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The stage of priming: Are intertrial repetition effects attentional or decisional? ☆

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Abstract

In a visual search task, reaction times to a target are shorter when its features are repeated than when they switch. The present study investigated whether these *priming effects* affect the attentional stage of target selection, as proposed by the *priming of pop-out account*, or whether they modulate performance at a later, post-selectional stage, as claimed by the *episodic retrieval view*. Secondly, to test whether priming affects only the target-defining feature, or whether priming can apply to all target-features in a holistic fashion, two presentation conditions were invoked, that either promoted encoding of only the target-defining feature or holistic encoding of all target features. Results from four eye tracking experiments involving a size and colour singleton target showed that, first, priming modulates selectional processes concerned with guiding attention. Second, there were traces of holistic priming effects, which however were not modulated by the displays, but by expectation and task difficulty.

Keywords: Attention; Visual search; Intertrial effects; Priming of pop-out; Episodic retrieval

1. Introduction

The present study will be concerned with intertrial priming effects in pop-out search tasks: In a typical visual search experiment, participants have to find a certain, pre-specified target among a group of nontargets. Pop-out search tasks are characterised by targets that differ in a single feature from the remaining nontarget items, which are homogeneous with respect to that feature. Examples for pop-out searches in everyday life would be a green apple among red ones or searching for red berries among green leaves.

Psychophysical experiments have shown that targets constituting an odd man out or *singleton* can be found as the first item in the display, which obviates the need for elaborate search. This is experimentally validated by the absence of corresponding set size effects. When the target only differs in a conjunction of features from the nontargets, or when the nontargets are very heterogeneous, the time needed to find the target increases linearly with the number of items in the display. Such set size effects indicate that attention cannot be guided directly to the search target, but selects the target by a more or less stochastic process. In turn, in pop-out search, search performance is independent of the number of nontargets. This finding is taken to show that attention can be immediately deployed to the target item when it constitutes a singleton e.g., Yantis (1998).

However, search performance in pop-out search is also modulated by the search history. When the target and nontarget features are repeated compared to the previous, $n-1$ trial, reaction times are shorter than when target and nontarget have changed their features. This intertrial

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effect was first reported in a study by Maljkovic and Nakayama (1994), in which participants had the task to find a target that could be either green or red while the nontargets were presented in the opposite colour. The results showed that response times were shorter when the assignment of colours to target and nontargets remained the same, compared to the previous, $n-1$ trial, than when it switched. In the studies of Maljkovic and Nakayama, this intertrial effect only pertained to the target-defining feature and was not related to the response. The response-related feature was constituted by the target's shape, and repeating the target shape in turn did not result in any facilitation. This led Maljkovic and Nakayama (1994) to propose that the intertrial effect was due to facilitation on the attentional stage: According to their *priming of pop-out hypothesis*, repeating the target enhances the pop-out effect of this feature in subsequent trials, which increases its capability to summon attention to its position.

Other studies however produced conflicting evidence. In a study of Huang, Holcombe, and Pashler (2004), significant intertrial facilitation effects could be found not only for the target-defining feature, but also for the response-related and task-irrelevant target features. In their Experiment 1, participants had to search for a bar that was either smaller or larger than the rest of the items and to respond to the orientation of this odd-sized bar. Additionally, all items in the display were coloured white or black, but their colour was in no way relevant to the task. In this experiment, repetitions of the response-related orientation or the task-irrelevant colour of the target also led to facilitation, but their effects strongly depended on intertrial contingencies of the target-defining feature. Repeating the response-related or task-irrelevant item only led to faster responses when the target-defining feature was also repeated. In turn, repeating the response-related or the task-irrelevant feature even slowed reaction times when the target-defining feature switched.

The authors argued that this complex result pattern is incompatible with the hypothesis that priming only pertains to the target-defining feature (Huang et al., 2004). Additionally, the authors concluded that intertrial facilitation effects apparently do not operate on processes of attentional selection, but are located on a later, decisional level: "[P]riming cannot occur only at the perceptual or searching stage, since before the target is found there is no access to its orientation or colour..." (Huang et al., 2004, p. 20). According to the *episodic retrieval hypothesis* of Huang et al. (2004), visual search includes several successive processing stages: The first stage is searching for the target. The second stage involves a decision whether a selected candidate target is in fact the target. The last stage is selection and execution of a response (cf. Huang et al., 2004). On the episodic retrieval view, repeating the target from the previous trial facilitates processes on the second, decisional stage of processing. That is, after an item has been attentionally selected, verification procedures check whether this element matches the episodic memory of the target features in the previous trial(s). Importantly, the verification procedure operates on holistic representations of the previous target: Episodic memory traces are thought to contain information about relevant as well as irrelevant target features and facilitate or hamper decisions as a function of whether they coherently favour a "same" or "different" judgment (Huang et al., 2004). More precisely, if the target is absolutely identical to the previous one or else does not agree in a single feature with the previous target, comparing the relevant and irrelevant features will all cohere in a "same" or "different" judgment, thus speeding up verification procedures. If, on the other hand, only some of the features overlap (as is the case when the target-defining feature is switched while irrelevant features are repeated), inconsistencies in the matching process will arise, that are time-consuming.

