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Eye movements and familiarity effects in visual search

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Abstract

Familiarity with the distractors around an unfamiliar target facilitates visual search. Three Experiments examined whether the effect occurs because fixations are (a) shorter and fewer, (b) shorter, but more abundant, (c) equally long, but fewer, or (d) longer, but fewer when distractors are familiar. Results indicated comparably long, but fewer fixations when distractors are familiar. Hence, the theory that unfamiliar distractors need longer processing is discounted. In a fourth Experiment, a gaze-contingent moving window paradigm was used to control peripheral processing. Results revealed a wider span of effective processing for familiar distractors. A hypothesis based on low-level physiological processes is introduced to account for the familiarity effect.

Keywords: Eye movements; Visual search; Attention; Visual span; Familiarity

1. Introduction

A number of studies have shown that familiarity with the distractors around an unfamiliar target facilitates visual search (Reicher, Snyder, & Richards, 1976; Richards & Reicher, 1978; Johnston, Hawley, & Farnham, 1993; Wang, Cavanagh, & Green, 1994; Lubow & Kaplan, 1997). However, the reason for the facilitation with familiar distractors is not clear. Facilitation occurs in the form of fast manual reaction times (MRTs), irrespective of the number of distractors in a display. Familiarity-contingent fast MRTs may reflect the influence of cognitive processes on the early stages of the acquisition of visual information during search. A possible explanation for the effect is that familiarity facilitates the grouping of distractors (see Wang et al., 1994). This grouping of the irrelevant but familiar clutter, in turn makes an unfamiliar target salient, and easy to find. However, when the distractors are unfamiliar, grouping is less efficient and a familiar target is not salient within the irrelevant clutter. Wang et al. (1994) rejected this explanation. They found that search rates were fast only when an unfamiliar target was embedded in familiar distractors. A familiar target among familiar distractors did not elicit fast search rates. The results were similar when target and distractors were both unfamiliar. Hence, Wang et al. (1994) advanced an explanation of search based on the efficient orienting of attention towards nonstandard (or unfamiliar) stimuli embedded within standard (or familiar) stimuli. They suggested that whereas familiar elements can be processed rapidly, unfamiliar elements require extra resources and ought to attract attention to themselves to begin the special analysis. Thus, when both target and distractor are familiar, or unfamiliar, attention is not differentially drawn to the target and search rates are slow. Search rates are slow also for a familiar target among unfamiliar distractors because attention is differentially drawn to the distractors. However, when an unfamiliar target is embedded within familiar distractors, attention is differentially drawn to the target, and this facilitates search. A similar explanation was made by Treisman (Treisman, 1985; Treisman & Gormican, 1988) for search elements with standard and non standard (color or shape) attributes. For convenience, we shall refer to this explanation as the *attention capture* hypothesis.

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Fast MRTs to indicate the end of search may *also* reflect the use of a wide window of effective processing around each eye fixation. This span of effective processing[1] in visual search has been shown to be adjustable as a function of stimulus conditions (Rayner & Fisher, 1987a,b; Motter & Belky, 1998a,b; Bertera & Rayner, 2000), and can be independent of cognitive processing (Geisler & Chou, 1995). Thus, it is possible that when an unfamiliar target is embedded within familiar distractors, observers acquire information from a wider span and the target is found more quickly. Conversely, when distractors are unfamiliar, the span may be narrower and the target is available within the processing range less frequently. For convenience, we shall refer to this explanation as the *processing span* hypothesis. The attention capture and processing span hypotheses need not be mutually exclusive. If attention capture does occur, it would probably occur within the observer's processing span. Hence, a wider processing span probably allows for attention capture (if it occurs) over a wider area of the stimulus display.

One purpose of the present study was to describe the dynamic process involved in searching among familiar and unfamiliar distractors. Despite their utility, MRTs alone are insufficient for understanding the mechanisms of visual search (Zelinsky, 1996; Findlay & Gilchrist, 1998; Greene, 1999). Indeed, in the studies that have shown facilitation with familiar distractors, displays were presented for durations that permitted movement of the eyes (although eye movements were not monitored). This being the case, it is imperative that eye movement measures are included in the formulation of a theory that accounts for the *familiarity effect*. In the present study, we evaluated MRTs, fixation durations, and the number of fixations made in search of a target as a function of distractor/target familiarity. As with Wang et al.'s (Wang et al., 1994) study, familiarity was defined by observers' experience with the English alphabet. Given that the familiarity effect is most noticeable with larger numbers of distractors (e.g. Wang et al., 1994), the present study restricted search to an eight-element display.

With respect to describing the dynamic process of search, four eye movement hypotheses (labeled a, b, c, and d below) were tested. We hypothesized that fast search occurs because eye fixations are (a) shorter and fewer, (b) shorter, but more abundant, (c) equally long, but fewer, or (d) longer, but fewer when an unfamiliar target is embedded within familiar distractors.

These hypotheses were inspired by eye movement findings in reading and visual search. For example, during reading, high frequency words tend to be fixated for shorter durations than low frequency words (see Rayner (1998) for a review). Given that familiarity in the present experiment was based on the English alphabet, familiarity may be likened to word frequency in reading. Hence, the familiarity effect may occur as a result of fast serial processing (via short eye fixations) of the familiar distractors (see hypotheses a and b above). In contrast, the frequency effect observed in reading has been shown to disappear in visual search (Rayner & Fischer, 1996; Rayner & Raney, 1996). When instructed to search for a target word in text, low frequency words are not fixated longer than high frequency words. Thus, in visual search studies like those to be reported here, observers may make equally long fixations for familiar and unfamiliar distractors. If fixation durations are equally long, observers would necessarily have to make fewer fixations with familiar distractors for the familiarity effect to occur (i.e. hypothesis c above). Finally, in visual search, more meaningful distractors may be fixated for longer durations. When observers search among distractors that provide information about the relative location of a target, fixations are longer than when the distractors are semantically meaningless (Hooge & Erkelens, 1998; Greene & Rayner, 2001). If familiar distractors are considered more meaningful, they may engage fixations for longer periods than unfamiliar distractors, and observers would have to make fewer fixations to exhibit faster search (i.e. hypothesis d above).

