftward asymmetry when reading Arabic. If evidence of this shift in asymmetry were obtained it would show for the first time that a leftward asymmetry occurs for reading Arabic and would provide a novel indication that the asymmetry of the central perceptual span is modified by the overall direction of reading.

To investigate this issue, we used a version of the gaze-contingent moving window technique that differed from that used in previous research (e.g., McConkie & Rayner, 1975, 1976; Pollatsek et al., 1981). Since the inception of this paradigm, its general principle has been that text within a specified window around the point of fixation is shown normally and text outside this window is obscured. In previous research, obscuring text outside the window has typically been achieved by replacing each letter with an x or another letter in order to obscure letter identities while preserving other characteristics of the text. However, while this approach is suitable for manipulating the perceptual span in printed English, where each individual character is spatially separate and distinct from its neighbours and has a constant width within a typeface, the same approach is not suitable for printed Arabic, which is a cursive script and where the same letters have variable widths and shapes depending on their location within words (e.g., Boudelaa & Marslen-Wilson, 2001). As a result, letter replacements would perturb grossly the normal format of Arabic text and produce changes that were artefactually different from those produced for English. Consequently, the present study avoided these problems by using visual filters to obscure the visibility of letters outside each specified window whilst leaving the original letter content of both

languages unchanged (see Figure 1). Previously, this approach has been used successfully for investigating the overall perceptual span in English (Paterson, McGowan, & Jordan, 2013) and preliminary investigations showed that it was ideal for revealing differences, should they occur, between the central perceptual span used for reading Arabic and English.

Method

Participants. Participants were 12 native Arabic speakers from the University of Leicester who had English as a second language at the level of proficiency required for postgraduate study. All participants were right handed, demonstrated right hemifield dominance for Arabic and English words, and had normal or corrected-to-normal visual acuity, as determined by a Bailey-Lovie Eye Chart (Bailey & Lovie, 1980).

Design and Materials. Stimuli were 120 Arabic sentences and 120 matched English sentences that were close paraphrases of the Arabic sentences. Across languages, sentences were matched for numbers of words (Arabic, mean=11; English, mean=11) and characters (Arabic, mean=57, English, mean=59). Each sentence was shown entirely as normal or with normal text only within a window around the point of fixation. Five types of windows were used: one symmetrical, two extending leftwards, and two extending rightwards. The symmetrical window was used to provide a baseline window condition and extended just 0.5° each side of fixation (.5_.5). The two leftward windows extended 1.5° to the left and 0.5° to the right (1.5_.5), and 2.5° to the left and 0.5° to the right (2.5_.5). In a similar vein, the two rightward windows extended $.5^\circ$ to the left and 1.5° to the right (.5_1.5), and $.5^\circ$ to the left and 2.5° to the right (.5_2.5). Text outside each window was obscured by using MATLAB to leave only spatial frequency content with a peak frequency of 2.20 cycles per degree (cpd) and low-pass and high-pass cut-off frequencies of 1.65-3.30 cpd (see Patching & Jordan, 2005a, 2005b). Custom software ensured that each window moved in close synchrony with eye movements, and display changes were made within 10-12 ms. The phenomenological experience was that each window moved in perfect synchrony with the eyes during reading. Within each language, 2.5° of text encompassed approximately 9 letters.

All 240 sentences were randomized and sampled using a Latin square design so that each participant saw 20 different sentences in each of the 6 display conditions in each language. This ensured that all sentences were shown equally often in each condition in the experiment and that sentences in each language were shown only once to each participant. Arabic and English sentences were presented in separate sessions in a randomized order, and order of sessions was counterbalanced across participants. An additional 12 sentences were used as practice items at the beginning of each session.

Apparatus and Procedure. Eye movements were recorded using an Eyelink 2K eye-tracker with a spatial resolution of .01°. Sentences were displayed on a 19 inch monitor and eye position was sampled at 1000 Hz using corneal reflection and pupil tracking. On each trial, participants fixated a location on the right (for Arabic displays) or left (for English displays) of the screen and a sentence was then presented with its first letter at the fixation location. Participants were instructed to read normally and for comprehension, and answered a comprehension question after each sentence. Calibration was checked between trials and the eye-tracker was recalibrated as necessary.

