What makes the preview benefit: Foreknowledge of features, locations, or both?

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Abstract

Previewing distracters in a visual search task enhances the efficiency of visual search. Watson & Humphreys (1997, 2003) proposed that the preview benefit rests on active inhibition of previewed stimuli, supplemented by an anticipatory feature set which enhances search of new items. Using a color-form conjunction search task we studied the effects of previewing distracter locations, distracter features, or both, the latter with and without local distracter changes at the onset of the search display. When subjects previewed distracter location markers search efficiency improved, albeit the effect not being large. In contrast, previewing distracter features produced large efficiency enhancements, with search time per item nearly halved compared to no preview. Moreover, for preview of distracter features the preview benefit was practically not disrupted by local spatial-temporal changes at the onset of the search display. Adding valid distracter location foreknowledge to the foreknowledge of distracter features did not enhance the efficiency of visual search. The results indicate that foreknowledge of features is most crucial for the preview benefit, and suggest that it is the anticipatory feature set rather than inhibition of old items which enhances item processing speed.

Keywords: visual search, preview benefit, conjunction search

1. Introduction

Watson and Humphreys (1997) found evidence that the human visual system uses the temporal segmentation of events to prioritize new objects over old ones. The authors had participants search feature conjunction targets formed by letter-color conjunctions (e.g., finding a blue H among green Hs and blue As). Tasks of this kind are attention demanding, and are highly sensitive to the number of search elements in the display, commonly termed set size. The **r**eaction time versus **s**et size **f**unction (RSF) was found to be linear, with a slope of about 26ms/item. When participants performed a single feature search (e.g. searching a blue H among blue As) the RSF was relatively flat, with a slope of about 14 ms/item. When the authors presented all the green Hs, which made up half of all distracter elements, one second before all the blue elements entered the screen, they found an RSF which was parallel to the RSF for single feature

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search. Hence, the authors concluded that the search time per item for a conjunction search with distracter preview and for single feature search is the same.

In control experiments Watson and Humphreys revealed a variety of side conditions for the preview benefit. The distracters must be shown at least 400 ms before the search display, indicating active distracter stimulus processing during the preview period (Watson & Humphreys, 1997). The long duration of the temporal gap suggests that it is not simply attentional capture of the new items that facilitates search, since automatic capture operates more rapidly (Yantis & Jonides, 1984). Moreover, parallel attention demanding tasks interfere with the preview benefit, indicating that the underlying process absorbs resources instead of being a simple cueing mechanism (Watson & Humphreys, 1997; Humphreys, Watson, & Jolicoeur, 2002).

There is evidence that sensitivity is reduced at the previewed locations, since the previewed distracters appear to have reduced contrast (Allen & Humphreys, 2007), and luminance changes are harder to detect at the previewed locations, compared to neutral positions which have not been visited before (Humphreys, Kyllingsbaek, Watson, Olivers, Law, & Paulson 2004). Since the preview benefit is accompanied by impairment of stimulus processing at the previewed positions and is resource-demanding, the authors concluded that the previewed positions are encoded and actively inhibited (Watson & Humphreys, 1997, Watson, Humphreys, & Olivers, 2003). This conclusion is corroborated by fMRI studies, which demonstrate that there is enhanced activity at the preview stage in early feature selective and higher control areas, while, at search, the activity in early feature selective areas is reduced while the activity in higher level areas is maintained (Allen, Humphreys, & Matthews, 2008; Payne & Allen, 2011).

These findings suggest involvement of two processing stages. At the first stage the locations of old (previewed) items are encoded, and a spatial marking template is established. Afterwards, inhibition is applied to the positions of the marking template, and the spatial segmentation of old and new items is maintained, thus prioritizing the new items (Watson & Humphreys, 1997, 2005; Watson, Humphreys, & Olivers, 2003; Allen, Humphreys, & Matthews, 2008). Along with this reasoning, the key mechanism of the preview benefit was supposed to be spatial.

While it is true that actively ignoring the previewed distracter locations at search is sufficient to turn the conjunction search into a single feature search, this does not necessarily imply that the underlying mechanism that enhances item processing is indeed spatial. Note that in common preview paradigms the preview display reveals not only distracter locations, but, at the same time, informs about distracter *features*. Having previewed green H's the observer knows that the target is not green. Consequently she/he might then only search for the deviant letter in the search display whilst ignoring green items. Previewing distracters in a conjunction search task thus informs the observer about locations *and* features. The foreknowledge about the nature of the distracters is sufficient to infer a search rule for the target features. If, as in the original experiment by Watson & Humphreys (1997), there are only two possible instances of color and shape, the preview of distracter stimuli let observers infer a search regime that is equivalent to a single feature search (here: search deviant letter in the blue items).

Indeed, there is evidence that the foreknowledge about features provided by the preview display affects search performance. When old and new items share the same color, the preview benefit is strongly attenuated (Gibson & Jiang, 2001). Further, there are carry-over effects during search based on feature similarity with previously ignored items (Olivers & Humphreys, 2002; Braithwaite, Humphreys, & Hodsoll 2003). These findings suggest that both feature and location information are subject to inhibition when old (i.e., previewed) items are processed. Studying the impact of changes at the new locations, Watson and Humphreys (2005) found that adding irrelevant color disks at new positions in the preview display affects search performance only if they share color with the new items. This suggests that foreknowledge of features provided by the preview display is used to form a positive anticipatory set for the new items in order to facilitate search.

