Journal of Experimental Psychology:
Human Perception and Performance
2003, Vol. 29, No. 4, 779–792

0096-1523/03/$12.00 DOI: 10.1037/0096-1523.29.4.779

Visual Change With Moving Displays: More Evidence for Color Feature Map Inhibition During Preview Search

Melina A. Kunar
University of Wales, Bangor

Glyn W. Humphreys
University of Birmingham

Kelly J. Smith
The Medical Sciences Teaching Centre

Preview search with moving stimuli was investigated. The stimuli moved in multiple directions, and preview items could change either their color or their shape before onset of the new (search) displays. In Experiments 1 and 2, the authors found that (a) a preview benefit occurred even when more than 5 moving items had to be ignored, and (b) color change, but not shape change, disrupted preview search in moving stimuli. In contrast, shape change, but not color change, disrupted preview search in static stimuli (Experiments 3 and 4). Results suggest that preview search with moving displays is influenced by inhibition of a color map, whereas preview search with static displays is influenced by inhibition of locations of old distractors.

The real world is full of moving images, as objects move or as people move around objects. A person's ability to act on these objects, however, is fundamentally limited (e.g., Allport, 1993). People need means of selecting objects for action to optimize behavior, and this selection process needs to be sensitive not only to the spatial locations of relevant stimuli but also to temporal differences between old items that are no longer relevant for action and new items that are. Selection needs to operate in both space and time.

The Preview Benefit in Search

Recent studies of the spatiotemporal dynamics of visual selection have used variants of spatial search paradigms, but with the presentations of the stimuli being staggered over time. In their initial study, Watson and Humphreys (1997) adapted a standard color–form search task (target = blue *H*, distractors = green *H*s and blue *A*s) by presenting the distractors in one color as a preview prior to presenting the second set of distractors plus the target (when present). Despite the final display being the same as in the conjunction condition, Watson and Humphreys found that search in the preview condition was greatly facilitated, and, in terms of the search slope, the preview condition was as efficient as a single-feature condition in which the blue letters were presented alone. The temporal interval between the onsets of the preview and the search displays was sufficient for selection to be "blind" to the old stimuli.

Subsequent studies have demonstrated that this preview benefit in search occurs not only with static stimuli but also when the old (preview) and new (search display) stimuli move (Olivers, Watson, & Humphreys, 1999; Watson & Humphreys, 1998). However, unlike search with static items, preview search with moving stimuli appears to be contingent on color similarity between the old and new displays. For instance, Olivers et al. (1999) used displays just containing white letters, with the target and distractor letters consisting of the same basic features (horizontal and vertical line elements; the target was an inverted *T* and the distractors were upright and 90° rotated *T*s). With static stimuli, there was a clear preview benefit even though there were no color differences between the old and new displays. Search was more efficient when one set of distractors (upright *T*s) appeared before the second set and the target (rotated *T*s and an inverted *T*), compared with when all the distractors appeared simultaneously (see also Theeuwes, Kramer, & Atchley, 1998). With moving stimuli the preview advantage was abolished: Performance in the preview condition did not differ from performance when all the distractors were presented together. In this case, color segmentation between the displays facilitated search. Watson (2001) extended these results by showing that a preview advantage could be obtained with moving stimuli even when there were no color differences, but this was contingent on the old and new stimuli forming separate groups defined by common motion. In Olivers et al. (1999), the moving stimuli scrolled off the bottom of the screen and reappeared at the top, which may have disrupted the perception of common motion. When the wraparound procedure was prevented, to keep local

Melina A. Kunar, School of Psychology, University of Wales, Bangor, Gwynedd, United Kingdom; Glyn W. Humphreys, Behavioural Brain Sciences Centre, University of Birmingham, Edgbaston, Birmingham, United Kingdom; Kelly J. Smith, The Medical Sciences Teaching Centre, Oxford, United Kingdom.

This work was supported by a Biotechnology and Biological Sciences Research Council studentship to Melina A. Kunar and by a Medical Research Council grant to Glyn W. Humphreys.

Correspondence concerning this article should be addressed to Melina A. Kunar, School of Psychology, Brigantia Building, University of Wales, Bangor, Gwynedd LL57 2DG, United Kingdom. E-mail: m.kunar@bangor.ac.uk

motion relations between the stimuli constant, a preview advantage emerged. Thus, with moving displays, linkage by a common property (motion type or color) seems critical to the effect.

Accounts of the Preview Benefit

Several accounts can be put forward to explain the preview benefit in search. One proposal is that it reflects a form of *onset capture* of attention, when the new stimuli appear in the field. Consistent with this, Donk and Theeuwes (2001) found no preview benefit when the new items were isoluminant with their background. However, this account fails to explain several other aspects of the data. For example, the capture of attention by new onsets seems limited to about 4 stimuli (Yantis & Jones, 1991), yet the preview benefit can be found for up to 15 new elements (Theeuwes et al., 1998). In addition, evidence on carryover effects and on the effects of occlusion on the preview advantage all argue against this proposal. Gibson and Jiang (2001) and Olivers and Humphreys (2002) have shown that it is difficult to detect a new target if it shares its color with the old stimuli. Olivers and Humphreys, for example, used preview displays that differed in color from search displays. On some occasions, previews were omitted and the search display could have the same color as the preview on the preceding trial. In addition, there could be a secondary task present when the previews occurred. Prior work has shown that the preview effect is reduced under secondary task conditions (e.g., Watson & Humphreys, 1997). Olivers and Humphreys found that search on trials without a preview was slowed if the earlier preview was not presented along with a secondary task, and search was speeded when the earlier preview had appeared under secondary task conditions. This suggests that there was a negative carryover across trials based on the preview and the later search display having the same color. This negative color carryover effect was reduced under secondary task conditions, consistent with color-based inhibition then being lower. Such a negative carryover effect is difficult to explain in terms of new object capture (see Theeuwes, 1992). Kunar, Humphreys, Smith, and Watson (2003) also demonstrated that the preview advantage survived occlusion, when old items moved behind an occluder before reappearing along with the new stimuli. In contrast to this, the preview benefit was abolished if the old stimuli “blinked” off for a duration matching the occlusion period and then were represented with the new elements. The transient changes produced by blinking were matched by those produced by occlusion, yet occlusion had little effect on preview search. Thus the effect is not simply dependent on the presence of transient onsets in the new display, but rather it is influenced by some representation of the old items that survives occlusion and that helps participants guide their search to new stimuli (and not to the old, when they onset again with the new items).

A somewhat different account was proposed by Watson and Humphreys (1997). They suggested that in addition to any effects of attentional capture by new onsets, search of the new items could be prioritized by inhibitory filtering of old distractors, a process they termed *visual marking.* The argument for visual marking is consistent with other work indicating that a representation of the old items is important for preview search. Kunar, Humphreys, and Smith (2003) found that, if the preview items are only presented briefly before the search set, a preview benefit can still be elicited if participants see an earlier (“top-up”) presentation of the preview items. Thus the representation of the old items needs to be encoded (and, presumably, inhibited) before a search advantage occurs. Consistent with the argument for inhibition, Olivers and Humphreys (2002) and Watson and Humphreys (2000) have both demonstrated that it is difficult to detect a probe presented at the location of old items, when participants are engaged in search for new stimuli.

To explain the contrasting results with moving and static stimuli (e.g., Olivers et al., 1999), Watson and Humphreys (1998) suggested that inhibitory filtering of old distractors operated in a flexible manner. When the old items were static, they could be filtered on the basis of their locations. However, when the old items moved, location-based filtering would not be efficient. In these circumstances, filtering was based on an inhibition of a common attribute that linked the old items, such as their color (Watson & Humphreys, 1998) or their common motion (Watson, 2001). The evidence that color differences between old and new stimuli are not necessary to generate a preview effect fits with the idea of filtering by location. Nevertheless, the results on negative carryover effects also indicate that color may be used if it is available as a cue to segment old and new items, even in static displays (Olivers & Humphreys, 2002). For example, a filtering process based on “old” locations could be enhanced if the preview stimuli group (e.g., by common color), so that there can be “spreading suppression” between the elements (see Duncan & Humphreys, 1989, for this idea applied to spatial search). If suppression also spreads to new items sharing this color, then detection would be impaired (as has been found).

