Language Mediated Visual Search: The Role of Display Preview

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Abstract

Visual search efficiency is increased when the search target's identity is revealed incrementally via language while the display is in view. One view posits that search efficiency is increased because language enhances perceptual processing. We examined an alternative view that increased efficiency is due to delaying the onset of target-seeking eye movements, allowing a preview of the search array. Two eye-tracking experiments tested these alternatives. Observed patterns of eye movements indicated that increased efficiency with concurrent language was not likely due to linguistic enhancement of perceptual processes.

Keywords: language comprehension; visual search; efficiency.

Introduction

In visual search for a target defined by one feature (feature search) reaction times are independent of the number of distractors. In contrast, when the target is defined by two features (conjunction search), reaction times increase with the number of distractors. This effect is mitigated when different kinds of information are made available before search begins. For example, knowledge of what color subset the target will appear in (e.g., Egeth, Virzi, & Garbart, 1984, Friedman-Hill & Wolfe, 1995), a preview of non-target locations (e.g., Watson & Humphreys, 1997, 2002), and a preview of locations that potentially do contain the target (e.g., Hannus et al., 2006; Olds, Cowan, & Jolicœur, 2000a, 2000b; Rutishauser & Koch, 2007) all reduce the effect of an increasing number of distractors (set size). When search time is independent of set size, the search process is said to be *efficient.*

Spivey, Tyler, Eberhard, & Tanenhaus (2001) provided evidence that visual search efficiency can be mediated linguistically. Participants were presented a classic conjunction search task in which they had to indicate the presence or absence of a target defined by both color and orientation. When the target's identity was revealed incrementally through speech (e.g., 'red horizontal') while the search display was in view, search was as efficient as in feature search (as indexed by near zero response time by set size functions). This benefit to search is termed *linguistic assistance.*

To account for this increase in efficiency, it was proposed that, due to the incremental nature of language, the perception of the auditory stimulus (e.g., the word 'red') together with perception of features of the visual stimulus (the color red) enhanced the salience of the subset of items matched to this feature in the cognitive representation of the search display (i.e., the salience map; see Reali et al., 2006 for an elaboration of this point). Spivey et al.'s interpretation of this interaction between language and perceptual processing was that participants executed two nested feature searches instead of a single conjunction search.

The concept of nested feature search is not well specified in the visual search literature. To our knowledge the concept was introduced by Spivey et al. (2001) to explain their results. Based on their description, two nested feature searches can be thought of as a sequence of pop-out searches. First, the (spatially noncontiguous) subset of items matching the color named in the linguistic cue is isolated attentionally due to the increased salience of these items. Then, the oddly oriented target pops-out from within this set. For example, as soon as participants hear the word 'red' (or enough of it to distinguish it from the word from 'green'), the salience of the red subset of items in the display is boosted relative to the salience of the green items. This effectively reduces the number of items to be searched by half and makes the presence of an item of differing orientation easily detectable in the set of red items. The critical idea here is that hearing a word that describes the target's features automatically biases the perceptual system towards items that match that feature by means of enhancement in the salience map.

Gibson, Eberhard, and Bryant (2005), however, demonstrated that the benefit of linguistic assistance reported by Spivey et al. (2001) is limited to slow speech rate (3.0 syllables/second) or to smaller set sizes with faster speech rate (4.8 syllables/second). Slower speech would provide participants with more viewing time of the search display before hearing the identity of the target. That is, more viewing of the search display provides additional information about potential target locations independently of the information conveyed by the speech cue.

Evidence of linguistic assistance suggests that top-down processing can bias perceptual processes towards certain environmental features to enhance bottom-up information. Therefore, evidence that these effects are due to other (bottom-up) information acquired before search begins, would place important constraints on what influence top-down processing can have on bottom-up processes.

The present study tests these accounts by examining eye movement data while participants performed conjunction visual searches. If the benefit of linguistic assistance reported by Spivey et al. (2001) is the result of nested feature searches it should be reflected in eye movements. The pattern of reaction time data and eye movement data should be more similar to patterns observed during feature rather than conjunction search. In single feature searches both RT slopes and fixation slopes are shallower with fewer fixations overall than in conjunction searches (Williams et al., 1997; Zelinsky & Sheinberg, 1997). Consider how the data would differ between a single and a nested pair of feature searches. By definition, a feature search is one in which search is highly efficient. That is, RTs and fixations are less dependent on set size than in a conjunction search. A second feature search would add a constant to the RT and fixation count. The slope would still be very shallow but the y-intercept would increase by the amount of time it takes to resolve the second feature (cf. Watson & Humphreys, 1997; Watson & Inglis, 2007). This is exactly what Spivey et al. (2001) report for their RT by set size functions, but they attributed the increase in y-intercept to the delay in hearing the word describing the second feature (i.e., orientation: vertical or horizontal).

