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Previewing distracters reduces their effective contrast

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Abstract

In a visual search task, when half the distracters are presented earlier than the remainder ('previewed'), observers find the target item more efficiently than when all the items are presented together—the preview benefit. We measured psychometric functions for contrast increments on Gabors that were presented as a valid preview for subsequent search, and when they were a non-predictive (dummy) preview. Sensitivity to contrast increments was lower (rightwards shift of the psychometric function) on valid, compared to dummy previews. This is consistent with an account of the preview benefit in terms of active inhibition, equivalent to lowering the contrast of previewed items that are being actively ignored.

Keywords: Attention; Contrast sensitivity; Inhibition; Marking; Visual search

1. Introduction

It is useful to be able to ignore the visual information currently present so that new information arriving at the eye can be attended efficiently. The ability to ignore old information has been investigated using the preview procedure in visual search experiments. In this procedure, one set of distracters is shown as a preview, prior to the other items. Search is then more efficient (in terms of reaction times and accuracy) than when all the items appear together (Watson & Humphreys, 1997). This preview benefit indicates that the visual system can use the temporal separation of the first and second set of items to guide selection of a target. How this occurs, however, is unclear. Here we investigate how the representation of an item changes when it is presented as a preview, compared to when it is not.

The preview benefit may stem (at least in part) from inhibition applied to the locations of the previewed distracters or 'visual marking' (Watson & Humphreys, 1997). Alternative accounts of the preview benefit suggest that previewed items are not suppressed. For example, the new, to-be-searched items may benefit from simply being temporally segmented from the old, previewed, items, enabling observers to attend directly to the newer items (Jiang & Wang, 2004), or attention may be automatically captured by the newer items on each trial (Donk & Theeuwes, 2001, 2003) or it may be biased towards empty locations where new items can appear.

The visual marking account of preview search was initially supported by studies measuring luminance increment detection at the locations of previewed items compared to detection at other display locations, whilst participants also performed the preview search task. Accuracy for detecting a luminance probe adjacent to the previewed items was lower than accuracy for detecting a similar probe near a newer item (Watson & Humphreys, 2000). Similarly, reaction times are slower to luminance increments added to the previewed, compared to the newer, items (Braithwaite, Humphreys, & Hulleman, 2005).

In these cases luminance increment detection was performed after the onset of the second display on each trial and thus it is difficult to discriminate between accounts which require a change in the representation of the previewed items (such as visual marking) and those that propose only enhancement of the newer items. To determine whether the previewed items are inhibited (or suppressed)

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independent of processes acting on the newer items, it is necessary to test during the preview period.

When measuring detection performance during the preview presentation, by definition, only the previewed items are displayed. It is important, therefore, to balance the local luminance lateral interactions in any luminance detection task. Humphreys, Jung Stalmann, and Olivers (2004) presented equiluminant search items on a luminance defined grid, such that the local luminance environment was equivalent around both previewed items and empty locations. Accuracy was lower for luminance increments on previewed items, compared to empty grid locations. Agter and Donk (2005), on the other hand, measured reaction times to luminance increments at the locations of previewed and empty locations after the offset of the previewed items. They found slower reaction times to probes at previewed locations when the previewed items were a different colour to the newer items, but not when there was no colour difference. Whilst this is consistent with inhibition based on colour it does not require inhibition based on the previewed items or locations. However, it is also possible that the offsetting of the display interfered with the maintenance of the inhibition.

In the present study, we measured detection of a contrast increment (creating a local luminance increment and decrement) during the preview display. We compared performance where the first items presented are a valid preview (as in the above studies), which restricts the possible target locations, with to that then the first display is identical but not predictive of the target location (dummy preview). This condition has not been included previously in studies using probe detection to assess attentional allocation during preview search (though see Olivers et al., 2005; Pollmann et al., 2003, for the use of this condition in studies using fMRI to examine the neural substrates of preview search). The dummy preview display matches the displays used in the preview but under conditions where participants may be less actively biased against the previewed locations. Furthermore, we compare conditions where participants perform both search and increment detection with a condition where they perform only increment detection. In many previous studies (Agter & Donk, 2005; Braithwaite, Humphreys et al., 2005; Watson & Humphreys, 2000) the probe task has been interleaved with the search task. Although participants performed only one task on each trial, across trials participants performed two tasks. Using our methods we are able to separate the impact of dual tasks on performance from the effect of the preview. Finally, we measure the full psychometric function for detection of the contrast increment. Although, reduced percent correct detection (or slower reaction times) of probes at previewed locations does support some sort of change in responsiveness at old locations, it does not discriminate between different accounts of this change (see Cameron, Tai, & Carrasco, 2002). Different accounts can be separated by an analysis of the full psychometric function. For example, a change in the slope of the psychometric function indicates a differential change in responsiveness at higher and lower visibilities or a change in the amount of noise in the system; A leftwards (or rightwards) shift in the psychometric function, however, is likely to reflect a general change in sensitivity, similar to a change in contrast of the stimulus; Finally, a change in the maximum percent correct, is likely to reflect changes in response gain in the system. All these possibilities were tested here.

