NOT FINAL VERSION

A psychophysical investigation into the preview benefit in visual search

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Running Head: Psychophysics of Preview

In preview search, half of the distracters are presented ahead of the remaining distracters and the target. Search under these conditions is more efficient than when all the items appear together (Watson & Humphreys, 1997). We investigated the mechanisms contributing to this preview benefit using an orientation discrimination task. In a display of vertical Gabors (all equidistant from fixation) one Gabor (chosen at random) was tilted (left or right). When half the non-tilted Gabors were previewed, thresholds increased less with the number of Gabors. In a further experiment, orientation noise was added to some of the Gabors. When all Gabors were presented simultaneously, orientation thresholds for the target increased. The effects of noise on thresholds was reduced, however, when the noisy Gabors were presented as a preview. Furthermore, there was less effect of noise in the preview condition than when observers were cued to a subset of Gabors (with a cue presented prior to the Gabors, adjacent to their positions). Visual information can be effectively excluded from the previewed locations to a greater degree than when attention is directed to a subset of display items. The implications for understanding the mechanisms involved in preview search are discussed.

Keywords: Preview Benefit; search, attention, attentional cueing, distracter inhibition, spatial uncertainty

Introduction

In the cluttered visual environment it is often useful to be able to ignore information currently present so that one can orient to new visual information, for example, when waiting for a friend arriving at a railway station. This ability to restrict search to newer visual items has been explored using the preview search paradigm. In this procedure, one set of search distracters is shown as a preview, prior to the other items. Search in this preview condition is more efficient than when all the items appear together (Watson & Humphreys, 1997). This preview benefit on search shows that that the visual system can use temporal cues to guide selection of target items. How this occurs, however, is unclear. In the present study we measure whether visual noise can be excluded when it is a preview and compare the effects of the preview display to explicit cueing of the positions of the newer items in search. The experiments test whether attention capture by the newer items and cueing of attention to the positions of the newer stimuli are sufficient to account for the preview benefit in search.

Preview search was first examined in detail by Watson and Humphreys (1997). They argued that the preview benefit stemmed (at least in part) from inhibition actively applied to the locations of the previewed distracters – a process they termed visual marking. This argument was supported by studies investigating luminance increment detection at the locations of previewed items compared to at other display locations. When observers prioritise search for the target, luminance increments are harder to detect on previewed items than on the newer, non-previewed items (Watson & Humphreys, 1998) or at unoccupied 'neutral' locations (Humphreys, Jung Stalmann, & Olivers, 2004a;, see also Agter & Donk, 2005). These results suggest that sensitivity might be lower at previewed locations for previewed items. Alternative accounts of the preview benefit, however, do not require that the previewed distracters are inhibited. For example, the new, to-be-searched items may benefit from being temporally segmented from the old, previewed, items, enabling observers to attend directly to the newer items (Jiang & Wang, 2004). Further possibilities are that, attention is simply captured by the newer items on each trial in an automatic fashion (Donk & Theeuwes, 2001; Donk & Theeuwes, 2003), or that attention is biased by the preview towards empty locations where new items can appear.