Thus, if greater efficiency with linguistic assistance is a result of nested feature searches the RT and fixation by set size slopes should be shallower than in a condition in which the target is revealed before each trial. On the other hand, if the increased search efficiency is due to previewing of the display there should be a delay of target-seeking saccades with linguistic assistance as participants sample the search display before the search target identity is fully revealed. If this is the case, then search efficiency as indexed by measures of fixations will more similar that of conjunction search than feature search.

In order to test these hypotheses, we replicated Spivey et al.'s (2001) Experiment 1. We established three criteria for evaluating participants' eye movements to determine whether they were performing two nested feature searches. The first criterion, used by Spivey et al. and Reali et al. (2006), is shallower RT by set size function. This measure is widely accepted as an indicator of feature search. The second criterion is the fixation by set size slope, which should be smaller in two nested feature searches than in a serial conjunction search. The third criterion is the average distance from the location of the last fixation to the target location which should be larger in nested feature search than in conjunction search.

As mentioned above, the notion of nested feature searches is not well specified. A close approximation to Spivey et al.'s (2001) description can be found in visual searches in which part of the visual display is previewed prior to the onset of the entire display. Watson and Inglis (2007) found that "nested" feature searches (their Preview condition) had the same RT by set size slope as the single feature search (their Half Element Baseline condition) but larger intercepts which reflects a delay in target-seeking eye movements as a result of showing one subset of items followed by the other. This is consistent with the findings using linguistic assistance in which the onset of target-seeking eye movements was delayed due to incrementally revealing the search target identity and not the distractor sets in the search display.

Regarding fixations, Watson and Inglis (2007) reported that a "nested" feature search was identical to the single feature search in both slope and mean number of fixations and both measures were less than the slope and intercept of the conjunction search.

The third criterion is based on the logic that if on target present trials the search target is detected via pop-out then the distance of the location of the last fixation to the location of the target should on average be larger in (nested) feature searches than in conjunction. For example, in Boot, Becic, and Kramer (2009) participants performed an efficient search (titled among vertical lines) and an inefficient search (T among Ls). To evaluate the effect of search task on last fixation to target location distance, we reanalyzed their data using a 2 Search Task (efficient, inefficient) between by 3 Set Size (4, 8, 12) within mixed-design ANOVA. The distance of the last fixation location to the target location for the efficient search (M = 226.58 pixels) was much greater than that in the inefficient search (M = 68.93 pixels), $F(1,78) = 18.71$, $p < .001$. The average distance of the last fixation to the target decreased for larger set sizes, $F(2,156) = 3.75$, $p = .026$. The interaction was not significant, $F < 1$.

Experiment 1

In order to create eye-movement profiles an experiment was conducted to replicate findings reported in Spivey et al.'s (2001) Experiment 1, in which the target identity was revealed to participants either before the start of each trial (Advanced) or while the search display was in plain view (Concurrent) via an audio file that contained the query "*Is there a [color] [orientation]?*" Eye-movements were recorded in both conditions.

If increased efficiency in the Concurrent condition is a result of two nested feature searches then search slopes and means calculated for response latencies and number of fixations should be shallower than in the Advanced condition. Furthermore, overall distance to the target of the last fixation on a trial should be larger in the Concurrent condition than in the Advanced condition.

Methods

Participants Twenty students at Florida State University participated for partial course credit. All participants reported normal or corrected-to-normal vision.

Stimuli Four sound files were created by splicing recordings of each of the spoken color and orientation adjectives into the end of one sound file that contained the opening query "Is there a…" using a digital audio editor (Audacity). The duration of the query was 998 ms and the average duration of each final sound file was 2357 ms for an average of 3.18 syllables per second.