These findings support the notion of at least two mechanisms contributing to the preview benefit. The first mechanism serves encoding old positions into a spatial position template at preview, and applying active inhibition to the template positions during search. Due to the spatial segmentation of the visual field, new positions are prioritized, thus reducing spatial uncertainty at search (Watson & Humphreys, 2005). The second mechanism is featural, and segments the feature space into to-be-ignored and to-be-attended features during search. In the case of conjunction search, this mechanism allows to infer a precise search rule about possible target features which guides the observer while scanning the set of new items.

The most intriguing aspect of the preview benefit is that previewing distracters does not only cut down absolute search time by limiting the set of items to inspect, but it reduces the search time *per item*. This indicates that the underlying mechanism effectively reduces the amount of information that has to be processed when going from item to item. If there are two mechanisms involved in the preview effect, we may ask which one – the spatial or the featural – has the stronger contribution to the efficiency enhancement of visual search.

In a recent study Persike and colleagues (Persike, Meinhardt-Injac, & Meinhardt, 2013) had participants detect target faces in a set of distracter faces. At preview, the participants viewed distracter location markers, or the actual distracter faces. A preview benefit in terms of search time per items was found only when the actual distracter faces were previewed, while previewing distracter location markers alone did not enhance the efficiency of visual search compared to the no preview condition. Further, the efficiency of visual search and the preview benefit was much stronger for familiar faces (celebrities), compared to unfamiliar faces which the participants had never seen before. These results already hinted at content-specific mechanisms and existing long-term memory representations independent of spatial memory as determinants of the preview benefit.

The present study was designed to assess and segregate the effects of spatial foreknowledge and feature foreknowledge provided by the preview displays in a visual search task with elementary visual features. In a conjunction search task with form-color targets preview displays provided information about distracter features with and without providing information about distracter locations. The search stimuli were designed such that effects of local changes at the distracter positions were kept at a minimum. We found that foreknowledge of distracter features strongly enhanced search efficiency, regardless of whether the actual distracters were previewed or distracter sample stimuli which likewise revealed the color-form conjunction of the distracters. Surprisingly, adding foreknowledge of distracter locations to the foreknowledge of distracter features did not further enhance search efficiency. We thereby report evidence that it is

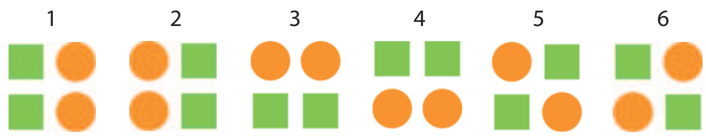

Figure 1: Stimulus micropatterns used in the experiment. The figure shows the 6 possible ways in which two squares of one color and two circles of another color can be arranged as 2×2 micropatterns.

the foreknowledge of features, not the foreknowledge of locations that enhances item processing speed within the preview benefit.

2. Methods

2.1. General experimental outline

In the present study we constructed the search task similarly to the tasks used by Persike et al. (2013), and Allen & Humphreys (2007). The search array followed a circular arrangement, and contained either 8 or 12 stimulus elements. In target-present trials the array contained one *deviant* stimulus, in which the color-to-form assignment realized among the distracters was reversed (see Stimuli). The task of the participants was to indicate whether a deviant was present, or not. Prior to the search array a preview display was shown, which informed the participants about distracter stimulus properties. Reaction time (RT) and accuracy (proportion correct) were measured.

2.2. Stimuli

Stimulus micropatterns. Target and distracter stimuli were built from 2×2 micropatterns, consisting of 2 circles and 2 squares. There are 6 ways of setting up 2×2 micropatterns with two forms on two locations (see Fig. 1). We used orange and light green as colors, which were calibrated for iso-luminance. In order to create distracters, one of the two assignments of color to form (orange + square, light green + circle or orange + circle, light green + square) was selected at random for a trial. Thereafter the distracter positions on the circular search array were filled by selecting from the 6 possible micropatterns at random. A target was created by reversing the color-to-form assignment chosen for the distracters for one single 2×2 micropattern in the display.

Positions markers. Dotted light gray disks were used as position markers. The diameter of the disks was the edge length of the virtual square formed by the 2×2 micropatterns.

2.3. Preview conditions

Five preview conditions were used (see Fig. 2). In the *no preview* condition (No) a fixation screen appeared, followed by markers on half the number of the stimulus positions within the array, which persisted for 750 ms. The markers were uninformative with respect to the target position in the search array, and included the target position in 50% of the trials. In *distracter position preview* (Pos) also half of the stimulus positions in the array were marked, but the markers indicated true distracter positions of the search array. In *distracter stimulus preview* (Pos

+ F) the actual distracter stimuli of the search display were shown at half of the array positions, cueing distracter positions *and* their features. The previewed items remained on the screen, and were complemented by the remainder elements of the search display after 750 ms. In *distracter stimulus preview with feature change* (Pos + F′) distracter stimuli were shown, but when the new items were added at the onset of the search display the previewed distracters were replaced by new ones with the same color-form assignment. This was done by randomly choosing one out of the five remaining 2×2 micropatterns with the same color-to-form assignment, but with a different local arrangement of the 2 circles and the 2 squares. In *distracter feature preview* (F) we used the same preview displays and the same procedure as in Pos + F′, but the preview stimulus locations included the target position in 50% of the trials, and were therefore uninformative with respect to the target position in the search array (see Fig. 2).

