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Research Report

# Visual search in temporally segregated displays: Converging operations in the study of the preview benefit

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**Abstract**

Preview benefit is an attentional phenomenon that enables observers to selectively search through new information in the visual field. In a preview search task, objects are presented in two sets, separated by a time interval (preview interval), and with the second set (new objects) containing the target. Event-related brain potentials (ERPs) were used to investigate whether preview benefit occurs via maintenance of inhibition of the old objects during the preview interval. ERPs time-locked to a color probe indicated that the old objects were actively attended rather than inhibited during the preview interval. Follow-up behavioral experiments produced converging results. The results suggest that, although participants might be using inhibition at later stages of the preview interval, they are not maintaining inhibition on the old objects throughout most of the preview interval.


*Theme:* Neural basis of behavior
*Topic:* Cognition

*Keywords:* Visual attention; Preview benefit; ERP

## 1. Introduction

In a dynamic visual world around us, it is often important to bias selection towards new, previously unattended information. For example, when we are looking for a shuttle in an airport parking lot, it might be a good strategy to narrow the search to moving vehicles, and to exclude the parked cars from detailed examination. A recently discovered attentional phenomenon, termed the preview benefit, confirms this observation. It is defined in terms of faster search rates when two sets of visual objects are presented at different points in time, compared to when they are presented simultaneously [27]. When the second set (new objects) arrives, its elements are interspersed among the elements of the first set (old objects). The target, if present, is always located within the second set of objects. It has been shown that the number of old objects in the display has a limited effect on the search slopes in the preview paradigm, suggesting that observers are able to restrict their search to the new objects and ignore the presence of the old physically interspersed objects [26,27].

The preview benefit does not seem to have substantial capacity limitations, since it has been observed with up to 15 new and 15 old (previewed) objects [5,26]. It is also not affected if previewed objects change color; however, the benefit is abolished when they undergo a large luminance change at the time the new objects are presented [15,27]. Watson, Humphreys, and colleagues [10,27,28] proposed that the mechanism that produces the preview benefit is top–down inhibition (termed “visual marking”), applied to previewed distractors during the preview interval.

The main evidence for the inhibitory nature of the preview benefit comes from the studies using a probe

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detection paradigm [23,28]. The authors found that when preview search was the primary task, detection of the probe after the preview interval was significantly worse at the locations of the old objects than at the locations of the new objects. However, such impairment was not evident when probe detection task was the only task participants had to perform. Furthermore, the top–down involvement in the preview benefit is also supported by studies that introduced a demanding secondary task in the preview interval, which decreased the preview benefit [23,27].

Although there seems to be some evidence supporting the inhibition account, an alternative explanation for the preview benefit has been recently proposed by Donk and Theeuwes [5,6]. They argued that inhibition of the old objects is unnecessary and that the preview benefit can be explained by attentional capture by onsets of the new objects [30]. The authors showed that unless the presentation of the new objects is accompanied by a luminance increment, the preview benefit is abolished ([5]; see also [24]). In addition, they argued that prioritization of the new objects occurs in a bottom–up fashion, since the preview benefit was observed even when the search target was twice as likely to appear in the old set than in the new set of objects [6].

It is worth noting, however, that in the attentional capture literature, it is typically reported that not more than four objects can be prioritized for search [4,30]. In the preview benefit studies, however, this number is substantially higher (up to 15 objects, [26]). In a recent study [2], we demonstrated that up to 14 objects defined only by luminance transients could be prioritized for search. Thus, it is possible that a similar attentional prioritization also takes place in the preview paradigm.

The slow time-course of the preview benefit is also often taken as evidence against the onset capture account. Generally, it takes at least 400–500 ms to observe some preview benefit and takes 600 ms or longer to fully filter the old objects from search [11,27]. Humphreys and colleagues [10] proposed that the preview interval is used for (1) establishing an inhibitory attentional set, (2) consolidating a representation of old objects, and (3) maintaining the representation using visual resources. They showed that the preview benefit is disrupted by visual secondary tasks, both when they begin at the start of the preview interval and when their presentation is delayed (i.e., the secondary task starts sometime during the preview interval). However, auditory secondary tasks disrupted the preview benefit only when their onset was synchronized with the start of the preview interval.

A similar conclusion regarding setting up and maintaining inhibition of old objects during the preview interval was also reached by Jacobsen and colleagues [14], who observed a sustained negative event-related brain potential (ERP) wave in the preview interval from 350 to 750 ms after the presentation of the first display. This ERP component was enhanced in a preview search task relative to a control condition, in which the search target could appear either at the old or at the new object location. This broadly distributed negativity appeared larger at frontal and central sites and larger over the left than right hemisphere. As acknowledged by the authors, based on its time-course, morphology, and scalp topography, this component did not resemble any ERP components previously reported in the literature, which complicates its interpretation as an index of setup and maintenance of inhibition. Unfortunately, the interpretation of the results of the Jacobsen et al. [14] study is also difficult, since the search was not more efficient in the preview search condition (49.8 ms/object) than in the control condition (40.3 ms/object). Finally, it is also possible that the ERP data are influenced by electrooculographic (EOG) activity.

Although the long duration of the preview interval is often taken as the evidence for inhibition, it was recently demonstrated that the preview effect could also be observed with an interval of only 50 ms [7], as long as the old objects are not presented with a luminance onset. According to the onset capture account, the long preview interval is necessary to prevent the onsets of the old and new objects from interfering with each other. When the old objects are presented without a luminance onset, the preview interval can be significantly reduced [7] or possibly even eliminated [2].

There are two major difficulties in testing the inhibition hypothesis of the preview benefit directly. First, it is difficult to measure attention allocated to the old objects during a preview interval without interfering with the primary task (search task). Secondly, a baseline is needed in order to make an unambiguous inference about active inhibition of the old objects.

### *1.1. The present study*

The present study used both electrophysiological and behavioral techniques to determine if the preview benefit results from inhibition of the old objects, maintained throughout the preview interval. Using event-related potentials is advantageous since this method provides a precise measure of brain dynamics of attentional allocation without interfering with an ongoing behavioral performance. Converging use of ERPs and behavioral measures can result in a more complete understanding of the mechanisms underlying the preview benefit.

In ERP studies of spatial cueing and visual search, it has been demonstrated that P1 and N1 components reflect attentional modulation of early sensory processing, and appear to be localized in extrastriate cortex [21,22]. P1 and N1 were shown to be larger at validly cued locations relative to invalidly cued locations in spatial cueing tasks [8,20], and at the location of the target, relative to the locations of the distractors in visual search tasks [18,19]. These data suggest that differences in P1 and N1 amplitude from some neutral baseline condition should be found if attention modulates the processing of the old objects during the preview interval. If the old objects are inhibited, the amplitude of the components should be smaller than the baseline, if the old objects are attended, the amplitude should be larger than the baseline, and if the old objects are not processed, the amplitude should be similar to the baseline.

In Experiment 1, we recorded event-related brain potentials (ERPs) time-locked to an irrelevant probe, presented during the preview interval before the new objects appeared. The probe constituted an equiluminant color change of the old objects, which has been shown not to disrupt the preview benefit, unlike large changes in luminance [27,29]. P1 and N1 elicited by the probe were compared in the preview search condition and two baseline conditions. In one baseline condition, participants were instructed to attend to the old objects in order to memorize their identity (memory task), while in the other baseline condition, participants were to focus attention on the center of the screen in order to detect a subtle change to a fixation cross (focused attention task). Physically, both of the baseline conditions were identical to the preview condition except for the very last display panel of the trial (see Fig. 1).

The focused attention baseline is used to determine if there is an active suppression at the locations of the old objects. Although some studies demonstrated that a very narrow focus of attention could result in inhibitory surrounds [25], our pilot work suggested that the focused attention task used in the present study was relatively easy, since it produced rather low error rates. Therefore, most attentional resources were expected to be directed to the center and spare resources to be allocated to the periphery. For example, according to the perceptual load hypothesis, if the load for the task performed at fixation is low, the remaining attentional resources would be allocated to the peripheral stimuli [16]. Thus, it is predicted that if the old objects are actively inhibited in the preview search condition, this should be manifested in decreased amplitude of the P1 and N1 components in the preview condition relative to the focused attention condition, assuming that the ERP components are a sensitive enough measure to detect this difference.