Although the episodic retrieval account presents an interesting and challenging alternative to the priming of pop-out account, it must be contended that their critique on the priming of pop-out account does not seem to be wholly justified. Specifically, the finding that intertrial facilitation also occurs for response-related and task-irrelevant features does not call into question the view that priming facilitates processes on the attentional stage. It is important to note that hypotheses about which features are subject to priming are logically different from hypotheses about the processing stage at which they come into play and thus should be kept apart. It is clearly imaginable that attention might be guided by holistic target representations, and in fact such a view has been put forward by Hillstrom (2000). Similarly, the finding that priming only pertains to task-relevant features should not already count as evidence for an attentional account, because decisional or post-selectional processes could in principle as well be restricted to the task-relevant features. Thus, questions about the *object of priming* or what features are subject to priming, and about the *stage of priming*, that is, whether intertrial effects affect attentional or decisional processes, should be regarded as different hypotheses that require independent empirical evidence.

The aim of the present study was to investigate these questions and to gather independent empirical evidence for both of them. In the following, I will give a brief overview over the empirical evidence relating to both questions, and outline the way in which the hypotheses of the priming of pop-out and episodic retrieval view will be tested.

2. The stage of priming: Attentional or decisional?

The main aim of the present study was to explore whether intertrial facilitation effects operate on the attentional level, or on a post-selectional level. So far, the available evidence on this question is rather mixed and does not clearly favour one view over the other. Results from cuing studies support the attentional view: Goolsby and Suzuki (2001) showed that both pre-cueing of the target position and presenting the target alone in the search display reduced or even eliminated the effect of the previous, $n-1$ trial. The absence of repetition facilitation effects in conditions where the target does not have to be attentionally sought for in turn indicates that priming facilitates attention shifts to the target position. On the other hand, in a study of Huang and Pashler (2005) priming effects were also eliminated when the stimuli were presented in very brief displays. This might indicate that priming does not operate on an early stage of target detection and selection, but only speeds responses at a later, post-selectional stage (Huang & Pashler, 2005; see also Prinzmetal, McCool, & Park, 2005). In turn, eye tracking studies once more indicate that feature priming affects processes at the attentional stage: in a saccade task, the time needed to initiate a saccade to the search target (“saccadic latency”) decreased as the number of repetition trials increased (Kowler, Martins, & Pavel, 1984; McPeek, Maljkovic, & Nakayama, 1999). Although these studies were not specifically designed to investigate whether priming affects the attentional stage, the finding parallels previous findings about cumulative priming effects found in the manual response times (RTs) (e.g., Maljkovic & Nakayama, 1994). The finding that cumulative priming effects were already present in the saccadic latencies in turn was taken to show that repeating the target speeds early processes of target detection and selection (McPeek et al., 1999).

In the present study, eye movement measures were also invoked, to find out whether priming affects the attentional or post-selectional stage. Taking eye movements as indicator for covert attention shifts might also be criticised, because it presupposes a close connection between covert attention shifts and eye movement behaviour. In contrast it is common knowledge that covert attention shifts can be dissociated from eye movements. Covert attention shifts are possible even when the eyes remain fixated at a certain location on the screen (e.g., Posner, 1980). However, this only shows that overt eye movements do not automatically follow every covert shifts of attention, but can be withheld (specifically, when participants are instructed not to make any eye movements). This however does not contradict the claim that whenever there are eye movements, they can be used as indicator for covert attention. In order to demonstrate this, it would be necessary to show that in the presence of eye movements, covert and overt attention can dissociate. Studies investigating this question conversely found that the two are closely related to each other. Specifically when participants have to make an eye movement to a certain location, they are apparently incapable to simultaneously attend to an item at a different location (Deubel & Schneider, 1996). This suggests that eye movements are usually preceded by covert shifts of attention to a location, and may be taken as an indicator for covert shifts of attention.

Contrary to previous eye tracking studies, the present study did not measure eye movements in a saccade task, but in a standard visual search task. This was done for the following reasons: First, with a saccade task, the relative contributions of attentional and post-selectional processes cannot be assessed. Saccadic latencies can only show that an effect affects target detection and selection processes, but cannot reveal anything about post-selectional processes. Therefore it is still an open question whether and to what extent post-selectional processes might contribute to the priming effect. A second, more general, problem with saccade tasks arise because priming effects are usually measured and assessed in a different task that requires different responses. In the compound search task most commonly used for assessing priming, responses are typically based on features that are different from the target-defining feature. For instance, participants are required to respond to the shape of a search target defined by colour, or to discriminate between two possible orientations of a size singleton target (e.g., Hillstrom, 2000; Huang et al., 2004; Huang & Pashler, 2005; Maljkovic & Nakayama, 1994, 1996). Conversely, in a saccade task, participants only have to make a fast eye movement to the location of the target, or target-defining feature. These differences between the involved tasks might give rise to different intertrial effects. Therefore, it may be doubted whether the priming effect found in a saccade task is identical to the priming effect found in standard visual search task. To circumvent these complications, the present study did not use a saccade task, but a standard visual search task in which participants had to search for a pop-out target and responded to another feature by pressing a key.