These theories of preview search can be differentiated on various grounds. Unlike ideas of automatic attention capture or segmentation into older and newer temporal groups, proposals for active inhibition and for active directing of attention to empty locations hold that preview search depends upon the 'attentional set' of the observer. Data from probe dot detection studies and from fMRI studies of preview search are consistent with this. For example, the reduced detection for probe dots on old stimuli depends on participants prioritising newer items for search, and the effect is eradicated when probe dot detection is the primary task (Belopolsky, Theeuwes, & Kramer, 2005; Humphreys, Stalmann, & Olivers, 2004b; Watson & Humphreys, 2000). Poor detection on older items is not automatic. In fMRI studies, preview search is associated with enhanced activity linked to the preview display (Allen, Humphreys, & Matthews, 2006; Olivers, Smith, Matthews, & Humphreys, 2005; Pollmann et al., 2003). This enhancement occurs even in 'dummy' conditions when previews are not followed by the newer items, and when comparisons are made relative to when exactly the same displays appear but, in contrast to preview search, the previews are replaced on a majority of trials by displays where all the items occupy new locations in search (reducing the incentive to suppress the previewed stimuli). These 'active' accounts of preview search are also consistent with data on the effects of dual tasks performed during the preview period, which reliably decrease the preview benefit (Olivers & Humphreys, 2002; Humphreys, Watson, & Jolicoeur, 2002; Watson & Humphreys, 1997). In contrast, the same dual tasks have minimal effects if performed prior to baseline tasks, where the newer items are not preceded by a preview. This indicates that taking attention away from the preview, rather than attention away from the onset of the newer items, is disruptive to search. Probe detection studies also show that attention tends initially to actively engage on the preview, prior to attention being withdrawn (Humphreys et al., 2004b). This fits with data from ERP showing that early ERPs to probes at old locations can initially be boosted (Belopolsky, Peterson, & Kramer, 2005), whilst there is also a slower sustained ERP response found under preview conditions relative to when participants actively search preview items (Jacobsen, Humphreys, Schroger, & Roeber, 2002). Behaviourally the preview effect also has a relatively long time course, with previews of 400ms or longer being required to optimise search (Humphreys et al., 2004a; Watson & Humphreys, 1997). It should be noted however that Donk & Verburg (2004) have argued that the long time course of preview search is due to participants having to suppress a response to the onset of the new items. However, their study failed to include the appropriate baselines to test whether there was a preview benefit. Humphreys, Olivers, & Braithwaite (2005) used items that were not defined by onsets and included appropriate baselines to demonstrate the presence of a preview effect. They confirmed the long time course of the effect. Of course, automatic as well as active, attention-dependent processes may also contribute to search (Belopolsky et al., 2005). Indeed the small benefit that occurs even with relatively short intervals between the preview and newer items is consistent with a contribution from automatic capture and/or segmentation of the displays (cf. Humphreys et al., 2004a).

In the present study we examine these issues further using, for the first time, a psychophysical approach to measuring preview search. We measure orientation discrimination thresholds for targets in a preview search display with and without orientation noise, as well as comparing preview search to a condition where we explicitly cued the positions of the newer items in the search task. We ask whether preview search is effective in reducing the effects of noise from older items in search displays, and whether previews are more effective in this than cues to the locations of the items that would normally comprise the second display in the preview condition (a condition encouraging active attention to the locations of the critical search items).

According to signal detection approaches to visual search (see Verghese, 2001, for a review) each item in a search display provokes a noisy representation in the visual system. If the representation of the target does not overlap with the representations of the distracters then search for that target is easy and/or rapid. If, however, the representation of the target and the distracters overlap, then search for the target is difficult and/or slow. In particular, search should be difficult if both the target and the distracters fall within the bandwidth of the cell responsive to the target-defining property. Thus, difficult search may be produced either by varying the values of this defining property (i.e. adding distracter heterogeneity, or making the distracter values properties more similar to the target properties; see Duncan & Humphreys, 1989) or by presenting distracters spatially close to the targets (i.e: within the same receptive field). According to this framework, cueing a target can be beneficial because it reduces spatial uncertainty (Morgan, Ward, & Castet, 1998) allowing the visual system to focus its resources at the correct location. Attention can be directed to a target with either peripheral or central cues (Cheal & Lyon, 1991). Peripheral cues can automatically capture attention. Central cues, in contrast, allow for voluntary shifts of attention based on the information content of the cue. It has been proposed that peripheral cues lead to an improvement in performance via a rapid-acting but transient attention network (Cameron, Tai, & Carrasco, 2002), whereas central cues tend to improve performance via a slower but sustained processs (Lu & Dosher, 2000). The long time course of the preview benefit suggests that it may be driven by a slow, sustained type process (Watson et al., 1997) acting during the preview display