One reason for introducing the memory task baseline is to demonstrate that ERPs elicited by a non-salient equiluminant color change probe are sensitive to attentional manipulation. Therefore, the ERP components in the memory task are expected to be greater than in the focused attention task. In addition, the preview benefit could also involve active attention to the old objects, for example, as a part of a process of segregation from the new objects and maintenance of their representation as a group [3,10,11, 14,15]. For example, Jiang et al. [15] showed the importance of temporal grouping in the preview benefit. Braithwaite, Humphreys, and Hodsoll [3] have also demonstrated that the preview benefit is increased when old and new objects can be segregated by color. If the preview effect involves attention to the old objects during the preview interval, the ERP components in the preview condition should have comparable amplitude to the components in the memory condition, in which attention has to be allocated to the old objects in order to memorize their identity.

Experiment 2 was a control experiment, designed to investigate whether participants adopted a strategy of inhibiting the old objects during the short period between

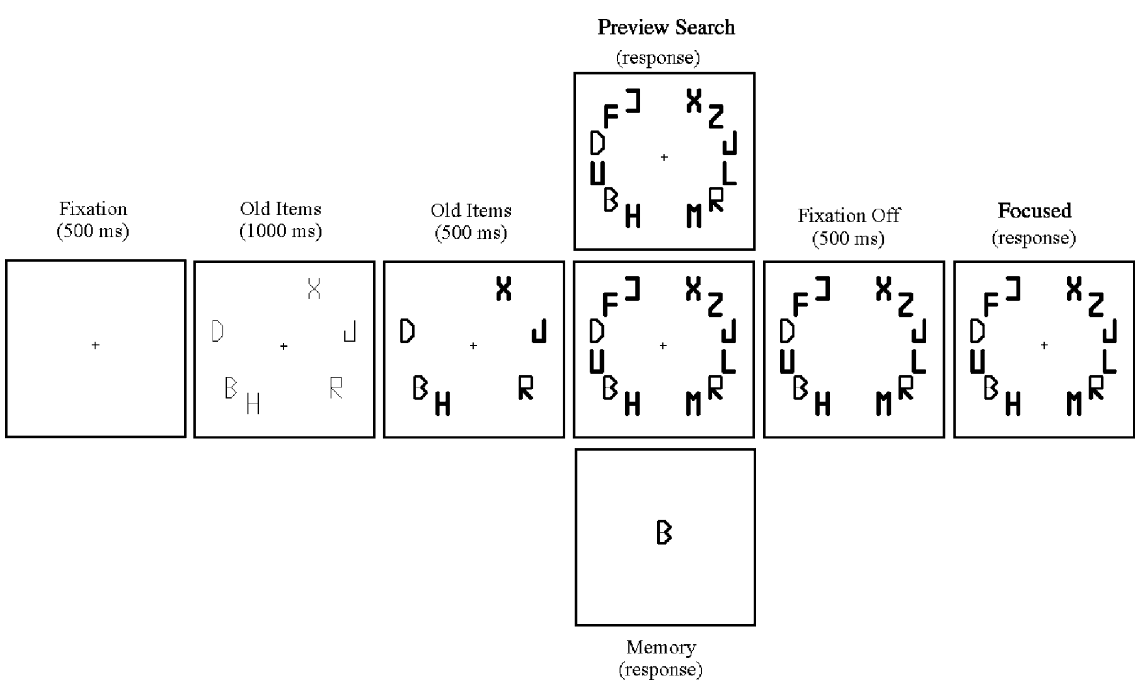


Fig. 1. Temporal order of events in the preview, focused attention, and memory conditions in Experiment 1. Thicker lines are used to illustrate an equiluminant change from gray to green.

the probe and the presentation of the new objects. The goal of Experiment 3 was to replicate the ERP findings from Experiment 1 using reaction time (RT) measures. Along with a focused attention baseline condition, a new diffuse attention baseline condition was also used in Experiment 3.

## 2. Experiment 1

The goal of this experiment was to test whether the preview benefit results from inhibition, maintained at the locations of the old objects throughout the preview interval. ERPs were time-locked to the irrelevant color change occurring during the preview interval. P1 and N1 components elicited by the probe in the preview search condition were compared against the two baseline conditions, the memory task and the focused attention task.

If the preview benefit does not involve active inhibition of the old objects during the preview interval, the amplitude of the ERP components should be similar in the focused attention and in the preview search conditions. However, if the old objects are actively inhibited, then the amplitude of the ERP components should be smaller in the preview search condition than in the focused attention condition. In case the preview benefit involves attention to the old objects during the preview interval, P1 and N1 amplitude should be comparable in the preview search and memory conditions.

In order to make claims about the type of attentional allocation in the preview interval, it was important to demonstrate the preview benefit behaviorally. Therefore, we included a full-item search baseline, which was identical to the preview search task, except that all the objects were presented at the same time.

### 2.1. Method

#### 2.1.1. Participants

Thirteen right-handed student volunteers, between 18 and 27 years old (average age 21.3, 6 males) were paid to participate in the experiment. All participants had normal or corrected-to-normal visual acuity and normal color vision, tested by Ishihara Color Blindness Test [12]. The data from one participant were excluded from the analysis due to excessive eye movements.

#### 2.1.2. Apparatus

A Micron 166 MHz computer running custom software was used for stimulus generation, presentation, sending event codes to the amplifier, and recording participants' reaction time (RT) data. Stimuli were presented in 16-bit color depth on 21-in. SVGA monitor. Participants' heads were stabilized by means of a chin rest located 90 cm from the monitor. Electrophysiological data were acquired using a separate Micron 166 MHz computer and SynAmps amplifier and Neuroscan software (Compumedics Neuroscan).

#### 2.1.3. Stimuli

Stimuli were all the letters of the alphabet, except for "I", "N", "Q", "T", and "Y", approximately 0.4° in width and 1° in height. They were painted in light gray (30 cd/m$^2$) against a black background. All letters were presented around the circumference of an imaginary circle in the center of the screen, with a radius of approximately 2.9° (see Fig. 1). The old objects changed their color to equiluminant green (30 cd/m$^2$). The new objects were also presented in green. The fixation cross was approximately 0.3°, painted in white (63 cd/m$^2$) in the center of the screen.

Since changes in the appearance of items can lead to differences in ERP components not related to attention, it is critical to keep the appearance of the items as similar as possible across conditions, allowing confidence that changes in ERP components are due to attentional manipulations. All the letters were similar to each other in their physical dimensions. However, extra caution was taken in designing the displays for each subject. For the first half of trials, the displays were generated by randomly assigning the letters to the predefined locations in the left and right visual fields. Then, the letters in the left and right visual field were swapped and these "mirrored" displays were assigned to the second half of trials. On each trial, a certain display was pseudorandomly picked from this pool generated in advance.

#### 2.1.4. Design

The experiment contained three main tasks (preview search, focused attention, and memory), during which EEG was recorded, and an additional full-item search task, in which no EEG was recorded. The full-item search task was introduced in order to obtain a behavioral measure of the preview benefit. The total display size of 8 or 12 objects was used in all of the tasks, except for the memory task. In the memory task, only 4 or 6 objects were presented.

The three main tasks (preview search, focused attention, and memory) were presented in separate blocks of 40 trials. The order of these tasks was counterbalanced across participants, and each task was repeated eight times. This resulted in 24 experimental blocks (960 trials) or 8 cycles of 3 tasks per subject. Therefore, the subjects performed a set of 3 blocks, each with a different task, then another set of 3 blocks with the tasks in the same order, and so on, until this cycle was repeated 8 times. Each block started with 4 practice trials that were not used in the analysis. The sequence of 24 blocks was immediately preceded and followed by a block of full-item search trials (80 trials). Each of the main tasks contained an equal number of trials.

In the focused attention condition, on approximately 22% of the trials, the fixation cross blinked during the preview interval, and the fixation cross blinked after the preview interval on the rest of the trials. This manipulation was used to encourage the participants to pay attention to the fixation cross continuously throughout the trial. Only the data from trials in which the blink occurred after the preview interval were analyzed.