In conditions Pos + F′ and F the distracters were replaced by other instances representing the same color-form conjunction when the new elements were added to the display. This means that there was local change at the previewed distracter positions at the onset of the search display. However, with maintaining the same global stimulus outline as a 2×2 micropattern and by employing smooth iso-luminant colors a ”switch” effect at the old positions that could possibly trigger spatial re-grouping is hardly perceived. Watson and colleagues (Watson & Humphreys, 2002; Watson, Braithwaite, & Humphreys, 2008) found evidence that if there are synchronous changes of old items with the new items, these changes are not disruptive if they concern only task-irrelevant feature manipulations. The local changes in conditions Pos + F′ and F at search are in line with this, since the featural content of the distracter stimuli is unaffected by the local rearrangements within the micropatterns.

2.4. Participants

30 students of psychology participated in the present study (mean age 23.1; age range 20-32). 22 participants were female. The participants were paid for participation.

2.5. Apparatus

The experiment was executed with Inquisit 3 runtime units. Patterns were displayed on NEC Spectra View 2040 TFT displays at 1600×1200 resolution with a refresh rate of 60 Hz. The luminance of the white background of the screen was 115 cd/m^2. The colors light-green and orange were calibrated to a luminance of about 59 cd/m^2 using a ColorCal colorimeter from Cambridge Research Systems. No gamma correction was used. The room was darkened so that the ambient illumination approximately matched the illumination on the screen to a fair degree. Patterns were viewed binocularly at a distance of 70 cm. Stimulus micropatterns in the preview and search array measured approximately 100×100 pixels, which corresponds to $2.08° \times 2.08°$ measured in degree of visual angle at 70 cm viewing distance. To create the preview and search arrays, stimuli were placed on the edges of a regular octagon (set size 8) or dodecagon (set size 12), with the topmost stimulus always at the 12 o'clock position (see Fig. 2 for examples with a set size of 8 stimuli). Each stimulus center was about 320 pixels or $6.65°$ degree visual angle away from the center of the screen. Participants used a distance marker but no chin rest. They gave responses on an external Cedrus RB-830 response pad with built-in

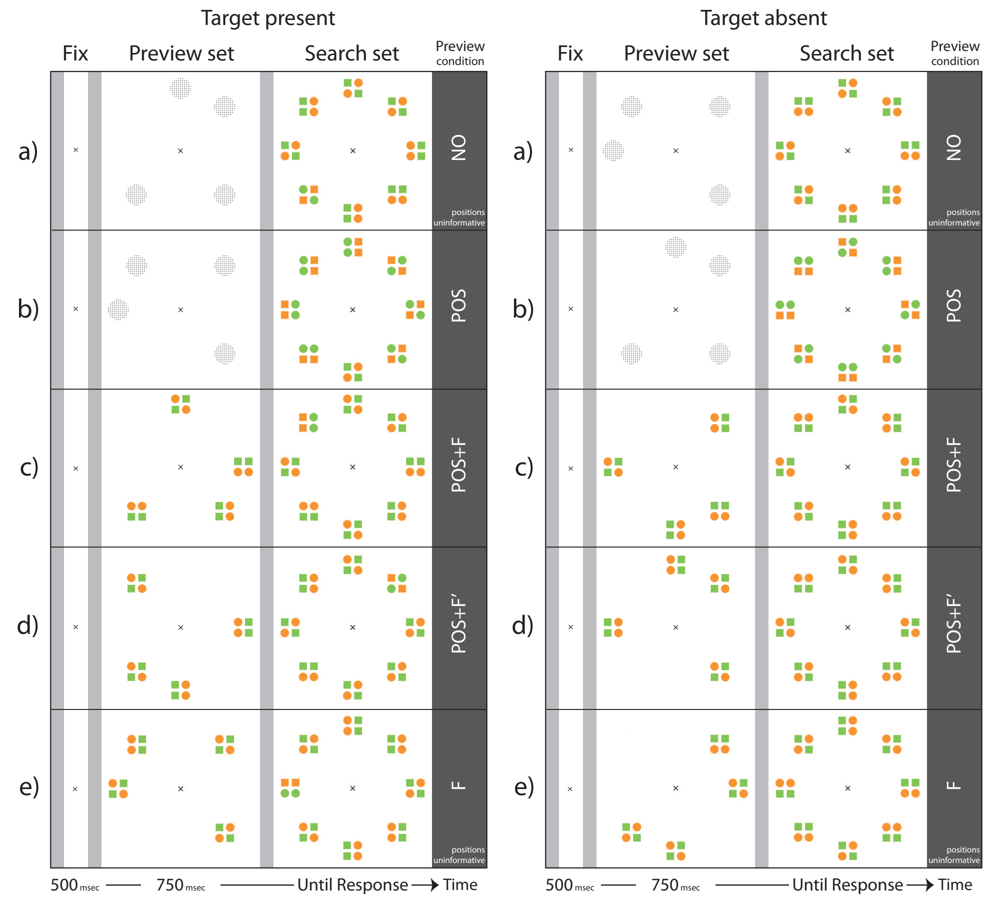

Figure 2: Summary of the 5 preview conditions used in the experiment in the target-present (left) and the target-absent variety (right). The lower row shows the temporal structure of a trial. The stimulus arrangements are shown for the set size of 8 elements only.

clock for precise reaction time measurements. Acoustical feedback was given via headphones. A brief ”tack”-tone indicated that the response was correct, a ”tacktack”-tone signalled an error.