The search displays contained red and green rectangles randomly distributed across an invisible 8x8 matrix on a black background that occupied approximately 21° of visual angle both vertically and horizontally at a viewing distance of 60 cm. The rectangles subtended 2.1° of visual angle in

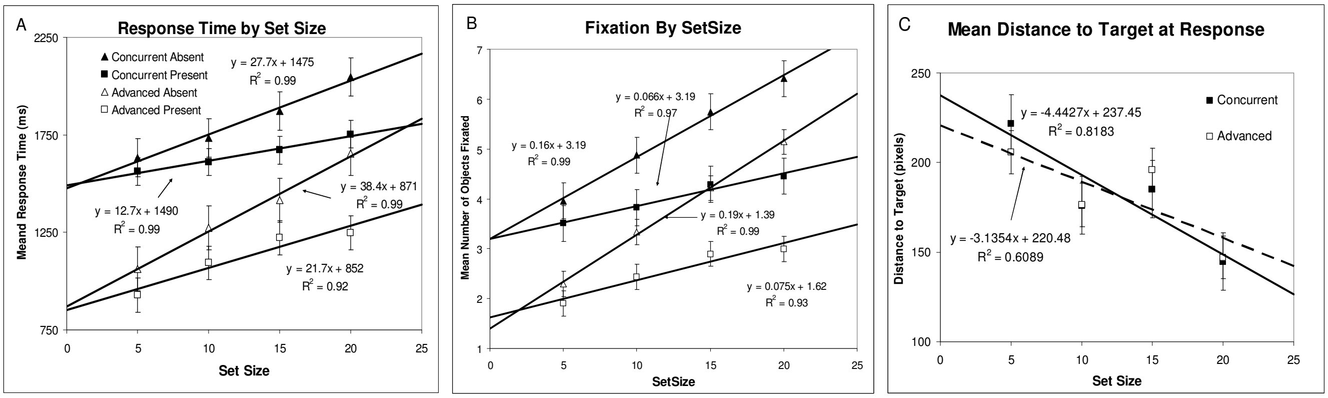

Figure 1. Efficiency of visual search in the Concurrent and Advanced conditions of Experiment 1 for each set size by response latencies (A), mean number of fixations per trial (B), and mean distance to target location from location of the last fixation per trial (C). Error bars represent ± 1 standard error of the mean pooled across set size.

length and 1° of visual angle in width. Adjacent rectangles were separated by an average of 2.6°. Each display included red-vertical and green-horizontal or red-horizontal and green-vertical distractor rectangles plus one target rectangle with a unique combination of color and orientation relative to the other objects in the display. Set sizes were 5, 10, 15, and 20. Displays were created by randomly placing the rectangles in the 8x8 matrix for a total of 320 trials with 40 target present and 40 target absent displays in each set size. Participants saw the same 320 displays in random order.

Apparatus Eye movements were recorded with an Eyelink CL (SR Research) eye tracker sampling from the right eye at 1000 Hz and a spatial resolution of 0.1°. An eye movement was considered to be a saccade if its acceleration reached 8,000°/sec^2 or its velocity reached 30°/sec. The display presentation was controlled by a Pentium PC attached to a CRT monitor placed 60 cm away from a chin rest. The display resolution was 1024 by 768 pixels. A 9-point calibration and validation procedure was used.

Procedure Participants responded with right- and left-trigger button presses on a game controller to indicate target presence or absence, respectively. Each trial began with a drift correction which was immediately followed by a fixation cross for 250 ms. In the Concurrent condition the fixation cross remained on the display for another 1000 ms while the preamble, "Is there a…", was presented auditorily. The onset of the search display and the spoken color adjective were synchronized such that the distractors were in full view while the identity of the target was incrementally revealed. In the Advanced condition the search target was visually presented for 1000 ms after which it was immediately replaced by the search display. In both conditions the search display remained on the screen until a response was made. On each trial feedback was visually displayed for 1000 ms that indicated if the given response was correct or incorrect. Participants were asked to respond as quickly as they could without sacrificing accuracy.

Results

On each trial latency and accuracy of the response was recorded as well as the location and number of fixations. Any fixation that fell within a 40 pixel radius from the center of one of the 60 by 30 pixel rectangle stimuli was considered to be an object fixation. Trials with saccade latencies greater than 80 ms, RTs greater than 3000 ms and with incorrect responses were excluded from analysis.

The data for each measure are presented in Figure 1. Note that these data replicate the pattern of increased search efficiency in the Concurrent condition reported by Spivey et al. (2001) for the RT analysis. The critical Set Size by Target Presentation interaction was significant, $F(3,54)=6.74$, $p=.001$. For target present trials the slope in the Concurrent condition (12.73) was significantly shallower than the Advanced condition (21.72), $F(1,18)=12.78$, $p=.002$, but only marginally significant for target absent trials (27.7 v. 38.4), $F(1,18)=3.14$, $p=.093$. As expected, mean response latencies in the Concurrent condition (1735 ms) were longer than those in the Advanced condition (1237 ms), $F(1,18)=20.15$, $p<.001$.

