Research Article

Unique Temporal Change Is the Key to Attentional Capture

Adrian von Mühlenen, Mark I. Rempel, and James T. Enns

University of British Columbia, Vancouver, British Columbia, Canada

ABSTRACT—Attentional capture ***refers to the observation that some events break through and attract one's attention even when one is engaged in a task for which these events are irrelevant. Previous research, focusing primarily on spatial factors, has shown that a new object is more salient in this regard than an abrupt change in an object's features. Here we show that feature changes can be as effective as new objects in capturing attention, provided that they occur during a period of temporal calm. Conversely, both feature changes and new objects are far less effective in capturing attention when they occur simultaneously with other display changes, such as coincident with the initial onset of the display or with small visual transients that occur during a display transition. These results highlight the importance of considering both space and time in studies of attentional capture; the most effective stimulus is unique in both dimensions.***

The focus of people's attention depends greatly on their goals and expectations (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). Yet some events still break through and interrupt observers, regardless of their current task set. What governs this bias to novelty? The most widely accepted view, the *new-object hypothesis*, states that only events that signal the appearance of a new object are effective in capturing attention (Yantis & Hillstrom, 1994; Yantis & Jonides, 1984). Studies consistent with this hypothesis have shown that abrupt changes to the features of already-registered objects often do not capture attention (e.g., changes in color—Jonides & Yantis, 1988; Theeuwes, 1990, 1995; changes in luminance—Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; changes in motion—Hillstrom & Yantis, 1994; Yantis & Egeth, 1999).

Address correspondence to Adrian von Mühlenen, Department of Psychology, Ludwig-Maximilians-University, Leopoldstrasse 13, 80802 Munich, Germany, e-mail: avm@lmu.de, or to James T. Enns, Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, British Columbia, Canada V6T 1Z4, e-mail: jenns@psych.ubc.ca.

Yet there are challenges to the new-object hypothesis, specifically from reports that feature changes sometimes capture attention. For example, Turatto and Galfano (2000, 2001) reported that a color change captured attention when visual search participants were relatively inexperienced. Horstmann (2002) reported that a color change captured attention when it was surprising. Franconeri and Simons (2003) reported that several types of motion captured attention, provided their onset preceded the display transition by 150 ms, whereas Abrams and Christ (2003) argued that the critical factor was onset of motion, not motion per se. Franconeri, Hollingworth, and Simons (2005) used dynamic occlusion to show that new objects captured attention only when they were accompanied by abrupt luminance transients.

These results leave open the possibility that the neural signals from features changes that capture attention have a slower time course than the signals from feature changes that do not capture attention. For example, if color is signaled by relatively slow *parvocellular* neurons and luminance transients by relatively fast *magnocellular* neurons (Breitmeyer & Ganz, 1976; Lennie, 1993), then color changes may have to occur earlier than object onsets to have comparable effects. Similarly, if changes in an existing object are signaled more slowly than the onset of a new object (Kahneman, Treisman, & Gibbs, 1992), they would have to occur earlier to be equally effective in capturing attention. Perhaps abrupt feature changes are simply weaker exogenous cues than are object onsets (Posner, Snyder, & Davidson, 1980). We refer to these differential-latency ideas collectively as the *delayed-signal hypothesis*.

Here we point to a temporal factor that is critical to the capture of attention, over and above any of these considerations. In short, we propose that attention is captured by events that are temporally unique, and we refer to this as the *unique-event hypothesis*. The results of two experiments show that some feature changes capture attention as effectively as new objects do, provided that they occur when the rest of the display is static. Conversely, these same feature changes do not capture attention when they occur simultaneously with other display changes, such as the sudden onset of all items or the deletion of some line segments in all items. The results show that the unique-event hypothesis applies not only to changes in color and in motion (Experiment 1), but also to the sudden onset of new objects (Experiment 2).

We used the preview-search method (Todd & Van Gelder, 1979; Yantis & Jonides, 1984), in which participants first see a circular preview display of figure eights that remain on view for 1 s. Between two and four line segments of each figure eight are then deleted to reveal a search display of letters; we refer to this change as the display transition. Two letters are arbitrarily designated as targets for report. Attentional capture is indexed by the relative ratio of response time (RT) slopes, taken over the number of letters in the display, for two different types of targets. The numerator in the ratio is the RT slope from target letters that replace figure eights in the display (unchanged), and the denominator is the RT slope from target letters that suddenly appear in empty preview locations or that undergo a sudden change in color or motion (changed). This index is based on the assumption that when a unique item draws attention to itself, it will slow search if it happens to be one of the distractor letters, and it will speed search if it happens to be the target.