2. Experiment 1: Effect of previewing distracters on orientation discrimination thresholds

Previous studies have shown that previewing some of a set of distracters improves orientation thresholds (Allen & Humphreys, 2007). The displays used here were the same as those used by Allen and Humphreys (2007) and included a standard preview condition (half the distractors appear before the second set of items, and remain in their original locations when the new items, including the target appear) and a full set baseline condition in which all the items appear together. In addition, a new condition was added in which the search display was preceded by an invalid, or dummy, preview. This dummy preview display contained the same number of items as the preview display. However, unlike in the preview condition, the target can be in any location in the subsequently presented search display. These different conditions are blocked and the participants know which condition they are doing. Thus, in the preview condition they can exclude the previewed items and locations from search however in the dummy preview condition they should not do so. Kunar and Humphreys (2006) have reported that there can be some benefits for search from presenting such items prior to the search display, perhaps from passive processes. However, relative to the full set baseline, the benefits should be strongest in the standard preview condition, when the locations of the previewed items are also kept constant. Hence we predict an ordered pattern of search performance in which, in terms of the effects of display size on orientation discrimination thresholds, full set > dummy preview > standard preview.

2.1. Methods

2.1.1. Participants

There were 20 participants who all had normal or corrected to normal vision and who received a small fee in return for participation.

2.1.2. 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 26 cd/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

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by 768 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 100 cm 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.

2.1.3. Stimuli

The stimuli were arrays of Gabor micro patterns (see Fig. 1a). All Gabors had a modulation frequency of 2.2 cycles/deg and Gaussian envelope sigma of 0.07°. Gabors were arranged in a circle (radius 3°) around the fixation marker. In common with the majority of prior visual search and preview studies, when there were more display items, they were more densely presented. In the full set condition, all Gabors appeared at once (for 200 ms). There were two display sizes, containing a total of 16 or 24 Gabors. In the preview and dummy preview conditions, half these Gabors were presented prior to the rest in a preview display for 1000 ms followed by the remainder of the Gabors (200 ms). Simultaneously with the presentation of the second group of Gabors, one Gabor was tilted clockwise ($p = 0.5$) or anticlockwise ($p = 0.5$) of vertical. The tilt of the target item was varied (using a method of constant stimuli) such that performance went from chance to perfect (typically five levels of tilt).This tilted Gabor was the search task target. In the valid preview condition the target Gabor was randomly chosen from the second group and was never in the previewed group, this is shown in Fig. 1a. In the dummy preview condition, the target could be one of the second group or one of the first group could change into the target (with equal likelihood). When the target was one of the first group participants may have seen a brief illusory motion as a vertical item became tilted. This would have occurred simultaneously with the presentation of the remaining items. In practice the multiple local luminance increments and decrements from the multiple new items were far more salient than the motion cue.

2.1.4. Procedure

On each trial, participants indicated with a button press whether the target item was tilted to the left or right. A second button press indicated that they were ready to proceed with the next trial. In the preview condition, participants knew that the target would always appear in the second group. For each participant, data were averaged over 3 runs (450–600 trials) and fit with a cumulative Gaussian function using the fmins function from Matlab and the psignifit toolbox (http://www.bootstrap-software.org/psignifit). The threshold performance was taken as the orientation tilt required for the observer to correctly indicate the direction of tilt on 75% of trials. The slope was taken as the derivative of the function at the same point. The curve was allowed to asymtote below 1, constrained to vary between 0.5 and 1, and an error rate of 0.02 was used. 10,000 bootstrap replications of the fit were carried out (Foster & Bischof, 1997; Wichmann & Hill, 2001a, 2001b). The distribution of the estimates of the threshold (and slope) of the bootstrapped data was used to estimate the goodness of fit of the Gaussian function and 95% confidence intervals (CIs) for the threshold estimate (reflecting errors in fitting the curve). When the threshold estimate was not within the 95% CI, this was taken to mean that the curve did not fit the data well, and more data was collected from this participant.