2.6. Procedure

A Yes/No forced choice search task was used. The five preview conditions, each with two set sizes, were run in 10 blocks with 48 trials, 24 of which contained a deviant in the search array (target-present trials) and 24 contained no target (target-absent trials). The participants were instructed to indicate the presence of a deviant stimulus in the circular search array, and were informed about the nature of the preview condition as well as the task by info screens preceding each block. Before each block 12 probe trials were administered to assure that the task was understood. The temporal order of events in a trial sequence was: fixation mark (500 ms) - preview (750 ms) - search array (until response). Acoustical trial by trial feedback about correctness was given by brief tone signals (see Fig. 2). Each participant had to go through 600 trials for each experiment, which took about three quarters of an hour. The order of the

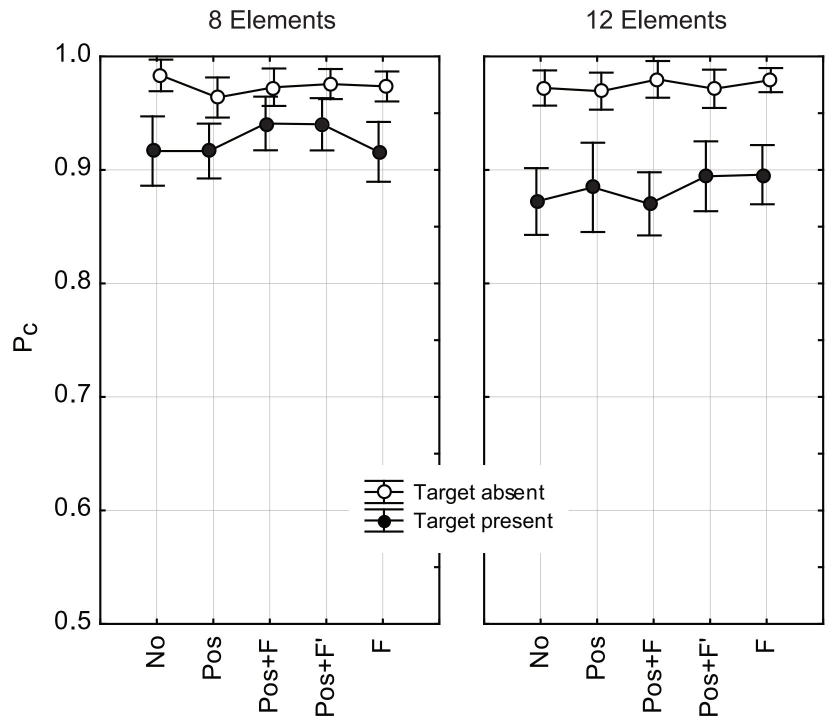

Figure 3: Mean proportion correct rates for all preview conditions and set size = 8 (left) and set size = 12 (right). Filled symbols indicate data for target-present trials, open symbols for target-absent trials. Error bars indicate 95% confidence intervals.

experimental blocks was randomized for each participant. Participants were free to make brief pauses between the experimental blocks.

3. Results

3.1. Accuracy

Accuracy was generally high, above 95%, in target-absent trials, but lower in target-present trials ($F(1, 29) = 81.80, p < 0.001$, partial $\eta^2 = 0.74$; see Fig. 3). For the larger set size proportion correct remains constant in target-absent trials, but falls in target present trails (set size $\times$ trial type, $F(1, 29) = 18.55, p < 0.001$, partial $\eta^2 = 0.39$). As indicated by the flat curves across preview conditions obtained for both set sizes (see Fig. 3) the preview conditions have no significant influence on accuracy ($F(4, 116) = 1.15, p = 0.335$, partial $\eta^2 = 0.04$). The fact that accuracy is independent of preview condition suggests that observers tried to maintain a constant response strategy. However, the response pattern in target-present and target-absent trials shows that participants generally tended to avoid false alarms (erroneously signalling target presence) at the cost of producing more misses (overlooking targets). As expressed by the set size $\times$ trial type interaction, this strategy led to more misses at the larger set size (see Fig. 3). When compared to results obtained with identical experimental procedures but with face stimuli (Persike et al., 2013) the accuracy rates with the elementary feature conjunction stimuli