EXPERIMENT 1

We first tested the effectiveness of abrupt changes in color and motion with the four conditions shown in Figure 1a. These experimental conditions were compared with a baseline onset condition in which a new item always appeared during the display transition. They are labeled according to the time that elapsed between the display transition and the change in an item. In two conditions, the unique item was presented simultaneously with other display events, either at preview onset (−1,000 ms) or at the display transition (0 ms). In the other two conditions, the unique item appeared either shortly before (−150 ms) or shortly after (+150 ms) the display transition.

The new-object hypothesis predicts that none of these conditions should produce attentional capture because there are no new objects. The delayed-signal hypothesis predicts that feature changes will be effective only when they occur in advance of the display transition. In contrast to both of these hypotheses, the unique-event hypothesis predicts that attentional capture will be stronger when a feature change occurs just before, or even just after, the display transition than when it occurs simultaneously with other display changes.

The color change involved a combined change in hue (gray to red) and luminance (bright to dark). Pilot tests, consistent with many previous reports, showed that this change did not capture attention when it occurred simultaneously with the display transition. The abrupt motion change involved a circular motion pattern of one of the letters, in order not to confound variations in motion with differences in the configuration of the search display. Pilot tests also showed that the target letter was still readily identified when it was moving in this circular pattern, provided that the item was stationary for a brief period immediately before or after the display transition. Accuracy was reduced somewhat when the target letter was in constant motion, but this was not a condition under which we tested accuracy in this study.

Method

Participants

One hundred five participants (78 women, age range: 18–44 years), all reporting normal or corrected-to-normal visual acuity, received extra course credit for participating in a 1-hr session. None were aware of the purpose of the study.

Stimuli

Displays were presented on a Dell 17-in. CRT monitor (600× 800 resolution, 85 Hz) controlled by a Pentium III-300 computer running Presentation® software (Version 0.76). Participants sat with their eyes 57 cm from the screen in a dimly lit room (total screen: 32° × 24°). A preview display of figure eights was followed by a search display of letters. Letters were randomly distributed among eight locations, evenly spaced on an imaginary circle at an eccentricity of 5.5°. The target (*H*, *U*) and distractor (*E*, *P*, *S*, *C*, *F*, *L*) letters were selected randomly and equally often, with the constraint that only unique letters were presented on a given trial. On every trial, one of the display items underwent a unique change, but the location of this change did not predict target location.

Letters were obtained by erasing two to four of the line segments from each figure eight. Items were 2° × 1.2°, lines were 1 pixel wide and colored either light gray (luminance = 40 cd/m^2) or red (luminance = 12 cd/m^2). The background was black (luminance = 0.5 cd/m^2). In the *color-change* condition, we attempted to equate the relative salience of the gray and red items against the black background by reducing the luminance of the unique red hue relative to the gray hue of the remaining letters. Note that previous studies have reported failures of capture for even more extreme changes in luminance (Enns et al., 2001). In the *motion-change* condition, one item moved in a circle (diameter = 0.57°) at a speed of 12°/s. At the display transition, the moving item was always "aligned" (i.e., same eccentricity) with the other items.

Procedure

Participants rapidly pressed one of two keys to report each target letter, while maintaining response accuracy of at least 95%. A trial began with the presentation of three, five, or seven placeholders. After 1,000 ms, line segments were removed to reveal letters. In the onset condition, one new letter appeared in an unfilled location at the display transition. In the color-change condition, one of the original items changed color either (a) 1,000 ms before, (b) 150 ms before, (c) simultaneously with, or (d) 150 ms after the display transition. In the motion-change condition, one of the original items either (a) began moving