2.2. Results and discussion

Example psychometric functions for four participants are shown in Fig. 2. When there were 24 Gabors presented (right plots), the presentation of some of these items as a valid preview (open squares and thick line) improved participants ability to discriminate the orientation of the tilted item, compared to when all the items were presented at once (full set). The average orientation threshold for the target as a function of the number of Gabors is shown in Fig. 3a which also shows average data from the dummy preview condition. As expected, when all the Gabors appear at once (full set) the orientation discrimination threshold for the target is much larger when there are 24 Gabors, compared to when there are 16. When half the Gabors appear early as a preview (solid squares), thresholds do not change as much with the number of Gabors. When half the Gabors are presented early, but participants expect the subsequently presented Gabor to be either an old or new Gabor (dummy preview, triangles) thresholds increase with the number of Gabors presented in the second set. To assess the effectiveness of the preview, we compared the thresholds at the large and small set sizes using the threshold increment per item. This is defined as

$$\text{Thresh Inc} = \left(\frac{\text{Threshold for 24 Items} - \text{Threshold for 16 Items}}{8}\right) \quad (1)$$

This threshold increment measure is similar to a time/item slope value in standard visual search measured with reaction times data and is show in Fig. 3b. The preview benefit is usually characterised in terms of a change in slope so we used our threshold increment value as the dependant variable in our analysis. An ANOVA comparing the three levels of the condition variable revealed that there was a significant increase in the threshold increment across the conditions ($F(2,38) = 5$ $p = 0.01$, partial $\eta^2 = 0.21$). Planned tests of within subjects contrasts, in keeping with our prediction of ordered orientation thresholds, revealed a significant linear decrease of threshold increment per item over the three conditions ($F(1,19) = 9.1$ $p = 0.007$, partial