We can ask, therefore, whether previewing items improves performance by reducing uncertainty during the processing of the representations of the target. This reduction in uncertainty could come about in at least two ways. One is that the uncertainty concerning the target could be reduced by suppression of the previewed set of distractors. This would make it less likely that distractor locations, and the features of distractors in those locations, would compete for selection with the target. This would be consistent with the visual marking explanation of the preview benefit (Watson & Humphreys, 1997). Alternatively, there could be a reduction in spatial uncertainty if, on each trial, observers use the preview items as guides for selective attention, directing attention to the empty locations where the new (to be searched) items will appear. There is some work indicating that the benefit found from previews in search can be matched when participants are given a cue for selection, Peterson, Belopolsky, & Kramer (2003) used motion to indicate subset of distracters within a search display. Placeholders indicating the future locations of search items were briefly rotated. Participants were able to selectively attend to the items in the 'moved' locations (although not the converse, 'static' locations) and this produced a benefit similar to that found in preview displays. Peterson et al. (2003) suggested that this form of selective attention underlies the preview benefit. On the other hand, Watson et al (1997) found no benefit when observers were presented with place markers instead of a preview. The methods used in both studies would allow participants to attend to a subset of items – however they produced conflicting results. To investigate the different sources of uncertainty reduction we measure the effect of adding noise to the previewed items. If participants can exclude information from the previewed items this noise will not affect their performance in the preview condition. If the preview benefit depends on a slow suppressive process during the preview display then the ability to exclude noise will be greater for relatively long compared with relatively short preview durations. We then compare performance in a preview condition to performance when participants are explicitly cued to the locations of the newer items in the search displays. If the previewed items act to guide attention to the locations of the newer items, we should find equivalent results in the cueing and previewing conditions.

The present study

In the present study we ask how the preview benefit is operationalised in the visual system, and whether search over time requires a slow sustained selective attention process. We first replicate the preview benefit effect using an orientation discrimination paradigm. We then investigate how effectively information is excluded from the previewed locations by adding orientation noise to the previewed items. If the preview benefit acts by reducing the number of display locations contributing to performance, then noise in the preview should have a reduced effect on performance relative to when a full-set of distractors are presented along with the target. We found that this was the case. The benefit also increased as the preview duration increased, contrary to accounts in terms of temporal segmentation and attention capture by local onsets. Following this, we compared performance in the preview condition to that found when we explicitly cued either (i) items that were not the target or (ii) a group of items that included the target. Performance in the preview condition was better than either form of cueing condition, suggesting that selective attention directed to the locations of the newer search items cannot account for the preview benefit.

General Methods

Observers

There were 4 paid observers, all naïve to the purpose of the experiment. Two were experienced psychophysical observers (AGC, BA). All observers received one training session to familarise them with the procedures.

Equipment

Stimuli were presented on a Mitsubishi Diamond Scan 50n monitor driven by an ATO Rage 128y graphics card. The screen had a mean luminance of $26cd/m^2$. The experimental programs were written on an Apple Macintosh G3 computer using the Matlab environment and the Psychophysics Toolbox and Video Toolbox packages (Brainard, 1997; Pelli, 1997). The monitor had a resolution of 1024 x 768 pixels and a frame refresh rate of 85 Hz. One pixel on the screen was $0.27\ mm^2$. The screen was viewed binocularly at approximately 100cm from the screen, although no restraints were used. The non-linear relationship between the voltage supplied to the display and the output luminance was corrected using a look-up table. Prior to the experiment, luminance values at the screen were measured using a photometer. These were used to create a look-up table to voltages which corrected for the non-linearities of the screen such that an equal voltage increment led to an equal luminance increment at the screen.

Stimuli

The stimuli were arrays of Gabor micro patterns (see Figure 1). The spatial frequency of the modulation was 2.2 cycles/deg and of the envelope was 0.07 cycles/deg.

Vertically orientated Gabors were arranged in a circle, with a radius of 3 degrees around the fixation marker. The display contained 8, 12, 16 or 24 Gabors. When all the Gabors were presented at once they were positioned at regular intervals around the circle. One Gabor (chosen randomly) was tilted clockwise (p=0.5) or anticlockwise (p=0.5) of vertical. This tilted Gabor is termed the target. The orientation of the target item was varied using a method of constant stimuli such that the range of orientations used spanned the psychometric function when possible (i.e 5 to 10 levels between 0°and 64°). On preview trials, half of the Gabors were presented prior to the rest. The positions of the previewed Gabors were selected randomly from the full set of possible positions on that trial. After a duration of either 250ms (short preview) or 1000ms (long preview), the remainder of the Gabors were added to the display. The display then stayed on the screen for 250ms (or 500ms in one case, see Exp 1a). In the preview condition the target Gabor was always in the second group and never in the previewed group.