A second purpose of the study was to explore relationships between attention capture and processing span on the familiarity effect in visual search. Both hypotheses predict longer search when distractors are unfamiliar. If unfamiliar elements require extra resources and capture attention (e.g. Wang et al., 1994), then average fixation durations may be longer for unfamiliar distractors relative to familiar distractors. However, this need not be the case if the visual system deals with the increased processing demands of unfamiliar elements by reducing the processing span (e.g. Shulman & Wilson, 1987). Relative processing span may be assessed by limiting peripheral processing. The underlying logic of this procedure is that, search performance should be more greatly disrupted for tasks that make more effective use of the peripheral information (i.e. tasks that utilize a wider processing span). Peripheral processing can be limited by using a gaze-contingent moving window paradigm described in Experiment 4 (Bertera & Rayner, 2000, see also Rayner, 1998). Generally, the experimenter defines a gaze-contingent foreground display window (around the area of fixation) that is different from a background (peripheral information) display region. Experiment 4 was designed specifically to examine the relative span of effective processing by using the gaze-contingent moving win-

[1] For convenience, we refer throughout this article to the processing span. In other contexts, the terms perceptual span and span of effective stimulus have been used to refer to the region from which observers obtain useful information during a fixation.

dow paradigm when distractors are familiar and unfamiliar.

2. Experiment 1: free search

In Experiment 1, observers searched for a familiar target among unfamiliar distractors, or vice versa. First, we expected that the traditional effect of longer manual reaction times with unfamiliar distractors would be found (Reicher et al., 1976; Richards & Reicher, 1978; Johnston et al., 1993; Wang et al., 1994; Lubow & Kaplan, 1997). We also anticipated that the eye movement data would be instrumental in describing the dynamic process involved in the familiarity effect, as described in the introduction.

2.1. Method

2.1.1. Subjects

Six University of Massachusetts students were paid $8.00 to participate in the experiment. They were all native speakers of English and were unaware of the hypotheses. Their ages ranged between 18 and 31 years and they all had normal or corrected-to-normal vision.

2.1.2. Stimuli

The stimulus display consisted of eight elements arranged equi-distant around an invisible circle. The diameter of the circle was 8.33°. Each element (0.56 × 1.05°) was configured to form either the letter Y, or a non-standard form. Two conditions were tested in the experiment. In the familiar distractor (FD) condition, a non-standard element form was embedded within Ys (see Fig. 1A). In the unfamiliar distractor (UD) condition, the letter Y was embedded within non-standard elements (see Fig. 1B). Displays were presented at a suprathreshold intensity level on a video monitor.

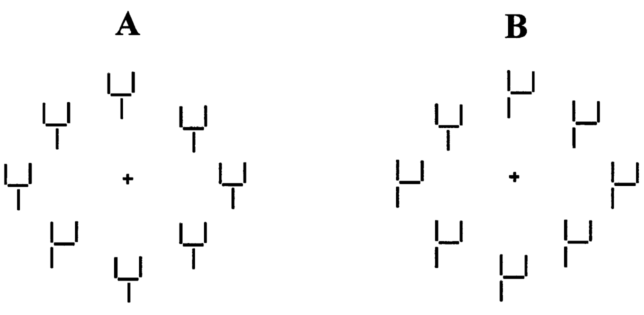

Fig. 1. Kinds of displays presented to subjects. In panel A, the target appears among a familiar set of (Y) distractors (i.e. FD condition). In panel B, the familiar target appears among an unfamiliar set of distractors (i.e. UD condition).

2.1.3. Apparatus

Eye movements were recorded (right eye only) by an SMI Eyelink head-mounted tracker. The 600 g headband was fitted for each observer, such that it was comfortable with extended use. Eye positions were sampled at 250 Hz by an infra-red (940 nm) video-based system that also compensated for head movements. Gaze positions were accurate within 0.5°. A saccade was recorded when eye velocity exceeded 35° s^{-1}, or eye acceleration exceeded 9500° s^{-2}.

2.1.4. Procedure

A session consisted of a block of 96 FD trials followed by 96 UD trials, or vice versa. Within a block, the target was absent in half (i.e. 48 randomly selected) of the trials. Each block of trials was preceded by 20 practice trials (or a maximum of 30 trials if observers requested more practice after the first 20 practice trials). There was a 5–6 min rest period between trial blocks. Observers were made aware of the letter Y as a target or distractor. Their task was to respond as quickly but as accurately as possible, on the computer keyboard, to indicate the presence of the target (right index finger on # 8 key) or the absence of the target (left index finger on # 4 key). Trials were terminated by the key press response, or after 4000 ms. When ready to receive each new trial, observers were required to fixate a central disk for automatic eye-drift correction. An experimenter-initiated display replaced the disk immediately after drift-correction.

At the end of the session, each observer was asked to report the condition (FD or UD) in which search was easier to perform. This allowed us to assess the observers' awareness of difficulty of search. During pilot tests of the stimuli, we noticed that our two pilot observers searched for the target in different stereotypical ways. For instance, one of them almost always searched in a counter-clockwise manner. Given the potential for noise from individual differences in search strategy, observers in the experiments were also asked what strategy, if any, was used to search for the target.

2.2. Results and discussion

Despite individual differences in reported search strategies, every observer reported that search was subjectively easier in the FD condition than in the UD condition.