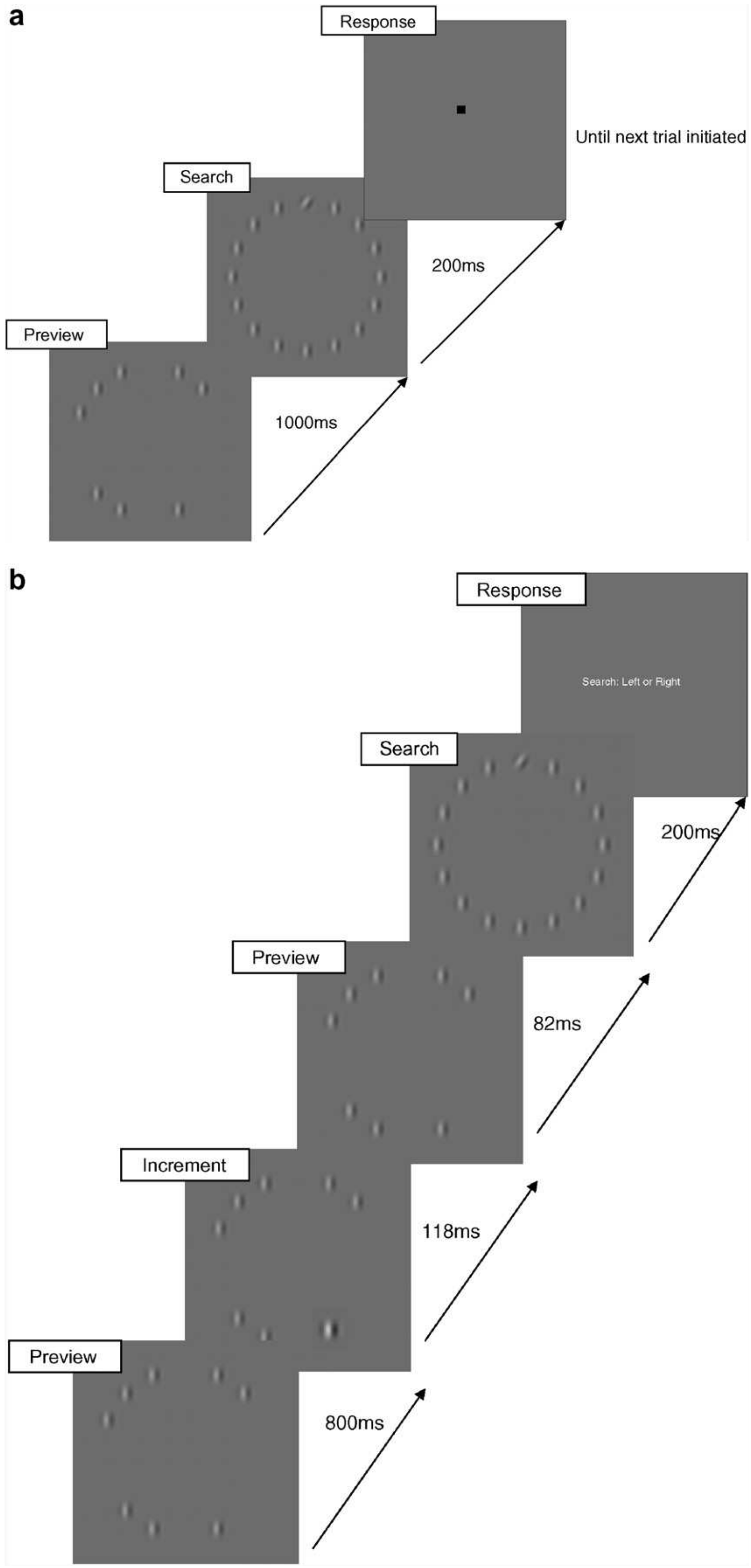

Fig. 1. Illustration of stimuli used in the experiment. (a) Illustration of stimuli used in Section 2. The first (dummy or valid) preview contained half the total number of Gabors. An example from the preview condition is shown (b). Illustration of Section 3, including contrast increment presented during the preview display (shown). In both experiments, the remaining Gabors then joined the previewed Gabors and participants searched for the tilted Gabor.

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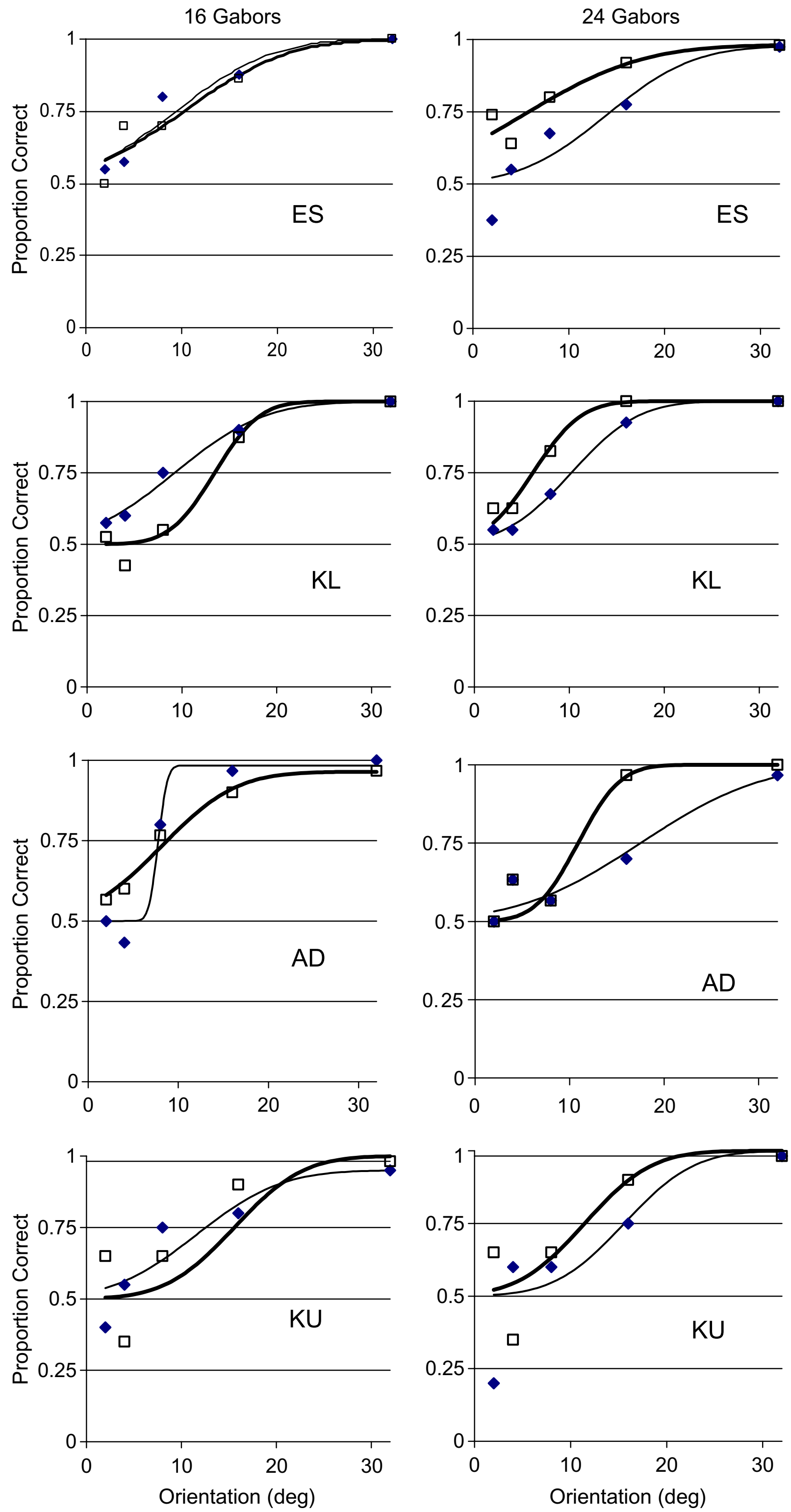