In some conditions, orientation noise was added to some of the non-target Gabors. In these cases the orientation of the modulation of the noisy Gabors was chosen from a normal distribution with mean at vertical and standard deviations of between 5° and 30°.

Insert Figure 1 here

Procedure

On each trial, the observers' task was to indicate whether the target Gabor was tilted clockwise or anticlockwise of vertical. Observers made a key-press to indicate their response and a further key-press to indicate they were ready to continue with the next trial. Observers were instructed to fixate at the fixation marker and were informed that since the target could appear at any location that fixating centrally was their best strategy. Each run of the experiment contained 20 trials at each of the levels of target tilt. Each observer performed a minimum of 3 runs for each condition. Observers typically completed 6 to 12 runs per session.

The data were averaged across runs, separately for each observer. The data were then fitted with a cumulative Gaussian function. The threshold performance was taken as the orientation required for the observer to correctly indicate the target's orientation on 75% of trials. 10,000 bootstrap replications of the fit were carried out (Foster & Bischof, 1997; Wichmann & Hill, 2001b; Wichmann & Hill, 2001a) which were used to estimate the goodness of fit of the Gaussian function and 95% confidence intervals (CIs) for the threshold estimate. When the fit of the cumulative Gaussian fell outside the 95% percentile of possible fits, more raw data were collected for that function. Where error bars are shown for individual data, it is these 95% CIs that are shown. Where results are reported for the group, error bars are +/- 1 standard deviation. ANOVAs were used, unless mentioned otherwise, for group statistics.

Results

Experiment 1: Preview Search and noise exclusion

There were three parts to Experiment 1. In the first part we established that orientation discrimination thresholds are related to the number of Gabors presented in our display. We then replicated the preview benefit (previously found in reaction time studies) using a psychophysical accuracy paradigm. Finally, we measured whether observers are able to exclude noise from previewed distractors.

Experiment 1a: Search Functions - Baseline

To establish the basic search performance for our observers, the tilt required to discriminate the orientation of the target was measured as the number of vertical non-target items was increased. All Gabors were presented simultaneously (i.e. no preview) for 250ms and 500msec. The mean thresholds across observers are shown in Figure 2. The orientation discrimination threshold increased with the number of non-target items ($F_{(1,5)}$=21.6 $p<0.0005$). This is in line with previous reports (e.g. Morgan et al., 1998). Although the presentation duration did not affect the magnitude of the effect of the number of distracters across the group ($F_{(1,3)}$=0.77 p=0.445), for the investigations into the preview benefit we chose the duration that produced the largest effect of the number of distracters for each observer individually. For AGC this was 500msec and for the other observers the presentation duration was 250ms.

Insert Fig 2 here

Experiment 1b: Preview Search Replication

Next we sought to replicate the performance benefit found in reaction time studies with our orientation discrimination paradigm. Performance when the previewed items were presented for 250ms and 1000ms prior to the remaining items is shown in Figure 3. For 3 observers, thresholds were lower in the preview conditions (diamonds and squares) than when all the items were presented simultaneously (crosses). For the remaining observer (CEG) when there was a long preview (squares) the threshold did not increase with the number of Gabors presented, suggesting that here too, previewing distracters improved performance. Over the group the increase in threshold with increasing numbers of distracters was less in the preview conditions than the non-preview conditions (paired samples t-test $t_{(3)}=3.7$ $p=0.03$ two tailed). This is similar to a slope effect in a reaction time study.

One of the features of the preview benefit in reaction time studies is that it shows a relatively long time course, with optimal search occurring with preview durations of 500ms or longer (Humphreys et al., 2004b; Humphreys et al., in press; Watson & Humphreys, 1997). The preview duration, however, did not have a clear effect on performance in this first experiment. Observers in this experiment undertook a larger number of trials than is typical in a reaction time study and it is possible that this extended practice could have reduced the impact of the preview duration by helping some observers to either encode and suppress items more rapidly or by tuning their detection earlier to the locations or onsets of the upcoming items.