One other account of the preview benefit is that it stems from the application of FINSTs (“fingers of instantiation”) to the old stimuli that then enables these old stimuli to be ignored in search. Pylyshyn and colleagues (Pylyshyn, 1989, 1994; Pylyshyn & Storm, 1988) proposed that a limited number of FINSTs (up to four or five) can be applied in parallel to visual displays, with each FINST providing a spatial index that enables identification processes to access the information present at the indexed locations. The evidence used to support this idea is relevant to the present experiments. Pylyshyn and Storm (1988) presented observers with several white crosses at the start of each trial, and a subset of the crosses were designated as targets (these crosses underwent a transient brightening). All the crosses then moved in multidirections before stopping, and participants then had to discriminate which of the crosses were the original targets. Pylyshyn and Storm found that participants could keep track of about four or five crosses, which they attributed to the limited capacity of the FINST mechanism. To apply the idea of FINSTs to preview search, we would have to suggest that FINSTs assigned to the old stimuli can be used to direct search away from irrelevant locations (in addition to being used to direct attention to relevant locations, as in the original tracking experiments). It is not clear how this might be done. In addition, as we have noted, studies of preview search show that up to 15 old items can be ignored, and there is no evidence to suggest a discontinuity in search when more than 5 old items are present (Theeuwes et al., 1998; Watson & Humphreys, 1997). However, it could be argued that FINSTs are applied to groups of old items, so that capacity limits have not been apparent in prior studies. In the present study, we examine preview search with stimuli that move in multiple directions, making the displays similar to those used in original tracking studies of Pylyshyn and Storm (1988). Under these circumstances we would expect FINSTs to be applied to single items, so that capacity limitations become more evident.

Probing Preview Search With Visual Change

This article also uses visual change to examine factors that contribute to the preview benefit in search. As we have noted, some changes to old stimuli can disrupt the preview advantage (e.g., blinking the old stimuli off and then re-presenting them with the new items; Kunar, Humphreys, Smith, & Watson, 2003; Watson & Humphreys, 1997). However, other changes do not (e.g., when transient changes to the old items are attributable to occlusion; Kunar, Humphreys, Smith, & Watson, 2003). Watson and Humphreys (2002) examined the effects of a variety of visual changes on preview search with static items. Old items could change their shape, their luminance, or their color on the arrival of the new stimuli. Changes to the shapes of the old items disrupted the preview benefit (even when there were no global luminance changes at the locations of the old stimuli). In contrast, changes to the luminance or to the color of the old stimuli had little effect. To account for these data, Watson and Humphreys proposed that inhibitory filtering of old distractors operated on location maps sensitive to changes in shape but insensitive to changes in color or luminance (at least within some margin). The insensitivity of the effect to color is consistent with marking being ecologically important, because it may be robust to variations due to shadow or alterations in lighting in a scene.

In the present study, we extended this prior work on visual change to moving stimuli. Like Watson and Humphreys (2002), we examined the effects of shape and color change on preview search. If any form of inhibitory filtering differs with moving and static displays (Watson & Humphreys, 1998), then we can expect contrasting effects to emerge. In particular, and opposite to Watson and Humphreys (2002), color change may be very disruptive to performance and shape change may not, if moving previews are filtered by inhibition applied to a color map. This was tested in Experiments 1 and 2. Experiments 3 and 4 provided a replication of Watson and Humphreys (2002), using static displays, to confirm that the opposite effects do indeed occur as a function of whether the old and new stimuli move.

Experiment 1: Preview Search With Multiple Directions of Motion

Experiment 1 investigated whether a preview benefit in search occurs when stimuli move randomly around a screen. Previous research (e.g., Olivers et al., 1999; Watson & Humphreys, 1998) has shown a preview advantage with moving items; however, in these studies all stimuli have moved unidirectionally, maintaining a constant configuration in relation to each other. This experiment determined whether old stimuli moving in multiple directions can be ignored and, if so, how. We investigated whether featural properties, such as the shape and color, of the items are important or whether the old items can be ignored on the basis of their spatiotemporal characteristics (e.g., based on each item's trajectory alone). We also assessed how many moving items can be ignored. Pylyshyn and Storm (1988) found observers could track with attention up to about five items moving randomly, in multiple directions. We asked whether we are limited to ignoring about five old items moving randomly or whether preview search is not limited in this way.

Method

Participants

Twenty-four participants (4 male and 20 female) took part for the attainment of course credits. Their ages ranged from 18 to 33 years (mean age = 21.3 years), and they were all taken from a population of undergraduates at the University of Birmingham, Birmingham, United Kingdom. All of the participants had normal or corrected-to-normal eyesight.

Stimuli

All of the stimuli were produced by a Turbo Pascal computer program and were run on a Pentium computer with VGA graphics card. The dimensions of the letters and blocks in all of the experiments were 5 mm wide × 7 mm high. The distractor items were either blue *A*s or green *H*s, and the target item was always a blue *H*. However, the *H*s were programmed so that half the time the bars of the *H* were above the midpoint along the *y*-axis and the others had the bar below the midline. All letters appeared randomly within an invisible 12 × 12 matrix, of dimensions approximately 90 mm wide × 105 mm high.

There were four search conditions: a single-feature, a conjunction, and two preview conditions (a green *H* preview and a red block preview). In the conjunction and preview conditions, there were 4, 8, 12, or 16 items in total in the search displays. In the single-feature condition, the number of distractors was halved, providing a baseline measure of search efficiency when only blue distractor letters were present. In theory, if old items can be ignored with perfect efficiency in the preview condition, then slopes of the search functions even with a full set of distractors (old and new) should be the same as that with the half set of distractors (the single-feature baseline). In each condition, the target was always present.

Design and Procedure

In the experiment, each search condition was presented in a separate block (for single-feature, conjunction, and each of the preview displays). The experimental blocks each contained 80 trials (20 per display size). The order of the blocks was counterbalanced, and participants were given a practice session before each condition. The experiment lasted approximately 30 min.

In the single-feature condition, the fixation dot appeared initially for 1,000 ms. Blue items (blue *A*s and a blue *H*) then appeared and began to move smoothly across the screen. Each item could move up, down, left, or right to produce the appearance of randomly generated, "Brownian" motion. When each item reached the edge of the invisible matrix, they changed their vectors and began to move in the opposite direction, so that all items were visible on the screen for the duration of the trial. Participants were asked to maintain fixation until the blue items appeared and then to search, as quickly but as accurately as possible, for the blue *H*, responding to whether the bar was "high" or "low." Responses were made on a keyboard (either *m* or *z*) and were counterbalanced across participants. The conjunction condition was similar to the single-feature condition, except that green *H*s also appeared with the blue items.

In the green *H* preview condition, the fixation dot appeared for 1,000 ms. Green *H*s then appeared and began to move. After another 1,000 ms, moving blue items appeared on the screen, and participants were asked to search for the blue *H*. Again participants were instructed to keep their eyes on the fixation dot until the blue items appeared on the screen. The red block preview condition was similar except that, after the fixation dot appeared in the center of the screen for 1,000 ms, moving outlines of red rectangles appeared on the screen. After a further 1,000 ms the red blocks changed their shape and color, to become green *H*s that moved along the same trajectory. Moving blue items (blue *A*s and a blue *H*) were also added to the screen, simultaneously with this change. In each condition, there was a timeout display period of 10,000 ms. Examples of each display can be seen in Figure 1.

Results

Reaction times (RTs) more than three standard deviations away from the mean of each condition were eliminated. Figure 2 shows the mean correct RTs as a function of display size for Experiment 1. The error rates are given in Table 1, and Table 2 shows the descriptive statistics.

RTs

A two-way within-subjects analysis of variance (ANOVA), with condition and display size as its main variables, was used to compare the RTs for all conditions. There was a reliable main effect of condition, $F(3, 69) = 27.91$, $p < .01$, and of display size, $F(3, 69) = 128.54$, $p < .01$. The Condition $\times$ Display Size interaction also reached significance, $F(9, 207) = 9.36$, $p < .01$. There was a reliable linear trend for the green *H* preview condition, $F(1, 23) = 147.24$, $p < .01$, and also for the red block preview, $F(1, 23) = 91.65$, $p < .01$. Individual comparisons were then made for the main effects and interaction (calculated by subtracting the RT for the lowest display size from that of the highest display size) of each preview condition with the baseline conditions. The comparison with the single-feature baseline provides a test of performance if the old distractors had no impact on search. The comparison with the conjunction baseline provides a test of performance if the old distractors had a full impact on search. The statistics reported below have each been adjusted accordingly in line with Scheffé's post hoc statistical correction.