Fig. 2. Data and psychometric functions for four example participants in the baseline experiment. Performance is plotted for a range of orientations of the target Gabor. Each row shows data from a different participant. Left side plots show data from when there were 16 Gabors. Right side plots show data from when there were 24 Gabors. Diamonds and fine lines show data from the full set search condition (all items on at once). Open squares and thicker lines show data from when there was a valid preview of half the items.

$\eta^2 = 0.32$; full set: 0.45°, dummy preview 0.19°, preview 0.13°). As found previously (Kunar and Humphreys, 2006) the presence of the dummy preview does aid search performance, however performance improves still more when the first display is a genuine preview. This is consistent with the operation of both passive and active processes

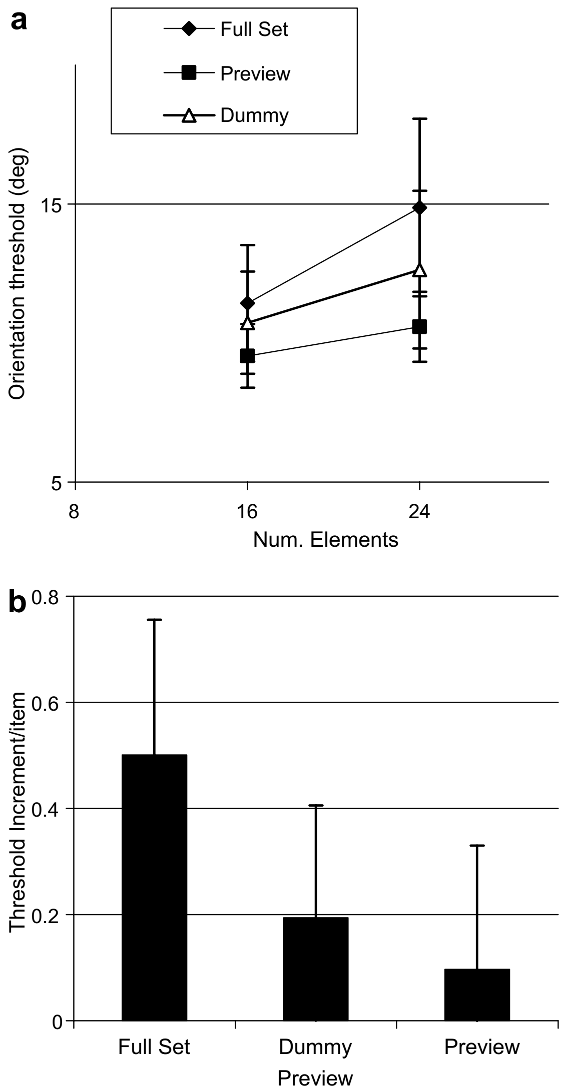

Fig. 3. Average orientation thresholds for a target Gabor presented amongst 16 or 24 upright Gabors. Gabors were either presented simultaneously (full set—diamonds) or half the Gabors were presented 1000 ms earlier than the remainder. In the valid preview condition, the target was always in the second group of Gabors. In the dummy preview condition, the target could be in any position. (a) Thresholds for each number of Gabors; (b) threshold increment per item (see text). Error bars are 1 standard deviation of the group.