#### 2.1.5. Procedure

Before the start of the experiment, participants were affixed with the recording electrodes and then seated comfortably in front of the computer monitor. First, participants completed a heterochromatic flicker fusion test [13] in which they matched the luminance of the green and gray colors. It was followed by a practice block, containing 10 trials for each of the main tasks. Participants were instructed to keep their eyes on the fixation cross (which was on the screen throughout the entire block) until the last display panel of the trial.

The temporal order of events is shown in the Fig. 1. Following 500 ms after the participant pressed a spacebar to initiate the trial, the first set of objects was presented. It was always half of the total display size, i.e., either 4 or 6 objects. They stayed on the screen for 1000 ms and then changed color to equiluminant green (probe). The last display panel of the trial was presented 500 ms after the probe and was different for each task.[1] In the preview search task, the second set of objects (4 or 6 objects) was interspersed among the first set of objects and participants were instructed to search for the target, either "C" or reversed "C". The target was always presented in the second set of objects. In the focused attention task, the last display panel was very similar to the preview search task; however, the participants were to determine if the fixation cross blinked once (was turned off for 40 ms) or twice (i.e., it was turned off for 40 ms, stayed on for 50 ms and then went off again for 40 ms) sometime during the trial.[2] The blink could occur during the preview interval (instead of the color change probe) or 500 ms after the presentation of the new objects. In the memory condition, the participants were to determine if the letter, presented in the last display panel had been presented earlier in the first set of objects (4 or 6 objects). The full-item search baseline condition presented at the very beginning and at the very end of the experiment was identical to the preview search condition, except that all objects appeared simultaneously (8 or 12 objects) and therefore, there was no probe. In all tasks, stimuli stayed on until the response was made.

Participants were also instructed that the probe was irrelevant to any of the tasks. In all of the tasks, except for the memory task, the participants were instructed to be as fast and as accurate as possible. For the memory task, the participants were just instructed to be as accurate as possible. Participants responded by pressing either a "z" or a "/" key for "C" or "reversed C" (preview search), one or two blinks (focused attention), and for old or new letter (memory), respectively.

#### 2.1.6. Recording system

The EEG was recorded using a 32-channel QUIK-CAP system (Compumedics Neuroscan). Electrodes F7, F3, Fz, F4, F8, FT7, FC3, FC4, FT8, T3, C3, Cz, C4, T4, TP7, CP3, CP4, TP8, T5, P3, Pz, P4, T6, OT1, OT2, O1, OZ, and O2 were located at standard positions according to the International 10–20 System. During the recording, the left mastoid (A1) served as a reference electrode. Prior to averaging, data were re-referenced offline to the algebraic average of two mastoids, $X_t - (1/2)\,(A2_t)$, where $X$ is the electrode and $t$ is the time point in milliseconds. Vertical electrooculogram (EOG) was recorded using a pair of electrodes placed above and below left eye in line with the pupil. Horizontal EOG was recorded from electrodes attached to the outer canthus of the left and right eyes. All electrodes were Ag/AgCl electrodes, filled with QUIK-Gel electrolyte (Neuromedical Supplies). All impedance levels were kept below 10 k$\Omega$. EEG and EOG signals were amplified with a bandpass of 0.1–50 Hz and digitized at 250 Hz. The data were acquired during the experimental block in a continuous mode. The gain was 5000 for the EEG channels and 500 for the EOG channels.

#### 2.1.7. Data analysis

In all experiments reported in this paper, RTs twice the size of a cell mean or shorter than 100 ms were excluded from analysis (less than 2.7% of the trials).

All ERP waveforms were time-locked to the presentation of the probe. EEG and EOG were epoched offline into periods of 600 ms, starting 100 ms prior to the onset of the probe, and ending 500 ms after the probe. The epochs were filtered offline with 1–40 Hz bandpass filter. EEG trials containing eye blinks, eye movements, DC offset correction and trials with incorrect behavioral responses were excluded from the averaged waveforms. Average exclusion rate was less than 25% for all the averages.

EEG was averaged separately for the preview search, focused attention, and memory conditions, and separately for the two set sizes. The analysis was centered at the posterior electrode sites (T5, T6, P3, P4, O1, O2, OT1, and OT2). The amplitude of P1 and N1 was quantified as peak amplitude within the latency windows of 150–250 ms and 200–300 ms, respectively. Amplitudes for all components were measured relative to the mean voltage in a 100-ms pre-stimulus baseline.

### 2.2. Results

#### 2.2.1. Behavioral data

To establish the preview benefit, the behavioral performance in the first and the last two blocks (160 trials total) of the preview search condition was compared to the full-item

[1] A longer preview interval used here allowed time for the ERPs to the onset of the old objects to resolve and also, to have enough time for the probe ERPs to resolve. Several studies have shown that a preview benefit is observed with the preview intervals of 1500 ms and longer ([24,25]; see also Experiment 3 in this paper).

[2] In the focused attention task, the probe was not presented on the trials when the fixation cross blinked early, before the new objects were presented. These probe trials were transferred to a condition when the fixation cross blinked late, after the appearance of the new objects.

search condition. These blocks were selected to have the same number of trials and minimize the effects of practice and fatigue across the preview search and full-item search baseline conditions.

Repeated measures analysis of variance (ANOVA) on mean correct RT with the condition (preview search or full-item search) and total display size (8 or 12 objects) as factors showed that participants responded faster in the preview than in the full-item search condition [$F(1,11)$ = 18.84, $P < 0.005$; 650 ms and 806 ms, respectively], as well as that RT increased as a function of the number of distractors [$F(1,11) = 36.57$, $P < 0.001$]. The preview benefit was evidenced by the fact that the search was less affected by the number of distractors in the preview search condition (14.0 ms/object) than in the full-item condition [28.8 ms/object; $F(1,11) = 7.88$, $P < 0.05$]. Fig. 2A presents the mean correct RTs for the preview and full-item search conditions as a function of display size.

The analysis of mean error rates (1.8% for the preview and 2.5% for full-item search conditions) yielded no significant main effects or interactions.

Overall, participants were rather accurate (<11% errors) in all of the tasks. Mean error rates were different across the preview search, focused attention and memory conditions [$F(2,22) = 22.23$, $P < 0.001$]. Participants made more errors in the memory condition [11%; $F(1,11)$ = 32.91, $P < 0.001$] and in the focused attention condition [8%; $F(1,11) = 37.39$, $P < 0.001$] than in the preview condition (2%). Participants were equally accurate in the focused attention and memory conditions [$F(1,11) = 2.09$, $P = 0.18$].

### 2.2.2. Electrophysiological data

The ERPs elicited by the color probe are presented in Figs. 3A and B. It appeared that the latencies for P1 and N1 were about 50 ms longer than typically reported [17]. This was most likely due to the use of a non-salient equiluminant color probe in the present experiment, and it has been shown previously that there is a difference in the speed of processing of color and luminance information in the brain [1,9].

Repeated measures analyses of variance (ANOVA) were performed separately for P1 and N1 components with condition, display size, electrode hemisphere, and electrode site as factors (Geisser–Greenhouse correction was applied, where necessary). For P1, the main effect of condition was not significant [$F(2,22) = 0.76$, $P = 0.44$]. There was a main effect of electrode site [$F(3,33) = 13.22$, $P < 0.005$]. A significant interaction between condition and electrode [$F(6,66) = 2.97$, $P < 0.05$] suggested that P1 amplitude in the memory and preview search conditions was larger than in the focused attention condition mainly at the parietal sites. However, in a follow-up analysis at the parietal electrode sites, the main effect of condition did not reach significance [$F(2,22) = 2.04$, $P = 0.15$]. Effects of condition were not different across the display sizes [$F(2,22) = 1.87$, $P = 0.18$] or hemispheres [$F(2,22) = 0.96$, $P = 0.40$]. Other main effects or interactions were not significant.