A first approach to distinguish between the priming of pop-out hypothesis and episodic retrieval hypotheses would involve testing whether priming affects the time before or after visual selection of the target: The episodic retrieval account asserts that holistic verification processes pertaining to the target account for the priming effect, and thus predicts that priming will only affect processes after selection of the target. In turn, the priming of pop-out hypothesis asserts that intertrial contingencies modulate target selection and thus only affect processes before the target is selected in each trial. The most straightforward way to distinguish between the decisional and attentional view on priming would thus be to test whether and to what extent priming occurs in the durations before and after visual selection of the target. According to this scheme, priming would be classified as decisional or post-selectional, if it modulates the *target fixation durations*, that is, the duration the eyes remain fixated on the target after selecting it. In turn, priming would be regarded as attentional if it affects the *target fixation latencies*, that is, the duration needed to fixate the target (measured from the onset of the search display).

However, the choice of target fixation latencies and target fixation durations to indicate attentional versus post-selectional processes might also be criticised: Although measuring the target fixation latencies and durations might be sufficient to test the specific hypotheses of the priming of pop-out and episodic retrieval account, it might be claimed that these measurements are insufficient to test attentional

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versus decisional priming in the broader context of visual search theories. Current theories of visual search propose a concept of attentionality that is much narrower and does not include all processes involved in localising the target. Most current theories of visual search, like *Feature Integration Theory* (Treisman, 1982, 1988) and *Guided Search* (Wolfe, 1998) propose that visual search commences in two stages, a pre-attentive stage in which basic features are processed in parallel at all locations of the visual field, and a second, focused attention stage, in which processing is capacity-limited and restricted to a single item or group of items. Most researchers nowadays might be inclined to restrict the term "attentional" to processes involved in the guidance of attention, that is, to processes at the pre-attentive stage (e.g., Theeuwes, 1993).

With this notion of attentionality, the duration needed to select the target, or target fixation latency, would not necessarily be viewed as the best way to measure attentional effects. This is because in the present search task, it is possible to erroneously select a nontarget prior to target selection. However, processes concerned with nontarget rejection, or deallocation of attention from an already selected item would naturally not be regarded as attentional, but as post-selectional, because these processes are clearly not involved in the guidance of attention.

To test the question of attentional versus decisional priming effects in the broader context of current visual search theories, two provisions seem to be in order. First, it is necessary to take possible contributions of decisional processes before selection of the target into account. To that aim, the *nontarget fixation durations* that is, the durations that the eyes were fixated on the nontarget items, were also assessed in the course of the present experiments. Second, to provide measurements of attentional processes that solely rest on processes (potentially) involved in the guidance of attention, a different attentional measure was included. Data were exclusively sampled from the first eye movement in each trial, that is, before selection of any items. More precisely, the *proportion* of correct *first saccades* and the *saccadic latencies* of these saccades were taken as attentional measures. These measures should meet the criteria for attentionality by two-stage theories of visual search: If priming already modulates the precision of the first saccade, or the time needed to initiate a saccade to the target, it seems to be safe to conclude that priming affects pre-attentive processes that guide selection.

Table 1 summarises the different sub-groups of the selectional and post-selectional views, and the affected dependent eye movement measures according to predictions. The table only gives a rough overview over the paradigmatically affected measure, and should not be regarded as an own theoretical statement. Naturally, it is also possible to regard these different sub-groups or categories not as different views, but as providing necessary and sufficient conditions for categorising an effect as attentional or post-selectional, or as ranking the quality of evidence for the attentional *versus* decisional view. Whether the delineated hypotheses are regarded as own theoretical positions or classifications of evidence is insubstantial.

3. The object of priming

As outlined in the introduction, the priming of pop-out and episodic retrieval hypothesis also differ with respect to the proposed object of priming, or what features are subject to priming. According to the priming of pop-out hypothesis, priming should primarily pertain to the target-defining or "attention driving" feature. In contrast, the episodic retrieval hypothesis proposes that priming pertains to all target features, including task-irrelevant features, in a holistic fashion.

The available evidence relating to the question whether priming operates on holistic target representation or only pertains to the target-defining feature is widely divergent: Some studies found interactions between priming of the target-defining and the response-related or a task-irrelevant

Table 1
Overview of the affected measures assuming different stages of priming

	Stage of priming			
	Attentional/selectional		Decisional/post-selectional	
	Common view	Priming of pop-out	Common view	Episodic retrieval
Stage of priming: Affected processes	All processes concerned with guidance of attention	All processes that help to find the search target	Processes not involved with guiding attention	Processes not involved in search, after target selection
Measures	Duration from the beginning of a trial to the first selection of any item	Duration from the beginning of a trial until selection of the target	Duration that the eyes are focused on any item, prior to and after target selection	Duration that the eyes are focused on the target, after target selection
Predicted result pattern	Priming effects in accuracy and latency of first saccade in each trial	Priming effects in the target fixation latency (i.e., duration until first selection of the target)	Priming in nontarget fixation durations, and possibly, in the target fixation durations	Priming effects in the target fixation durations (i.e., durations eyes remain fixated on target after selection)

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Table 2
The predicted result patterns assuming different objects of priming

	Priming of pop-out Feature-based	Episodic retrieval Holistic	Flexible view Both feature-based and holistic
Object of priming	Only target-defining feature	All target features	In holistic presentation condition, priming of all target features; in the separate presentation condition priming only of the target-defining feature
Predicted result pattern	Only priming of target-defining feature occurs. No priming of response-related features	Priming of response depends on priming of target-defining feature	In separate presentation condition only priming of target-defining feature; in the holistic condition, priming of the response should depend on priming of the target-defining feature
In statistical terms	Main priming effect of target-defining feature; no priming for response-related feature	Two-way interaction between priming of target-defining and response-related feature	Three way-interaction between presentation condition, and priming of target-defining and response-related features: two-way interaction only in holistic presentation condition, not in separate presentation condition

feature, which has usually been interpreted to support the holistic priming view (Hillstrom, 2000; Huang et al., 2004). In other studies, priming effects relating to task-irrelevant or the response-related feature have either been completely absent or were much reduced, and did not reliably interact with priming of the target-defining feature (Becker, 2007; Goolsby & Suzuki, 2001; Maljkovic & Nakayama, 1994, 2000).