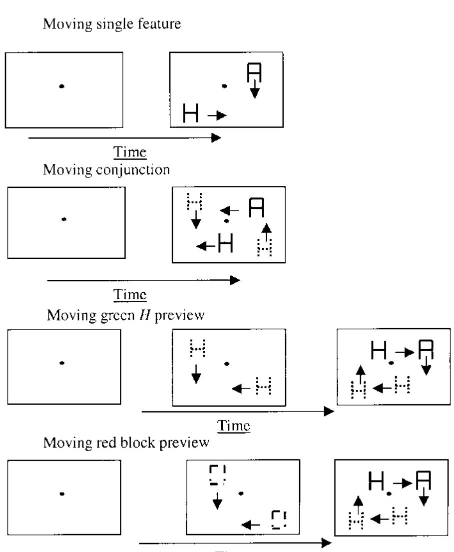

Figure 1. Example displays from Experiment 1. Solid lines represent blue; dotted lines represent green; mixed solid and dotted lines represent red.

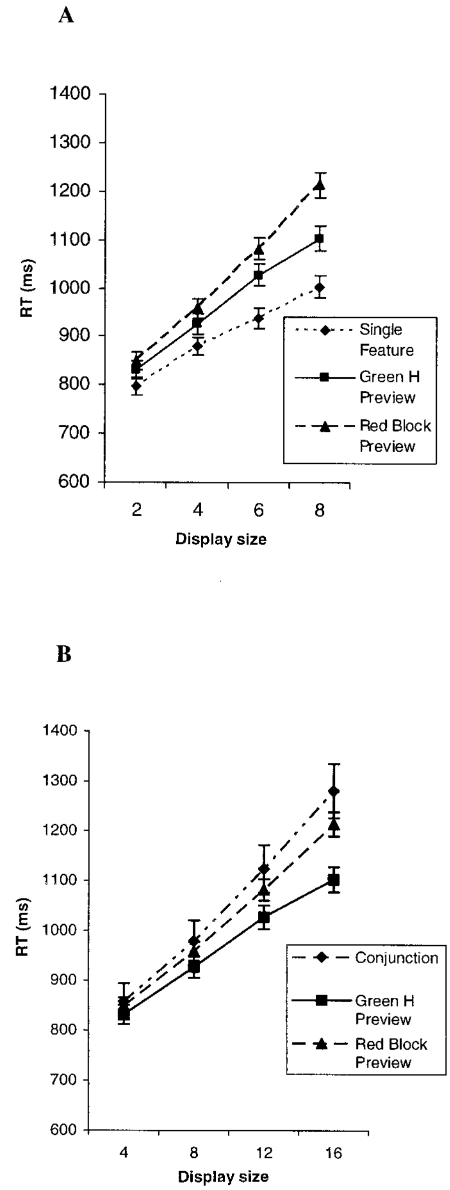

Figure 2. A: Mean correct reaction times (RTs) in Experiment 1 for the single-feature and preview conditions. B: Mean correct RTs in Experiment 1 for the conjunction and preview conditions. Error bars represent the percentage of error for each condition.

Green H *preview.* There was no main effect of condition between the single-feature and green *H* preview, $F(1, 69) = 3.45$, *ns*, but there was a main effect of display size, $F(1, 69) = 49.17$, $p < .01$. There was no reliable Condition $\times$ Display Size interaction of the single-feature and green *H* preview condition, $F(1, 92) = 2.02$, *ns*. Comparing the conjunction and preview condition, we found that both the main effects for condition, $F(1, 69) = 5.88$, $p < .05$, and display size, $F(1, 69) = 104.29$, $p < .01$, were significant. RTs in the conjunction condition also increased more

Table 1
Percentage of Errors in the Search Conditions Across Experiments 1–4

Experiment and condition	Display size 4	8	12	16
1				
Single feature	3.75	2.71	3.13	8.13
Conjunction	3.33	2.71	3.96	7.92
Green *H* preview	5.21	1.04	3.96	8.33
Red block preview	3.13	1.67	3.13	8.75
2				
Single feature	3.89	5.56	4.17	7.50
Conjunction	2.78	4.17	3.33	8.06
Green *H* preview	2.50	1.94	6.11	7.50
Red block preview	5.56	3.61	5.28	8.06
Green block preview	2.50	3.33	6.11	7.50
Red *H* preview	2.50	3.89	5.83	7.50
3				
Single feature	6.43	5.00	7.86	6.07
Conjunction	2.86	1.79	3.21	7.50
Green *H* preview	4.29	5.71	4.64	7.50
Red block preview	3.21	5.00	3.93	7.86
Green block preview	3.21	5.71	1.79	8.57
Red *H* preview	2.86	2.86	3.21	7.86
4				
Single feature	1.43	3.21	4.29	7.50
Conjunction	4.29	3.57	1.79	7.50
Green *H* preview	3.21	2.86	5.00	6.07
Green block preview	5.36	2.14	2.14	8.57
Green *Z* preview	1.79	1.79	3.93	6.07

with display size than those in the green *H* preview, $F(1, 92) = 9.98$, $p < .01$.

Red block preview. RTs in the single-feature condition were slower than those in the preview condition, $F(1, 69) = 11.12$, $p < .01$, and RTs increased with display size, $F(1, 69) = 70.46$, $p < .01$. It was also found that RTs in the preview condition increased more with display size than those in the single-feature baseline, $F(1, 92) = 11.97$, $p < .01$. There was no main effect of condition between the conjunction and red block preview, $F(1, 69) = 0.90$, *ns*; however, there was a main effect of display size, $F(1, 69) = 134.45$, $p < .01$. The Condition $\times$ Display Size interaction between the conjunction and the red *H* preview failed to reach significance, $F(1, 92) = 2.29$, *ns*.

Errors

The error rates were generally low in each experiment and followed the same trends as the RT data. These data were not analyzed further.

Discussion

Search performance was more efficient in the green *H* preview condition than in the conjunction search condition; overall RTs were reduced and effects of display size on search were less. This preview benefit occurred even though all the previewed items were moving along multidirectional pathways and thus could not be grouped by common motion. In addition, the old distractors could not be grouped by forming a constant configuration (see Watson, 2001). However, somewhat different results emerged when the old previews were red blocks that changed to green *H*s on the appearance of the new stimuli. There was no reliable difference between RTs in this condition and those in the conjunction condition. Hence there is no evidence that participants were able to prioritize their search to just the new stimuli in this condition, so that fewer items are searched than in the conjunction baseline. Critically, search itself was no more efficient even when previews were shown. This provides direct evidence that a change in the properties of the old items had an impact on search for the new stimuli.

So, how do these data fit with the three theoretical accounts of the preview effect that we outlined in the introduction: onset capture, inhibitory filtering of old distractors, or the inhibitory application of FINSTs? Examining the first account, we can explain the data using an onset capture theory. According to the onset capture view, the new stimuli should be selected in priority to the old items irrespective of whether the old items move in a single direction or in multiple directions. Therefore, it is not surprising that a preview benefit emerged in the green *H* preview condition. However, changes to the shape and color of the preview items, in the red block preview condition, may have led to the preview items being treated as new stimuli again (Watson & Humphreys, 2002) and so no preview benefit would emerge.

We can also explain the results in terms of inhibitory filtering. According to this account, a common property linking the preview items can be inhibited so that they become deprioritized for selection when the new stimuli appear. Because there was no common motion across the old set, the linking property here might be color (Watson & Humphreys, 1998). Providing the old items have a common color, and this is distinct from the color of the new set, then previews should be deprioritized even if the old stimuli move in multiple directions (as in the green *H* preview condition here). However, the color change in the red block preview condition should be disruptive to search because it will render ineffective any color-based inhibition of the old moving set. This idea that color is crucial to the present effects was tested in Experiment 2.