N1 amplitude elicited by the color probe was different across conditions [$F(2,22) = 5.15$, $P < 0.05$]. There was also a main effect of electrode site [$F(3,33) = 4.59$, $P < 0.05$]. Effects of condition were marginally different across hemispheres [$F(2,22) = 3.39$, $P = 0.06$], suggesting that the difference between the amplitude in the preview condition

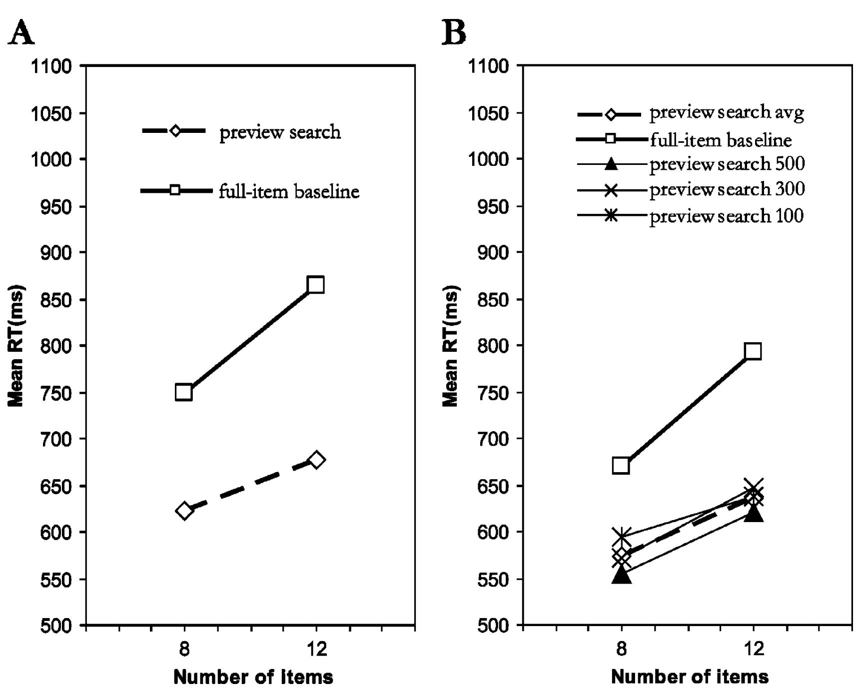


Fig. 2. (A) Mean response times in the preview search and full-item baseline conditions as a function of display size in Experiment 1. (B) Mean response times in the preview search condition with 500, 300, and 100 ms probe SOA and full-item baseline condition as a function of display size in Experiment 2.

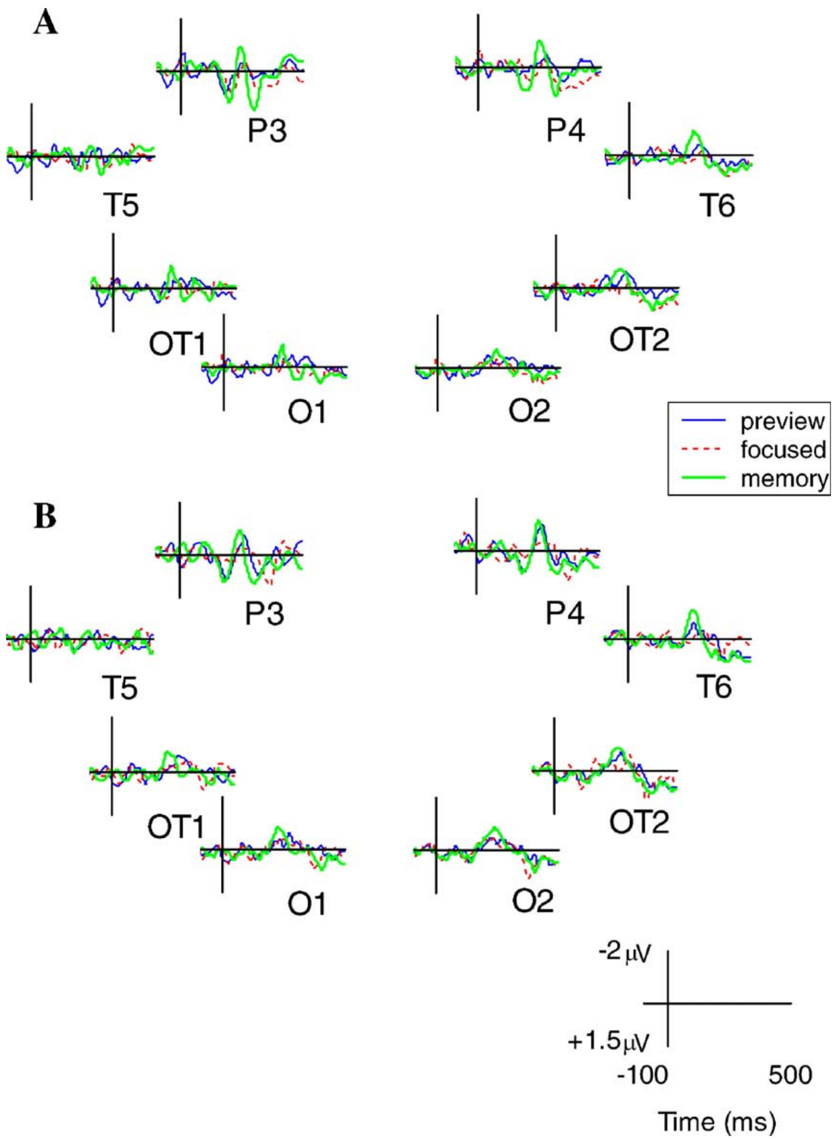


Fig. 3. (A) ERPs time-locked to the color probe for the display size of 8 objects in Experiment 1. (B) ERPs time-locked to the color probe for the display size of 12 objects in Experiment 1.

and in the focused attention condition was greater in the right hemisphere. Although the difference in N1 amplitude between the preview search condition and the focused attention condition might appear greater for display size 12 than for 8, the effects of conditions were not significantly different across display sizes [$F(2,22) = 0.10$, $P = 0.91$]. It is possible that this apparent difference was due to some jitter in N1 latency across the participants, which was circumvented by using peak amplitude measures. To provide some support for this possibility, we performed an additional comparison of N1 amplitude in the preview and focused attention conditions for the display size 8 only. N1 was marginally greater in the preview condition than in the focused condition [$F(1,11) = 4.49$, $P = 0.06$], supporting the possibility of a variability in N1 latency. In addition, later in the paper (Experiment 3a), we replicate the lack of difference in condition effects between the display sizes using behavioral measures. Other main effects or interactions were not significant.

Pair-wise comparisons showed that amplitude in the memory and preview search conditions was greater than in the focused attention condition [$F(1,11) = 5.76$, $P < 0.05$ and $F(1,11) = 8.98$, $P < 0.05$, respectively], and was not different between the memory and the preview search conditions [$F(1,11) = 0.58$, $P = 0.46$].

### 2.3. Discussion

The present results demonstrate that ERP components elicited by the equiluminant color probe are sensitive to attentional manipulation. While the preview benefit was observed behaviorally, the P1 and N1 components were larger in the preview search than in the focused attention condition. Indeed, the P1 and N1 were equivalent in amplitude in the preview search and the memory conditions. This pattern of results suggests that the old objects are actively attended rather than inhibited in the preview interval, at least 500 ms prior to the onset of the new objects.

Humphreys and colleagues [10,11] recently suggested that it is necessary to maintain the inhibited representation of the old objects throughout the preview interval in order to observe the preview benefit. Although the present results are consistent with the existence of a maintenance component of the preview benefit, the representation of the old objects that is being maintained during the preview interval seems to be attended, not inhibited, at least 500 ms before the appearance of the new objects.

There is, however, a possibility, that the results from Experiment 1 are due to the fact that participants adopted a strategy of inhibiting the old objects only after the color change probe occurred. It has been shown that, in some cases, the preview interval of 500 ms was enough to produce at least partial preview benefit [11]. This possibility was examined in Experiment 2.