One rather obvious difference between studies that found holistic priming effects and those that failed to find such interactions concerns the construction of the stimuli. In studies which failed to show holistic processing, the target-defining and response-related stimuli constituted two different objects placed in the same location. For instance, participants had to respond to the orientation of an arrow or bar which was placed in the centre of a square, with properties of the square constituting the target-defining feature (Becker, in press). In contrast, in the studies of Hillstrom (2000) and Huang et al. (2004), the target-defining, task-irrelevant and response-related feature were all bound together in a single object; that is, they consisted of a coloured bar of a certain size and orientation (Hillstrom, 2000; Huang et al., 2004). As Huang et al. (2004) pointed out, this integrated presentation of all features into a single object may have prompted holistic processing of all target features. In turn, such a holistic encoding or processing strategy might be discouraged by presenting target-defining and response-related features in separate objects—interestingly, these remarks seem to constitute an entirely different view: According to such a "flexible view", priming can either pertain only to the target-defining feature, or to the whole target object, depending on whether the make-up of the target stimulus promotes holistic encoding or not.

In the present study, all these different views about priming of the response-related feature should be taken into account. To that aim, the intertrial contingencies of the target-defining and the response-related feature were varied independently of each other, so that performance could be checked for possible interactions between priming of the target-defining and response-related feature. In half of the experiments, the target-defining feature was a size singleton, in the other half, it was a colour singleton, whereas the response-related feature was always the orientation of a bar that could be tilted 45° to the right or left.

The possibility raised by the flexible view, that priming can pertain both to the target-defining feature or to all target features depending on the construction of the stimuli, was also taken into account, by invoking two different presentation conditions. In the *separate presentation condition*, the target-defining feature and response-related features were constructed as two distinct objects: a square possessed the target-defining feature, whereas the response-related feature was instantiated by a bar of a certain orientation. In the *holistic presentation condition*, the squares were all erased, and the bars themselves possessed the target-defining features. The hypotheses and predictions of the discussed views are delineated in Table 2.[1]

The experiments in the present study were designed as follows: in Experiment 1, participants had to detect a size singleton target that could be either larger or smaller than the remaining items. In the second experiment, the search target was a colour singleton which was randomly coloured white or black. The same search targets and stimulus conditions were also used in Experiments 3 and 4, but in those experiments, the target-defining feature varied in a predictably alternating sequence. Moreover, in all conditions, the set size of all items varied between 5 and 7 items. This was done to ensure that the target could be found by perform-

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[1] With the help of Tables 1 and 2 it is now also clearly visible that hypotheses about the stage of priming are entirely independent from the hypotheses concerning the object of priming: The proposed result patterns from a holistic, feature-based or flexible view might occur at any stage of the search process, because they might affect any of the dependent measures, that is, in the target fixation latencies, as well as in the initial saccades or in the target or nontarget fixation durations.

ing an efficient search, that is, that the search target indeed constituted a pop-out item.

4. Experiment 1

In Experiment 1, participants had to search for a size singleton target which was either smaller or larger than the remaining items. After they had found the search target, they had to report the orientation of a bar by pressing a key.

One aim of the Experiment 1 was to find out whether priming pertains only to the target-defining feature, as proposed by the priming of pop-out account, or whether it also includes the response-related item, in a holistic fashion, as proposed by the episodic retrieval view (see Table 2). To that aim, intertrial effects were assessed for one trial back, equally for the target-defining feature size and the response-related feature orientation. To investigate whether holistic priming effects depend on the way the target-defining and response-related items are presented, as proposed by the flexible view, search performance was tested in two different presentation conditions: In the separate presentation condition, participants had to search for a square that could be either larger or smaller than the remaining items. The response-related bar was presented as a separate object in the centre of the square. In the holistic presentation condition, the response-related bar itself was presented in a larger or smaller size. The response-related bars had the same size in both presentation conditions, to ensure equal perceptual discriminability of the items across conditions. Example displays from the separate and holistic presentation conditions of Experiment 1 are depicted in the top row of Fig. 1.

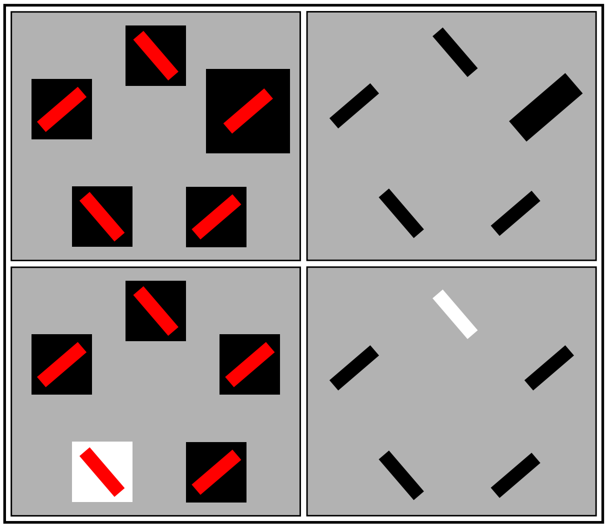

Fig. 1. Example of stimulus displays in Experiments 1–4, set size 5. The top panels depict examples for the size search condition of Experiments 1 and 3, with the separate presentation condition on the left, and the holistic presentation condition on the right hand side. The bottom panels analogously depict examples of displays in the colour singleton search condition of Experiments 2 and 4.