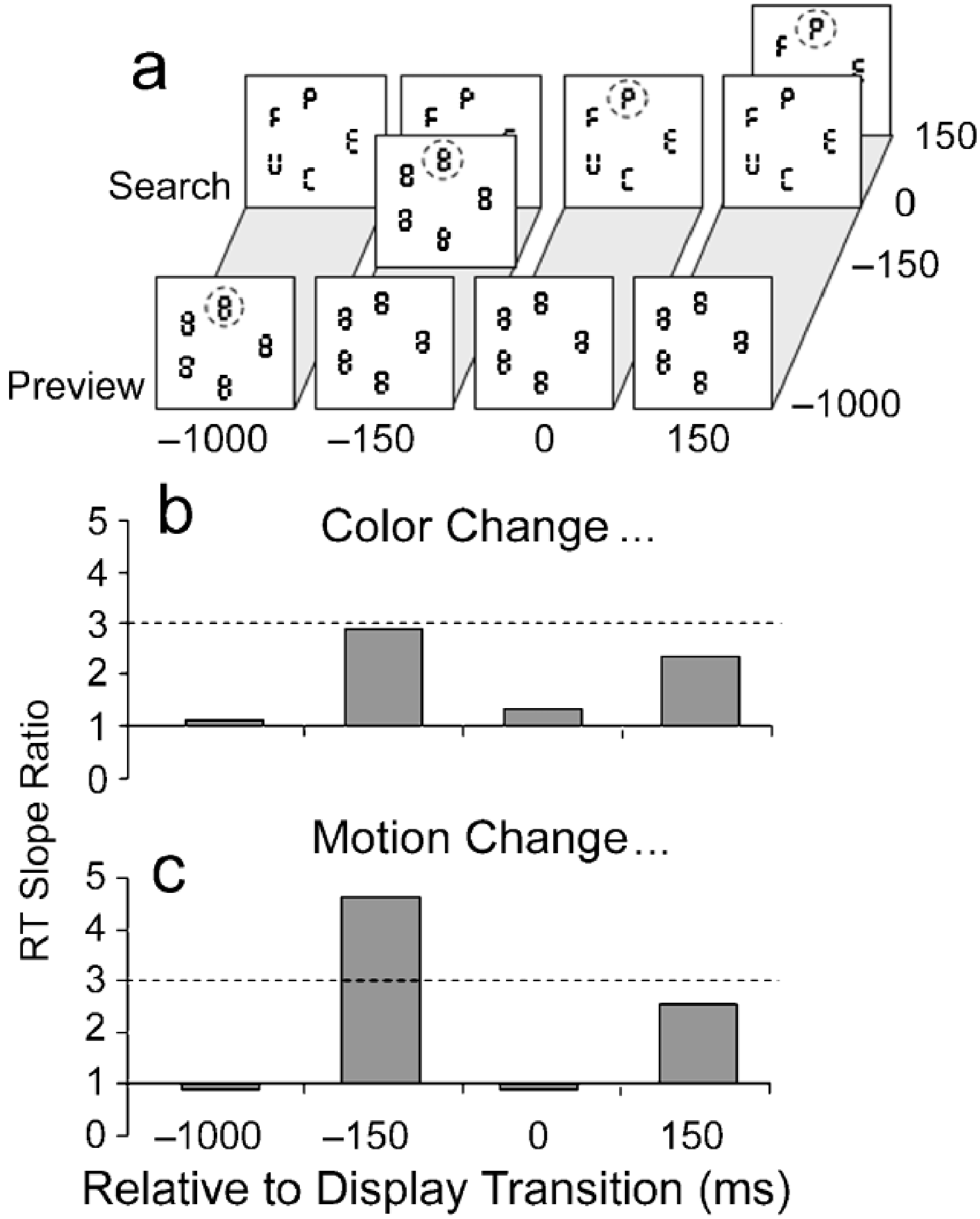

Fig. 1. Experiment 1: illustration of the stimulus sequences (a) and results for the color-change (b) and motion-change (c) conditions. In the feature-change conditions, a unique color or motion change occurred in one of the items (circled for illustrative purposes here) at one of four possible times: in the preview display (−1,000 ms), just prior to the display transition (−150 ms), at the display transition (0 ms), or just after the display transition (150 ms). The millisecond values on the bottom of the illustrated stimulus sequences are labels for the timing conditions; the millisecond values on the right indicate the passage of time in each sequence. In the graphs, attentional capture is indexed by the ratio of the response time (RT) slope on trials in which the target was an unchanged item to the RT slope on trials in which the target was a unique item. The dotted lines represent the standard attentional-capture effect in the onset condition.

1,000 ms before the display transition and stopped at the display transition, (b) began moving 150 ms before the display transition and stopped with it, (c) began moving at the display transition and continued moving until the response, or (d) began moving at the display transition and stopped moving 150 ms after the transition, making movement offset a unique event. Participants received 45 practice trials prior to testing, which occurred in blocks of 45 trials, with short breaks between blocks.

Design and Analysis

Different participants were tested in each of the four timing conditions and in the color- and motion-change conditions. All participants were also tested in the onset condition in order to assess their susceptibility to attentional capture. Onset and feature-change conditions were run in separate sessions, in a counterbalanced order. In each session, display size (3, 5, or 7) and target type (change item or no-change item) were varied randomly. Each session had 450 trials, divided into 90, 150, and 210 trials for display sizes of 3, 5, and 7, respectively. Thus, for each display size, there were 30 trials in which the target was the change item, and 60, 120, or 180 trials (for display sizes of 3, 5, and 7, respectively) in which the target was the no-change item.