According to the third account, old items are ignored because they are tracked using a limited set of FINSTs, which may be used to direct attention away from stimuli in the preview. For the FINST

Table 2
Descriptive Statistics for the Search Functions in Experiment 1

Condition	Slope (ms/item)	Intercept (ms)	Mean RT (ms)	*SD* (ms)
Single feature	16.84 (33.68)	735.7	904.1	130.9
Conjunction	35.34	707.0	1,060.4	226.9
Green *H* preview (shape and color identical)	22.83	743.7	971.9	168.5
Red block preview (shape and color change)	30.44	721.4	1,025.8	231.9

Note. Number in parentheses corresponds to slope calculated with Display Sizes 2, 4, 6, and 8. RT = reaction time.

argument, it again should not matter if the old items move in multiple directions, provided capacity limitations on performance are not exceeded. We attempted to assess this here by varying the number of old items. If FINSTs were applied to a limited set of old distractors, we ought to expect a "dog leg" in the search functions; preview search should be efficient with up to four or so old items, but then effects of the number of old distractors should emerge (with the slope for this function matching that found in the conjunction baseline). There was no evidence for this, however. Also the finding that color and shape changes disrupt the preview advantage with moving stimuli contradicts the FINST account. According to Scholl and Pylyshyn (1999), FINSTs can be maintained across shape and color changes provided the spatiotemporal properties of stimuli are maintained. In the red *H* preview condition, the spatiotemporal properties of the previews were maintained, but the disruption still occurred. Therefore we suggest that the FINST account sits the least easily of the three with these data.

To test these different proposals, we separately assessed the effects of color and shape change in Experiments 2 and 3. Old items could either change their color (red *H*s to green *H*s), their shape (green blocks to green *H*s), or both their color and shape (red blocks to green *H*s, as in Experiment 1). For a new-onset–capture account, we might expect some effect of changing either the color or the shape of the old items when the new stimuli appear, if the changed properties lead to the old items being categorized as new by the visual system. However, there is no reason to think that there should be qualitative differences in the effects of the changes with moving and with static displays. Watson and Humphreys (2002) found that shape change was much more disruptive for preview search than color change, and this might be because "new shape" characterizes the new stimuli. For an onset capture account, the same effects should follow with moving elements. The inhibitory filtering account makes the opposite prediction. If old items are deprioritized by color-based inhibition, then changes to their color may be disruptive to search; on the other hand, there may be relatively little influence of shape change.

Experiment 2: Color Versus Shape Change With Moving Displays

Method

Participants

Eighteen participants (4 male and 14 female) took part for the attainment of course credits. Their ages ranged from 18 to 33 years (mean age = 23.1 years), and they were all taken from a population of undergraduates at the University of Birmingham. All of the participants had normal or corrected-to-normal eyesight.

Stimuli

The stimuli were identical to those used in Experiment 1, except that two more preview conditions were added. In one, moving outline green rectangles appeared on the screen, and in the other, moving red *H*s appeared on the screen. In both conditions the green rectangles or the red *H*s, respectively, turned into green *H*s when the blue items were added.

Design and Procedure

The single-feature, conjunction, preview, and red block preview conditions were exactly the same as Experiment 2. However, two other preview conditions were added. In the first new condition, a fixation dot appeared on the screen for 1,000 ms, before moving outlines of green rectangles were added. These moved in different directions for 1,000 ms before they turned into green *H*s. At the same time blue items were added to the screen and participants were asked to respond to the blue *H*. The second new preview condition was similar except that moving red *H*s appeared 1,000 ms after the fixation dot. After a further 1,000 ms these too turned into green *H*s and blue items were added. In both conditions participants were asked to keep their eyes on the fixation dot until the blue items appeared on the screen. Example displays can be seen in Figure 3.

Results

Figure 4 shows the mean correct RTs as a function of display size for Experiment 2. The error rates are given in Table 1, and Table 3 shows the descriptive statistics.

RTs

A two-way within-subjects ANOVA, with condition and display size as its main variables, was used to compare the RTs for all conditions. There was a reliable main effect of condition, $F(5, 85) = 13.44$, $p < .01$, and of display size, $F(3, 51) = 140.59$, $p < .01$. The Condition × Display Size interaction also reached significance, $F(15, 255) = 6.21$, $p < .01$. There was a reliable linear trend for the green *H* preview condition, $F(1, 17) = 92.19$, $p < .01$; for the red block preview condition, $F(1, 17) = 122.15$, $p < .01$; for the green block preview condition, $F(1, 17) = 85.64$, $p < .01$; and for the red *H* preview condition, $F(1, 17) = 86.12$, $p < .01$. Individual comparisons were then made for the main effects and interaction (calculated by subtracting the RT for the lowest display size from that of the highest display size) of each preview condition with the baseline conditions.

Green H *preview.* Considering the single-feature and green *H* preview conditions first, there was a main effect of condition, $F(1, 85) = 2.12$, $p < .05$, and of display size, $F(1, 51) = 31.93$, $p < .01$. There was also a significant Condition × Display Size interaction, $F(1, 102) = 6.30$, $p < .05$. RTs in the green *H* preview condition increased more with display size than those in the single-feature condition. More importantly, comparing the conjunction and green *H* preview conditions, there were main effects

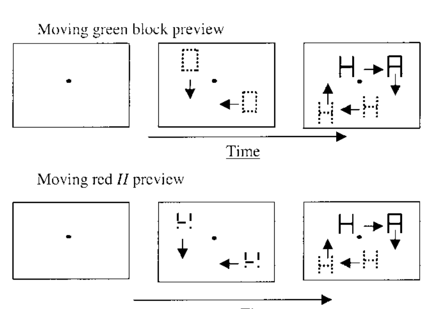

Figure 3. Example displays from Experiment 2. Dotted lines represent green; solid lines represent blue; mixed solid and dotted lines represent red.

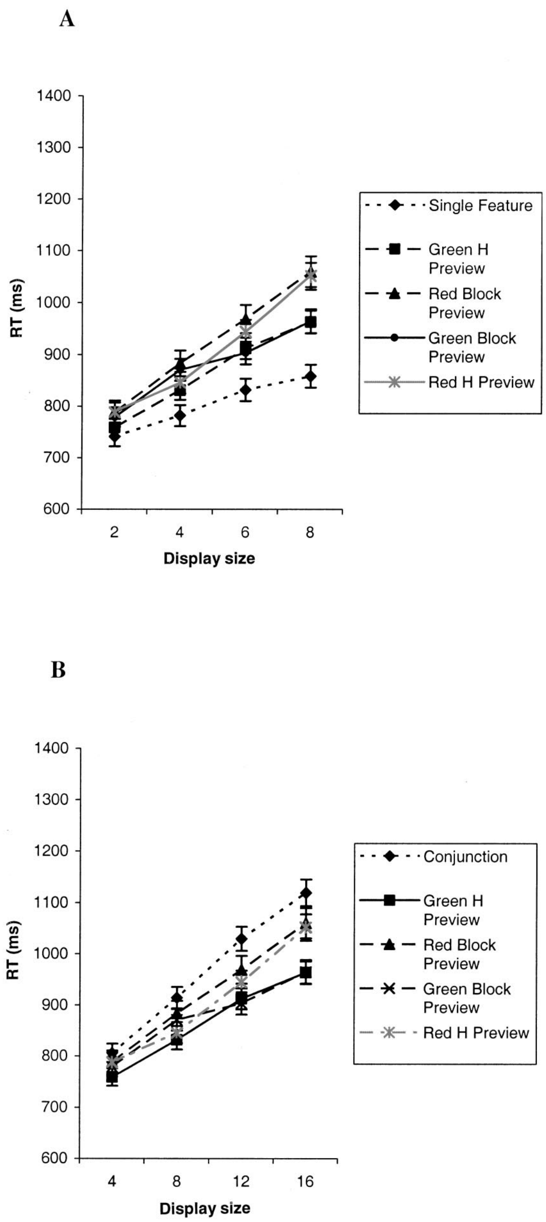

Figure 4. A: Mean correct reaction times (RTs) in Experiment 2 for the single-feature and preview conditions. B: Mean correct RTs in Experiment 2 for the conjunction and preview conditions. Error bars represent the percentage of error for each condition.

of both condition, $F(1, 85) = 5.47$, $p < .05$, and display size, $F(1, 51) = 82.94$, $p < .01$. There was also a reliable Condition × Display Size interaction, $F(1, 102) = 8.22$, $p < .01$. RTs in the conjunction condition increased more with display size than those in the green *H* preview.

Red block preview. RTs in the single-feature condition were slower than those in the preview condition, $F(1, 85) = 7.96$, $p < .05$, and increased with display size, $F(1, 51) = 46.53$, $p < .01$. It was also found that RTs in the red block preview condition increased more with display size than those of the single-feature baseline, $F(1, 102) = 19.54$, $p < .01$. There was no main effect of condition between the conjunction and the red block preview, $F(1, 85) = 0.95$, *ns*; however, there was a main effect of display size, $F(1, 51) = 105.42$, $p < .01$. The Condition × Display Size interaction between the conjunction and the red block preview failed to reach significance, $F(1, 102) = 0.919$, *ns*.