Results

Participants showed high levels of comprehension for Arabic and English (response accuracy to questions was over 90% for each language). Reading rates (calculated as words per minute) are shown in Figure 1, and fixation duration (the average length of fixational pauses during reading), number of fixations (the number of these fixational pauses), number of regressive saccades (backwards movements in the text), and progressive saccade length are reported in Table 1. For each measure, effects of language (Arabic, English) and display condition (normal plus 5 window types) were analyzed using a repeated measures Analysis of Variance, computing error variance over participants (F_1) and stimuli (F_2). Post-hoc comparisons used Bonferroni-corrected t-tests.

Reading rates. Main effects were found for language, $F_1(1,11)=6.89, p<.025, \eta_p^2=.39,$

$F_2(1,119)=224.69, p<.001, \eta_p^2=.65$, due to an overall higher reading rate for Arabic, and display condition, $F_1(5,55)=55.33, p<.001, \eta_p^2=.83$, $F_2(5,595)=87.51, p<.001, \eta_p^2=.42$, together with an interaction of these factors, $F_1(5,55)=13.95, p<.001, \eta_p^2=.56$, $F_2(5,595)=64.28, p<.001, \eta_p^2=.35$. For each language, post-hoc comparisons showed that reading rates were lower than normal for all window conditions (all $ps<.05$), indicating that each window was effective at reducing the overall perceptual span. However, a different pattern of effects was observed across windows for each language. For Arabic, post-hoc comparisons showed that reading rates were lowest for .5_.5, higher for .5_1.5, higher again for .5_2.5, higher again for 1.5_.5, and highest of all for 2.5_.5 ($ps<.05$). For English, post-hoc comparisons showed that reading rates were also lowest for .5_.5, but equally higher for 1.5_.5 and 2.5_.5, higher still for .5_1.5, and highest of all for .5_2.5 ($ps<.05$).

Fixation Durations. Main effects were found for language, $F_1(1,11)=18.75, p<.01, \eta_p^2=.63$, $F_2(1,119)=337.05, p<.001, \eta_p^2=.74$, due to overall shorter durations for Arabic, and display condition, $F_1(5,55)=78.49, p<.001, \eta_p^2=.88$, $F_2(5,595)=175.81, p<.001, \eta_p^2=.60$, together with an interaction of these factors, $F_1(5,55)=50.97, p<.001, \eta_p^2=.82$, $F_2(5,595)=128.30, p<.001, \eta_p^2=.52$. For Arabic, post-hoc comparisons showed that fixation durations were longer than normal for all window conditions ($ps<.05$) except for those offset leftwards (1.5_.5 and 2.5_.5). Across windows for Arabic, fixations were longest for .5_.5, equally shorter for .5_1.5 and .5_2.5, and equally shortest of all for 1.5_.5 and 2.5_.5 ($ps<.05$). For English, fixation durations were longer than normal for all window conditions ($ps<.05$) except for those offset rightwards (.5_1.5, .5_2.5). Across windows for English, fixations were longest for .5_.5, equally shorter for 1.5_.5 and 2.5_.5, and equally shortest of all for .5_1.5 and .5_2.5 ($ps<.05$).

Number of Fixations. The main effect of language was marginal for participants, $F_1(1,11)=3.86, p<.08, \eta_p^2=.26$, $F_2(1,119)=130.27, p<.001, \eta_p^2=.52$, but there was a reliable main effect of display condition, $F_1(5,55)=34.30, p<.001, \eta_p^2=.76$, $F_2(5,595)=43.45, p<.001, \eta_p^2=.27$, and

an interaction of these factors, $F_1(5,55)=6.23, p<.001, \eta_p^2=.36, F_2(5,595)=32.39, p<.001, \eta_p^2=.21$.

For Arabic, post-hoc comparisons showed that more fixations than normal were made for all window conditions and, across windows, most fixations were made for .5_.5, fewer for .5_1.5, equally fewer still for .5_2.5 and 1.5_.5, and fewest of all for 2.5_.5 ($ps<.05$). For English, post-hoc comparisons showed that more fixations than normal ($ps<.05$) were made for all window conditions except .5_2.5. Across windows for English, most fixations were made for .5_.5, equally fewer for 1.5_.5 and 2.5_.5, fewer still for .5_1.5, and fewest of all for .5_2.5 ($ps<.05$).

Progressive Saccade Length. The main effect of language was marginal for participants, $F_1(1,11)=4.77, p<.06, \eta_p^2=.30, F_2(1,119)=247.49, p<.001, \eta_p^2=.68$, but there was a reliable main effect of display type, $F_1(5,55)=22.46, p<.001, \eta_p^2=.67, F_2(5,595)=54.96, p<.001, \eta_p^2=.32$, and no interaction of these factors, $F_s<1.2$. Post-hoc comparisons showed that progressive saccades for both languages were shorter than normal for all window conditions ($ps<.05$) and did not differ across window conditions.