Average manual reaction times (MRTs) were calculated and subjected to a factorial ANOVA. These data are illustrated in Fig. 2A. On average, MRTs were faster by 446 ms when the target was present (1421 vs. 1867 ms, $F(1,5) = 25.52$; $P < 0.01$) and were faster by 573 ms for the FD condition relative to the UD condition (1357 vs. 1930 ms, $F(1,5) = 11.11$; $P < 0.05$). There was no significant interaction between target presence

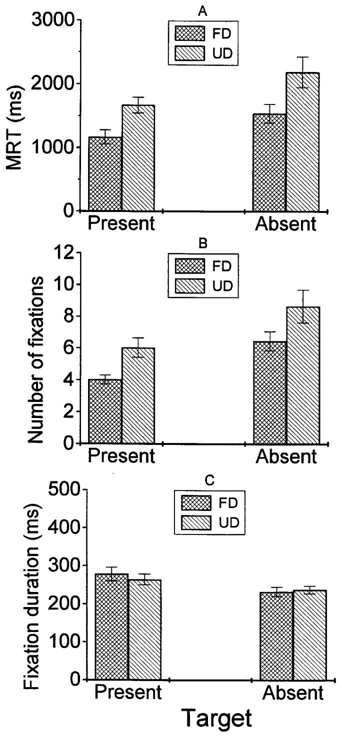

Fig. 2. Manual reaction times, number of fixations and average fixation durations in Experiment 1.

and distractor condition ($F(1,5) = 1.29$; $P < 0.05$). The MRT results are consistent with the subjective reports of the observers.

The average number of fixations was subjected to a factorial ANOVA. These data are illustrated in Fig. 2B. On average, fewer fixations were made when the target was present than when it was absent (5.03 vs. 7.55, $F(1,5) = 33.16$; $P < 0.01$). In addition, fewer fixations were made in the FD condition compared to the UD condition (5.25 vs. 7.34, $F(1,5) = 10.54$; $P < 0.05$). There was no significant interaction between target presence and distractor condition ($F < 1$).

Average fixation durations were calculated and subjected to a factorial ANOVA. These data are illustrated in Fig. 2C. Across distractor conditions, fixations were longer by 37 ms for target-present trials (271 vs. 234 ms, $F(1,5) = 43.78$; $P < 0.01$), but were not systematically different between FD and UD search (255 vs. 250 ms, $F < 1$). Hence, a significant interaction occurred between target presence and distractor condition ($F(1,5) = 9.36$; $P < 0.05$).

Given that fixation durations are influenced by cognitive processing of foveal information (see Rayner, 1998), we suspected that it might be possible that average fixation durations were not systematically different between FD and UD because of noise introduced by individual differences in search strategy. In order to minimize this possible influence, initial fixation durations were analyzed. Initial fixation averages were clearly longer than overall fixation averages. Unlike average fixation duration, there was no main effect of target presence (417 ms (present trials) vs. 425 ms (absent trials), $F < 1$). As with average fixation duration, there was no difference between FD and UD search (413 vs. 418 ms, $F < 1$), and no interaction ($F < 1$). Hence, if noise was introduced by individual differences, it was present at the start of search.

In summary, faster MRTs in the FD condition clearly replicate the familiarity effect (e.g. Wang et al., 1994). With respect to our purpose of describing the dynamic process involved in searching among familiar and unfamiliar distractors, the findings are consistent with hypothesis c: Fast search with familiar distractors occurred because fewer fixations were made. Given that fixation durations were not systematically different for the two distractor-type conditions, these results do not support the prediction that attention capture may lead to longer fixation durations for unfamiliar distractors. Thus, the increased processing demands of unfamiliar distractors may cause observers to use a narrower processing span, rather than longer fixations. This idea is tested formally in Experiment 4.

3. Experiment 2: minimum fixation procedure

In Experiment 2, we attempted to standardize search strategies by instructing observers to determine the presence/absence of the target with minimal eye movements. If fixation duration is a sizable contributor to the familiarity effect, it should likely be influential if observers use a strategy that encourages long fixations.

3.1. Method

3.1.1. Subjects

Six University of Massachusetts students were paid $8.00 to participate in the experiment. They were native English speakers and their ages ranged between 20 and 39 years. All observers had normal or corrected-to-normal vision and were unaware of the purpose of the experiment. None of them had participated in Experiment 1.

3.1.2. Procedure

The stimuli and apparatus were the same as in Experiment 1. Each observer was instructed to fixate the central fixation cross (see Fig. 1) for as long as possible in their attempt to find the target. If eye movements were needed to search for the target, observers were encouraged to minimize them as much as possible. At the end of the session, each observer reported the counterbalanced condition (FD or UD) in which search was easier to perform. As before, this allowed us to assess the observers' awareness of difficulty of search.

3.2. Results and discussion

As in Experiment 1, all observers reported that search was easier in the FD condition relative to the UD condition. On average, MRTs were faster by 700 ms when the target was present (1573 vs. 2273 ms, $F(1,5) = 41.96$; $P < 0.01$). MRTs were faster by 659 ms for the FD condition relative the UD condition (1594 vs. 2253 ms, $F(1,5) = 37.87$; $P < 0.01$). There was no significant interaction between target presence and distractor condition ($F < 1$). These data are illustrated in Fig. 3A.

On average, fewer fixations occurred when the target was present (4.55 vs. 7.77, $F(1,5) = 29.92$; $P < 0.01$). Fewer fixations were made in the FD condition compared to the UD condition (4.67 vs. 7.65, $F(1,5) = 23.13$; $P < 0.01$). There was no significant interaction between target presence and distractor condition ($F(1,5) = 1.03$; $P > 0.05$). These data are illustrated in Fig. 3B.

Average fixation duration across distractor conditions was longer by 59 ms for target-present trials (359 vs. 301 ms, $F(1,5) = 142.05$; $P < 0.001$). Although fixations were 60 ms longer in the FD condition than the UD condition, the effect was only marginally significant (360 vs. 300 ms, $F(1,5) = 4.27$; $P = 0.09$). No significant interaction occurred between target presence and distractor condition ($F(1,5) = 3.31$; $P > 0.05$). These data are illustrated in Fig. 3C.