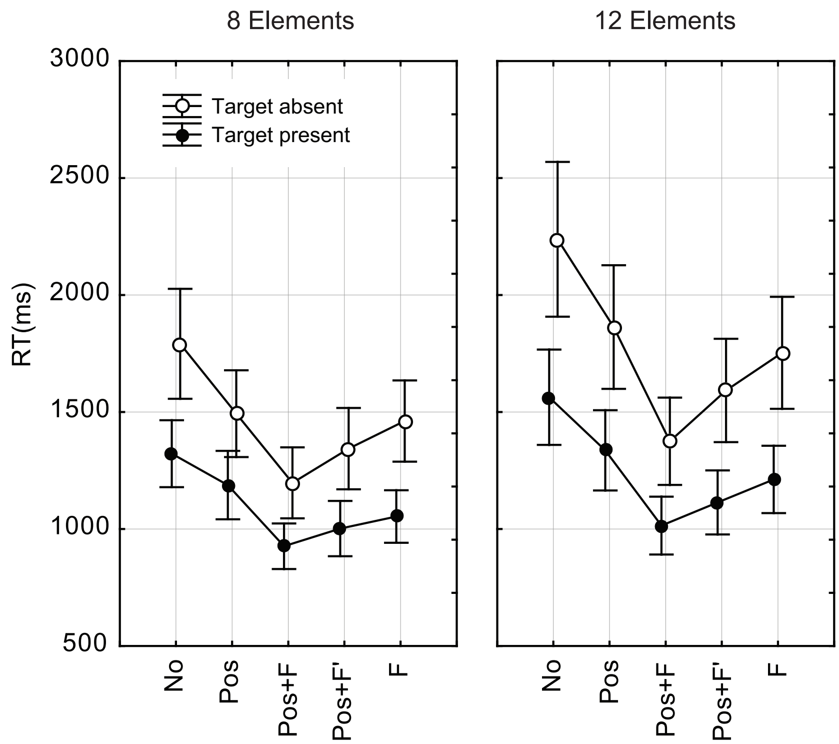

Figure 4: Mean reaction times for correct judgements for all preview conditions and set size = 8 (left) and set size = 12 (right). Filled symbols indicate data for target-present trials, open symbols for target-absent trials. Error bars indicate 95% confidence intervals.

follow the same results pattern, but at higher levels and with a less pronounced accuracy drop in target-present trials.

3.2. RTs

Reaction times of correct responses are modulated by set size ($F(1,29) = 65.40, p < 0.001$, partial $\eta^2 = 0.69$), trial type ($F(1,29) = 107.31, p < 0.001$, partial $\eta^2 = 0.78$), and preview condition ($F(4,116) = 44.94, p < 0.001$, partial $\eta^2 = 0.61$; see Fig. 4). All three two way interactions and the three way interaction prove to be significant. The latter, however, just reaches the 5% alpha level ($F(4,116) = 2.50, p < 0.045$, partial $\eta^2 = 0.08$), while the RT data shown in Fig. 4 assume rather parallel courses.

The reader may recall that the accuracy data are not modulated by preview condition (see Fig. 3). Evaluating accuracy and RT together, however, shows that there is a strong downward shift of RT curves for target-present trials relative to target-absent trials. Apart from more element comparisons which are necessary in target-absent trials, this may be due to a strategy of the participants to respond more risky in target-present trials (see above). The difference in RTs for target-present and target-absent trials should therefore diminish if the RT data are corrected for accuracy. In order to compensate for response strategy we decided to use the RT_{adj} measure, obtained by dividing RT by P_c at the level of individual data. This transformation cancels

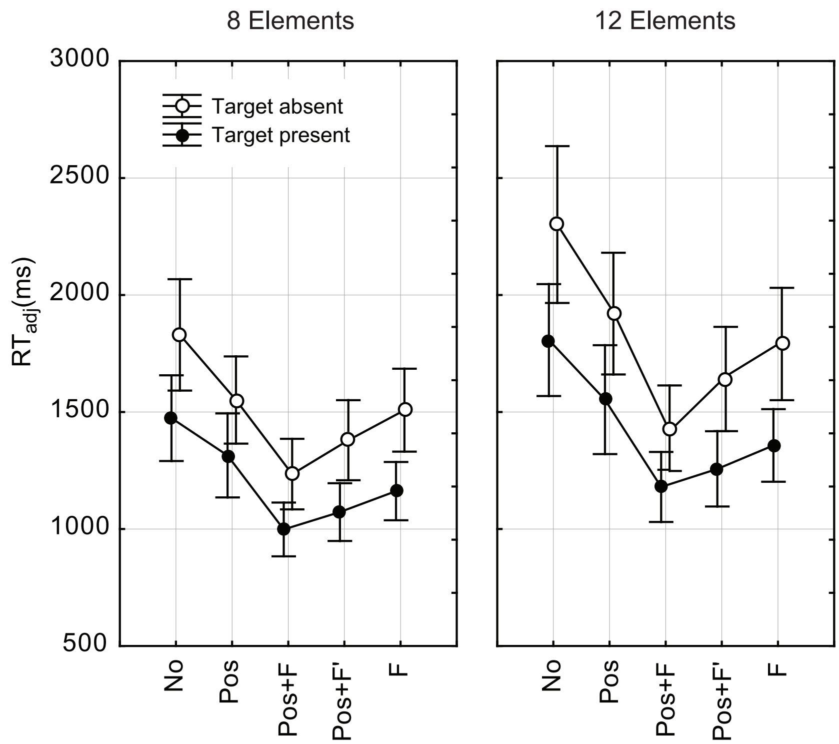

Figure 5: Adjusted reaction times $RT_{adj} = RT/P_c$ for all preview conditions. The left panel shows data for the smaller set size (8), the right panel for the larger set size (12). Error bars illustrate the 95% confidence intervals.

the effects of speed-accuracy trade-off, and is frequently used in the preview benefit paradigm when subjects tend to hurry with their responses at the cost of making more errors (Mevorach, Humphreys & Shavley, 2006; Allen et al., 2008; Persike et al., 2013).

Fig. 5 shows the results for the RT_{adj} measure. As the uncorrected reaction times (see Fig. 4), the curves for target-absent and target-present trials take approximately parallel courses when plotted as a function of preview condition, but with a reduced displacement between the two. ANOVA reveals that the adjusted RT data are modulated by set size ($F(1, 29) = 87.77, p < 0.001$, partial $\eta^2 = 0.75$), trial type ($F(1, 29) = 61.97, p < 0.001$, partial $\eta^2 = 0.68$), and preview condition ($F(2, 58) = 41.394, p < 0.001$, partial $\eta^2 = 0.58$). Also, all three two-way interactions are significant, but the three-way interaction set size $\times$ trial type $\times$ preview condition now fails significance ($F(4, 116) = 1.89, p = 0.12$, partial $\eta^2 = 0.06$), confirming parallelism of the curves shown in Fig. 5. The displacement of the target-absent curve relative to the target-present curve is larger for the larger set size (set size $\times$ trial type, $F(1, 29) = 7.93, p < 0.01$, partial $\eta^2 = 0.21$), indicating a decrease of efficiency in target-absent trials, which is expected when the observers use element-wise search strategies where, among others, revisiting of already inspected positions may occur.