Median correct RT was calculated for each participant, condition, target type, and display size. RT slope was obtained through linear regression. The index of attentional capture was the ratio of the RT slope when the target was an unchanged item to the RT slope when the target was a unique item. Because this study was aimed at determining the conditions under which color and motion changes were as effective as sudden onsets in causing attentional capture, only data from participants with a capture index significantly greater than 1.0 in the onset condition were included. This procedure eliminated 7 participants. Analyses of variance (ANOVAs) were used to examine the between-participants factors of timing (−1,000 ms, −150 ms, 0 ms, or +150 ms), testing order (onset or feature-change condition first), and feature context (onset condition paired with color- or motion-change condition), in addition to the within-participants factors of target type and display size.

Results

Errors

Because the main dependent measure is correct RT, it is important to know if participants were trading response speed for accuracy. The data for mean errors, shown in Table 1, indicate that this was not a problem. Errors occurred on only 3.1% of trials, and they were slightly positively correlated with RT, $r_s(96) = .18$; when responses were slower, they also tended to be less accurate (see error and correct-RT data in Tables 1 and 2, respectively).

Sudden-Onset RT

The RT slopes for the no-onset and onset targets in the onset condition were 30.0 and 10.1 ms/item, respectively, generating a capture index of 3.0. This value served as a baseline for comparison with performance in the color- and motion-change conditions. ANOVA revealed significant effects of target type, $F(1, 80) = 240.42$, $p < .001$, $\eta^2 = .75$, and display size, $F(2, 160) = 173.38$, $p < .001$, $\eta^2 = .68$, as well as a Target Type × Display Size interaction, $F(2, 160) = 78.06$, $p < .001$, $\eta^2 = .49$.

In addition, RT was generally faster in the second session ($M = 618$ ms) than in the first ($M = 653$ ms), $F(1, 80) = 4.11$, $p < .05$, $\eta^2 = .05$, and there was a significant interaction of testing order and target type, reflecting a larger difference between no-onset and onset RTs in the first session (mean difference = 101 ms) than in the second session (mean difference = 64 ms), $F(1, 80) = 11.92$, $p < .001$, $\eta^2 = .01$. Most important, the Target Type × Display Size interaction, reflecting the capture index, was not significantly affected by testing order, feature context, or timing.

TABLE 1
Mean Percentage Errors

Timing and target	Display size 3	5	7
Sudden onset (Experiment 1)			
0 ms			
Onset	4.3	3.0	2.9
No-onset	6.3	2.2	2.2
Color change (Experiment 1)			
−1,000 ms			
Change	2.6	2.1	1.7
No-change	1.9	2.5	2.5
−150 ms			
Change	3.1	2.2	1.9
No-change	1.7	3.9	2.2
0 ms			
Change	2.5	2.4	2.1
No-change	1.9	2.2	1.7
+150 ms			
Change	2.8	1.7	2.4
No-change	1.7	2.5	1.9
Motion change (Experiment 1)			
−1,000 ms			
Change	7.4	5.8	5.3
No-change	5.3	4.7	2.5
−150 ms			
Change	4.7	2.7	2.9
No-change	2.8	2.2	1.9
0 ms			
Change	6.5	6.0	5.1
No-change	3.9	5.0	4.2
+150 ms			
Change	4.2	2.7	2.5
No-change	3.3	3.6	3.9
Sudden onset (Experiment 2)			
−150 ms			
Onset	5.2	—	2.7
No-onset	3.7	—	2.6
0 ms			
Onset	2.2	—	2.4
No-onset	2.4	—	2.8
+150 ms			
Onset	4.4	—	3.0
No-onset	1.8	—	2.4

Color-Change RT

The attentional-capture index for color-change trials was calculated separately for each timing condition, based on the mean RT slopes for no-change and change targets. Figure 1b shows