Green block preview. Considering the single-feature and green block preview condition, there was no main effect of condition, $F(1, 85) = 3.09$, *ns*, but there was one of display size, $F(1, 51) = 28.19$, $p < .01$. There was no significant Condition × Display Size interaction, $F(1, 102) = 3.85$, *ns*. Comparing the conjunction and green *H* preview conditions, there was a main effect of both condition, $F(1, 85) = 4.15$, $p < .05$, and display size, $F(1, 51) = 77.28$, $p < .01$. There was also a reliable Condition × Display Size interaction, $F(1, 102) = 11.67$, $p < .01$. RTs in the conjunction condition increased more with display size than those in the green block preview.

Red H *preview.* RTs in the single-feature condition were slower than those in the preview condition, $F(1, 85) = 5.78$, $p < .05$, and increased with display size, $F(1, 51) = 44.64$, $p < .01$. It was also found that RTs in the red *H* preview condition increased more with display size than those of the single-feature baseline, $F(1, 102) = 17.59$, $p < .01$. There was no main effect of condition between the conjunction and red *H* preview, $F(1, 85) = 0.17$, *ns*; however, there was a main effect of display size, $F(1, 51) = 102.55$, $p < .01$. The Condition × Display Size interaction between the conjunction and the red *H* preview failed to reach significance, $F(1, 102) = 1.41$, *ns*.

Color Versus Shape Change

As we were interested in the effect of a color change or a shape change on the preview benefit, a further three-way ANOVA, with main effects of shape change, color change, and display size, was conducted on the four preview conditions alone. There were reli-

Table 3
Descriptive Statistics for the Search Functions in Experiment 2

Condition	Slope (ms/item)	Intercept (ms)	Mean RT (ms)	*SD* (ms)
Single feature	10.01 (20.02)	703.4	803.5	132.1
Conjunction	26.39	703.1	967.0	206.0
Green *H* preview (shape and color identical)	17.35	692.7	866.2	150.6
Red block preview (shape and color change)	22.45	700.6	925.0	257.6
Green block preview (shape change)	14.70	732.2	879.2	200.0
Red *H* preview (color change)	22.19	685.3	907.1	194.8

Note. Number in parentheses corresponds to slope calculated with Display Sizes 2, 4, 6, and 8. RT = reaction time.

able main effects of color change, $F(1, 17) = 6.72$, $p < .05$, and of display size, $F(3, 51) = 139.04$, $p < .01$, but no reliable effect of shape change, $F(1, 17) = 0.56$, *ns*. None of the interactions involving shape change were significant. There was a significant interaction, however, between color and display size, $F(3, 51) = 5.99$, $p < .01$. RTs increased more with display size when a color change occurred in the preview benefit than when the color stayed the same.

Discussion

The results were clear. There was a benefit for search with old green *H* and green block distractors, when compared with RT data in the conjunction baseline.[1] This occurred even when the preview items changed their shape (i.e., in the green block preview condition). In contrast, search deteriorated if the old items changed their color. Performance with red *H* and red block previews did not differ from the conjunction baseline (in terms of search slopes). These data strongly suggest that color change disrupts the preview benefit in search with moving stimuli, whereas shape (and luminance) changes do not.

Previously, we noted that effects of color and shape change can be accommodated by both the new onset capture and the inhibitory filtering (visual marking) accounts of preview search (cf. Donk & Theeuwes, 2001; Watson & Humphreys, 1997). For the new onset capture account, there is little reason to think that the factors critical to the definition of the stimuli differ according to whether the stimuli are moving, so, following Watson and Humphreys's (2002) study with static items, we might expect shape change to have a greater effect than color change (and certainly if changes to transient onsets are important). We did not find this. Shape change had no effect on search efficiency, and color change was disruptive. The results do fit with the inhibitory filtering account, though, if this filtering operates by color when stimuli move (and by location when old and new stimuli are static). Color change should be disruptive when stimuli move, and changes to location information (through shape change) should be important with static displays (Watson & Humphreys, 2002). To provide a stronger test of whether the differences between moving and static stimuli do occur, in Experiment 3 we attempted to replicate the Watson and Humphreys (2002) result. For instance, it could be that the color changes here did generate variations in luminance that were stronger than those produced by the shape changes. If so, similar disruptive effects of color change should occur with static displays.

Experiment 3: Color Versus Shape Change With Static Displays

Method

Participants

Fourteen participants (1 male and 13 female) took part for the attainment of course credits or monetary payment. Their ages ranged from 19 to 34 years (mean age = 21.8 years), and they were all taken from a population of undergraduates at the University of Birmingham. All of the participants had normal or corrected-to-normal eyesight.

Stimuli

The stimuli were identical to those used in Experiment 2, except that the stimuli did not move but instead remained stationary in the field.

Design and Procedure

All conditions were exactly the same as those in Experiment 2; however, here all items were static, whether they were in the first or second presentation. Example displays can be seen in Figure 5.

Results

Figure 6 shows the mean correct RTs as a function of display size for Experiment 3. The error rates are given in Table 1, and Table 4 shows the descriptive statistics.

RTs

A two-way within-subjects ANOVA, with condition and display size as its main variables, was used to compare the RTs for all conditions. There were reliable main effects of condition, $F(5, 65) = 13.80$, $p < .01$, and of display size, $F(3, 39) = 111.64$, $p < .01$. The Condition × Display Size interaction was also reliable, $F(15, 195) = 6.80$, $p < .01$. Individual comparisons were then made between each preview condition and baseline condition.

Green H *preview.* Examining the single-feature and green *H* preview first, we found a significant effect of display size, $F(1, 39) = 23.63$, $p < .05$. However, there was no main effect of condition, $F(1, 65) = 0.57$, *ns*; neither was there a reliable Condition × Display Size interaction, $F(1, 78) = 3.68$, *ns*. When comparing the conjunction and green *H* preview, there was a reliable effect of both condition, $F(1, 65) = 6.10$, $p < .05$, and display size, $F(1, 39) = 65.01$, $p < .01$. Likewise, there was also a reliable Condition × Display Size interaction, $F(1, 78) = 9.95$, $p < .01$. RTs in the conjunction condition increased more with display size than those in the green *H* preview.

Red block preview. RTs in the single-feature condition were slower than those in the red block preview condition, $F(1, 65) = 9.62$, $p < .01$, and increased with display size, $F(1, 39) = 37.20$, $p < .01$. It was also found that RTs in the red block preview condition increased more with display size than those of the single-feature baseline, $F(1, 78) = 15.68$, $p < .01$. There was no main effect of condition between the conjunction and red block preview, $F(1, 65) = 0.02$, *ns*; however, there was a main effect of display size, $F(1, 39) = 86.17$, $p < .01$. The Condition × Display Size interaction between the conjunction and the red block preview failed to reach significance, $F(1, 78) = 1.24$, *ns*.

Green block preview. RTs in the single-feature condition were slower than those in the preview condition, $F(1, 65) = 3.98$, $p = .05$, and increased with display size, $F(1, 39) = 38.29$, $p < .01$. It was also found that RTs in the green block preview condition increased more with display size than those of the single-feature baseline, $F(1, 78) = 17.08$, $p < .01$. There was no main effect of

[1] The data show, however, that only the green block preview (which involved a shape change) was as efficient as the single-feature baseline. Although it is not clear why the green *H* preview did not share the same search advantage, the overall message that a shape change does not disrupt preview search remains unaffected.