Insert Figure 3 here

Experiment 1c: Adding Noise to the Previewed Gabors

To investigate what information can be excluded when some Gabors are previewed we added orientation noise (or jitter) to the previewed Gabors. Figures 4 and 5 show orientation discrimination thresholds (y axis) for the target in the conditions where orientation noise was added to half the elements. Although graphs of the group effects are shown all observers showed the same pattern of results. The magnitude of noise added to the previewed Gabors is presented on the x axis. These noisy Gabors were either displayed at the same time as the rest of the Gabors or 250ms or 1000msec earlier. As expected, when orientation noise was added to some distractors and these were not previewed, thresholds rose dramatically. If the preview benefit is due to perfect exclusion of information from the previewed items, then adding noise to these previewed items will not affect performance. Although several theories propose that previewed information is excluded, no previous studies have attempted to measure how well this is done.

When there was a total of 16 Gabors (Figure 4), previewing the noisy Gabors greatly improved performance and noise exclusion, for all observers, compared to when all the items were presented simultaneously (diamonds). An ANOVA with factors of condition (no preview, short preview, and long preview) and noise level (5, 10, 15, 20) showed a main effect of condition ($F_{(2,6)}=28.8$ $p=0.001$), noise level ($F_{(3,9)}=74.6$ $p<0.0005$) and a significant interaction ($F_{(6,18)}=10.5$ $p<0.0005$). A separate ANOVA comparing just the long and short preview conditions indicated that the long preview was significantly different from the short preview ($F_{(1,4)}=12.8$ $p=0.037$).

When there was a total of 24 Gabors (Figure 5) the advantage of previewing the noisy Gabors was much less obvious, however, the different conditions were still significantly different from each other ($F_{(1,4)}=8.2$ $p=0.04$, greenhouse gleisser corrected). The two different preview durations were also significantly different from each other ($F_{(1,4)}=7.9$ $p=0.05$)

Insert figure 4 here

Insert figure 5 here

Experiment 2: Preview vs Cueing

In Experiment 1, observers were able to exclude orientation noise from the previewed locations. Furthermore, they were better able to do this when the preview was presented for longer durations. The 250ms separation between the preview and the newer search items should be sufficient both to achieve temporal segmentation of the displays and to allow attention to be selectively captured by the new items (Yantis & Gibson, 1994). The improvement in performance with the longer preview, when noise was added to the distractors, suggests that some process additional to temporal segmentation and/or local onset capture contributes to performance. The reduced effects of distractor noise, for example, suggests that the preview enables participants to decrease the number of display locations being monitored. This might come about if observers use the preview items to guide their attention towards the empty locations that are subsequently occupied by the newer, search items (e.g., if participants attend to the gaps). This may not, however be adequate to explain the preview benefit and in Experiment 2 we test this idea. In Experiment 2 we measured performance in a similar task to Experiment 1, but using visual cues to indicate the locations of the items to be searched. If the preview benefit is solely due to attending to a smaller number of possible target locations, then the results for Experiments 1 and 2 will be similar. On the other hand, if the preview benefit involves more than reductions in uncertainty due to attending to fewer potential target locations, we will not be able to match the results of Experiments 1 to those in Experiment 2.

In Experiment 2 we tested whether observers could achieve the level of performance found in preview conditions when they were cued to attend to a subset of Gabors that included the target (Attend Adjacent). In a further condition, observers were told to direct their attention away from the 'cued' locations (Attend Gaps). The task in this latter condition is more similar to that in a preview condition – where participants must direct their attention away from the presented items, into the empty locations.

<u>Method</u>

The method was the same as Experiment 1, except for the details below. As in Experiment 1, the target Gabor (chosen randomly) was tilted clockwise (p=0.5) or anticlockwise (p=0.5) of vertical. Unlike in Experiment 1, all Gabors were presented simultaneously. Prior to the presentation of the Gabors, half of the possible Gabor locations were each cued by a small (diameter = 12 pixels, see Figure 1) dark square. These cues are adequate to direct attention to the items' locations at the durations used here (Cheal & Lyon, 1991). These squares were presented for 250msec or 1000msec prior to the presentation of the Gabors and remained present whilst the Gabors were on the screen. The meaning of these squares depended on the condition and was clearly explained to the participants. The order of conditions was counterbalanced between observers.