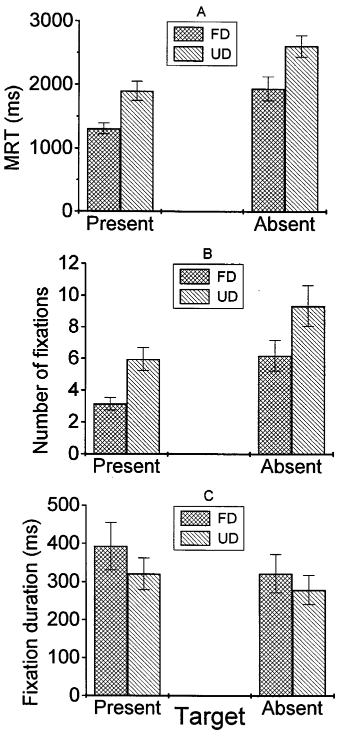

Fig. 3. Manual reaction times, number of fixations and average fixation durations in Experiment 2.

Given that observers were instructed to fixate the central fixation cross for as long as possible as they tried to find the target, initial fixation durations were averaged and analyzed. There was no main effect of target presence (710 ms for present trials vs. 766 ms for absent trials, $F(1,5) = 2.39$; $P > 0.05$). There was also no significant difference between FD search (712 ms) and UD search (764 ms) ($F(1,5) = 1.49$; $P > 0.05$). Finally, there was no interaction effect ($F < 1$). The null effects found here (despite large inter-condition differences) were probably due to large individual differences in initial fixation durations. Initial fixation durations were between 700 ms and 1000 ms for three observers, and between 400 and 600 ms for the remaining three. Thus, variances (for the ANOVA) were quite large.

In summary, the results of Experiment 2 were similar to those of Experiment 1. Search occurred more rapidly in the FD condition, with fewer fixations. Average fixations were numerically longer in the FD condition relative to the UD condition, though the difference had a slightly large (9%) chance of being explained by sampling error. These results support hypothesis c (as with Experiment 1), although an argument can be made for a more liberal interpretation to support hypothesis d (longer, but fewer when an unfamiliar target is embedded within familiar distractors). In either case, the results do not support an attention capture idea that predicts longer fixation durations for unfamiliar distractors.

4. Experiment 3: vernier acuity-type search

As with previous findings (e.g. Wang et al., 1994), the results of Experiments 1 and 2 demonstrate that familiarity with distractors (and not the target) facilitates visual search. A pertinent question at this stage concerns the level of operation of the familiarity effect. Does it occur as a result of relatively outstanding combinations of local features within a particular search array (e.g. an X among Cs), or is it based on an observer's semantic interpretation of information that the element conveys? Empirical data show overwhelmingly that an element with relatively outstanding features is readily found (e.g. Treisman & Gelade, 1980). For instance, a T is less easily found among Ls (similar features) than among Os. Among Os, the T has relatively odd features and pops out. More generally, an element with straight-line features is more easily found among curved-lined elements than among straight-lined elements, and vice versa. This is so regardless of the semantic properties associated with the elements. Although the empirical data are not as overwhelming, semantic interpretation (or high level categorization) too has been shown to affect search times (Jonides & Gleitman, 1972). During visual search, a letter is readily

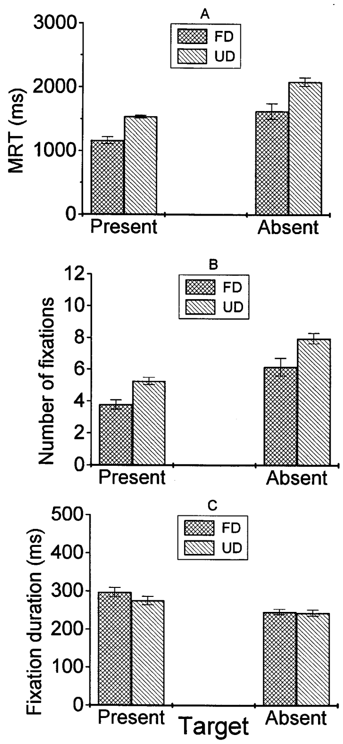

Fig. 4. Manual reaction times, number of fixations and average fixation durations in Experiment 3.

found (as indexed by MRTs) among single-digit numerals and a digit is readily found among letters (Jonides & Gleitman, 1972). In the Jonides and Gleitman study, semantic interpretation was manipulated by instructing observers to perceive the target O either as the letter oh, or the digit zero. The target O was more easily found as an oh among digits and as a zero among letters. Otherwise (as oh among letters and zero among digits), search was less efficient. Similarly, Brown, Enns, and Greene (1993) demonstrated that instructing observers to perceive Y junctions as 3D corners of cubes can influence visual search. Thus, observers' semantic interpretation of a physical stimulus within a display can influence visual search.

Our target and distractors always had very similar features (see Fig. 1). However, one element was more familiar. In Experiments 1 and 2, observers were told to search for the nonsense target among Ys, or the Y among nonsense distractors. This way, the semantic interpretation of the four-line elements was emphasized. In Experiment 3 we sought to manipulate this semantic interpretation. Observers were instructed to find the target by localizing the position of the bottom line in the four-line elements, thus de-emphasizing the semantic interpretation. In effect, observers performed a vernier acuity task (e.g. Westheimer & McKee, 1977; Greene & Brown, 2000) with multiple stimuli. If the familiarity effect is a result of semantic interpretation of objects, the prediction is that the effect should disappear in Experiment 3. Otherwise, if the familiarity effect is a result of experience with the visual environment (i.e. perceptual learning; Gibson, 1969), the effect should occur in Experiment 3.