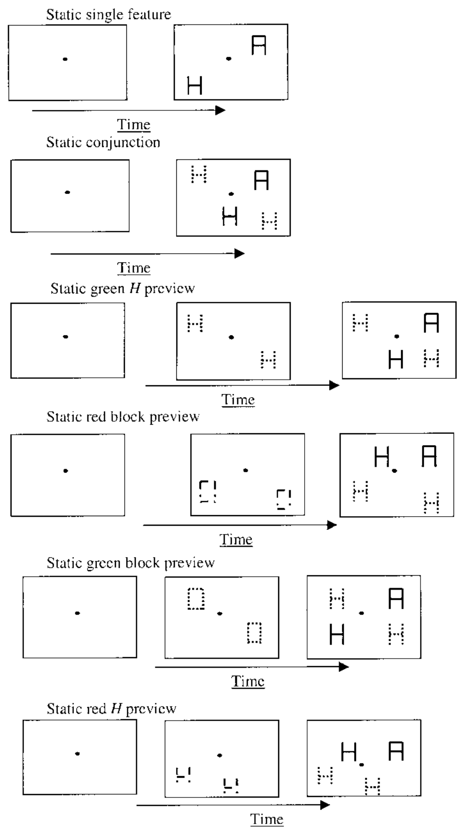

Figure 5. Example displays from Experiment 3. Solid lines represent blue; dotted lines represent green; mixed solid and dotted lines represent red.

condition between the conjunction and green block preview, $F(1, 65) = 1.52$, *ns*; however, there was a main effect of display size, $F(1, 39) = 88.56$, $p < .01$. The Condition × Display Size interaction between the conjunction and the green block preview failed to reach significance, $F(1, 78) = 0.88$, *ns*.

Red H *preview.* There was no main effect of condition between the single-feature and red *H* preview, $F(1, 65) = 1.03$, *ns*; however, there was a main effect of display size, $F(1, 39) = 24.13$, $p < .01$. The Condition × Display Size interaction was also significant, $F(1, 78) = 3.98$, $p < .05$. When comparing the conjunction and red *H* preview, we found a reliable effect of both condition, $F(1, 65) = 4.89$, $p < .05$, and display size, $F(1, 39) = 65.65$, $p < .01$. Likewise, there was also a reliable Condition × Display Size interaction, $F(1, 78) = 9.47$, $p < .01$. RTs in the conjunction condition increased more with display size than those in the red *H* preview.

Color Versus Shape Change

A further three-way ANOVA, with main effects of shape change, color change, and display size, was conducted on the four preview conditions alone. There were reliable main effects of shape change, $F(1, 13) = 13.70$, $p < .01$; color change, $F(1, 13) = 5.21$, $p < .05$; and display size, $F(3, 39) = 106.61$, $p < .01$. There was a significant interaction between shape and display size, $F(3, 39) = 12.27$, $p < .01$. RTs increased more with display size if the shape of the preview items altered. None of the interactions involving color change were reliable.

Discussion

The effects of visual change in this experiment went in the opposite direction to those found in Experiment 2 (with moving displays). Now, shape (and luminance) change was disruptive to search, and color change had no reliable effect. Comparing the RTs across display size of the green block preview and the red *H* preview to the conjunction baseline, we see that only the red *H*

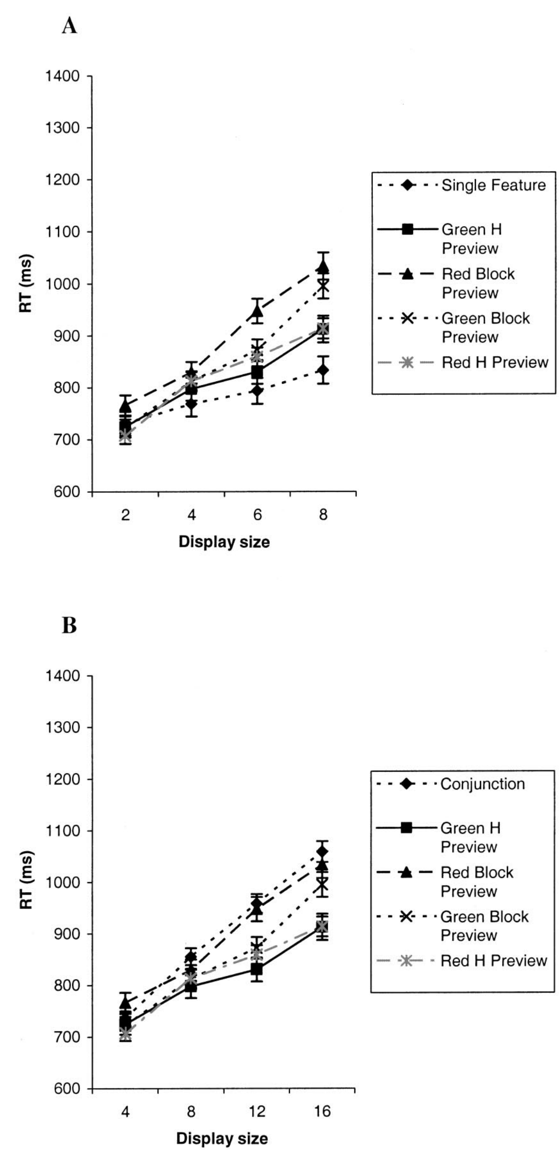

Figure 6. A: Mean correct reaction times (RTs) in Experiment 3 for the single-feature and preview conditions. B: Mean correct RTs in Experiment 3 for the conjunction and preview conditions. Error bars represent the percentage of error for each condition.

Table 4
Descriptive Statistics for the Search Functions in Experiment 3

Condition	Slope (ms/item)	Intercept (ms)	Mean RT (ms)	*SD* (ms)
Single feature	9.24 (18.48)	694.6	787.0	99.4
Conjunction	26.30	653.6	916.6	164.6
Green *H* preview (shape and color identical)	14.75	670.0	817.4	129.8
Red block preview (shape and color change)	22.86	682.9	911.5	166.7
Green block preview (shape change)	22.16	645.5	867.1	153.1
Red *H* preview (color change)	15.67	671.2	827.8	113.0

Note. Number in parentheses corresponds to slope calculated with Display Sizes 2, 4, 6, and 8. RT = reaction time.

preview showed a difference.[2] It is difficult to attribute these findings to the effects of luminance change being larger in the color than in the shape change condition because (a) the red and green colors were roughly isoluminant with one another, and (b) there is then no reason to expect opposite effects with static and with moving displays. The opposite effects are difficult to explain in terms of an onset capture account, but they do fit with an argument for inhibitory filtering of old distractors. With static items, filtering may be location based; changes to the shapes occupying particular locations disrupt any inhibition. However, with randomly moving items, inhibition may be color based; changes to the colors of the old items then impair search.

The data demonstrate that a shape change disrupts the preview benefit in static stimuli. However, the present stimuli also unwittingly combined a change in category type (i.e., the preview item changed from a geometric shape to a letter) along with the shape change. Although this should not have affected the results (as it is most likely that the local luminance change at the position of the old distractors, giving them a different identity, disrupts the preview benefit), we examined this in Experiment 4. Here the green block preview condition with static items was repeated alongside another condition involving a letter changing its shape to another letter (e.g., a green *Z* turning to a green *H*). This latter condition still involves a shape (and thus luminance) change of the preview items but does not involve a change of stimulus category. If it is the luminance and object identity change that disrupts the preview effect, then no benefit should again be found here. However, if the switch in category was critical, then a preview benefit should emerge because here the category of the old items was maintained.

Experiment 4: Within-Category Shape Change Using Static Items

Method

Participants

Fourteen participants (1 male and 13 female) took part for the attainment of course credits or monetary payment. Their ages ranged from 18 to 31 years (mean age = 20.5 years), and they were all taken from a population of undergraduates at the University of Birmingham. All of the participants had normal or corrected-to-normal eyesight.

Stimuli

The stimuli were similar to those used in Experiment 3 for the single-feature, conjunction, green *H* preview, and green block preview conditions. In the green *Z* preview condition, the dimensions of the *Z* fell within the area of 5 mm × 7 mm.

Design and Procedure

The single-feature, conjunction, green *H* preview, and green block preview conditions were exactly the same as in Experiment 3. In the green *Z* preview condition, a fixation dot appeared in the center of the screen for 1,000 ms followed by static green *Z*s. These remained on the screen for 1,000 ms before they changed their shapes to form green *H*s. At the same time static blue items (blue *A*s and a blue *H*) were added to the array. Participants were asked to keep their eyes on the fixation dot until the blue items appeared on the screen and were then asked to begin their search. Example displays can be seen in Figure 7.

Results

Figure 8 shows the mean correct RTs as a function of display size for Experiment 4. The error rates are given in Table 1, and Table 5 shows the descriptive statistics.

RTs

A two-way within-subjects ANOVA, with condition and display size as its main variables, was used to compare the RTs for all conditions. There were significant main effects of condition, $F(4, 52) = 11.65$, $p < .01$, and of display size, $F(3, 39) = 80.20$, $p < .01$. The Condition × Display Size interaction was also reliable, $F(12, 156) = 6.91$, $p < .01$. Individual comparisons were then made between each preview condition and the single-feature and conjunction baseline.