## 3. Experiment 2

The goal of this behavioral experiment was to test whether, in Experiment 1, participants could have adopted a strategy of inhibiting the old objects after the color probe was presented 500 ms before the appearance of the new objects. In this experiment, we used both the preview search condition and the full-item search condition; however, in the preview search condition, the color probe was presented at three different SOAs (500, 300, and 100 ms) relative to the onset of the new objects, while keeping the total preview interval constant (1500 ms). If the participants chose to inhibit the old objects after the presentation of the probe, then the preview benefit should be significantly reduced or abolished when the probe occurs at the two shorter SOAs, since, according to the visual marking hypothesis, there would not be enough time (less than 500 ms, [11]) for the inhibition to accrue. However, if the magnitude of the preview benefit does not change with the probe SOA, it would mean that the participants are not adopting a strategy of inhibiting the old objects after the probe occurs.

### *3.1. Method*

#### *3.1.1. Participants*

Eight right-handed student volunteers, between 19 and 33 years old (average age 23, 7 females) were paid to participate in the experiment. All participants had normal or corrected-to-normal visual acuity and normal color vision, tested by Ishihara Color Blindness Test [12].

#### *3.1.2. Apparatus*

The same apparatus as in Experiment 1 was used in this experiment, except the apparatus for recording electrophysiological data.

#### *3.1.3. Stimuli*

The stimuli were identical to the stimuli used in the preview and full-item search conditions of Experiment 1.

#### *3.1.4. Design*

There were two search conditions, preview and full-item search, which were manipulated within-subjects. These conditions were presented in separate blocks (6 blocks per condition; total of 432 trials), with the order counterbalanced across subjects. In both conditions, the total display size was either 8 or 12 objects. In the preview search condition, the color probe could occur 500, 300, or 100 ms prior to the appearance of the new objects. The total preview interval was kept constant at 1500 ms. The trial order within a block was randomized.

#### *3.1.5. Procedure*

Before the start of the experiment, participants matched the luminance of the green and gray colors using the heterochromatic flicker fusion test [13]. The time-course of the trial for the full-item search condition was identical to Experiment 1. The time-course of the trial for the preview search condition was similar to Experiment 1, except that in addition to the probe occurring at 500 ms SOA relative to the onset of the new objects, the probe could also occur at 300 or 100 ms SOA. The rest of procedure was the same as in Experiment 1.

### *3.2. Results*

Repeated measures analysis of variance (ANOVA) on mean correct RT with the condition (preview search, averaged across the probe SOA, or full-item search) and total display size (8 or 12 objects) as factors showed that participants responded faster in the preview than in the full-item search condition [$F(1,7) = 10.0$, $P < 0.05$; 604 ms and 732 ms, respectively]. RT increased as a function of the number of distractors [$F(1,7) = 39.76$, $P < 0.001$]. The preview benefit was observed since the search was about twice as efficient in the preview search condition (15.4 ms/object) than in the full-item search condition [30.4 ms/object; $F(1,7) = 29.49$, $P < 0.005$].

In order to compare the magnitude of the preview benefit across the different probe SOAs, the mean search slopes at different probe SOAs in the preview condition were compared in a repeated measures analysis of variance (ANOVA). There was no difference between the search slopes at different probe SOAs [$F(2,14) = 0.56$, $P = 0.59$]. Importantly, the search at all probe SOAs in the preview condition was more efficient than in the full-item search condition [16.6 ms/object at 500 ms SOA, 19.0 ms/object at

300 ms SOA, 10.5 ms/object at 100 ms SOA; $F(1,7)$ = 32.07, $P < 0.005$, $F(1,7) = 5.75$, $P < 0.05$, $F(1,7) = 6.08$, $P < 0.05$, respectively]. Fig. 2B presents the mean correct RTs for the preview search and full-item search conditions as a function of display size and probe SOA.

The analysis of mean error rates (3.7% for the preview and 3.3% for the full-item search conditions) yielded no significant main effects or interactions.

To verify that the participants in Experiment 1 and Experiment 2 used the same strategy, we also compared the behavioral performance between the two experiments (Figs. 2A and B). For example, one could argue that the participants in Experiment 2 started inhibiting before the color change, while the participants in Experiment 1 started inhibiting after the color change. If that was the case, there should be a difference in the magnitude of the preview effect across the two experiments, since the preview effect emerges around 500 ms, but reaches its optimum around 1000 ms [11,27]. Analysis of variance (ANOVA) was performed on mean correct RT with experiment as between-subject factor and the condition (preview search, averaged across the probe SOA in Experiment 2, or full-item search) and total display size (8 or 12 objects) as within-subject factors. The interaction between experiment, condition, and display size was not significant [$F(1,18) = 0.03$, $P = 0.88$], indicating that the magnitude of the preview effect was similar in Experiment 1 and 2.

### 3.3. Discussion

The results indicate that participants did not adopt a strategy of inhibiting the old objects after the color change probe. The preview benefit was similar independently of whether the probe was presented at a 500-ms, 300-ms, or 100-ms SOA in relation to the onset of the new objects. More specifically, the robust preview benefit observed with the 100-ms SOA is unlikely to be due to participants rapidly switching tasks and inhibiting the old objects. A similar result was also reported by Jiang and colleagues [15], who demonstrated that polarity reversal of the old objects during the preview interval also did not interfere with the preview benefit. In addition, the magnitude of the preview benefit in this experiment was very similar to Experiment 1, suggesting that, in both experiments, participants were using the whole preview interval to prioritize selection for the new objects.

Importantly, these results suggest that it is unlikely that the participants in Experiment 1 adopted a strategy of inhibiting the old objects after the probe was presented. Thus, Experiment 2 confirms our original conclusion that the participants were attending to the old objects, and not inhibiting them during the preview interval.

As mentioned in the Introduction, one of the major difficulties in testing the inhibition hypothesis of the preview benefit is finding an adequate baseline condition. It is possible that because of a narrowly tuned attentional focus, induced by the focused attention baseline in Experiment 1, it was difficult to compare this condition to the preview search and memory conditions, which induced a much wider attentional focus. That is, the focused attention task might have pulled attention away from the periphery, leading to a decrease in the P1 and N1 amplitude. A task that would induce a diffuse, unfocused attentional state may be a more appropriate baseline condition.

In Experiment 3, our goal was to replicate the findings from Experiment 1 using reaction time measures, and then to test if they still hold when the performance in the preview search condition was compared against a new diffuse attention baseline condition.

## 4. Experiment 3

The goal of this experiment was to provide converging behavioral evidence that the old objects are attended during the preview interval. The same tasks as in Experiment 1 were also used here. In addition, the performance in the preview search condition was compared against a new baseline task that was designed to induce a diffuse attentional state. To measure attentional processing, we used a secondary probe detection task, similar to the one used by Humphreys and colleagues [23,28]. Importantly, we used the same color change probe as in Experiment 1, presented 500 ms before the onset of the new objects.

If participants are continuously inhibiting the old objects during the preview interval, we would expect them to be slower and less accurate in responding to the probe in the preview search condition than in both focused and diffuse attention baseline conditions. However, if participants are attending to the old objects during the preview interval, we would expect the performance in the preview search condition to be similar to the performance in the memory condition, in which participants must actively attend to the old objects to perform the task successfully.

### 4.1. Method

#### 4.1.1. Participants

Twenty-four right-handed student volunteers, between 19 and 26 years old (average age 21, 14 females), were paid to participate in the experiment. All participants had normal or corrected-to-normal visual acuity and normal color vision, tested by Ishihara Color Blindness Test [12]. The participants were either assigned to Experiment 3a or Experiment 3b.

#### 4.1.2. Apparatus

The same apparatus as in Experiment 2 was used in this experiment.

#### 4.1.3. Stimuli

Stimuli were similar to the stimuli in Experiment 1. The important difference was that equiluminant color change probes were presented only in 25% of the trials. In addition, in Experiment 3b, instead of a blinking fixation cross, a white shape, either a square or a triangle (0.3°), could be flashed anywhere within the 9.5° square around the center of the screen.

*4.1.4. Design*

The design of the experiment, except for a few changes, was very similar to the design of Experiment 1. Experiment 3a contained three primary tasks: the preview search task, the memory task, and the focused attention task. Experiment 3b contained two primary tasks: the preview search task and a diffuse attention task. Both experiments also contained a secondary probe detection task. The equiluminant color probes were presented on 25% of the trials in each task, and occurred 500 ms before the onset of the new objects.