4.1. Method

4.1.1. Subjects

Six University of Massachusetts students were paid $8.00 to participate in the experiment. They were all native English speakers and their ages ranged between 20 and 24 years. Each had normal or corrected-to-normal vision. None had participated in Experiments 1 and 2 and they were all naive concerning the purpose of the experiment.

4.1.2. Procedure

The stimuli and apparatus were the same as in Experiments 1 and 2. The stimuli were described to the observers as sets of four lines. Their task was to find the target by localizing the position of the bottom line in the search array. In one condition, the target was present when the bottom line was located between the other two vertical lines (this is the UD condition in Experiments 1 and 2). In the other condition (i.e. the FD condition in Experiments 1 and 2), the target was present when the bottom line was collinear with the left vertical line. At the end of the session, observers reported the counterbalanced condition in which search was easier to perform. As before, this allowed us to assess the observers' awareness search difficulty. As a measure of the subjective effect of the instructions on the observers, they were also asked to describe their search strategies.

4.2. Results

There were individual differences in observers' perception of difficulty and search strategy. Four observers found the FD condition easier to perform than the UD condition. Their subjective assessment of difficulty therefore matches the assessments of observers in Experiments 1 and 2. However, one observer reported that the UD condition was subjectively easier, and one found the conditions comparable in difficulty. Were the observers using the emergent semantic interpretation (i.e. the more familiar Ys)? Three observers reported that they did not think about the letter Y, or any emergent global shape. One observer noticed the Ys, but concentrated on localizing the bottom line, as instructed. Finally, two observers noticed and made use of the Ys. In spite of these individual differences in subjective reports, the quantitative data were similar for all observers. This provides some support for the involvement of low-level mechanisms in the familiarity effect.

Fig. 4A shows average MRT results. MRTs were faster by 507 ms when the target was present than when it was absent (1349 vs. 1856 ms, $F(1,5) = 44.34$; $P < 0.01$). They were also faster by 418 ms in the FD condition relative to the UD condition (1393 vs. 1811 ms, $F(1,5) = 51.37$; $P < 0.01$). There was no significant interaction between target presence and distractor condition ($F(1,5) = 3.42$; $P > 0.05$).

Fewer fixations occurred when the target was present than when it was absent (4.52 vs. 7.06, $F(1,5) = 66.52$; $P < 0.01$). Also, fewer fixations were made in the FD condition than the UD condition (4.97 vs. 6.61, $F(1,5) = 53.93$; $P < 0.01$). There was no significant interaction between target presence and distractor condition ($F(1,5) = 3.12$; $P > 0.05$). These data are presented in Fig. 4B.

Average fixation duration across distractor conditions was longer by 42 ms for present trials than absent trials (286 vs. 244 ms, $F(1,5) = 83.81$; $P < 0.001$). Average fixation duration was not systematically different between FD and UD search (271 vs. 259 ms, $F(1,5) = 2.85$; $P > 0.05$). No significant interaction occurred between target presence and distractor condition ($F(1,5) = 3.27$; $P > 0.05$). These data are illustrated in Fig. 4C.

As with Experiments 1 and 2, initial fixation durations were averaged and analyzed. There was no main effect of target presence (444 ms for present trials vs. 440 ms for absent trials, $F < 1$) and there was no significant difference between FD search (439 ms) and UD search (445 ms) ($F < 1$). Finally, there was no interaction effect ($F < 1$).

4.3. Discussion of Experiment 3

In this experiment we attempted to minimize high level semantic interpretation of the stimulus display by emphasizing local elements. We hypothesized that the familiarity effect would disappear if the underlying mechanism was semantic interpretation of objects, but would be elicited if the underlying mechanism was perceptual learning of features encountered in the environment. Despite individual differences in subjective perceptions of search difficulty, the quantitative data were similar for all observers. It is noteworthy that these individual differences in high-level perception of difficulty were not present in Experiments 1 and 2, where the semantic interpretation of elements was emphasized. The findings in Experiment 3 clearly show faster search in the FD conditions, thus the familiarity effect was not extinguished. This suggests that the familiarity effect may be due to low-level perceptual learning of typical feature configurations, and not the result of semantic interpretation (or categorization). The implication of this is that a meaningless pattern should elicit the familiarity effect if it is presented repeatedly. Repetition may change the way it is perceived in a stimulus array relative to other elements that have not been experienced with similar frequency (i.e., repetition may affect perceptual learning). This now familiar (but semantically meaningless as a category) element should elicit the familiarity effect. Indeed, Wang and Cavanagh (1993) found just that. Repetition of an unfamiliar Chinese character over many sessions allowed the non-Chinese observer to acquire some familiarity for it, which in turn allowed for an effect of familiarity.

5. Experiment 4: gaze-contingent procedure

The results of Experiments 1–3 do not support an attention capture idea that predicts longer fixations for unfamiliar distractors. Does this then mean that the familiarity effect occurs because effective processing occurs over a wider area when distractors are familiar? This issue was addressed in Experiment 4.

5.1. Method

5.1.1. Observers

Four University of Detroit Mercy students participated in the experiment. Ages were between 20 and 37 years. Each had normal or corrected-to-normal vision. None had participated in Experiments 1–3 and they were unaware of the purpose of the study.

5.1.2. Stimuli

The display again consisted of eight elements arranged equi-distant around an invisible circle. The diameter of the circle was 10.12°. Each element ($1.36° \times 1.23°$) was configured to form either the letter Y, or the non-standard form used in Experiments 1–3. Two conditions were tested in the experiment. In the FD condition, a non-standard element form was embedded within Ys (see Fig. 1A). In the UD condition, the letter Y was embedded within non-standard elements (see Fig. 1B). Eye movements were again recorded (right eye only) by an SMI Eyelink head-mounted tracker with the same settings as that used in Experiments 1–3. Displays were presented at a suprathreshold intensity level on a video monitor running at optimal refresh rate. The experiment utilized a gaze-contingent moving window technique such that elements of the display outside the window definition were invisible (i.e. nothing was presented outside of the window). The SMI Eyelink gaze-contingent window code operates by first storing a background bitmap (to draw outside the window) and a foreground bitmap (to draw within the window). Once drawn, during a trial, the code redraws those parts of the display that changed because of the window's gaze-contingent movement. The window moved with an average delay of 14 ms. Pilot observations (on three observers not included in the experiment) demonstrated that display change was seamless (they did not notice any observable delay).