TABLE 2
Mean Correct Response Time

Timing and target	Display size 3	5	7	Response time slope	Capture index
Sudden onset (Experiment 1)					
0 ms					
Onset	576	591	616	10.1	3.0
No-onset	618	673	738	30.0	
Color change (Experiment 1)					
−1,000 ms					
Change	600	676	736	34.1	0.9
No-change	622	687	745	30.6	
−150 ms					
Change	585	632	633	11.8	2.9
No-change	665	712	802	34.3	
0 ms					
Change	554	626	655	25.1	1.3
No-change	609	687	744	33.8	
+150 ms					
Change	551	590	607	13.9	2.4
No-change	571	644	702	33.0	
Motion change (Experiment 1)					
−1,000 ms					
Change	617	679	746	32.3	0.9
No-change	623	668	740	29.1	
−150 ms					
Change	582	605	611	7.2	4.6
No-change	632	684	764	33.0	
0 ms					
Change	615	678	755	35.0	1.0
No-change	620	683	755	33.7	
+150 ms					
Change	609	640	663	13.4	2.5
No-change	629	692	764	33.7	
Sudden onset (Experiment 2)					
−150 ms					
Onset	619	—	657	9.5	3.5
No-onset	644	—	779	33.6	
0 ms					
Onset	596	—	689	23.3	1.4
No-onset	641	—	773	33.0	
+150 ms					
Onset	717	—	778	12.8	2.4
No-onset	634	—	754	30.1	

that attention was captured in the −150-ms and the +150-ms conditions, but not in the −1,000-ms and the 0-ms conditions. This was confirmed by ANOVA: The Target Type × Display Size interaction was significant in the −150-ms condition, $F(2, 22) = 5.34$, $p < .05$, $\eta^2 = .33$, and the +150-ms condition, $F(2, 22) = 5.78$, $p < .01$, $\eta^2 = .34$, but not in the −1,000-ms condition, $F(2, 22) = 0.08$, $\eta^2 = .01$, or the 0-ms condition, $F(2, 22) = 1.13$, $\eta^2 = .09$. ANOVA comparing the color-change condition directly with the onset condition also supported this interpretation. The three-way interaction of Change Type (onset or color) × Target Type × Display Size was significant in the −1,000-ms condition, $F(2, 212) = 8.77$, $p < .001$, $\eta^2 = .08$; marginally significant in the 0-ms condition, $F(2, 212) = 2.76$, $p < .10$, $\eta^2 = .03$; and not significant in the −150-ms condition, $F(2, 212) = 0.19$, or the +150-ms condition, $F(2, 212) = 0.04$. These interactions point to a reduction in capture in the −1,000-ms and 0-ms conditions. Testing order had no significant influence either as a main effect or in interaction with other factors.

Motion-Change RT

Figure 1c shows the attentional-capture index for motion-change trials in each timing condition. As in the color-change condition, attention was captured in the −150-ms and the +150-ms timing conditions, but not in the −1,000-ms and the 0-ms timing conditions. ANOVA indicated a significant Target Type × Display Size interaction in the −150-ms condition, $F(2, 22) = 15.19$, $p < .001$, $\eta^2 = .58$, and the +150-ms condition, $F(2, 22) = 6.13$, $p < .01$, $\eta^2 = .36$, but not in the −1,000-ms condition, $F(2, 22) = 0.12$, or 0-ms condition, $F(2, 22) = 1.40$. ANOVAs that included the within-subjects factor of change type (onset or motion) revealed a significant three-way interaction in the −1,000-ms condition, $F(2, 212) = 9.05$, $p < .001$, $\eta^2 = .08$, and in the 0-ms condition, $F(2, 212) = 9.81$, $p < .001$, $\eta^2 = .08$, but not in the −150-ms condition, $F(2, 212) = 1.68$, or the +150-ms condition, $F(2, 212) = 0.13$. As in the color-change condition, capture was reduced when the change occurred 1,000 ms before or simultaneously with the display transition. Testing order was not significant, either as a main effect or in interaction with other factors.

EXPERIMENT 2

Experiment 1 showed that feature changes are very effective in interrupting a search task, provided that the changes occur during a period of temporal calm. The fact that these changes were effective not only when they occurred before the transition from preview to search display, but also when they occurred after this transition, indicates that feature changes are not merely signaled more slowly than sudden onsets by the visual system. Instead, this finding is consistent with the unique-event hypothesis, which is premised on the uncontroversial idea that the visual system is tuned very sensitively to change along many dimensions. Also, the capture index was as strong for new objects (with their attendant strong transients that activate magnocellular neurons) as it was for color changes (activating the slower parvocellular neurons), which suggests that visual search is interrupted at a place in the visual system that is beyond the influence of low-level differences in signal speed. This interpretation is consistent with previous reports that visual search is performed on relatively high-level representations (Cavanagh, Arguin, & Treisman, 1990; Enns & Rensink, 1990; Rensink & Enns, 1995, 1998; Trick & Enns, 1997).