For analysis of Number of Fixations neither the critical Set Size by Target Presentation interaction on cell means nor the Target Presentation main effect of the slopes were significant, *F*s<1.2. There were however, overall more fixations per trial in the Concurrent condition (4.44) than in the Advanced condition (3.04), $F(1,18)=13.54$, $p=.003$.

The only significant effect in the Distance analysis was the main effect of Set Size, $F(3,54)=16.76$, $p<.001$, which suggests that in both conditions searched more objects as Set Size increased. All other *Fs*<1.2.

More errors were made in target present than target absent trials, $F(1,18)=31.90$, $p<.001$, and as the Set Size increased, $F(3,54)=5.98$, $p=.001$, but were equal between Target Presentation conditions, $F<1.2$, although the Set Size by Target Presentation was marginally significant, $F(3,54)=2.40$, $p=.078$. Finally, there was greater increase in errors as Set Size increased for target present trials than for target absent trials, $F(3,54)=3.39$, $p=.024$.

Discussion

The Concurrent condition only passed one of three criteria that one would expect to find if it was a result of two nested feature searches. Greater efficiency in the Concurrent condition, as indexed by RT by Set Size slopes, must be a result of something other than nested feature searches. Gibson et al. (2005) reported that language assistance yielded shallower slopes for larger distractor sets when the speech rate was slow but not when it was fast. This finding suggests that slowing participants' search may be the source of greater efficiency as indexed by shallower RT slopes.

To evaluate eye movements for the onset of target-seeking saccades, two additional analyses were conducted by comparing eye movements on the first five fixations per trial in the Concurrent condition to the Advanced condition on target present trials. In the first analysis, fixations to objects of either color (Objects) was the dependent measure and in the second analysis the proportion of fixations to objects of the same color as the target (Matching Objects) was the dependent measure. The data are presented in Table 1. For both sets of data a 5 within (Fixation Number) by 2 between (Target Presentation) mixed ANOVA was conducted. As can be seen in the table, the proportion of fixations to Objects across all five fixations was the same in both the Concurrent and Advanced conditions. This conclusion is consistent with a non-significant main effect of Target Presentation and a non-significant interaction of Fixation Number by Target Presentation (both *F*s<1). There was a significant main effect of Fixation, $F(4,72)=51.28$, $p<.001$, which was driven by the fact that the first fixation was less likely to be directed towards an individual object.

The importance of these analyses is that in terms of looking at objects of any color the Concurrent and Advanced conditions cannot be considered different. In contrast, the analysis of Matching Objects indicates that participants in the Advanced condition made target-seeking saccades earlier in a trial. In this analysis the critical two-way interaction was significant, $F(4,72)=3.09$, $p=.02$. As can be seen in the Table, on the first fixation participants in both conditions looked at Matching Objects at a rate close to chance (0.5). However, during the second, third, and fourth fixations participants in the Advanced condition looked at significantly more Matching Objects than in the Concurrent condition. Participants in the Concurrent condition did not begin looking at Matching Objects at a rate above chance until the third fixation. Also, they did not fixate Matching Objects at the same rate as participants in the Advanced condition again until the fifth fixation. Because participants in the Concurrent condition did not know what they were searching for until between 300 and 600 ms into a trial, they were getting a preview of the display for about 500 to 600 ms, about two saccades, before starting their search.

These observations suggest that greater efficiency in the Concurrent condition may be a result of having more information about the display and not the content of the language, *per se.* Thus, if participants could be delayed in initiating target-seeking saccades, by means other than the incremental feature of language, while also having a period of preview of the search display the RT and Fixation search slopes should be similar to those in the Concurrent condition.

Table 1: Proportion of eye movements to Objects and Matching Objects

		Fixation Number				
Objects	Condition	1	2	3	4	5
	Concurrent	.06	.36	.35	.36	.39
	Advanced	.03	.35	.35	.37	.34
	Difference	.03	.01	.00	.01	.05
Match	Concurrent	.59	.52	.71†	.82†	.85†
	Advanced	.67	.84†	.88†	.91†	.80†
	Difference	.08	.32*	.27*	.09*	.05

Note. 'Objects' refers to fixations to any distractor. 'Match' refers only to distractors that are the same color as the target.

† Significantly different than chance (0.50), all *p*s <.003.