5.1.3. Procedure

Observers were made aware of the letter Y as a target or distractor, and their task was to respond as quickly but as accurately as possible, on the computer keyboard, to indicate that the target (which was always present this time) had been found. A session consisted of a block of 64 FD trials followed by 64 UD trials, or vice versa. Three window conditions were tested (No Window, Large window, Small window). For numerical analysis, relative window size was defined as the window size:video screen size ratio. The no window (NW) condition was always presented first, and was designed to replicate the familiarity effect found in Experiments 1–3. In this condition, the whole video screen was available for non-gaze-contingent foveal and peripheral viewing (relative window size = 1). In the large window (LW) condition, a gaze-contingent window was defined around the observer's point of fixation (relative window size = 0.5). The window allowed up to five elements on the screen to be seen at a time with any single fixation. In the small window (SW) condition, a similar gaze-contingent window was defined around the observer's point of fixation (relative window size = 0.25). This window allowed up to two elements on the screen to be seen at a time with any single fixation. The LW and SW conditions were counterbalanced among observers.

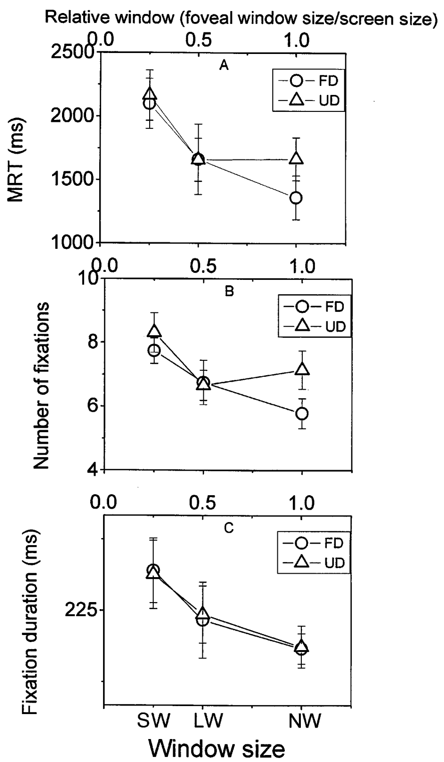

Fig. 5. Manual reaction times, number of fixations and average fixation durations as a function of window size, and distractor type in Experiment 4. Relative window sizes (top axis) were used in numerical analyses.

5.2. Results and discussion

The main question in Experiment 4 was whether search would be disrupted to a greater extent for FD search when peripheral processing was hindered. We hypothesized that this would be the case if generally a wider span of effective processing was used for FD search than for UD search. Fig. 5A and B present MRTs and number of fixations respectively, as a function of window size and type of distractor.

The results were quantified by analysis of trends (Keppel, 1982) as a function of relative window size. For MRT, there was a significant linear trend for FD search ($t(3) = -7.43$, $P < 0.05$), and for UD search ($t(3) = -4.59$, $P < 0.05$). There was also a significant quadratic trend in performance for UD search ($t(3) = 4.01$, $P < 0.05$), but not for FD search ($t(3) = 2.25$, $P > 0.05$). With respect to the number of fixations made in search of the target, there was a significant linear trend for FD search ($t(3) = -3.93$, $P < 0.05$), but not for UD search ($t(3) = -1.90$, $P > 0.05$). There was also a significant quadratic trend in performance for UD search ($t(3) = 2.91$, $P < 0.05$), but not for FD search ($t(3) = 0.79$, $P > 0.05$).

Fig. 5C shows that the fixation duration results are less discriminating. There was a linear trend for FD search ($t(3) = -6.35$, $P < 0.05$), and for UD search ($t(3) = -5.88$, $P < 0.05$). However there was no evidence of a quadratic trend for either FD search ($t(3) = 2.24$, $P > 0.05$), or UD search ($t(3) = 1.44$, $P < 0.05$). In sum, fixation duration increased as the foveal window became narrower (e.g. Bertera & Rayner, 2000), but consistent with the findings of Experiments 1–3, there was little difference between FD and UD search. For the FD condition, there was a steady increase in MRT, and in number of fixations as the foveal window became narrower, but this was not the case for the UD condition. For UD search, no disruption was evident between NW and LW. Thus, one can infer that the processing span for NW and LW was comparable. The greater disruption to search in the FD condition between NW and LW argues for a wider processing span when distractors are familiar.

6. General discussion

The present study had two main purposes. First, we sought to describe the moment-to-moment process involved in the familiarity effect. This was important because theoretical accounts of attention allocation during visual search tend to discount eye movements (Treisman & Sato, 1990; Grossberg, Mingolla, & Ross, 1994; Wolfe, 1994), but empirical evidence suggests that this may not be an optimal approach for a detailed understanding of active visual search (e.g. Rayner & Fisher, 1987a,b; Greene, Washburn, & Gonzalez, 1997; Zelinsky & Sheinberg, 1997; Findlay & Gilchrist, 1998; Motter & Belky, 1998a,b; Greene, 1999; Greene & Rayner, 2001). In visual search, MRTs reflect the end-product of a dynamic process that typically involves eye movements to bring objects of interest into foveal or near foveal vision. The uniqueness of our experiments lies in our evaluation of target and distractor familiarity (i) within the moment-to-moment framework of eye movements, and (ii) as a function of gaze-contingent moving windows.