Another aim of the present experiment was to find out whether priming modulates processes on the selectional or post-selectional stage. To that aim, eye movement data were assessed in the following way: To distinguish between different versions of the selectional and post-selectional views, first the attentional measures—that is, the target fixation latencies (i.e., the time needed to focus on the target), the proportion of initial saccades that directly go to the target and their saccadic latencies, were tested for priming effects. Second, the post-selectional measures were probed for priming effects, comprising the target fixation durations (i.e. the time the eyes remain fixated on the target after selection) and the nontarget fixation durations (i.e. the durations the eyes remained fixated on a nontarget). The predictions of the priming of pop-out and episodic retrieval view are depicted in Table 1, along with some more common views on attentional and post-selectional processes.

4.1. Methods

4.1.1. Participants

Eight students from the University of Bielefeld, Germany, took part in the experiment as paid volunteers (6€/h). Two of them were male, 6 female, and they had a mean age of 31. All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

4.1.2. Materials

An Intel Pentium^{R} 4CPU 3.00 GHz-Computer (tico) with a 19″ SVGA colour monitor (AOC) controlled the timing of events and generated the stimuli. Stimuli were presented with a resolution of 1024 × 768 pixels and a refresh rate of 99.9 Hz. For recording of eye movements, a video-based infrared eye tracking system (iViewX tracker, SMI, Teltow) with a spatial resolution of 0.1° and a temporal resolution of 240 Hz was used. Participants were seated in a dimly lit room, with their head fixated by the eyetracker's chin rest and forehead support, and viewed the screen from a distance of 92 cm. For registration of manual responses, a standard USB optical mouse was used. Event scheduling and reaction time measurement were controlled by the Presentation software (*Neurobehavioral Systems*).

4.1.3. Stimuli

The response-related stimuli consisted of five or seven bars (0.4° × 1.1°) oriented 45° to the left or right that could be red (19 cd/m^2) or black (0 cd/m^2). In the separated presentation condition, the bars were coloured red and located in the centre of black or white (92 cd/m^2) coloured squares. These squares could either be small (1.2° × 1.2°) or large (1.8° × 1.8°) and were located on the outlines of an imaginary circle with a diameter of 7.5°. In the holistic presentation condition, the response-related items themselves were either smaller (0.4° × 1.1°) or larger (1.2° × 1.8°) than the remaining items.

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All stimuli were equally spaced from each other, beginning at the 12o'clock position and the excentricity of the items was kept constant. In the set size 5 condition, the interitem distance between two neighbouring stimuli was 4.3°, and in the set size 7 condition, it was 3.1°; centre to centre. All stimuli were presented against a constantly grey background (50 cd/m^2). Fig. 1 depicts an example of the stimuli in each condition.

4.1.4. Design

The experiment consisted of the $2 \times 2 \times 2 \times 2$ within-subjects conditions "set size", "presentation condition", "intertrial contingencies of the target-defining feature", and "intertrial contingencies of the response-related feature". The presentation variable was blocked and the order of blocks balanced across participants. In the separate presentation block, participants searched for a black square that could be either larger or smaller than the remaining items, which were of the opposite size. In the holistic presentation condition, participants searched for an oriented black bar that was either larger or smaller than the remaining items (see Fig. 1, top row).

The remaining variables were all varied within blocks: Concerning the intertrial contingencies, the target size of the target and nontarget items was randomly drawn on each trial. Thus, the target size on a current trial n could either be the same as in the previous, $n-1$ trial constituting a "size repetition trial", or it could inherit the size previously associated with the nontargets, representing a "switch trial". In addition, the response-relevant items could also be repeated, constituting a "response repetition trial", or the response-related items could differ from the previous, $n-1$ trial, constituting a "different response trial".

The positions for the target as well as the orientation of the response-related item were drawn randomly, with the restriction that the number of right and left oriented bars in the display was always equal (exempting the target). Participants completed 220 trials in each presentation condition, yielding 440 trials per participant.

4.1.5. Procedure

Each trial started with the presentation of a small black fixation cross. Participants were instructed to fixate on the centre of the cross. At the beginning of each trial, a fixation control was implemented: The stimulus display was only presented if the tracking was stable (no blinks) and the gaze was within 50 pixels (1°) of the centre of the fixation cross, for at least 350 ms (within a time-window of 3000 ms). Otherwise, participants were calibrated anew (5-point calibration) and the next trial started again with the fixation control.

Upon presentation of the stimulus display, participants were required to make a fast and precise eye movement to the target singleton and to press the right mouse button when the response-related item was tilted to the right, and the left mouse button when it was tilted to the left. The stimulus display remained on screen until response, and was immediately succeeded by a feedback display. The feedback consisted in the black printed words "right" or "wrong" (in German, 14 pt.) which were presented centrally and remained on screen for 500 ms. After an intertrial interval of 500 ms, in which a blank grey screen was presented, the next trial started with the presentation of the fixation cross.