Since the general course of RT_{adj} across preview condition is equivalent for the two trial types and set sizes we executed pairwise tests of preview conditions on the main effects level

	Pos	Pos+F	Pos+F'	F	Pos	Pos+F	Pos+F'	F
No	268.22	636.73	515.69	398.72	0.0002	0.0000	0.0000	0.0000
Pos		368.54	247.47	130.50		0.0000	0.0008	0.2307
Pos+F			-121.04	-238.01			0.2974	0.0016
Pos+F'				-116.97				0.3397

Table 1: Pairwise mean differences of RT_{adj} for the five preview conditions (line category-column category, columns 2-5) , and probability p of the null hypothesis in a posteriori Scheffè test for a 5% alpha level (columns 6-9) with $n = 30$, $df_{condition} = 4$, $df_{res} = 116$, and $\sigma^2_{res} = 179492$.

with a-posteriori Scheffè tests. The results are shown in Table 1. Responses are significantly faster in each preview condition compared to no preview. Additional feature information with and without local distracter change at the onset of the search screen (Pos + F and Pos + F′) speeds up responses compared to previewing only position markers (POS). Previewing features but not positions (F) leads to a temporal advantage of 130 ms relative to previewing distracter location, but this advantage fails significance. Previewing distracter locations and features without local distracter change (Pos + F) is better than with local distracter change (Pos + F′), but the time difference is not significant. Compared to preview of just features without valid location information, however, only POS+F is significant. With local distracter change, previewing features and valid distracter locations (Pos + F′) or features alone (F) makes no difference in reaction time.

Note that the reaction times adjusted for accuracy follow the ordinal relation

$$RT_{adj}(No) > RT_{adj}(Pos) > RT_{adj}(C) > RT_{adj}(Pos + F') > RT_{adj}(Pos + F) \quad (1)$$

but not all pairwise comparisons in this chain are substantiated by statistical testing.

3.3. Efficiency measure

For analyzing the efficiency of visual search in terms of processing time per item we calculated slopes for the reaction time difference for both set sizes by dividing $RT_{adj}(12) - RT_{adj}(8)$ by the set size difference of 4. Slopes were then analyzed separately for target-present and target-absent trials. Figure 6 shows a replot of the data shown in Fig. 5, but as functions of set size (RSFs). Table 2 shows the slope estimates.

The slope measure exhibits a clear distinction between the preview conditions which convey feature information as opposed to the ones which do not. In target-present trials all preview conditions with feature information have RSFs with practically the same slope, being strongly parallel (see left panel of Fig. 6), while the functions for no preview, and, to smaller degrees, for distracter location preview, are clearly steeper. In target-absent trials there is, in principle, the same scheme of results for the RSFs, except the RSF for Pos+F being flattest. Numerical analysis (see Tab. 2), however, reveals a general scheme of results that is mostly independent of trial type. Preview of location makers leads to item processing times of about three quarters the time per item for no preview, while item processing time is nearly halved compared to no preview when observers have foreknowledge of features.

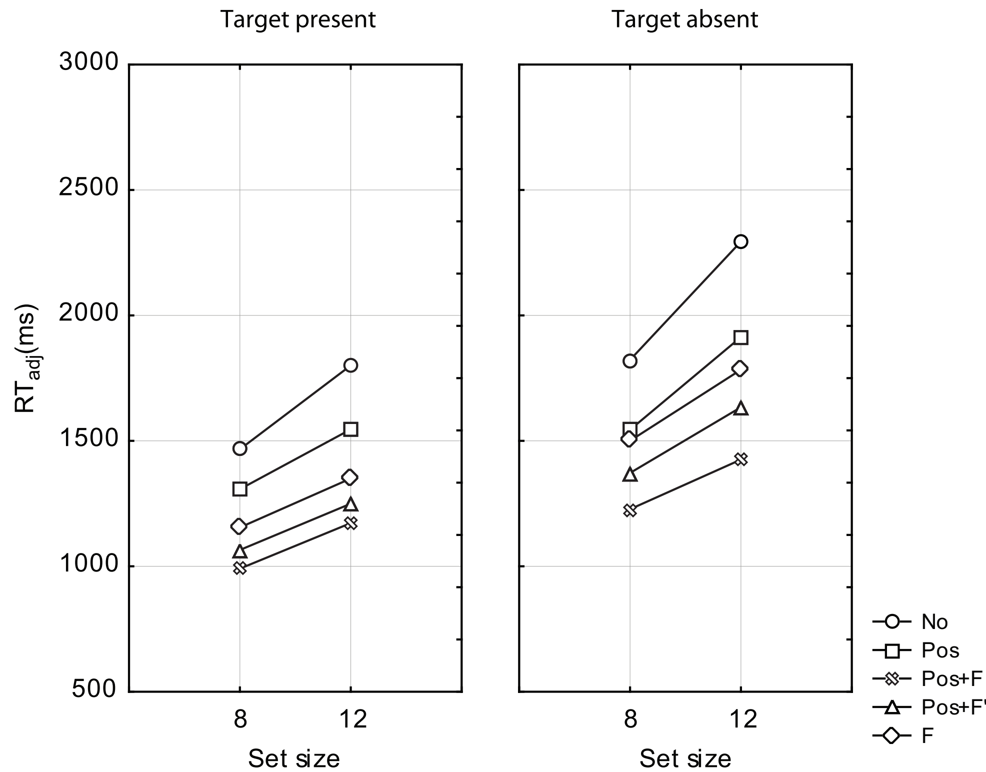

Figure 6: Adjusted reaction times, $RT_{adj} = RT/P_c$, for all preview conditions. The data are replotted from Fig. 5, but are shown as a function of set size.