in preview search (Mavritsaki, Heinke, Humphreys, & Deco, 2006). The role of the active process increases as the participant gains more information. The advantage for the preview over the full set condition also replicates our previous finding (Allen & Humphreys, 2007).

3. Experiment 2: Detection of increments

In the second experiment we tested increment detection. There were three conditions in the second experiment: valid preview, dummy preview and single task. In the two preview conditions, participants searched the Gabor display for an oriented Gabor amongst vertical Gabors and indicated if they saw a contrast increment in the display.

3.1. Stimuli

Stimuli were similar to those used in the first experiment, except that the orientation of the target Gabor was kept constant and the visibility of a contrast increment (see below) was varied, see Fig. 1b.

On half the trials, after 800 ms one of the Gabors (chosen randomly) increased in contrast for 118 ms before returning to its original contrast for the remainder of the preview (or dummy) display (rectangular on-off temporal function). The magnitude of the contrast increment was varied such that participants' performance ranged from chance to perfect on each run of the experiment. The remainder of the Gabors were then added to the display and remained on the screen for 200 ms. One Gabor was tilted clockwise ($p = 0.5$) or anticlockwise ($p = 0.5$) of vertical. This tilted Gabor was the search task target. In the valid preview condition the target Gabor was randomly chosen from the second group and was never in the previewed group (shown in Fig. 1b). In the dummy preview condition, the target could be one of the second group, or one of the first group could change into the target. The tilt of the target was chosen separately for each participant, set at a value where they had previously achieved above 80% correct based in the first experiment session (participants did not know how this baseline would be used). The level of tilt was also chosen to match performance in the different conditions, avoiding a confounding effect of difficulty difference. We selected a level of tilt where orientation discrimination ability, in the different tasks, converged above threshold. To illustrate: in Fig. 2, for each participant a point can be found, at around 10–20° on the *x*-axis where the two curves converge. Our assumption is that participants will be using the same processes/strategy to perform the task just above threshold as they do at threshold, thus we can allows match both stimulus and difficulty across tasks. The stimulus in the single task condition was the same as that in the valid preview condition.

3.2. Procedure

On each trial in the valid and dummy preview conditions participants responded to two tasks. After each trial a low contrast reminder instruction was displayed (“Search: Left or Right”) and participants indicated with a key press whether the target Gabor was oriented to the left or right. Feedback was given on every trial. A high tone indicated a correct response and a low tone indicated an incorrect response. After this, a second reminder instruction was displayed (“Increment: 1 or 0”) and participants indicated with another button press whether they had seen a contrast increment in the first display. A third button press indicated that they were ready to proceed. Participants were told when the target would appear as one of the new items (valid preview condition) and when the preview was not predictive of the target location (dummy preview condition) in the forthcoming display (and conditions were run in separate blocks). Participants were also told that searching for the oriented target was their main task, that they would be rewarded financially when they matched or bettered their prior performance and received feedback on their performance both during and at the end of each run. In the single task condition, the orientation discrimination task was omitted (and there was no feedback or reward). The contrast increment threshold was estimated using a method of constant stimuli. Performance was measured at a range of values of contrast increments allowing performance to vary from chance to perfect (typically five levels per run, with different sets of levels in different runs). Participants completed a total of 6000 trials for each condition, split into 6 separate runs. A 45 min session of practice was given to all participants before they began the experiment. For each participant, data were averaged over runs and fit with a cumulative Gaussian function (fitting details were as above). The threshold performance was taken as the contrast required for the observer to correctly detect the increment on 75% of trials and the slope as the derivate of the function at this point. All other methods were the same as above.