We asked whether the familiarity effect (e.g. Wang et al., 1994) occurs because fixations are (a) shorter and fewer, (b) shorter, but more abundant, (c) equally long, but fewer, or (d) longer, but fewer when distractors are familiar. In Experiments 1 and 3, fixations were equally long in the FD and UD conditions, and fewer fixations were made in the FD condition, supporting hypothesis c above. In Experiment 2, with observers instructed to minimize fixations, fixation durations were marginally longer in the FD condition. Hence, with the unnatural task of deliberately minimizing eye movement search, observers in Experiment 2 may have conducted some covert scanning without eye movements (e.g. Shepherd, Findlay, & Hockey, 1986; Zelinsky & Sheinberg, 1997).

The nature of the underlying mechanism was a second purpose of the study. Wang et al. (1994) suggested that an unfamiliar element in a search array requires extra processing and thus captures attention. Hence, if only one salient element is present (among familiar/non-salient distractors), attention is drawn to it and it is found rapidly. However, if the distractors are unfamiliar (and the target is familiar), attention is captured by the distractors and this hinders search for the target. While this explanation is attractive, there is another plausible explanation for the findings: faster search times may also be the result of a wider processing span when the target is unfamiliar and the distractors are familiar (e.g. Geisler & Chou, 1995). These two explanations need not be mutually exclusive, as it is possible to find evidence for both. In Experiment 4, we argued that if one type of search utilized a wider processing span, search would be more greatly disrupted when the information within the span is limited. The results clearly showed faster search, and greater disruption to search when the distractors were familiar, suggesting a wider span of processing in this condition. Thus, it may be argued that unfamiliar distractors do demand extra processing, and this results not in longer fixations, but in a narrowing of the processing span, such that fewer items are processed at any given time.

The distractor type asymmetries demonstrated by the present studies have important implications for visual search theory. Geisler and Chou (1995) showed that low level physiological mechanisms may be dominant in causing these kinds of asymmetries. In their study, search for a low spatial frequency target embedded within high spatial frequency distractors was consistently faster than vice versa. Much of the variation in multiple-fixation search times could be accounted for by each observer's psychophysically determined accuracy window (akin to predefined moving windows in Experiment 4 here). Furthermore, accuracy windows were wider for the low spatial frequency target embedded within high spatial frequency distractors. The decrease in ganglion cell density and increase in their receptive-field center size with eccentricity (e.g. Wassle, Grunert, Rohrenbeck, & Boycott, 1990) cause blurring and under-sampling of peripheral information. These low-level physiological limitations are reflected as faster drops in contrast sensitivity with eccentricity for high spatial frequency (SF) information. Hence, given that low SF information is better transmitted in the periphery than high SF information, distractors (i.e. noise) defined by higher SFs relative to the target (i.e. signal) are filtered out, leaving a good signal-to-noise ratio for the lower SF target (Geisler & Chou, 1995). When the reverse configuration is presented, poor transmission of the high SF target in the periphery produces a noisy patch that is comparable to the noisy well transmitted low SF distractors, leaving a poor signal-to-noise ratio (Geisler & Chou, 1995).

The influence of low-level physiological mechanisms is less obvious for many search asymmetries with broadband stimuli. For example, a Landolt C target is found quickly among circles irrespective of the number of circles present. However, one of these circles surrounded by Landolt Cs is rather difficult to find (Treisman & Gormican, 1988). A mirror image of the letter Z is easily found among distractor arrays of Zs, but a Z is not easily found among arrays of mirror image Zs (Wang et al., 1994). A target defined by anomalous illumination attributes is found quickly among distractors with scene-based illumination and 3D attributes (Enns & Rensink, 1990, 1991; Rensink & Cavanagh, 1993). The implication is that an infrequently encountered pattern/object is quickly found among frequently encountered patterns/objects. However, search for a frequently encountered pattern/object is slow among infrequently encountered patterns/objects. Can the familiarity effect be explained in terms of low-level physiological signal-to-noise ratios as the narrowband stimuli of Geisler and Chou (1995)? Within this framework, it may be that familiar stimuli are more easily filtered out in the periphery. We are unaware of any physiological study that has addressed this directly, but the inferior temporal (IT) cortex has been found to be involved in visual recognition, and cells in this area of awake monkeys are more active for non-memorized (i.e. unfamiliar) stimuli in delayed matching-to-sample tasks (Miller, Li, & Desimone, 1991; Li, Miller, & Desimone, 1993). As unfamiliar targets became more familiar with repeated presentation, there were decrements in cell response. No significant response decrement occurred for targets that were already familiar. Positron emission tomography (PET) results provide a human correlate of the findings from monkey cortex (Vandenberghe, Dupont, Bormans, Mortelmans & Orban, 1995). In a delayed matching-to-sample task, activity was localized to the temporal cortex. When the task was performed with familiar targets, only degraded blood flow activity occurred. In sum, unfamiliar object processing may be associated with elevated physiological activity. If this is the case, then an unfamiliar target among (easily filtered) familiar distractors may exhibit a good signal-to-noise ratio. However, a familiar target produces reduced activity (or noise) that is comparable to the noisy unfamiliar distractors, leaving a poor signal-to-noise ratio. From current physiological findings (Miller et al., 1991; Li et al., 1993), and the results of Experiments 1–3 in the present study, we hypothesize that perceptual learning (in low-level physiological mechanisms) may mediate the familiarity effect. In Experiment 4 we provided evidence from gaze-contingent moving window data that this mediation is also reflected in the size of the span of effective processing.

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References

Bertera, J. H., & Rayner, K. (2000). Eye movements and the span of the effective visual stimulus in visual search. *Perception & Psychophysics*, *62*, 576–585.

Brown, J. M., Enns, J. T., & Greene, H. H. (1993). Preattentive processing of line junctions can be altered by perceptual set. *Investigative Ophthalmology and Visual Science*, *34*(Suppl.), 1234.