Number of Regressions. Main effects were found for language, $F_1(1,11)=4.99, p<.05, \eta_p^2=.31, F_2(1,119)=292.68, p<.001, \eta_p^2=.71$, and display type, $F_1(5,55)=5.55, p<.001, \eta_p^2=.34, F_2(5,595)=14.96, p<.001, \eta_p^2=.11$, and an interaction of these factors, $F_1(5,55)=10.32, p<.001, \eta_p^2=.48, F_2(5,595)=17.17, p<.001, \eta_p^2=.13$. For Arabic, post-hoc comparisons showed that regressions were fewer than normal for 2.5_.5 windows ($p<.05$), no different from normal for 1.5_.5 windows, and equally more than normal for all other windows (.5_.5, .5_1.5, .5_2.5; ($ps<.05$)). Across windows, regressions for Arabic were fewest for 2.5_.5 windows, more for 1.5_.5, and equally most for .5_.5, .5_1.5, and .5_2.5 windows ($ps<.05$). For English, post-hoc comparisons showed that regressions were fewer than normal for .5_1.5 and .5_2.5 windows ($ps<.05$) and no different from normal for all other windows (.5_.5, 1.5_.5, 2.5_.5). Across windows, regressions for English were equally fewest for .5_1.5 and .5_2.5 windows compared to all other windows (.5_.5, 1.5_.5, 2.5_.5; $ps<.05$). No other differences were found.

Discussion

The findings of this study provide clear evidence that the central perceptual span extends further to the left when reading Arabic and further to the right when reading English and, therefore, that this asymmetry for each language is determined primarily by reading direction. Indeed, evidence of directional asymmetry in both languages was apparent not only in reading rates but also in the duration and number of fixations, indicating that each asymmetry facilitated the acquisition of information from text during each fixational pause. In both languages, therefore, it seems that reading benefits from forward directed asymmetries in the central perceptual span that allow text to be previewed to obtain valuable information about the location and identity of upcoming words. Consequently, when these asymmetric previews are not available (as in the appropriate window conditions of the present study), text during each fixation becomes more difficult to process and so reading rates become slower and fixations become longer and more frequent. Comparable differences in the influence of asymmetries across each language were also observed for regressions, indicating that forward-directed asymmetries in both languages helped avoid the need to recheck text that had already been passed. However, progressive saccade length was not affected by the particular type of windows used, suggesting that changes in the asymmetrical availability of information within the central perceptual span did not influence the targeting of progressive saccades. This distinction in our findings between when to move the eyes from fixation and where to move them next when progressing through text is consistent with other research (Rayner, 2009).

The directional asymmetry observed for English is consistent with previous indications concerning the perceptual span, but the leftward asymmetry observed for Arabic is especially striking because of the processing disadvantages that right hemisphere projections are known to provide for this language. In particular, not only is the right hemisphere generally non-dominant for language but evidence also suggests that this hemisphere is particularly unsuitable for processing Arabic words (Eviatar et al., 2004; Ibrahim & Eviatar, 2009, 2012). Consequently, as the directional asymmetry observed for Arabic text was clearly beneficial for reading, and presumably

develops from experience with this reading environment, it seems reasonable to conclude that this leftward asymmetry provides advantages for reading Arabic that are not outweighed by disadvantages of right hemisphere projections.

Indeed, the existence of a leftward perceptual span for Arabic suggests that disruption produced by right hemisphere projections may be offset by other factors, and two sources of influence seem likely. The first is a region of central vision around fixation that contains an intermingling of ganglion cells that project bilaterally to both hemispheres (see Jordan & Paterson 2009, for a review). The size of this region is unlikely to extend much more than 1° either side of fixation but this may nevertheless help ameliorate disadvantageous effects of unilateral right hemisphere projections. Indeed, even areas away from fixation where information projects unilaterally to just the right hemisphere may produce little or no functional division in processing between the two hemispheres because of interhemispheric interactions (Almabruk et al., 2011; Jordan, Almabruk, McGowan, & Paterson, 2011; Jordan, Fuggetta, Paterson, Kurtev, & Xu, 2011). Accordingly, the claims made by some researchers that a precise split in hemispheric projections occurs at the point of each fixation that exerts substantial effects on reading performance does not seem consistent with the clear beneficial effects of a leftward perceptual span for reading Arabic (e.g., Brysbaert & Nazir, 2005; Brysbaert, Vitu, & Schroyens, 1996). The second source of influence comes from the nature of textual reading. In particular, although individual lateralized presentations of stimuli indicate that the right hemisphere is remarkably poor at processing Arabic words, textual reading provides a rather different environment in which forward-directed attentional processes and contextual and semantic cues can help enhance the processing of upcoming words (Rayner, 2009). Consequently, although most of the visual field projects unilaterally to each contralateral hemisphere, the evidence of an influential leftward asymmetry when reading Arabic indicates that the beneficial effects of a leftward perceptual span are not wholly disadvantaged by right hemisphere projections.¹