3.3. Results

On the search task for the oriented target Gabor, one participant failed to perform above their criterion level (80–95% correct). Since it is impossible to know whether this participant was unable to attend to or unable to perform the orientation task these data were dropped from the experiment. Two further participants had different percentages of correct responses for the search task in the dummy and valid preview conditions. Since this may have reflected a different strategy in the two conditions (compared to Section 2) these participants were also dropped from the experiment. The focus of this study was on the performance on the contrast increment detection task. Data for four example participants are shown in Fig. 4. Previous studies have compared the percentage of correct detections of the increment when detection is the only task with when detection is conducted on a minority of trials embedded in a search task. Here, for each participant, it is possible to find a contrast where the proportion of correct responses to the single task (crosses) was above that found when the probe task was performed mixed with the valid preview condition (squares). Furthermore, it is always possible to find at least one point where increment detection performance in the dummy preview condition

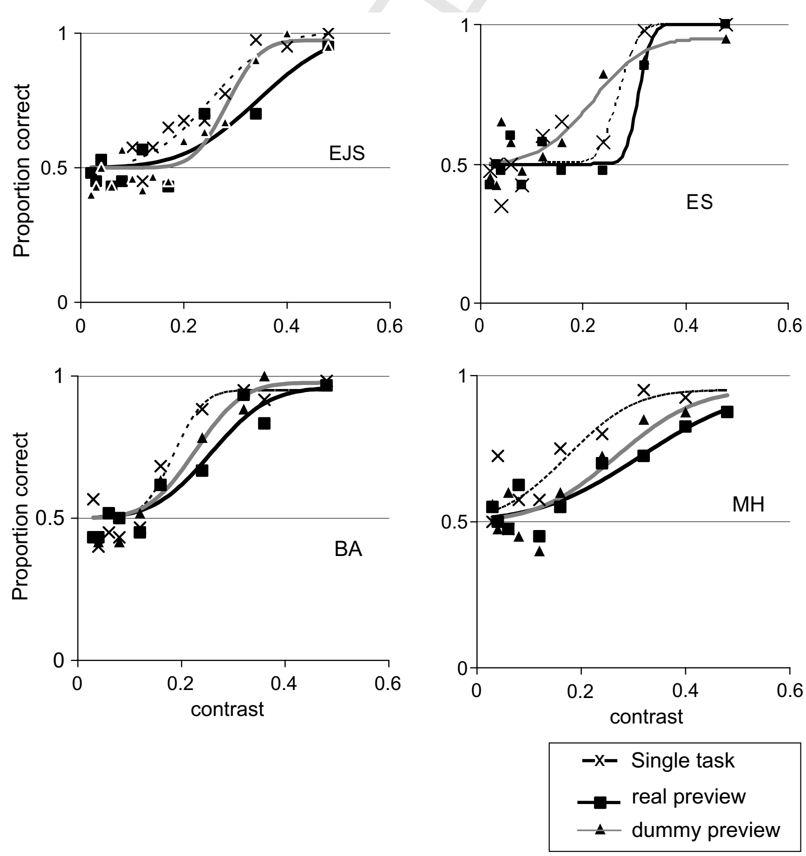

Fig. 4. Data and psychometric functions for four example participants performing the contrast increment task in the three conditions of Section 3. Proportion of correct detections is shown on the *y*-axis and contrast increment is shown on the *x*-axis. Crosses and dashed lined show data from the single task (probe task only) condition. Squares and solid lines show data from the real preview condition. Triangles and grey lines show data from the dummy preview condition.

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(triangles) was better than increment detection performance in the valid preview condition. Furthermore, averaged over the group at an increment contrast of 0.325 the percent correct detection was 85% when there was a valid preview, 88% when there was a dummy preview display and 93% when participants performed the increment detection task only. This illustrates that the methods used here replicated the previous finding that local increments are poorly detected on previewed items.

A consideration only of percent correct detection at one level of contrast ignores, however, the remainder of the psychometric function. There were no differences in the asymptote of the increment detection functions. Threshold and slope values, estimated from the fitted functions are shown in Fig. 5 averaged over all participants. The contrast increment required for 75% correct performance in the valid preview condition (black bars) was higher than that required when the increment detection task was performed alone (pale bars). An ANOVA comparing the three different levels of condition found a significant effect of the condition ($F(2, 24) = 8.7$ $p = 0.001$, partial $\eta^2 = 0.42$). Comparisons between the individual conditions showed that there was a significant difference between the preview and dummy preview conditions ($t = 2.2$, $df = 12$, $p = 0.047$), a significant difference between the single task and the dummy preview conditions ($t = 2.5$, $df = 12$, $p = 0.03$) as well as a significant difference between the preview and single task conditions ($t = 3.5$, $df = 12$, $p = 0.005$).