Before each block, participants were calibrated with a 5-point calibration and were given written instruction about the next block. Moreover, participants were instructed to respond to the target as fast as possible without making mistakes. On average, it took 45 min to complete the experiment.

4.2. Results

4.2.1. Data

In this and all subsequent experiments, data were excluded when the manual response exceeded 2000 ms, or when the eyes had not been fixating the target within 2000 ms after the beginning of the trial. Removing the outliers resulted in a loss of 6.3% of the data in Experiment 1.

4.2.2. Manual responses

The mean RTs in each intertrial condition are depicted in Fig. 2, separately for the two presentation conditions. The mean error scores in the corresponding experimental conditions are depicted in Table 3, for all experiments.

4.2.3. RTs

First, manual RTs were probed for a set size effect. This was done by calculating the search slope for each participant, and testing whether the individual search slope deviated significantly from zero. The results showed that the set size effect measured 10 ms/item and did not differ significantly from zero ($p > .08$). Data were then pooled over

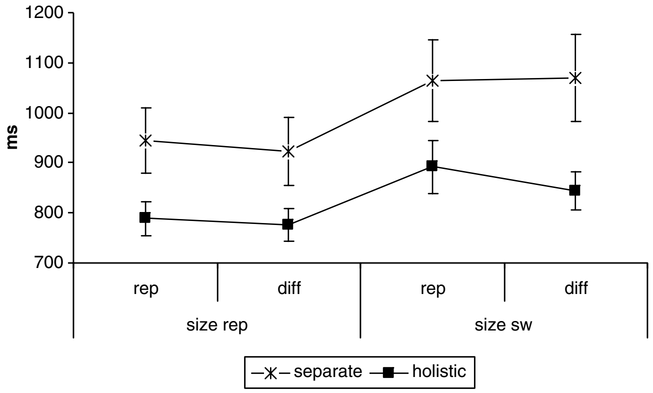

Fig. 2. Mean RTs of the size singleton search condition of Exp. 1, depicted as a function of whether the task-relevant feature size was repeated (size rep) or switched (size sw) and whether the response-related feature orientation was repeated (rep) or switched (diff). Error bars depict 1 SEM.

Table 3
Mean error scores for Experiments 1–4, as a function of intertrial contingencies of the target-defining feature (feature rep vs. feature switch) and the response (same resp vs. diff resp)

	Feature rep		Feature switch	
	Same resp	Diff resp	Same resp	Diff resp
Experiment 1				
Separate	1.06% (0.52)	0.88% (0.64)	2.36% (0.99)	3.47% (1.83)
Holistic	1.39% (0.72)	0.53% (0.35)	2.46% (1.24)	1.81% (0.92)
Experiment 2				
Separate	0.82% (0.55)	0.66% (0.44)	2.41% (1.24)	1.73% (0.91)
Holistic	0.87% (0.59)	1.78% (0.61)	2.22% (0.52)	1.43% (0.79)
Experiment 3				
Separate	3.88% (1.61)	2.29% (1.45)	6.68% (1.41)	3.57% (1.67)
Holistic	3.46% (1.11)	2.50% (1.00)	7.23% (2.76)	5.01% (2.35)
Experiment 4				
Separate	1.52% (0.53)	2.26% (0.80)	1.96% (0.67)	1.66% (0.64)
Holistic	2.14% (0.68)	2.32% (1.36)	3.84% (1.34)	1.44% (0.66)

Note. Mean errors are indicated in percent (%), and numbers in brackets indicate mean standard errors. *Separate* and *Holistic* denote the different presentation conditions.

the different set sizes to maximise statistical power for the next analyses.

For statistical analysis, a $2 \times 2 \times 2$ repeated-measures analysis of variance (ANOVA) including the variables "presentation condition" (separate *vs.* holistic), target $n - 1$ effect (repetition *vs.* switch) and response $n - 1$ effect (repetition *vs.* different) was calculated over the mean RTs of Experiment 1. The analysis showed, first, a significant main effect of the presentation condition ($F(1,7) = 11.21$; $MS_e = 43{,}695.93$; $p = .012$). On average, responses were 175 ms faster in the holistic presentation condition ($M = 825$ ms) than in the separate presentation condition ($M = 1000$ ms). Second, the priming effect of the target-defining feature was highly significant ($F(1,7) = 33.29$; $MS_e = 5{,}724.34$; $p = .001$), reflecting that mean RTs were speeded by 109 ms when the target size was repeated ($M = 858$ ms) than when it switched ($M = 967$ ms). However, repeating the target defining feature also interacted significantly with the presentation condition ($F(1,7) = 10.89$; $MS_e = 802.64$; $p = .013$). The interaction was due to larger priming effects of 132 ms in the separate presentation condition than in the holistic presentation condition, where it amounted to only 85 ms. The main effect of repeating the response also reached significance ($F(1,7) = 5.91$; $MS_e = 978.60$; $p = .045$), reflecting that mean RTs were 19 ms slower when the response was repeated ($M = 922$ ms) than when a different response was required ($M = 903$ ms). However, there was no interaction between priming of the target defining feature and the response, neither in the holistic nor in the separate presentation condition (both Fs < 1).