In the focused attention condition, just like in Experiment 1, on approximately 22% of the trials, the fixation cross blinked during the preview interval and the fixation cross blinked after the preview interval on the rest of the trials. In the diffuse attention condition on approximately 22% of the trials, a square or a triangle was briefly flashed during the preview interval and could appear anywhere in the region within and immediately around the circle of letters. On the rest of the trials, a square (triangle) was flashed after the new objects were presented. This manipulation was used to encourage the participants to use the specific attentional strategy (narrowly focused or diffuse) continuously throughout the trial.

Primary tasks were presented in separate blocks of 64 trials. The order of these tasks was counterbalanced across participants, and each task was repeated four times. The primary task blocks were immediately preceded and followed by the two blocks (48 trials each) of full-item search trials. As in Experiment 1, the full-item search condition was introduced in order to obtain a behavioral measure of the preview benefit.

*4.1.5. Procedure*

The procedure was similar to Experiment 1, except that the color probe occurred only on 25% of trials in each task. Another difference was that the experiment was changed from a self-paced to a forced-paced presentation with an intertrial interval of 500 ms.

Participants were instructed about the primary tasks (preview search, focused attention, and memory) in the same way as in Experiment 1. The diffuse attention task (see Fig. 4) was similar to the focused attention task; however, instead of a blinking fixation cross, a white square or a triangle was briefly (100 ms) flashed in the area around the center of the screen, the borders of which were just outside the imaginary circle on which the letters were presented. Participants were instructed that the square or triangle could occur anytime throughout the trial and could be flashed anywhere in the region within and immediately around the circle of letters, and were encouraged to diffuse their attention around that region.

In addition, the participants were also instructed about the secondary probe detection task. They were required to respond with a spacebar to the appearance of the probe as fast as possible and to abort the execution of the primary task. They were given feedback if they responded incorrectly or missed the probe.

*4.2. Results: Experiment 3a (focused attention condition)*

To establish the preview benefit, the behavioral performance in the primary task of the first and the last block of the preview search condition was compared to the full-item search condition.

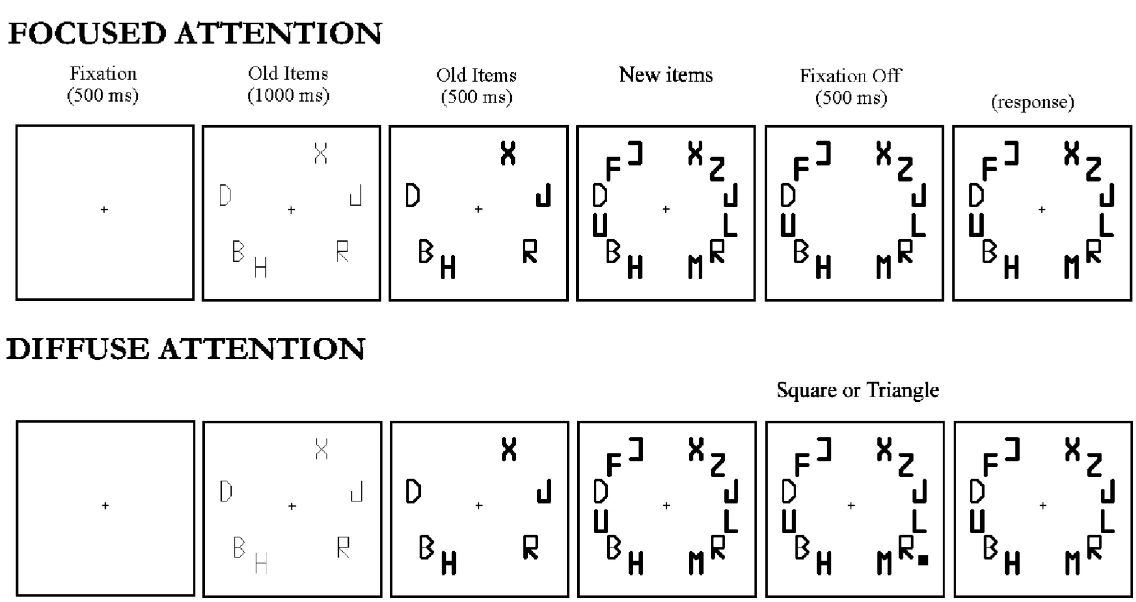


Fig. 4. Temporal order of events in the focused attention and diffuse attention conditions in Experiments 3a and 3b.

Repeated measures analysis of variance (ANOVA) on mean correct RT with the condition (preview search or full-item search) and total display size (8 or 12 objects) as factors showed that participants responded faster in the preview than in the full-item search condition [$F(1,11)$ = 40.47, $P$ < 0.001; 610 ms and 756 ms, respectively]. RT increased as a function of the number of distractors [$F(1,11)$ = 22.52, $P$ < 0.005]. The preview benefit was evidenced by the fact that the search was less affected by the number of distractors in the preview search condition (6.2 ms/object) than in the full-item condition [26.3 ms/object; $F(1,11)$ = 17.07, $P$ < 0.005]. Fig. 5A presents the mean correct RTs for the preview and full-item search conditions as a function of display size.

The analysis of mean error rates (3.2% for the preview and 2.4% for full-item search conditions) yielded no significant main effects or interactions.

Mean error rates were different across the preview search, focused attention, and memory conditions [$F(2,22)$ = 18.05, $P$ < 0.001]. Participants made more errors in the memory condition [9.7%; $F(1,11)$ = 37.95, $P$ < 0.001] and in the focused attention condition [6.6%; $F(1,11)$ = 18.81, $P$ < 0.005] than in the preview condition (2.2%). Participants were equally accurate in the focused attention and memory conditions [$F(1,11)$ = 4.21, $P$ = 0.07].

Repeated measures analysis of variance (ANOVA) on mean correct RT to the probe with the condition (preview search, focused attention, and memory) and total display size (8 or 12 objects) as factors showed that participants responded differently in the three tasks [$F(2,22)$ = 8.15, $P$ < 0.005]. Overall, RTs to the probe were not affected by the display size [$F(1,11)$ = 4.09, $P$ = 0.07]. Just like in N1 component analysis in Experiment 1, the effects of the tasks were not different across the display sizes [$F(2,22)$ = 0.06, $P$ = 0.94]. The mean correct RT to the probe in the three tasks is shown in Fig. 5B.

Pair-wise comparisons showed that participants were faster in the preview search (567 ms) and in the memory conditions (554 ms) than in the focused attention condition (615 ms) [$F(1,11)$ = 18.14, $P$ < 0.005 and $F(1,11)$ = 8.67, $P$ < 0.05, respectively]. Importantly, there was no difference in RT to the probe between the preview search and the memory conditions [$F(1,11)$ = 0.80, $P$ = 0.39].

Mean error rates for detecting the probe were not significantly different across the conditions [$F(2,22)$ = 2.05, $P$ = 0.15; 3.3% for the preview search, 1.7% for the focused attention, and 2.1% for the memory].

### 4.3. Results: Experiment 3b (diffuse attention condition)

To establish the preview benefit, the behavioral performance in the primary task of the first and the last block of the preview search condition was compared to the full-item search condition.

Repeated measures analysis of variance (ANOVA) on mean correct RT with the condition (preview search or full-item search) and total display size (8 or 12 objects) as factors showed that participants responded faster in the preview than in the full-item search condition [$F(1,11)$ = 22.78, $P$ < 0.005; 622 ms and 739 ms, respectively]. RT increased as a function of the number of distractors [$F(1,11)$ = 11.56, $P$ < 0.01]. The preview benefit was evidenced by the fact that the search was less affected by the number of distractors in the preview search condition (1.7 ms/object) than in the full-item condition [19.2 ms/object; $F(1,11)$ = 11.01, $P$ < 0.01]. Fig. 5C presents the mean correct RTs for the preview and full-item search conditions as a function of display size.

The analysis of mean error rates (3.2% for the preview and 3.1% for full-item search conditions) yielded no significant main effects or interactions.