There was also a significant effect of the condition on the slope of the psychometric function ($F(2, 24) = 8$ $p = 0.002$, partial $\eta^2 = 0.4$). The slope when participants performed the single task was significantly different from the dummy preview case ($t = 3.2$, $df = 12$, $p = 0.008$), and the valid preview ($t = 3.2$, $df = 12$, $p = 0.007$), however the slopes in the dummy and valid preview cases were not significantly different ($t = 0.57$, $df = 12$, $p = 0.58$). This suggests that any change in slope between the conditions reflects the difference in task demands between single and dual task conditions, and not changes in the representation of the valid preview. On the other hand, the difference in thresholds suggests that sensitivity to the preview is decreased in the valid preview condition and this is reflected in a rightwards shift of the psychometric function, equivalent to a decrease in contrast.

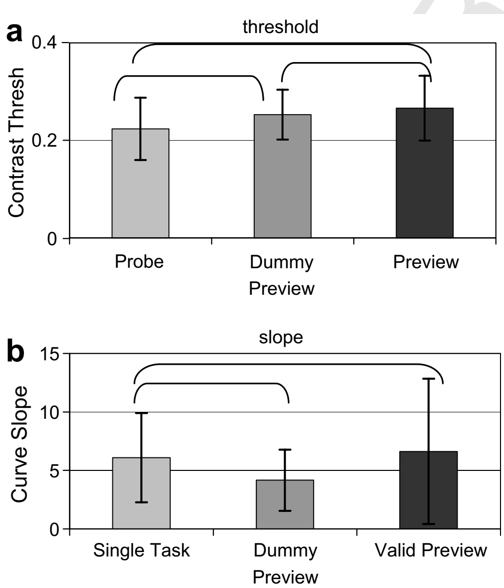

Fig. 5. Averaged contrast increment thresholds (a) and slopes (b) estimated from the fitted psychometric functions for the three conditions—single task, dummy preview and preview. Error bars reflect the 95% confidence intervals. Brackets indicate significant differences at the $p = 0.05$ level.

4. General discussion

We measured contrast increment detection on both valid and dummy previews, embedded in a search task. We extended previous findings by measuring the full psychometric function for detection during the preview display. Our data show a shift in the increment detection function on valid relative to dummy previews, suggesting that there is a decrease in sensitivity (equivalent to a decrease in contrast of the stimulus) for the previewed items. There was no evidence that the change in percent correct found in previous studies was due to a change in gain or noise between the conditions. These results are unlikely to be due to general adaptation to the previewed items over time or to performing a dual task, since performance in the valid preview condition was compared to performance in the dummy preview condition. Spatial uncertainty for the contrast increment probe was also equivalent for the different conditions, since the probe could always be presented in the same number of possible locations.

We extend the previous finding (Humphreys et al., 2004) that, when participants are prioritising search to upcoming stimuli, they are worse at detecting local luminance increments on previewed items, during the preview display. This is consistent with an account of the preview benefit in terms of suppression of the previewed items. It is also consistent with the findings of studies investigating increment detection in the second display of preview search procedure (Braithwaite, Watson, & Humphreys, 2005; Watson & Humphreys, 2000). However, in these latter studies, any differential in detection between previewed and newer items might arise not only from inhibition of the previewed items but from either (i) attentional capture by the new items, (ii) temporal grouping of the old and new or (iii) performing both detection and search in the same run (Donk & Theeuwes, 2001, 2003; Jiang & Wang, 2004). We found that performing the detection task as a dual task significantly decreased threshold and increased the slope of the psychometric function. This suggests that at least some of the change in detection found in these papers was due to the comparison of dual and single tasks. In the present paper, however, we show that there is no further change in slope

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between the dummy and valid preview conditions, only a change in threshold. This suggests that the slope change reflects the increase in noise due to the dual task but that contrast is effectively reduced by effectively previewing the items.

Our results appear to contradict those of Agter and Donk (2005), who failed to find evidence for inhibition when the preview and search items had the same colour. However, as noted in the Introduction, this may be because the preview disappeared prior to the appearance of the luminance probe in their experiment, and this may have re-set any suppression. Thus our study is important for indicating a suppression effect even without colour differences between the previewed and the subsequent items.

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