Green H *preview.* There was no reliable effect of condition between the single-feature and the green *H* preview condition, $F(1, 52) = 0.90$, *ns*; neither was the Condition × Display Size interaction reliable, $F(1, 65) = 0.41$, *ns*. However, the main effect of display size was significant, $F(1, 39) = 19.99$, $p < .01$. Comparing

[2] We again see here that when comparing the preview conditions with the single-feature baseline, the results seem less clear. Here the data from the red *H* preview condition were less efficient than those of the single-feature baseline. One particular explanation of this suggests that the preview benefit established here, although not disrupted, was less than if the color had not changed. This may be possible, but as the difference between the red *H* preview and the single-feature baseline was only marginal ($p = .05$), we do not want to put much weight on these findings. For more results showing that the effect of a color change on static preview search was minimal, see Watson and Humphreys (2002).

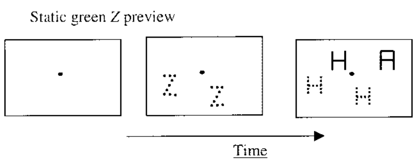

Figure 7. Example displays from Experiment 4. Dotted lines represent green; solid lines represent blue.

the conjunction and green *H* preview condition, we found a marginal effect of condition, $F(1, 52) = 3.25$, $p = .07$, and of display size, $F(1, 39) = 45.29$, $p < .01$. The Condition × Display Size interaction was also significant, $F(1, 65) = 9.81$, $p < .01$. RTs in the conjunction condition increased more with display size than those in the green *H* preview.

Green block preview. RTs in the single-feature condition were slower than those in the preview condition, $F(1, 52) = 3.98$, $p = .05$, and increased with display size, $F(1, 39) = 32.92$, $p < .01$. It was also found that RTs in the green block preview condition increased more with display size than those of the single-feature baseline, $F(1, 65) = 7.57$, $p < .01$. There was no main effect of condition between the conjunction and green block preview $F(1, 52) = 0.01$, *ns*; however, there was a main effect of display size, $F(1, 39) = 59.11$, $p < .01$. The Condition × Display Size interaction between the conjunction and the green block preview condition failed to reach significance, $F(1, 65) = 1.04$, *ns*.

Green Z *preview.* RTs in the single-feature condition were slower than those in the preview condition, $F(1, 52) = 5.35$, $p = .05$, and increased with display size, $F(1, 39) = 72.89$, $p < .01$. It was also found that RTs in the green *Z* preview condition increased more with display size than those of the single-feature baseline, $F(1, 65) = 9.50$, $p < .01$. There was no main effect of condition between the conjunction and green *Z* preview, $F(1, 52) = 0.19$, *ns*; however, there was a main effect of display size, $F(1, 39) = 67.17$, $p < .01$. The Condition × Display Size interaction between the conjunction and the green *Z* preview condition failed to reach significance, $F(1, 65) = 0.47$, *ns*.

Shape Change

Comparisons were made between the preview conditions to directly compare the effect of shape change. There was a reliable difference between the green H preview and the green block preview condition, $F(1, 65) = 4.5$, $p < .05$. RTs increased more with display size for the green block preview than for the green H preview. Likewise, RTs in the green *Z* preview increased more with display size than those of the green *H* preview, $F(1, 65) = 5.98$, $p < .05$. However, there was no reliable difference between the green block preview and the green *Z* preview, $F(1, 65) = 0.11$, *ns*.

Discussion

The data replicate the findings found in Experiment 3. Again it was shown that, when static displays are used, a shape change disrupts the preview effect and the search slopes of each condition resemble those in the conjunction baseline. Here the findings were extended to include shape changes that do not involve the preview item changing into an item from a different category (e.g., from a geometrical shape to a letter). In the green *Z* preview condition, the preview items remained letters throughout although they changed their identity and shape (from *Z*s to *H*s). Nevertheless, the data show that this change was sufficient for the preview effect to be erased. In fact, the search slope for the green *Z* preview was not different from the green block preview, suggesting that any shape change abolishes the preview benefit irrespective of whether there is a change in the category of the stimulus.

General Discussion

The results of the present experiments have shown the following. First, there is a preview effect in search when old displays

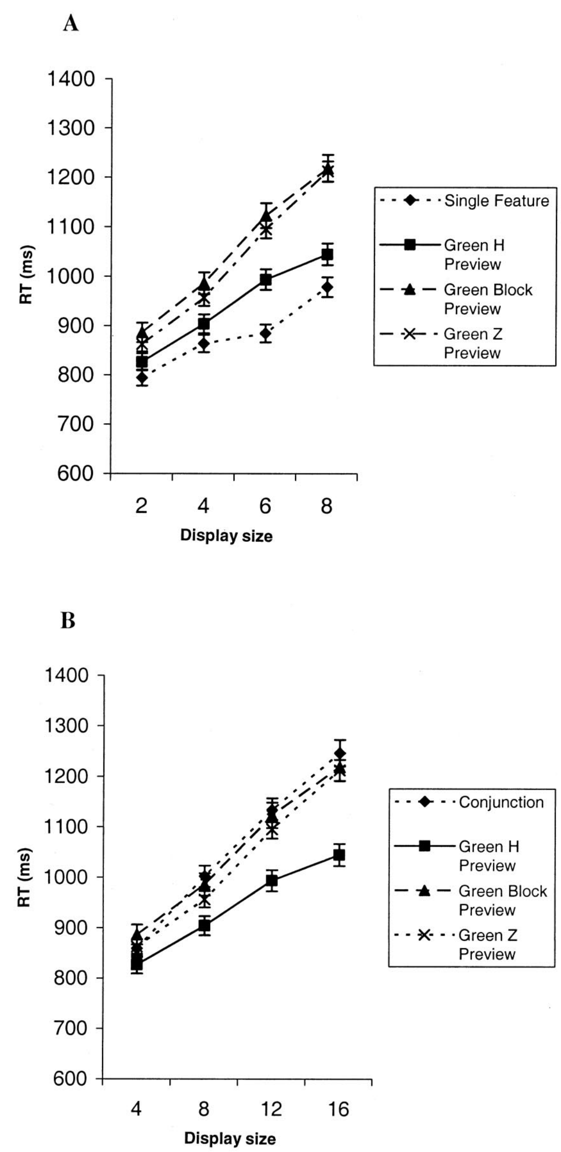

Figure 8. A: Mean correct reaction times (RTs) in Experiment 4 for the single-feature and preview conditions. B: Mean correct RTs in Experiment 4 for the conjunction and preview conditions. Error bars represent the percentage of error for each condition.

Table 5
Descriptive Statistics for the Search Functions in Experiment 4

Condition	Slope (ms/item)	Intercept (ms)	Mean RT (ms)	*SD* (ms)
Single feature	14.31 (28.62)	737.2	880.3	149.7
Conjunction	32.30	737.2	1,060.1	211.9
Green *H* preview (shape and color identical)	18.61	756.2	942.2	167.1
Green block preview (shape change)	28.33	770.1	1,053.4	286.3
Green *Z* preview (shape change)	29.73	734.4	1,031.6	200.0

Note. Number in parentheses corresponds to slope calculated with Display Sizes 2, 4, 6, and 8. RT = reaction time.

contain items that move in four separate directions. This effect did not seem to be limited to previews containing four or fewer items. There was an improvement in RTs with up to eight old and new items (at least). This goes against an account in terms of FINSTs. Second, spatiotemporal continuity of previewed items is not crucial for search. Search was disrupted when the old items changed their color and shape, even though their spatial continuity over time was preserved. This again argues against the FINST account of search, because this predicts little effect of either color or shape change when spatiotemporal contiguity is preserved (Scholl & Pylyshyn, 1999). Third, color but not shape change disrupts preview search with moving stimuli (Experiment 2). And, finally, shape change (both between and within category dimensions) but not color change disrupts preview search with static stimuli (Experiments 3 and 4; see also Watson & Humphreys, 2002).