Enns, J. T., & Rensink, R. A. (1990). Sensitivity to three-dimensional orientation in visual search. *Psychological Science*, *1*, 323–326.

Enns, J. T., & Rensink, R. A. (1991). Preattentive recovery of three-dimensional orientation from line drawings. *Psychological Review*, *98*, 335–351.

Findlay, J. M., & Gilchrist, I. D. (1998). Eye guidance and visual search. In G. Underwood, *Eye guidance in reading*, *driving*, *and scene perception* (pp. 295–312). Oxford: Elsevier.

Geisler, W. S., & Chou, K. (1995). Separation of low-level and high-level factors in complex tasks: visual search. *Psychological Review*, *102*, 356–378.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Meridith.

Greene, H. H. (1999). Temporal relationships between eye fixations and manual reactions in visual search. *Acta Psychologica*, *101*, 105–123.

Greene, H. H., & Brown, J. M. (2000). Amodal completion and localization. *Vision Research*, *40*, 383–390.

Greene, H. H., & Rayner, K. (2001). Eye-movement control in direction-coded visual search. *Perception*, *30*, 147–157.

Greene, H. H., Washburn, D. A., & Gonzalez, F. A. (1997). Simulating naturalistic demands for speeded judgment. *Behavior Research Methods*, *Instruments*, *and Computers*, *29*, 256–259.

Grossberg, S., Mingolla, E., & Ross, W. D. (1994). A neural theory of attentive visual search: Interactions of boundary, surfaces, spatial, and object representations. *Psychological Review*, *101*, 470–489.

Hooge, I. T. C., & Erkelens, C. J. (1998). Adjustment of fixation duration during visual search. *Vision Research*, *38*, 1295–1302.

Johnston, W. A., Hawley, K. J., & Farnham, J. M. (1993). Novel popout: empirical boundaries and tentative theory. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 140–153.

Jonides, J., & Gleitman, H. (1972). A conceptual category effect in visual search: O as letter or digit. *Perception & Psychophysics*, *12*, 457–460.

Keppel, G. (1982). *Design and analysis*: *a researcher's handbook* (2nd edn). New Jersey: Prentice-Hall.

Li, L., Miller, E. K., & Desimone, R. (1993). The representation of stimulus familiarity in anterior inferior temporal cortex. *Journal of Neurophysiology*, *69*, 1918–1929.

Lubow, R. E., & Kaplan, O. (1997). Visual search as a function of type of prior experience with target and distractor. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 14–24.

Miller, E. K., Li, L., & Desimone, R. (1991). A neural mechanism for working and recognition memory in inferior temporal cortex. *Science*, *254*, 1377–1379.

Motter, B. C., & Belky, E. J. (1998a). The guidance of eye movements during active visual search. *Vision Research*, *38*, 1805–1815.

Motter, B. C., & Belky, E. J. (1998b). The zone of focal attention during active visual search. *Vision Research*, *38*, 1007–1022.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*, 372–422.

Rayner, K., & Fischer, M. H. (1996). Mindless reading revisited: eye movements during reading and scanning are different. *Perception & Psychophysics*, *58*, 734–747.

Rayner, K., & Fisher, D. L. (1987a). Eye movements and the perceptual span during visual search. In J. K. O'Regan, & A. Levy-Schoen, *Eye movements*: *from physiology to cognition* (pp. 293–302). Amsterdam: North Holland.

Rayner, K., & Fisher, D. L. (1987b). Letter processing during eye fixations in visual search. *Perception & Psychophysics*, *42*, 87–100.

Rayner, K., & Raney, G. E. (1996). Eye movement control in reading and visual search: effects of word frequency. *Psychonomic Bulletin & Review*, *3*, 238–244.

Reicher, G. M., Snyder, C. R. R., & Richards, J. T. (1976). Familiarity of background characters in visual scanning. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 522–530.

Rensink, R. A., & Cavanagh, P. (1993). Processing of shadows at preattentive levels. *Investigative Ophthalmology and Visual Science*, *34*(Suppl.), 1288.

Richards, J. T., & Reicher, G. M. (1978). The effect of background familiarity in visual search. *Perception & Psychophysics*, *23*, 499–505.

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

Shulman, G. L., & Wilson, J. (1987). Spatial frequency and selective attention to local and global information. *Perception*, *16*, 89–101.

Treisman, A. (1985). Preattentive processing in vision. *Computer Vision*, *Graphics*, *and Image Processing*, *31*, 156–177.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychological Review*, *95*, 15–48.

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 459–478.

Vandenberghe, R., Dupont, P., Bormans, G., Mortelmans, L., & Orban, G. (1995). Blood flow in human anterior temporal cortex decreases with stimulus familiarity. *Neuroimage*, *2*, 306–313.

Wang, Q., & Cavanagh, P. (1993). Acquired familiarity effects in visual search with Chinese characters. *Investigative Ophthalmology and Visual Science*, *34*(Suppl.), 1236.

Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and popout in visual search. *Perception & Psychophysics*, *56*, 495–500.

Wassle, H., Grunert, U., Rohrenbeck, J., & Boycott, B. B. (1990). Retinal ganglion cell density and cortical magnification factor in the primate. *Vision Research*, *30*, 1897–1911.

Westheimer, G., & McKee, S. P. (1977). Spatial configurations for visual hyperacuity. *Vision Research*, *17*, 941–947.

Wolfe, J. M. (1994). Guided search 2.0 A revised model of visual search. *Psychonomic Bulletin & Review*, *1*, 202–238.

Zelinsky, G. J. (1996). Using eye saccades to assess the selectivity of search movements. *Vision Research*, *36*, 2177–2187.

Zelinsky, G. J., & Sheinberg, D. L. (1997). Eye movements during parallel-serial visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 244–262.