In the Attend Adjacent condition, observers were told that the target would always appear in one of the locations adjacent to the squares. The target always appeared in one of the locations adjacent to the cue-square. The rest of the cued locations contained upright Gabors. Orientation noise was added to remainder of the (uncued) Gabors. This condition tests whether an explicit cue can produce the same performance as previewing distracters.

In the Attend Gap condition observers were told that the target would always appear in one of the locations between those indicated by the square. The target never appeared in one of the locations adjacent to the squares. The rest of these locations contained upright Gabors. Orientation noise was added to the remainder of the Gabors.

Results and Discussion

Orientation thresholds for the target item are plotted for each level of noise in the unattended Gabors for the Attend Gap, Attend Adjacent and preview (re-plotted from Experiment 1) conditions in Figure 6. At the longer preview duration (6a) there was a significant effect of condition ($F_{(2,6)}$=5.1 p=0.05) as well as a significant effect of the level of noise ($F_{(3,9)}$=5.6 p=0.02). Thresholds were lower in the preview condition than in the either of the cued conditions (preview vs Attend Adjacent $F_{(1,3)}$=21.8 p=0.02); preview vs Attend Gaps $F_{(1,3)}$=8 p=0.067, borderline significant, and individually significant for 3 of the 4 observers, Attend Gaps and Attend Adjacent were not significantly different from each other $F_{(1,3)}$=1.5 p=0.31). At the shorter preview duration (6b), there was no significant effect of condition ($F_{(2,6)}$=1.2 p=0.37).

With short presentation durations, there was only a small and unreliable advantage for the preview condition compared to the cue conditions. With longer durations, however, the preview had a greater benefit than the cues, even though the preview presented less accurate information about the locations of the up-coming search stimuli. It seems that even when explicitly cued as to the location of the target, observers cannot match the performance they can achieve with a preview search display.

Insert figure 6 here

General Discussion

This study aimed to investigate whether noise can be excluded from previewed items and whether explicit cues to selective attention can match the benefit from a preview display. In Experiment 1, observers were able to exclude orientation noise at the locations of the previewed items. They were also better at excluding noise when the initial distractors were previewed for longer. In Experiment 2, we compared performance in the preview condition with performance when critical display items were cued. With the short preview duration, performance with the explicit cues was not significantly different from that with the preview. At the longer duration, however, performance in the preview condition was better than the cued conditions.

Attention Mechanisms

Excluding visual noise and spatial uncertainly reduction are likely to involve voluntary, sustained, attention mechanisms (Lu & Dosher, 2004; Lu et al., 2000; Morgan et al., 1998; Watson et al., 1997). Consistent with these mechanisms, observers were able to effectively exclude orientation noise from the previewed items and were even better at doing this with longer previews. One question, then, is whether there is sustained attention to the locations of the forthcoming (newer, search) items, or away from the preview items (e.g., suppression of the previewed stimuli). If attention to new locations were critical, then observers should receive the same benefit from previews and from cues allowing then to exclude an equivalent number of potential target locations. Experiment 2 examined performance when there were cues to the target (plus stimuli equivalent to the newer distractors in preview search), and also when the cues were to distractors (i.e., when the cues indicated where not to attend). Preview search was more efficient than both of these cases, at the longer preview duration. This slowly evolving benefit strongly suggests a role for a slow sustained inhibitory process, biasing search away from the old stimuli.

Against this idea, it could be argued that the preview was more effective even than the condition where the target's location was cued because the cues were only adjacent to, and not at the exact locations of, the critical stimuli. Furthermore, the onsets of the newer items could have helped direct attention to a sub-set of the display in the preview condition. The adjacency argument seems unlikely, though, given that previews occupied distracter locations, and so should have been even less effective than the cues in directing attention to the locations of the newer items. In addition, both this account and the idea of cueing attention by onsets fail to explain the selective improvement in preview search over time, as the preview duration increased. This is not to say, though, that processes such as onset capture by new items (and also temporal segmentation) do not contribute to preview search – they may, but they are insufficient, to explain our results as both onset capture and temporal segmentation ought to operate at both preview durations (Yantis & Gibson, 1994), yet here there were consistently greater benefits at longer durations.