* Significant difference between conditions, all *ps*<.02.

Experiment 2

The purpose of Experiment 2 was to create conditions that yielded search slopes and means that met all of the three criteria of two nested feature searches described previously. To do so, participants were prohibited from making any saccades at the beginning of each trial for 350 or 750 ms with the search display in plain view. If more efficient search in the Concurrent condition is a result of slowing responding then delaying participants' ability to initiate saccades at the beginning of each trial should estimate the RT slopes of the Concurrent condition. However, it is anticipated that with a sufficient delay the first one or two non-target-seeking saccades found in the Concurrent condition will not occur in the present experiment which would reduce the overall number of fixations and the fixation slopes. Also because of the preview, it is anticipated that the location of the last fixation relative to the search target will be greater than in the Concurrent condition. Thus, the current experiment is not intended to fully replicate the Concurrent condition. Rather it is intended to be a demonstration of what the eye movement profile of search with a delay in target-seeking saccades would be like. Differences on criteria two and three between Experiment 2 and the Concurrent condition of Experiment 1 are expected to be, at least partially, accounted for by the lack of non-target-seeking saccades at the beginning of each trial in Experiment 2.

Methods

Participants Sixteen students at Florida State University participated for partial course credit. All participants reported normal or corrected-to-normal vision.

Materials and Apparatus The same visual stimuli and eye tracking equipment were used as in Experiment 1.

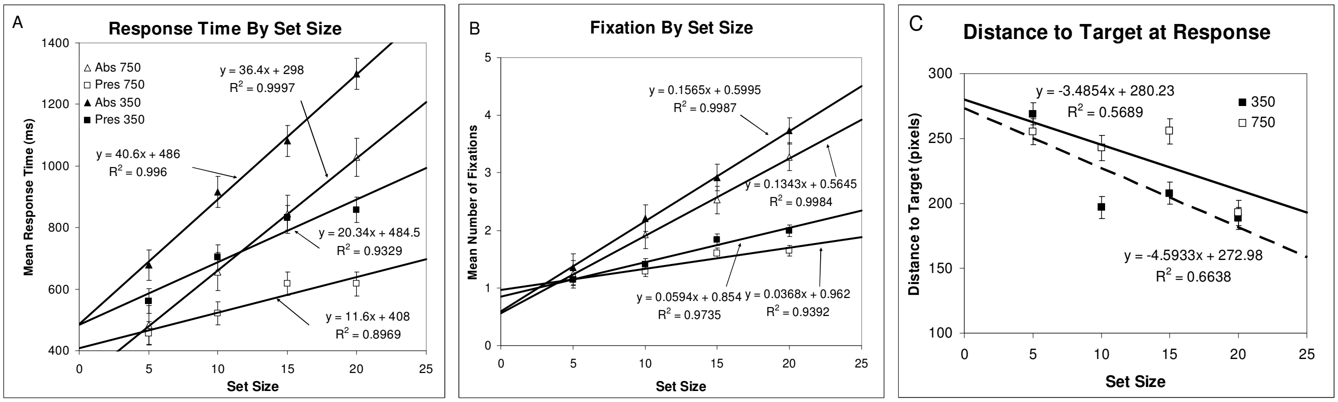

Figure 2. Efficiency of visual search in the Short and Long Delay conditions of Experiment 2 for each set size by response latencies (A), mean number of fixations per trial (B), and mean distance to target location from location of the last fixation per trial (C). Error bars represent ± 1 standard error of the mean pooled across set size.

Procedure After viewing the search target for 1000 ms, participants saw a fixation cross in the center of the display for 300 ms. At this point the search display was presented while the fixation cross remained on the screen for either 350 ms (Short Delay condition) or 750 ms (Long Delay condition) at which time the fixation cross disappeared while the rest of the search display remained. Participants were required to maintain their gaze at this central fixation until it disappeared which was their cue to begin their search. Trials on which eye movements traversed an invisible boundary with a diameter of 100 pixels around the fixation cross were forfeited.

Results

Trials with incorrect responses or RTs greater than 3000 ms were discarded. RTs were measured from the end of the delay period to the response. The data are displayed in Figure 2. For RTs, the critical Set Size by Delay condition interaction was significant, $F(3,45)=2.86$, $p=.047$. For target present trials the search slope was shallower in the Long Delay (11.6) than in the Short Delay (20.34), $F(1,15)=15.65$, $p=.001$, but not for target absent trials, $F<1.4$, $p>.25$. Overall responses were slower with a Short Delay (866 ms) than with a Long Delay (653 ms), $F(1,15)=141.44$, $p<.001$.