In the primary tasks, participants made more errors in the diffuse attention condition than in the preview search condition [14.9% and 3.2%; $F(1,11)$ = 65.68, $P$ < 0.001].

Repeated measures analysis of variance (ANOVA) on mean correct RT to the probe with the condition (preview search and diffuse attention) and total display size (8 or 12 objects) as factors showed that participants responded to the probe faster in the preview search task than in the diffuse attention task [555 ms and 590 ms, respectively; $F(1,11)$ = 10.86, $P$ < 0.01]. Overall, RTs to the probe were not affected by the display size [$F(1,11)$ = 3.20, $P$ = 0.10]. The effects of the tasks were also not different across the display sizes [$F(1,11)$ = 1.74, $P$ = 0.21]. The mean correct RT to the probe in the three tasks is shown in Fig. 5D.

Mean error rates for detecting the probe were not significantly different across the conditions [$F(1,11)$ = 0.30, $P$ = 0.59; 3.3% for the preview search and 3.8% for the diffuse attention].

### 4.4. Discussion

The present results corroborate the ERP findings from Experiment 1 using behavioral measures. In addition, we incorporated a new baseline task that induced a diffuse attentional state. As before, a preview benefit in search slopes was observed. Participants were faster in responding to the probe, presented during the preview interval, in the preview search condition than in both focused and diffuse attention conditions. Importantly, the participants were also just as fast in detecting the probe in the preview search condition as in the memory condition. The results suggest that participants are not continuously inhibiting the old objects during the preview interval, but rather are attending to them at least 500 ms before the onset of the new objects.

## 5. General discussion

We have reported three experiments examining whether the preview benefit (i.e., the ability of observers to exclude a

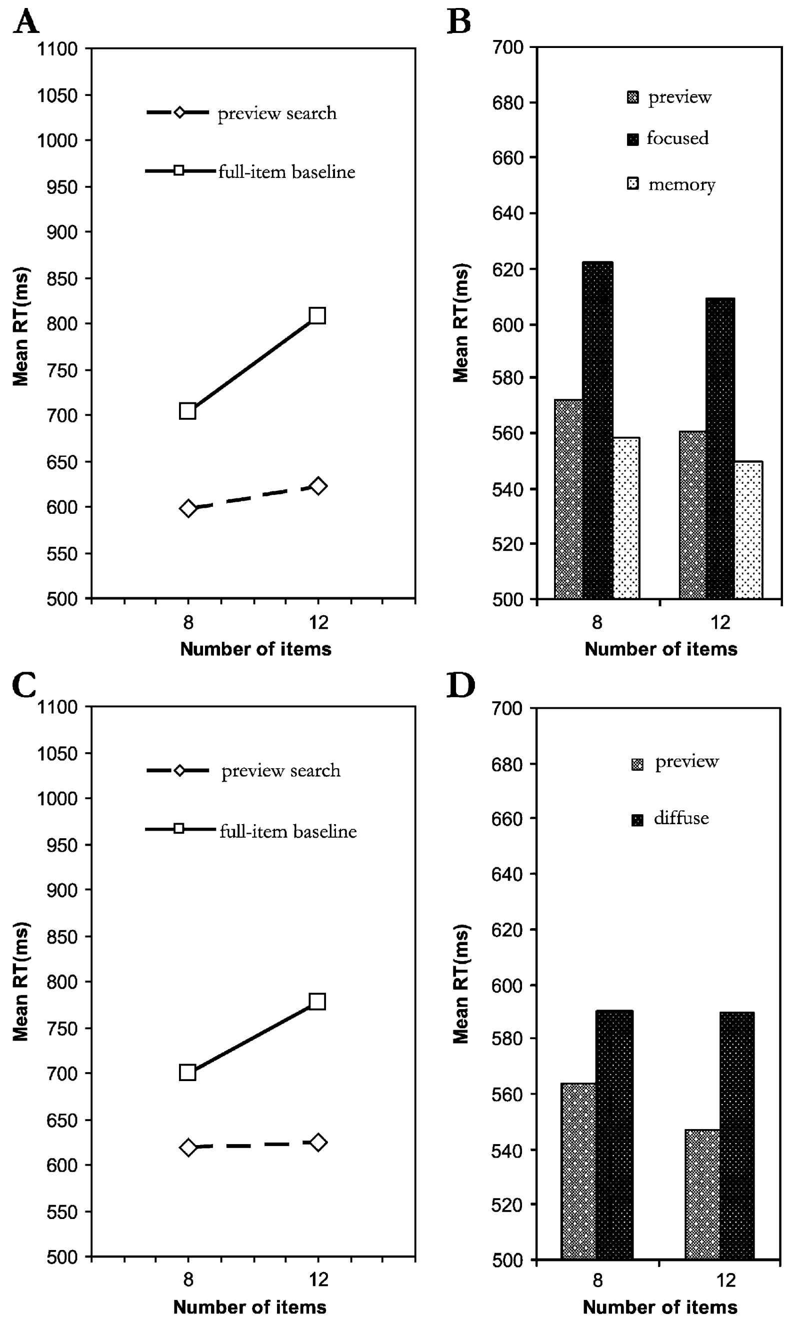


Fig. 5. (A) Mean response times in the preview search and full-item baseline conditions as a function of display size in Experiment 3a. (B) Mean response times to the probe in Experiment 3a. (C) Mean response times in the preview search and full-item baseline conditions as a function of display size in Experiment 3b. (D) Mean response times to the probe in Experiment 3b.

previously viewed set of objects from their visual search) occurs via continuous inhibition of its location during the preview interval. In Experiment 1, we recorded ERPs time-locked to an irrelevant color change in the preview interval. We found that P1 and N1 components had larger amplitude in the preview search task than in the focused attention task that induced a narrowly focused attentional state. Interestingly, the components in the preview search task were similar in amplitude to the components in the memory task, in which participants had to pay attention to the old objects to perform the task. Based on these results, we suggested that instead of inhibiting, participants were attending to the old objects in the preview interval.

In Experiment 2, we verified that participants did not adopt a strategy of inhibiting the old objects after the presentation of the probe. The magnitude of the preview benefit was the same when the probe appeared 500, 300, or 100 ms before the onset of the new objects.

In Experiment 3, we examined participants' response times to an occasional color probe, occurring during the preview interval, in the preview search, memory, and focused attention conditions, as well as in an additional diffuse attention condition. Participants were faster in the preview search condition than in the focused or diffuse attention conditions. Importantly, response times in the preview search condition were not different from the memory condition. These results corroborated our findings from Experiment 1 that participants are attending to, and not continuously inhibiting, the old objects in the preview interval.

### 5.1. The role of the preview interval

The present results have important implications for understanding the role of the preview interval in the preview benefit in visual search. Based on the long time-course of the preview benefit (600 ms or longer), dual-task interference analyses, and probe detection studies, Watson, Humphreys, and colleagues [10,11,23,27,28], concluded that the preview interval is used for setting up an inhibitory set, consolidating the representation of old objects and maintaining this inhibited representation.

In a recent study, Jacobsen and colleagues [14] observed a sustained negative event-related brain potential (ERP) wave in the preview interval from 350 to 750 ms after the presentation of the first display, which they also attributed to setting up and maintaining inhibition of the old objects. This ERP component was reduced in the control condition, in which there was no incentive to inhibit the old objects. Alternatively, these results could also be due to maintenance of attention at the old objects, since this component was even more negative in a condition in which participants had to search the first display upon its presentation.

Although our results demonstrated that old objects were attended in the preview interval 500 ms before the onset of the new objects, there still remains a possibility that inhibition occurred later in the preview interval, during or immediately after the arrival of the new objects. For example, in all previous probe performance studies, in which inhibition of the old objects was observed, the probe was always presented after the onset of the new objects, and never during the preview interval [23,28]. Note, however, that in the present study, the old objects were presented for 1000 ms prior to the probe and the probe did not interfere with the preview benefit (Experiment 2). Therefore, the participants had ample opportunity to inhibit the old objects and it is not clear why they would wait until the last 500 ms or later to switch from attention to inhibition. A possible tempting solution is to present a probe closer in time to the onset of the new objects; however, caution should be taken since processing of the probe at the old locations can then be affected by an attentional set towards the new objects, adopted in the preview search, but not in the baseline tasks.