Relationships to existing theories of preview search.

We suggest that the effects of the preview duration here are consistent with a relatively slow acting process in which noise associated with distractors is excluded from selection. This fits with an account in terms of visual marking (Watson & Humphreys, 1997) rather than automatic temporal segmentation and/or attention capture by local onsets. It is also consistent with prior psychophysical studies where, noise exclusion processes have been linked with a sustained attention mechanism (Lu et al., 2004; Lu et al., 2000; Watson et al., 1997). Other data indicate that performance under preview conditions is dependent on the attentional set of the observer (see Humphreys et al., 2004b; Watson & Humphreys, 2000, for behavioural evidence; see Allen et al., sub.; Pollman et al., 2003, for fMRI results), and the preview benefit can be disrupted when attention is distracted from the preview (Olivers et al., 2002; Humphreys et al., 2002; Watson & Humphreys, 1997). These last results suggest that the preview benefit is not simply due to automatic processes but instead involves active biases.

There is other evidence against onset capture providing a full account of performance. In particular, onsets are not necessary to generate the preview benefit in search, and evidence of onset capture is not sufficient to produce a benefit. Thus preview benefits can occur even when the previewed and newer items are not defined by onsets (Humphreys et al., 2004a; Humphreys et al., in press), and patients with parietal lesions can show evidence of onset capture without a preview benefit (Humphreys, Olivers, & Yoon, 2006). We suggest that a slow acting process of visual marking, in which distractors are excluded from selection, is needed to account for the overall pattern of data, including the results on noise exclusion here.

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Figure Legends

<u>Figure 1:</u> Illustrations of stimuli used in experiments. Left column of displays illustrates the first image seen by participants and the right column shows the final (second) display shown.

<u>Figure 2:</u> Mean thresholds for identifying the tilt (clockwise or anti-clockwise) of a single tilted Gabor, patch amongst different numbers of vertical Gabors. Squares show data from 500ms presentation, triangles from 250ms presentation. Error bars show +/- 1 standard deviation.

<u>Figure 3:</u> The effect on orientation thresholds, for four individual observers, for the target Gabor, of presenting half of the non-target items as a preview. Results for search without preview are shown with solid line and crosses; for when there was a 250ms preview with diamonds and dashed grey line and for 1000ms preview with squares. The x-axis title refers to the total number of items. Error bars are 95% confidence intervals.

<u>Figure 4:</u> Average orientation discrimination thresholds for a target Gabor when half the non-target Gabors have jittered orientations. 8 'noisey' Gabors are either presented at the same time as 7 vertical non-target Gabors and the target (diamonds) or they are presented earlier than the rest of the display with a preview duration of 250ms (triangles) or 1000ms (open squares). Error bars are group standard deviations.

<u>Figure 5</u>: As figure 5 but for displays containing a total of 24 Gabors. Error bars are group standard deviations. For clarity of display of the data points the y-axis cuts off the top of two of the error bars. These error bars end at 89° and 66° (external noise =10 and 20 respectively). These large estimates reflect the difficultly of estimating thresholds in noise with high levels of orientation variation

<u>Figure 6:</u> Cuing experiment. Average orientation thresholds for the target Gabor amongst 15 distracter Gabors as a function of the amount of orientation noise in some of the distracter Gabors. In the Attend Gaps condition (diamonds) the target was presented away from the areas that were cued and orientation noise was added to the Gabors adjacent to the cue-squares. In the Attend Adjacent (triangle), the target was in the areas adjacent to the cue-squares (and orientation noise was added to the Gabors that were not next to a cue-square). These conditions are compared to when orientation noise was added to previewed Gabors (crosses). (a) 250ms preview or cue duration. (b) 1000ms preview or cue duration. Error bars are +/- 1 standard deviation.