Trial type	Preview condition	Δ_s	a	q_{no}	q_{pos}
TP	No	333.92	83.48		
TP	Pos	238.60	59.65	0.71	
TP	Pos+F	181.54	45.39	0.54	0.76
TP	Pos+F'	184.59	46.15	0.55	0.77
TP	F	195.46	48.86	0.59	0.82
TA	No	471.65	117.91		
TA	Pos	369.50	92.38	0.78	
TA	Pos+F	219.06	54.76	0.46	0.59
TA	Pos+F'	261.75	65.44	0.55	0.71
TA	F	283.03	70.76	0.60	0.77

Table 2: Differences of the RT_{adj} measure for both set sizes, $\Delta_s = RT_{adj}(12) - RT_{adj}(8)$, slope estimates $a = \Delta_s/4$ for the RSFs (with 4 the set size difference), and ratio of slopes relative to no preview, q_{no}, and relative to preview of distracter positions, q_{pos}.

In order to test the RT_{adj} versus set size functions for parallelism we analyzed the RT_{adj} data for pairwise combinations of the preview conditions with separate ANOVAs, and evaluated

	Target present				Target absent			
	Pos	Pos+F	Pos+F'	F	Pos	Pos+F	Pos+F'	F
No	0.0188	0.0013	0.0122	0.0382	0.0669	0.0000	0.0002	0.0001
Pos		0.1540	0.2787	0.3968		0.0026	0.0063	0.0064
Pos+F			0.9304	0.7393			0.2287	0.0906
Pos+F'				0.7893				0.5693

Table 3: Probability p of the null hypothesis that there are just additive effects of set size and preview condition for pairwise combinations of preview conditions.

significance of the preview condition $\times$ set size interaction. The results are shown in Table 3.

The tests show that, in both trial types, the RSFs for no preview are steeper than the RSFs for all other preview conditions. In target-present trials the test for parallelism indicates that the curves for all preview conditions involving features are strongly parallel. In target-absent trials the tests among all preview conditions involving features also indicate lack of significance, suggesting that deviations from parallelism are negligible. In target-present trials the slope differences of the RSF for distracter location preview and all conditions involving preview of distracter features are not sufficient to surpass statistical significance, while for target-absent trials, the slope difference is sufficient to produce a significant ANOVA.

4. Discussion

Testing the effects of providing foreknowledge of distracter features and their locations via preview has shown that foreknowledge of features strongly improves visual search. The search time per item is nearly halved compared to no preview. The most striking finding of this study is that the three conditions that provide foreknowledge of features enhance the efficiency of visual search to *equal degrees*. The specific differences of these three conditions, imply that (i) in order to obtain a preview benefit it is sufficient to preview distracter examples that allow to infer the feature-based rule for the search, and (ii) adding valid distracter position information does not enhance search efficiency any further.

These findings challenge the notion that the preview benefit for the most part rests on local inhibition of the old items, as claimed in early conceptualizations (Watson & Humphreys, 1997). Our results indicate that only the foreknowledge of features is crucial for the strength of the preview benefit. Performance improvements in terms of search time per item emerge because the preview stimulus establishes a positive anticipatory feature set guiding visual search among the set of new items (Watson & Humphreys, 2005), not because of mere spatial selection of distracter positions.

4.1. The effects of distracter location preview

Distracter position preview was realized by using distracter position markers which did not share form or color with the distracter stimuli. Previewing these markers led to a significant reduction in reaction time, and also to a significant efficiency improvement. However, the effect of location preview on the efficiency of visual search is not large, and not in the order of magnitude we would expect from the preview benefit. Watson & Humphreys (1997) found that distracter preview enhanced efficiency from 26 ms/item without preview to about 14 ms/item with preview, which is nearly half the time per item. Preview benefits of comparable magnitude were also obtained in the present study, but only for the three preview conditions that provide foreknowledge of features. Likewise, in a similar search task but with face stimuli we found that previewing location markers led to a reduction in reaction time, but did not improve the search time per item at all (Persike et al., 2013).

It should be considered, however, that when neutral location markers are used to indicate distracter locations, the temporal segregation of events can elicit a spatial re-grouping of the old with the new stimuli at the moment when the new elements enter the display. The preview effect may be strongly attenuated, or even precluded in such stimulus arrangements (Jiang, Chun & Marks, 2002). Watson & Humphreys (2002) also found shape changes of distracters to strongly disrupt the preview benefit. Hence, the failure to find a strong preview benefit may be attributed to a possible re-grouping of old with new elements, since all elements change at one moment in time when the elements of the search display enter. Note, however, that even with spatial re-grouping, a facilitation effect of previewing spatial positions in terms of absolute reaction times still persists (see also Persike et al., 2013), only the preview benefit in terms of search time per items is alleviated. This is at odds with the notion that the grouping of distracter positions in the preview display does not survive the advent of new spatio-temporal events at all positions. The observer *is* able to memorize and exclude the marked positions from visual search. Therefore, she/he needs less time to scan the search display, albeit search time *per item* stays the same, because the observer applies the same operations to each item of the reduced versus the full item set. Compared to no preview, the observer processes the items in the same way since location preview allows no inference about stimulus content or the rules that may help to process items in the search set more efficiently.