4.2.4. Errors

Preliminary set size analyses showed that differences in the set size did not affect accuracy ($p > .87$). The same ANOVA conducted over the mean error scores yielded only a significant main effect of repeating the target-defining feature ($F(1, 7) = 11.97$; $MS_e = 3.25$; $p = .011$), which was due to the fact that participants committed 1.55%

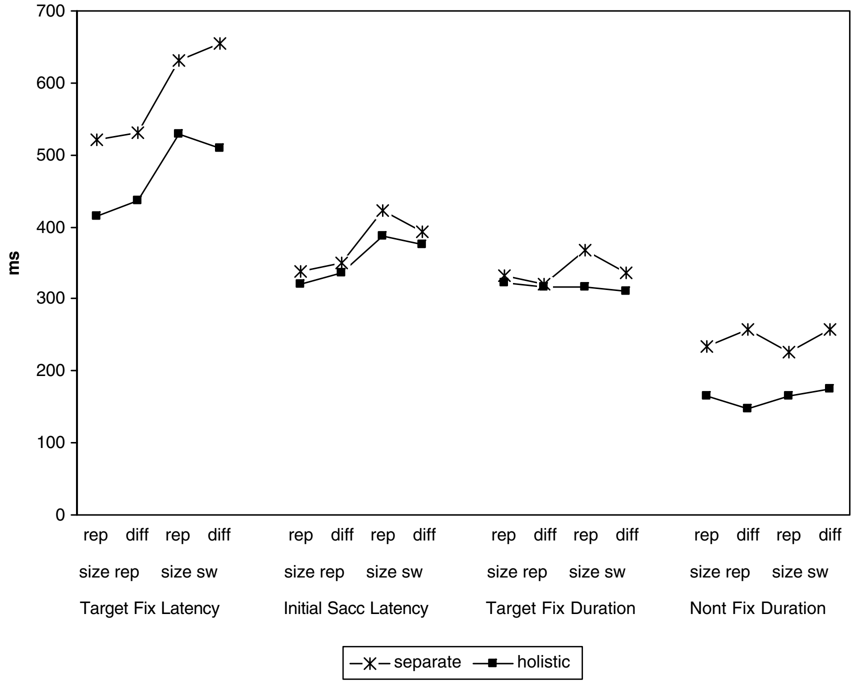

Fig. 3. Mean target fixation latencies (Target Fix Latency), initial saccadic latencies (Initial Sacc Latency), target fixation durations (Target Fix Duration) and nontarget fixation durations (Nont Fix Duration) of the size singleton search condition of Experiment 1. Means are depicted separately for repetitions and switches of the task-relevant feature size (size rep, size sw) and the response (rep, diff).

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Table 4
Mean proportion of first saccades on the target for Experiments 1–4, as a function of intertrial contingencies of the target-defining feature (feature rep vs. feature switch) and the response (same resp vs. diff resp)

	Feature rep		Feature switch	
	Same resp	Diff resp	Same resp	Diff resp
Experiment 1				
Separate	66.86% (6.74)	72.82% (4.62)	54.99% (7.72)	47.90% (5.63)
Holistic	85.91% (2.80)	84.27% (4.55)	59.74% (5.70)	63.53% (6.38)
Experiment 2				
Separate	91.61% (3.23)	94.79% (2.30)	86.02% (4.50)	83.08% (5.28)
Holistic	98.91% (0.80)	99.38% (0.41)	91.95% (1.64)	91.54% (2.59)
Experiment 3				
Separate	69.71% (5.22)	63.05% (5.78)	52.79% (6.58)	57.79% (5.15)
Holistic	85.66% (3.11)	85.65% (3.00)	64.35% (4.78)	64.71% (5.81)
Experiment 4				
Separate	91.36% (3.92)	91.12% (2.74)	84.38% (4.31)	83.25% (5.19)
Holistic	95.77% (1.74)	96.52% (1.81)	90.83% (3.13)	90.79% (2.81)

Note. Mean proportion of first saccades directed to the search target is indicated in percent (%). Numbers in brackets indicate mean standard errors. *Separate* and *Holistic* denote the different presentation conditions.

more mistakes on switch trials ($M = 2.52\%$) than on repetition trials ($M = 0.97\%$). None of the other main effects or interactions proved to be significant (all ps > .30), indicating that the results were not due to a speed-accuracy trade-off.

4.2.5. Eye movement data

The mean eye movement data in each condition of Experiment 1 are depicted in Fig. 3. Error bars were omitted from these charts because the error bars were almost always smaller than the plotting symbols. The mean proportions of initial saccades on the target are presented in Table 4.

For an analysis of the eye movement data, the same $2 \times 2 \times 2$ ANOVA was used as in analyses of the mean RTs and error scores. The results will be reported first for the ‘‘attentional’’ measures, that is, the target fixation latencies, and the proportion of first saccades on the target as well as the initial saccadic latencies. Second, results from analyses of the post-selectional measures will be reported, comprising the target fixation durations and the nontarget fixation durations.

4.2.6. Target fixation latencies

Statistical analyses of the mean target fixation latencies revealed, first, a significant main effect of the presentation condition ($F(1,7) = 11.89$; $MS_e = 16{,}992.37$; $p = .011$), reflecting that target fixation latencies were 112 ms shorter in the holistic presentation condition ($M = 472$ ms) than in the separate presentation condition ($M = 584$ ms) . Secondly, there was a significant main effect of repeating the target-defining feature ($F(1,7) = 42.33$; $MS_e = 4228.49$; $p < .001$). On average, target fixation latencies were 105 ms shorter at repetition trials ($M = 476$ ms) than at switch trials ($M = 581$ ms). None of the remaining effects approached significance (all ps > .21).