In sum, the nature of the perceptual span for languages read from right to left has received

very little attention and, for many years, the findings of only one study on this topic (Pollatsek et al., 1981) and for only one language (Hebrew) have been available in the literature. The present study now extends this earlier work to show that a leftward asymmetry in the central perceptual span occurs for Arabic and, for the first time in over 30 years, provides a new indication that the perceptual span is modified by the overall left/right direction of reading. Consequently, even though major writing systems (like Arabic, Hebrew, and English) differ fundamentally in their visual and linguistic complexity, it now seems more likely that a common component of reading across languages is the acquisition of information during each fixational pause from an area that extends asymmetrically in the direction of reading. It remains to be seen if further investigations of the relationship between the reading direction of a language and the nature of its perceptual span now proceed more quickly than before.

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Footnote

1. It is also worth noting that, for Arabic and English, performance advantages were sometimes observed when windows of normal text extended 2.5° in the direction opposite to reading (i.e., to the right in Arabic and to the left in English). One possibility is that this effect was influenced by the bilingual abilities of the participants taking part in our study. However, recent evidence (using English text) from non-Arab/English bilingual populations suggests that the leftward component of the perceptual span for English is actually substantially larger than is generally assumed (Jordan, McGowan, & Paterson, 2012; see also Apel, Henderson, & Ferreira, 2012; Binder, Pollatsek, & Rayner, 1999; Rayner, Castelano, & Yang, 2009). Accordingly, given the reciprocal nature of the central perceptual span across Arabic and English indicated by the present study, it may well be the case that reading generally benefits from information acquired from an area of text around the point of fixation that is more symmetrical than previously thought. This may also explain why greatly obscuring text in the direction opposite to reading ($1.5_{-.5}$ and $2.5_{-.5}$ for Arabic and $.5_{-1.5}$ and $.5_{-2.5}$ for English) produced fewer regressions than normal text. Here, when sufficient information was available in the direction of reading to achieve good comprehension, readers appear to have avoided making regressions because the spatial extent of information in that direction that is normally used for reading was greatly reduced.

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Figure Legends

Figure 1. Examples of Arabic and English sentences displayed entirely as normal and with text falling within central vision shown as normal while text outside is filtered (see Method section). In these examples, the location of the fixation is denoted by the vertical dashed line. Note that the visual appearance of the filtered text in the figure is approximate due to restrictions in resolution and print medium.

Figure 2. Mean reading rates (words per minute) for each display condition.

Arabic

English

Table 1

	Display Condition					
	Normal	.5-.5	1.5-.5	2.5-.5	.5-1.5	.5-2.5
Arabic						
Average Fixation Duration	252 (5)	311 (5)	257 (5)	260 (3)	289 (6)	286 (5)
Number of Fixations	11.4 (.5)	15.5 (.6)	13.3 (.5)	12.3 (.2)	13.9 (.4)	13.4 (.3)
Progressive Saccade Length	1.6 (.03)	1.3 (.03)	1.3 (.02)	1.5 (.02)	1.3 (.02)	1.4 (.02)
Number of Regressions	0.8 (.2)	1.3 (.2)	0.9 (.2)	0.6 (.2)	1.2 (.2)	1.3 (.3)
English						
Average Fixation Duration	276 (6)	340 (7)	323 (8)	318 (8)	283 (5)	286 (5)
Number of Fixations	13.9 (1.4)	20.1 (2.1)	18.0 (2.0)	18.0 (2.0)	16.2 (1.5)	14.6 (1.2)
Progressive Saccade Length	1.9 (.1)	1.5 (.10)	1.7 (.1)	1.7 (.1)	1.5 (.1)	1.6 (.1)
Number of Regressions	2.0 (.6)	3.0 (.8)	3.1 (.7)	3.3 (.8)	1.4 (.4)	1.5 (.4)

Durations are reported in milliseconds, saccade lengths are reported in degrees of visual angle, and Standard Errors are provided in parentheses.