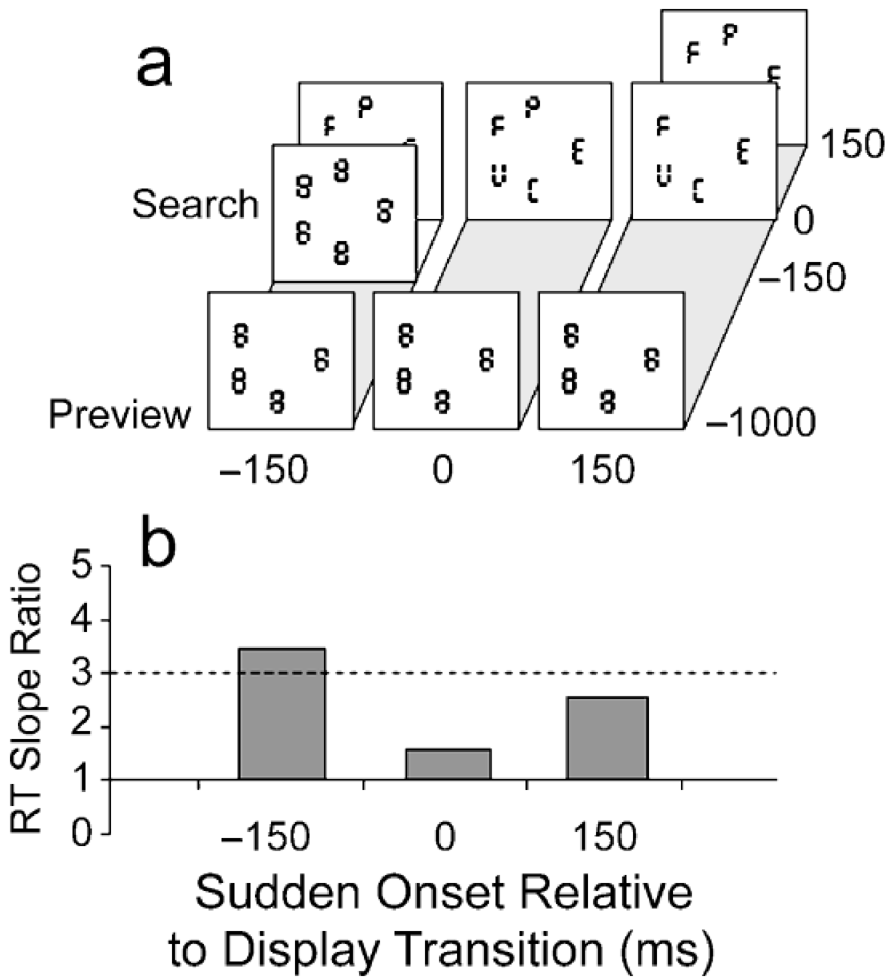

Fig. 2. Experiment 2: illustration of the stimulus sequences (a) and results (b). As shown in the illustration, the onset of the new object occurred at one of three different time points in the sequence. The millisecond values on the bottom of the illustrated stimulus sequences are labels for the timing conditions; the millisecond values on the right indicate the passage of time in each sequence. In the graph, attentional capture is indexed by the ratio of the response time (RT) slope on trials in which the target was an unchanged item to the RT slope on trials in which the target was the new item. The dotted line represents the attentional-capture effect in the blocked onset condition in Experiment 1.

But does the unique-event hypothesis also apply to the sudden appearance of new objects? Pilot tests indicated that blocking conditions in which new objects appeared before, during, and after the display transition resulted in ceiling effects, because all three conditions yielded strong capture. To facilitate their direct comparison, we used a mixed-trial design in which the three kinds of events occurred randomly within a block of trials.

Method

Twelve participants (10 women, age range: 19–27 years) were tested with methods identical to those for the onset condition of Experiment 1, with the exception that three timing conditions were randomly interleaved. The sudden-onset item was presented either (a) 150 ms before, (b) simultaneously with, or (c) 150 ms after the display transition (see Fig. 2a). The −1,000-ms condition was omitted because the added item was not unique when it appeared along with the figure eights. Only two display sizes (3, 7) were tested in an effort to maximize the amount of data collected for the three interleaved timing conditions. A total of 720 trials was subdivided into 240 trials for each timing condition. The 72 trials with a display size of 3 included 24 trials with onset targets and 48 trials with no-onset targets, and the 168 trials with a display size of 7 included 24 trials with onset targets and 144 trials with no-onsets.