A simpler explanation is that attention to the old objects during the preview interval is necessary for grouping them and maintaining their representation as a group, to assist in their segregation from the new objects later on. There is some evidence that grouping of the old objects is important for the preview benefit. For example, Jiang and colleagues [15] suggested that the preview benefit occurs as a result of temporal grouping and segregation of the old and new objects. Recently, Braithwaite, Humphreys, and Hodsoll [3] also demonstrated that the preview benefit was reduced when old objects had different colors.

Although grouping of the old objects seems to be an important component, it is not clear whether the preview benefit critically depends on it. However, what has been shown to be critical for the preview benefit is that the new objects are presented as abrupt onsets [5]. When the new objects are equiluminant with a background, the preview benefit is disrupted. As recently demonstrated by Donk and Verburg [7], prioritization of new objects is possible even with a very short preview interval (50 ms), as long as the old objects are not presented with a luminance onset. Likewise, as long as the new objects are accompanied by a luminance increment, a preview interval is not necessary [2]. The benefit of having a preview interval might be as mundane as preventing two succeeding magnocellular transients from interfering with each other or the preview may be necessary to allow sufficient time for attention, captured by the onset of the old objects, to be shifted to the new objects.

### 5.2. Conclusion

We conclude that, although participants might be using inhibition during the last 500 ms of the preview interval (independently of how long the preview interval is), or even after the presentation of the new objects, inhibition of old objects is not being maintained from the beginning and throughout most of the preview interval. Instead of maintaining inhibition, participants are attending to old objects in the preview interval, possibly in order to group them to facilitate their segregation from the new objects later on. We suggest that attention to the old objects during the preview interval might be an auxiliary mechanism, while attention to the luminance onsets of the new objects might be the critical mechanism underlying the preview benefit in visual search. Further research is needed to determine the relative importance of attention to the old objects in the preview interval.

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## References

[1] L. Anllo-Vento, S.J. Luck, S.A. Hillyard, Spatio-temporal dynamics of attention to color: evidence from human electrophysiology, Hum. Brain Mapp. 6 (1998) 216–238.
[2] A.V. Belopolsky, J. Theeuwes, A.F. Kramer, Prioritization by transients in visual search. Psychon. Bull. Rev. (in press).
[3] J.J. Braithwaite, G.W. Humphreys, J. Hodsoll, Color grouping in space and time: evidence from negative color-based carryover effects in preview search, J. Exp. Psychol. Hum. Percept. Perform. 29 (2003) 758–778.
[4] J.A. Burkell, Z.W. Pylyshyn, Searching through subsets: a test of the visual indexing hypothesis, Spat. Vis. 11 (1997) 225–258.
[5] M. Donk, J. Theeuwes, Visual marking beside the mark: prioritizing selection by abrupt onsets, Percept. Psychophys. 63 (2001) 891–900.
[6] M. Donk, J. Theeuwes, Prioritizing selection of new elements: bottom–up versus top–down control, Percept. Psychophys. 65 (2003) 1231–1242.
[7] M. Donk, R.C. Verburg, Prioritizing new elements with a brief preview period: evidence against visual marking, Psychon. Bull. Rev. 11 (2004) 282–288.
[8] M. Eimer, The time-course of spatial orienting elicited by central and peripheral cues: evidence from event-related brain potentials, Biol. Psychol. 53 (2000) 253–258.
[9] T.J. Gawne, T.W. Kjaer, B.J. Richmond, Latency: another potential code for feature binding in striate cortex, J. Neurophys. 76 (1996) 1356–1360.
[10] G.W. Humphreys, D.G. Watson, P. Jolicoeur, Fractionating the preview benefit in search: dual-task decomposition of visual marking by timing and modality, J. Exp. Psychol. Hum. Percept. Perform. 28 (2002) 640–660.
[11] G.W. Humphreys, S. Kyllingsbaek, D.G. Watson, C.N.L. Olivers, I. Law, O.B. Paulson, Parieto-occipital areas involved in efficient filtering in search: a time course analysis of visual marking using behavioral and functional imaging procedures, Q. J. Exp. Psychol., A 57A (2004) 610–635.
[12] Ishihara's Tests for Colorblindness, 24 plates edition, Kanehara and Co., Tokyo, 1989.
[13] H.E. Ives, Studies of the photometry of different colours: I. Spectral luminosity curves obtained by equality of brightness photometer and the flicker photometer under similar conditions, Philos. Mag. 24 (1912) 149–188.
[14] T. Jacobsen, G.W. Humphreys, E. Schroger, U. Roeber, Visual marking for search: behavioral and event-related potential analyses, Cogn. Brain Res. 14 (2002) 410–421.
[15] Y. Jiang, M.M. Chun, L.E. Marks, Visual marking: selective attention to asynchronous temporal groups, J. Exp. Psychol. Hum. Percept. Perform. 28 (2002) 717–730.
[16] N. Lavie, Perceptual load as a necessary condition for selective attention, J. Exp. Psychol. Hum. Percept. Perform. 21 (1995) 451–468.
[17] S.J. Luck, Neurophysiology of selective attention, in: H. Pashler (Ed.), Attention, Psychology Press/Erlbaum, Hover, 1998, pp. 257–295.
[18] S.J. Luck, S.A. Hillyard, The role of attention in feature detection and conjunction discrimination: an electrophysiological analysis, Int. J. Neurosci. 80 (1995) 281–297.
[19] S.J. Luck, S. Fan, S.A. Hillyard, Attention-related modulation of sensory-evoked brain activity in a visual search task, J. Cogn. Neurosci. 5 (1993) 188–195.
[20] S.J. Luck, S.A. Hillyard, M. Mouloua, M.G. Woldorff, V.P. Clark, H.L. Hawkins, Effects of spatial cuing on luminance detectability: psychophysical and electrophysiological evidence for early selection, J. Exp. Psychol. Hum. Percept. Perform. 20 (1994) 887–904.
[21] G.R. Mangun, H. Hinrichs, M. Scholz, H.W. Mueller-Gaertner, H. Herzog, B.J. Krause, L. Tellman, L. Kemna, H.J. Heinze, Integrating electrophysiology and neuroimaging of spatial selective attention to simple isolated visual stimuli, Vis. Res. 41 (2001) 1423–1435.
[22] A. Martinez, L. Anllo-Vento, M.I. Sereno, L.R. Frank, R.B. Buxton, D.J. Dubowitz, E.C. Wong, H. Hinrichs, H.J. Heinze, S.A. Hillyard, Involvement of striate and extrastriate visual cortical areas in spatial attention, Nat. Neurosci. 2 (1999) 364–369.
[23] C.N.L. Olivers, G.W. Humphreys, When visual marking meets the attentional blink: more evidence for top–down, limited-capacity inhibition, J. Exp. Psychol. Hum. Percept. Perform. 28 (2002) 22–42.
[24] M.S. Peterson, A.V. Belopolsky, A.F. Kramer, Contingent marking by transients, Percept. Psychophys. 65 (2003) 695–710.
[25] S.D. Slotnick, J.B. Hopfinger, S.A. Klein, E.E. Sutter, Darkness beyond the light: attentional inhibition surrounding the classic spotlight, NeuroReport 13 (2002) 773–778.
[26] J. Theeuwes, A.F. Kramer, P. Atchley, Visual marking of old objects, Psychon. Bull. Rev. 5 (1998) 130–134.
[27] D.G. Watson, G.W. Humphreys, Visual marking: prioritizing selection for new objects by top–down attentional inhibition of old objects, Psychol. Rev. 104 (1997) 90–122.
[28] D.G. Watson, G.W. Humphreys, Visual marking: evidence for inhibition using a probe-dot detection paradigm, Percept. Psychophys. 62 (2000) 471–481.
[29] D.G. Watson, G.W. Humphreys, Visual marking and visual change, J. Exp. Psychol. Hum. Percept. Perform. 28 (2002) 379–395.
[30] S. Yantis, E. Jones, Mechanisms of attentional selection: temporally modulated priority tags, Percept. Psychophys. 50 (1991) 166–178.