For the analysis of the Number of Fixations, the Set Size by Delay condition interaction was significant, $F(3,45)=3.58$, $p=.021$. Search slopes were shallower in the Long Delay than in the Short Delay condition in both target absent (.13 vs. .16), $F(1,15)=5.76$, $p=.03$, and the target present condition (.04 vs. .06), $F(1,15)=12.29$, $p=.003$. There were more fixations in the Short Delay (2.08) than in the Long Delay condition (1.83), $F(1,15)=29.82$, $p<.001$.

For the Distance analysis, the Set Size by Delay interaction was significant, $F(3,45)=10.96$, $p<.001$, with longer distance between the target location and that of the fixation at response in the Long Delay (237 pixels) than in the Short Delay (216 pixels), $F(1,15)=33.62$, $p<.001$. As in Experiment 1, the main effect of Set Size was significant, $F(3,45)=36.80$ $p<.001$, which suggests that in both conditions searched more objects as Set Size increased

Regarding errors, the Target by Set Size interaction was significant, $F(3,45)=5.26$, $p<.003$, indicating more errors as set size increased in the target present condition than in the target absent condition. There were overall more errors in the Long Delay condition, $F(1,15)=5.66$, $p=.031$, when targets were present, $F(1,15)=7.84$, $p=.013$, and as set size increased, $F(1,15)=4.86$, $p=.005$.

Discussion

The purpose of Experiment 2 was to evaluate search performance with a substantial free viewing period but without saccades. This was achieved by delaying the onset of target-seeking saccades relative to the onset of the search display. Search was more efficient with a longer delay. Delaying search by 750 ms resulted in an eye movement profile that satisfies all of the three criteria established for two nested feature searches.

General Discussion

The two experiments reported in this study provide evidence of limitations on higher-order cognitive processes, such as language processing, to directly constrain perceptual processes such as visual search. The first experiment replicated the finding reported by Spivey et al. (2001) that incrementally revealing the search target auditorily (as speech) concurrently with the visual search display reduces the slope of the RT by Set Size function in a conjunction visual search. A lack of evidence for nested feature searches in the eye-tracking data, however, suggests that this apparent increase in efficiency may be due to increased information about the display before the full identity of the search target was known. It appears that the first two saccades on a trial function to sample the search display in preparation for target-seeking saccades once the full identity of the search target is known. As a result of this delay responses in the Concurrent condition were slowed relative to the Advanced condition when the set size was small rather than speeded when the set size was large. Importantly, the second experiment further clarifies the benefits of (covertly) sampling the search display prior to the initiation of eye movements for the purposes of search. In conjunction visual search, top-down processes may only begin to influence the search process once the search display has been sufficiently sampled, in this case by covert shifts of attention.

The purpose of the delay manipulation of Experiment 2 was to demonstrate conditions under which eye movements during visual search would exhibit characteristics of search after previewing of the display. In fact, when the full search display lies within the useful field of view the data suggest that initially sampling covertly is more efficient than making eye movements for the same purpose. Indeed, previous research has shown that search in the typical conjunctive display can be at least as efficiently accomplished without eye movements (Klein & Farrell, 1989; Zelinsky & Sheinberg, 1997). The novel contribution of the current study is evidence that delaying eye movements during a substantial free viewing time results in more efficient subsequent oculomotor behavior, as indexed by measures of RT by set size functions, number of fixations, and the distance of the location of the last fixation per trial from the location of the target object.

The results of these experiments suggest that top-down knowledge acquired through the concurrent linguistic presentation of the search target does not interact with the initial acquisition of stimulus features of the search display. It is possible that visual search requires an initial cognitive representation of the search display before search can take place. The gap effect reported by Watson and Humphreys (1997) suggests that this process takes about 400 ms. Given the substantial increase of search efficiency with the 750 ms delay relative to the 350 ms delay, the data of Experiment 2 are consistent with this hypothesis. Specifically, top-down processing may be limited to interacting with perceptual processes until after enough bottom-up information has been gathered.

In conclusion, increased efficiency in the Concurrent (language) condition is likely not the result of two nested feature searches. Rather it is a result of delaying the onset of target-seeking saccades relative to the onset of the search display. The first few saccades in the Concurrent condition are limited to sampling the search display in preparation for target-seeking saccades once the target is known. Thus, more research is needed to clarify the role of linguistic processing-based enhancement of perceptual processes.

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