Results

Participants were again very accurate, making errors on only 3.0% of trials (Table 1), and errors were positively correlated with RT (Table 2), $r_s(12) = .20$. Figure 2b shows the capture index for each timing condition. As was the case for feature changes, attention was captured strongly when a new item appeared either shortly before or shortly after the display transition, but it was captured much less strongly when the new item appeared simultaneously with the transition. ANOVA indicated a significant Target Type × Display Size interaction in the −150-ms condition, $F(1, 11) = 15.41, p < .01, \eta^2 = .58$, and in the +150-ms condition, $F(1, 11) = 12.78, p < .01, \eta^2 = .54$, but not in the 0-ms condition, $F(1, 11) = 1.77, \eta^2 = .14$. An ANOVA that included timing (−150, 0, or +150 ms) as a factor revealed an additional significant interaction of timing and target type, $F(1, 11) = 19.50, p < .001, \eta^2 = .64$, and a marginally significant interaction of timing and display size, $F(2, 22) = 2.75, p < .10, \eta^2 = .20$. These interactions reflected decreased attentional capture in the 0-ms condition relative to the other two conditions. The difference in capture between the −150-ms and the +150-ms conditions was not significant, Timing × Target Type × Display Size, $F(2, 22) = 1.44, \eta^2 = .12$, but the difference between the 0-ms and the −150-ms and +150-ms conditions was significant, as indicated by a quadratic trend, $F(1, 11) = 4.44, p < .05, \eta^2 = .16$.

GENERAL DISCUSSION

This study reveals an important and previously neglected factor in the capture of attention by sudden, local display changes. Attention is captured most strongly when these changes occur against the background of an otherwise static display. Indeed, the results show that abrupt changes in the color or motion of an object are very effective in capturing attention, as is the abrupt onset of a new object, provided that these events are temporally unique. When the changes occur 150 ms before or after the display transition, attention is strongly captured by color, motion, and object onset. However, when these changes coincide with the display transition, or when they are present from the beginning of the preview display, attention is much less likely to be captured.

This pattern is predicted by the unique-event hypothesis, which asserts that the visual system is sensitively tuned to change along many dimensions. The results do not support the new-object hypothesis, because it does not account for the effective capture by feature changes in already-registered objects when the changes occur shortly before or after the display transition. The delayed-signal hypothesis also fails to predict these results in two ways: first, because it predicts that a unique item in the preview display should be sufficient to draw attention to itself (−1,000-ms condition) and, second, because it does not explain the effective capture of attention by color and motion changes that occur 150 ms after the display transition.

These results stand in sharp contrast to those of many previous studies. One point highlighted by the present comparisons is that the task context matters more than has previously been appreciated. The same display sequences that produce attentional capture in a blocked design (present Experiment 1: sudden onset; Yantis & Jonides, 1984) do not capture attention in the context of even more strongly capturing sequences (present Experiment 2). This serves as a strong reminder that there is no measure of capture that is unaffected by an observer's goals and expectations. The allocation of visual attention is likely always determined by a subtle interplay between the opposing forces of the observer's immediate task set and the general biological readiness to detect novelty (Folk et al., 1992, 1994).

A related point is that small procedural differences can have large consequences. For example, Abrams and Christ (2003) reported that the onset of motion at the display transition captures attention under conditions quite similar to those we used. Yet the motion in their displays was quite crude (display updated every 67 ms, 15 Hz) in comparison with the motion in the present study (display updated every 20 ms, 50 Hz), and this may have accentuated the attention-capturing quality of their motion signal. Similarly, Theeuwes (1995, Experiment 3) reported no capture by a color change even when it occurred 100 ms before the display transition. But in that study, the item that changed color was also never the target item, giving participants greater incentive to ignore it.

The most important finding of the present study is that attentional capture cannot be predicted solely by the spatial salience of an item. The most effective attention-capturing events are unique in both space and time. Previous research likely missed this point because it focused on spatial factors, that is, on the differences in the way color, luminance, shape, and motion were arranged geometrically in the display. "Salience" was based on an analysis of these spatial features frozen in time. Yet, in the present study, whether or not an event captured attention was determined as much by its temporal as by its spatial uniqueness. Potentially salient spatial features did not capture attention when they were presented well in advance of the search display, nor when they appeared simultaneously with the display transition. From our perspective, this is because there was display-wide noise coincident with the feature change (i.e., the onset of the entire display at −1,000 ms and the deletion of line segments from all the preview items at 0 ms). These same spatial differences captured attention very effectively when they occurred immediately before or after the display transition.