4.2. Foreknowledge of features with and without foreknowledge of locations

In the feature-only preview condition (F) the participants viewed preview stimuli that allowed to infer the feature-based search rule in advance, but the locations of the preview stimuli were uninformative for the search. In preview condition Pos + F′ the same stimuli were previewed but at valid distracter positions. Hence, comparing the results of both conditions reveals the effect of adding foreknowledge of positions to the foreknowledge of features. Reaction times are smaller in the Pos + F′ compared to the F condition, but the effect fails significance (see Fig. 5 and Tab. 1). The RSFs are strongly parallel for both conditions (see Fig. 6). Slope analysis and statistical testing reveal that there is practically no advantage in terms of processing time per item by providing additional valid distracter location information to the foreknowledge of features (see Tabs. 2 and 3). This indicates that both conditions are equivalent with respect to the handling of new items at search. It is just the content-based foreknowledge that accelerates item processing in the search display.

The conditions F and Pos + F′ are equivalent with respect to the temporal aspects of change. At the onset of the search display new items enter while old items change locally at the same time, being replaced by instances which represent the same color-form conjunction in a different configuration. So there is change at the old and the new positions. However, when isoluminant colors are used and with only local changes of elements within the 2×2 micropatterns while completely new stimulus patches are written on the white background at the new positions, the change events at old versus new positions are quite different in nature. Comparison with the Pos + F condition, where the old items are left untouched when the new items enter shows that there is no difference in search efficiency. This indicates that the spatio-temporal properties of the display, as realized in all three conditions which provide foreknowledge of features, do not affect the nature of item processing. The preview benefit in terms of efficiency is maintained despite the local changes at the old positions. Hence we find that there is resilience against the local changes at the old positions when new items enter the display. Resilience against local changes at the old positions corresponds to recent findings about the robustness of the preview benefit against strong luminance changes at the old positions (Watson, Braithwaite, & Humphreys, 2008). The authors found that luminance changes in the order of magnitude of 1:4 were disruptive for the preview benefit, but could be compensated by introducing a valid color grouping cue that separated old and new items. These findings indicate that feature-based grouping may override grouping based on temporal synchrony in visual search (see below).

While there are no differences in terms of efficiency, there are differences in terms of absolute reaction time (see Fig. 5). In the case of position preview, these effects are consistent with the view that observers are able to exclude the previewed locations from visual search. Memorizing the old positions and ignoring them at search should work best when there are no interleaved temporal events that may signal to the observer that the spatial grouping into old and new items should be revised. Therefore, ignoring the old items should work best when there are no changes at the old positions at all (see results for Pos+F).

4.3. The preview benefit is driven by enhanced feature-processing

In the seminal studies of the preview benefit (Watson & Humphreys, 1997) the effects of spatial marking and providing foreknowledge of features are confounded, since showing all green distracters informs the subject that a possible target will not be at the previewed positions and also that it will not be green. Our present results provide evidence that foreknowledge of distracter positions does not enhance the efficiency of visual search, while foreknowledge of features does, independent of the foreknowledge about positions. These findings support the view that there are at least two mechanisms involved in the preview benefit. The first mechanism serves spatial pre-selection, and encodes distracter positions into visual working memory. This mechanism excludes the old positions from the subsequent search but it does not enhance search efficiency at the new positions. The second mechanism employs feature- (or content-) specific information in order to enhance item processing while scanning the search display. As shown by existing evidence handling of feature-specific information at search comprises both inhibition of non-target features (Watson & Humphreys, 2000; Humphreys et al., 2004; Gibson & Jiang, 2001; Olivers & Humphreys, 2002), and enhancement of possible target features that can be inferred from the preview stimuli (Braithwaite & Humphreys, 2003; Watson & Humphreys, 2005; Watson et al., 2008).

The present findings clearly show that a mechanism that purely rests on the temporal synchrony of old and new item sets (Jiang, Chun & Marks, 2002), or on attentional capture triggered by spatio-temporal change (Donk & Theeuwes, 2001, 2003) cannot explain the enhancement of visual search in the preview benefit paradigm. Both theories state possible reasons why the absolute reaction times are reduced when there is distracter preview, since they postulate mechanisms of spatial segregation into to-be-attended and to-be-ignored items. Reaction time is thus reduced because the observer visits a reduced number of items to finish the search task. However, they do not explain why item processing in the attended item set should execute faster. Both accounts also have difficulties to explain why experimental trials that have different spatio-temporal structure but transmit the same content at preview lead to the same item processing speed.

In the present study it was demonstrated that revealing content or feature based information at preview which is useful to facilitate visual search is crucial for improving item processing speed, but excluding locations from search is not. Further, it was shown that if the spatio-temporal event structure is such that a strong local saliency difference occurs at both the positions of the old and the new items at the onset of the search display, the preview benefit is maintained. Further experimentation should address how the perceptual organization into old and new items depends on such local saliency changes within each item set during an experimental trial.

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