FINSTs and Visual Marking

Pylyshyn (1989) proposed that items initially undergo a preattentive “tagging” process that binds an internal reference point, by means of a limited number of FINSTs, to objects in the visual display. This tagging can occur independently and in parallel for each object and can remain bound to them as they move through space. Only after objects have been indexed in this way can they undergo further processing, such as recognition and discrimination (and, presumably, also inhibition). Pylyshyn and Storm (1988) showed that, when items were being tracked for selection, only four or five FINSTs could be applied. Our failure to find any discontinuity in the search functions here runs counter to the FINST argument. When the old items move in multiple directions, it seems likely that FINSTs would be applied to individual stimuli, so that any resource limits would become apparent as the display size increased (Pylyshyn & Storm, 1988). None of our results are consistent with this. It is also not clear, in terms of a FINST account, why color change should be disruptive. The FINST proposal predicts little effect of color change, at least if FINSTs are applied to object files that are maintained on the basis of their spatiotemporal continuity (see Scholl & Pylyshyn, 1999). On this view, object files for the old items may be maintained even when the stimuli undergo a color change, because the items continue to move in the same direction and with the same velocity (cf. Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992). Contrary to this, a color change proved detrimental to the preview benefit with moving stimuli.

New Onset Capture

The present results are difficult also for an onset-capture account of the preview benefit. This account correctly predicts that a preview effect should occur irrespective of whether the old items move randomly, because the old items are largely irrelevant unless it so happens that changes in the old items introduce dynamic noise into the selection process for new stimuli. The effects of altering the properties of the preview stimuli can be attributed to this (e.g., due to luminance variations produced by the color and shape changes). However, there is then no reason to expect opposite effects of change with moving and static displays, as we found.

Inhibitory Filtering of Distractors

Watson and Humphreys (1997, 1998) proposed that, in addition to attention being prioritized to a small number of new onsets, selection of new stimuli could be enhanced by deprioritizing selection for old stimuli. They proposed that an inhibitory filtering process, termed visual marking, was responsible for this. On this account, static old items may be deprioritized by inhibitory filtering of their locations. Location-based inhibition would not be efficient with moving stimuli, which would instead be deprioritized by inhibition of some common property, such as their color (Olivers et al., 1999; Watson & Humphreys, 1998) or movement direction (Watson, 2001). The present results are consistent with these proposals.

With moving previews, color change is detrimental to performance, as would be expected if old moving items were ignored by color inhibition. There is no inhibition for the changed colors, and so the old items in the changed color are not deprioritized. The idea that there can be color-based inhibition in search was proposed by Treisman and Sato (1990), among others. They argued that inhibition of a color map, for distractors, could allow search to be selectively guided to targets in a designated color. This can account for instances in which search for color-form conjunctions is relatively efficient (see Wolfe, Cave, & Franzel, 1989). Here we propose that this process of color-map inhibition can be deployed even more efficiently when distractors in different colors are temporarily separated. It could be that time itself acts as a segmentation cue, adding to effects of color-map inhibition; alternatively, the time interval between the old and new items enables a color map representing the old items to be inhibited in advance. In either case, search of new items is facilitated when they differ in color and in terms of their temporal onset, relative to distractor items.

With static previews, shape but not color change is important (see also Watson & Humphreys, 2002). One way in which static items could be ignored in search is by inhibition applied to a location master map. It is likely that activation in this map is sensitive to large luminance changes, and changes within the map may reset any inhibition. Consistent with this, Watson and Humphreys (1998) found that salient changes in the movement of old items (e.g., when these items suddenly stopped moving) disrupted search. The same argument can be applied to explain the effects of changing the shape of old, static stimuli (Watson & Humphreys, 2002). Changes in shape (regardless of whether they alter the category of the stimulus) cause a large bottom-up luminance variation within the location master map, sufficient to reset inhibitory marking. Under these circumstances, the old items may be released from location-based inhibition, to compete with the new stimuli. In contrast to this, color changes on the whole would not generate sufficient enough luminance variation so that location-based inhibition is spared. Here the overall luminance change at a given location would be less if an object changed its color and kept its shape than if the object changed its shape, whereby previously unoccupied areas would be illuminated.

Indirect evidence for location-based inhibition in static visual marking comes from recent brain imaging studies. For example, Pollmann et al. (2002) conducted a functional magnetic resonance imaging study investigating which brain areas may be involved in generating the preview effect. They found that under these conditions the superior parietal lobe, needed to spatially localize items (e.g. Ungerleider & Mishkin, 1982), showed early activation, consistent with location-based inhibition. This may explain why local luminance changes are sufficient to remove visual marking whereas color changes are not. For example, the parietal lobe is innervated by the magnocellular stream, which is highly sensitive to luminance change. Here large luminance changes brought about by a change in shape will be detected by magnocellular pathways and thus reset marking within parietal regions. However, as color changes are not detected by these brain regions, they will not affect static preview search.

Flexible Filtering

Our data mesh with the idea that filtering processes in visual search can operate in a flexible manner, depending on the constraints of the task. With static displays, location-based processes are effective; with moving displays, color-based filtering is more efficient. The flexibility of filtering will be useful in the real world, in which changes in the properties of a stimulus may be correlated with different factors. For example, when items are moving they may often change their overall shape to be projected through space (e.g., a bird flapping its wings). Color-based inhibition would enable such stimuli to be ignored, despite the shape changes that are present. Color-based inhibition may also be important to minimize effects of the number of old distractors on search, if the old items can be linked by a common property. On this view, a flock of birds may be ignored as easily as a single bird, provided all the individuals shared the same inhibited color.

Summary

This study found that old items moving in multiple, random directions can be ignored in visual search. In addition, changes to the color or shape of old items are differentially effective, depending on whether the stimuli move or are static. We account for the results in terms of previews being subject to inhibitory filtering (marking), which can be applied flexibly to different properties of distractors.

References

Allport, A. (1993). Attention and control: Have we been asking the wrong questions? A critical review of twenty-five years. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience* (pp. 183–217). Cambridge, MA: MIT Press.

Donk, M., & Theeuwes, J. (2001). Visual marking beside the mark: Prioritizing selection by abrupt onsets. *Perception & Psychophysics, 93,* 891–900.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 433–458.

Gibson, B. S., & Jiang, Y. H. (2001). Visual marking and the perception of salience in visual search. *Perception & Psychophysics, 63,* 59–73.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. A. Davies (Eds.), *Varieties of attention* (pp. 29–61). San Diego, CA: Academic Press.

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

Kunar, M. A., Humphreys, G. W., & Smith, K. J. (2003). History matters: The preview benefit in search is not onset capture. *Psychological Science, 14,* 181–185.

Kunar, M. A., Humphreys, G. W., Smith, K. J., & Watson, D. G. (2003). When a reappearance is old news: Visual marking survives occlusion. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 185–198.

Olivers, C. N. L., & Humphreys, G. W. (2002). Visual marking under attentional blink conditions: More evidence for top-down limited capacity inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 22–42.

Olivers, C. N. L., Watson, D. G., & Humphreys, G. W. (1999). Visual marking of locations and feature maps: Evidence from within-dimension defined conjunctions. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 52*(A), 679–715.

Pollmann, S., Weidner, R., Humphreys, G. W., Olivers, C. N. L., Müller, K., Lohmann, G., et al. (2003). Separating distractor rejection and target detection in posterior parietal cortex—An event-related fMRI study of visual marking. *NeuroImage, 18,* 310–323.

Pylyshyn, Z. W. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial-index model. *Cognition, 32,* 65–97.

Pylyshyn, Z. W. (1994). Some primitive mechanisms of spatial attention. *Cognition, 50,* 363–384.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision, 3,* 179–197.

Scholl, B. J., & Pylyshyn, Z. W. (1999). Tracking multiple items through occlusion: Clues to visual objecthood. *Cognitive Psychology, 38,* 259–290.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics, 51,* 599–606.

Theeuwes, J., Kramer, A. F., & Atchley, P. (1998). Visual marking of old objects. *Psychonomic Bulletin & Review, 5,* 130–134.

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

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In

D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 49–86). Cambridge, MA: MIT Press.

Watson, D. G. (2001). Visual marking in moving displays: Feature-based inhibition is not necessary. *Perception & Psychophysics, 63,* 74–84.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104,* 90–122.

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 946–962.

Watson, D. G., & Humphreys, G. W. (2000). Visual marking: Evidence for inhibition using a probe-dot detection paradigm. *Perception & Psychophysics, 62,* 471–481.

Watson, D. G., & Humphreys, G. W. (2002). Visual marking and visual change. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 379–395.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419–433.

Yantis, S., & Jones, E. (1991). Mechanisms of attentional selection: Temporally-modulated priority tags. *Perception & Psychophysics, 50,* 166–178.

Received September 20, 2001
Revision received January 7, 2003
Accepted January 28, 2003 ■