The present results help to resolve a long-standing paradox regarding exogenous orienting as indexed by attentional capture (Egeth & Yantis, 1997) versus attention cuing (Posner et al., 1980). As mentioned in the introduction, the attentional-capture literature has been dominated by results favoring the new-object hypothesis. In apparent contradiction to this hypothesis, attention-cuing studies have routinely reported the effectiveness of orienting to nonpredictive luminance increments and motion changes in existing display items. The cues are presented in advance of the target event and against the background of an otherwise calm visual display. These are precisely the conditions that gave rise to maximum attentional capture in the present study. The unique-event hypothesis therefore accounts for both the success of attentional cuing when salient changes occur in existing display items and for the failure of attentional capture when salient changes suddenly appear in the context of a spatially and temporally noisy background.

We also note that not all aspects of the new-object hypothesis are disconfirmed by the present results (see also Rauschenberger, 2003). Although the findings are clear in revealing the temporal conditions under which feature changes are maximally effective, new objects were still more effective than feature changes when they occurred during the display transition (compare the RT-slope ratio for onset and feature-change conditions at 0 ms in Experiment 1). That is, new objects were more effective than changes in color or motion in signaling through the noise of the line-segment deletions that occurred at that time. This means that there are some differences between the salience of new onsets and feature changes that remain to be understood. What the present results make clear is that researchers' understanding will not be complete until temporal and spatial factors are given equal consideration.

Acknowledgments—This research was supported by a German Deutsche Forschungsgemeinschaft Grant (FOR480) and a Swiss National Science Foundation fellowship (8210-064661) to A. von Mühlenen and by a Natural Sciences and Engineering Research Council Discovery Grant (Canada) to James T. Enns.

REFERENCES

Abrams, R.A., & Christ, S.E. (2003). Motion onset captures attention. *Psychological Science*, *14*, 427–432.

Breitmeyer, G.G., & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review*, *83*, 1–36.

Cavanagh, P., Arguin, M., & Treisman, A. (1990). Effect of surface medium on visual search for orientation and size features. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 479–491.

Egeth, H.E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology*, *48*, 269–297.

Enns, J.T., Austen, E.L., Di Lollo, V., Rauschenberger, R., & Yantis, S. (2001). New objects dominate luminance transients in attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 1287–1302.

Enns, J.T., & Rensink, R.A. (1990). Scene-based properties influence visual search. *Science*, *247*, 721–723.

Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.

Folk, C.L., Remington, R.W., & Wright, J.H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 317–329.

Franconeri, S.L., Hollingworth, A., & Simons, D.J. (2005). Do new objects capture attention? *Psychological Science*, *16*, 275–281.

Franconeri, S.L., & Simons, D.J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics*, *65*, 999–1010.

Hillstrom, A.P., & Yantis, S. (1994). Visual motion and attentional capture. *Perception & Psychophysics*, *55*, 399–411.

Horstmann, G. (2002). Evidence for attentional capture by a surprising color singleton in visual search. *Psychological Science*, *6*, 499–505.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics*, *43*, 346–354.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, *24*, 175–219.

Lennie, P. (1993). Roles of M and P pathways. In R.M. Shapley & D.M.-K. Lam (Eds.), *Contrast sensitivity* (pp. 201–213). Cambridge, MA: MIT Press.

Posner, M.I., Snyder, C.R.R., & Davidson, B.J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*, 160–174.

Rauschenberger, R. (2003). Attentional capture by auto- and allo-cues. *Psychonomic Bulletin & Review*, *10*, 814–842.

Rensink, R.A., & Enns, J.T. (1995). Preemption effects in visual search: Evidence for low-level grouping. *Psychological Review*, *102*, 101–130.

Rensink, R.A., & Enns, J.T. (1998). Early completion of occluded objects. *Vision Research*, *38*, 2489–2505.

Theeuwes, J. (1990). Perceptual selectivity is task dependent: Evidence from selective search. *Acta Psychologica*, *74*, 81–99.

Theeuwes, J. (1995). Abrupt luminance change pops out; abrupt color change does not. *Perception & Psychophysics*, *57*, 637–644.

Todd, J.T., & Van Gelder, P. (1979). Implications of a sustained-transient dichotomy for the measurement of human performance. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 625–638.

Trick, L., & Enns, J.T. (1997). Clusters precede shapes in perceptual organization. *Psychological Science*, *8*, 124–129.

Turatto, M., & Galfano, G. (2000). Color, form and luminance capture attention in visual search. *Vision Research*, *40*, 1639–1643.

Turatto, M., & Galfano, G. (2001). Attentional capture by color without any relevant attentional set. *Perception & Psychophysics*, *63*, 286–297.

Yantis, S., & Egeth, H.E. (1999). On the distinction between visual salience and stimulus-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 661–676.

Yantis, S., & Hillstrom, A.P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 95–107.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601–621.

(Received 10/21/04; Accepted 12/13/04;
Final materials received 2/17/05)