4.2.7. First saccades on target: proportion and latency

The ANOVA computed over the mean proportion of first saccades that directly went to the search target yielded a main effect of presentation condition ($F(1,7) = 27.42$; $MS_e = 94.37$; $p = .001$), reflecting that in the holistic presentation condition, significantly more saccades directly went to the target ($M = 73.4\%$) than in the separate presentation condition ($M = 60.6\%$). Moreover, significantly more saccades directly went to the target when the target-defining feature size was repeated ($M = 77.5\%$) than when it switched ($M = 56.5\%$; $F(1,7) = 42.91$; $MS_e = 163.32$; $p < .001$).

Concerning, next, the latencies of these saccades, the analysis showed, first, a significant effect of repeating the target size ($F(1,7) = 11.84$; $MS_e = 4{,}582.59$; $p = .011$). On average, latencies were shorter at feature repetition trials ($M = 336$ ms) than when the target feature switched ($M = 395$ ms). Second, the interaction between repeating the target size and response also reached significance ($F(1,7) = 9.58$; $MS_e = 511.30$; $p = .017$), reflecting that repeating the response shortened latencies by 14 ms, when the target size was repeated, whereas response repetition elongated latencies by 20 ms when simultaneously, the target size switched. None of the remaining effects approached significance (all ps > .30).

4.2.8. Target fixation durations

The duration the eyes remained fixated on the target after first selecting it did not show any effects of repeating the target-defining or response-related feature (all ps > .15). This negative result did not change when the ANOVA was instead calculated over the summed durations of all fixations on a target over a trial, instead of the first target fixation durations (all ps > .09).

4.2.9. Nontarget fixation durations

The mean duration the eyes remained fixated on a nontarget prior to target selection was only significantly affected by the presentation condition ($F(1,7) = 11.86$; $MS_e = 7{,}888.83$; $p = .0\ 11$). Mean nontarget fixation durations were significantly longer in the separate presentation condition ($M = 229$ ms) than in the holistic presentation condition ($M = 153$ ms). None of the remaining effects or interactions approached significant (all ps > .10).

4.3. Discussion

The absence of a set size effect in the data suggests that the size singleton target indeed constituted a pop-out item. Thus, it can be concluded that the priming effect in the mean RTs of Experiment 1 reflects the typical priming effect.

With regard to the question whether priming affects the attentional or decisional stage, the results clearly support the priming of pop-out view: Priming effects of the same magnitude as in the manual RTs were also found in the target fixation latencies, or the mean durations needed to visually select the target. In turn, no priming effects could be observed in the target fixation durations, indicating that post-selectional processes did not contribute to the priming effect observed in the RTs. This is incompatible with the episodic retrieval account, which suggested that priming effects might depend on post-selectional verification processes after selection of the target.

Moreover, the results also rule out contributions from post-selectional processes before selection of the target: Priming effects were absent in the nontarget fixation durations, indicating that nontarget rejection processes or attentional deallocation processes do not further contribute to feature priming effects. Instead, the finding that priming effects modulated the accuracy and speed of the first saccade indicates that priming plays a role in guiding selection. Therefore, priming effects must be classified as attentional even from the perspective of two-stage theories of attention.

Concerning the question about the possible object of priming, the results from Experiment 1 were not as clear-cut: The results from the manual responses in Experiment 1 failed to show any repetition effects pertaining to the response-related feature. This supports the priming of pop-out account, which predicted that intertrial repetition effects should primarily pertain to the target-defining feature, and not to any other features coincidentally associated with the target (see Table 2).

Contrary to the predictions of the holistic priming view, priming of the target-defining feature mostly failed to interact with response repetition effects. Traces of such an interaction could only be observed in the initial saccadic latencies, but not in any of the remaining measures. Whether this result can be taken to support an attentional version of the episodic retrieval view is not entirely clear (Hillstrom, 2000): Since no corresponding effects occurred in the mean RTs, Experiment 1 cannot be said to replicate previous results (Hillstrom, 2000; Huang et al., 2004). Therefore, it must be left open whether the effects found in the saccadic latencies indeed reflect holistic priming.

In turn, the results are again clear-cut with respect to the hypothesis of the flexible priming view: Contrary to the flexible view, manipulating the way of presenting the target-defining and response-related features failed to modulate the amount of holistic priming. There was only a main effect of the presentation condition, indicating that the task was easier with holistic than with separate presentation of target-defining and response-related features: Closer inspection of the results reveals that higher RTs in the separate than in the holistic presentation condition are presumably due to participants erroneously selecting a nontarget item before focusing on the target: In the separate presentation condition, significantly more saccades are initially directed to one of the nontargets (see Table 4), and the eyes also linger on them for longer than in the holistic presentation condition (see Fig. 3). Together, enhanced erroneous selections of nontargets and longer nontarget fixation durations apparently account for longer target fixation latencies in the separate presentation condition.

In sum, the results from the first experiment support the view of the priming of pop-out account, that priming operates on the attentional stage, without decisional processes contributing to priming. With regard to the object of priming, the results of Experiment 1 are slightly ambiguous: The majority of measures indicate that only the target-defining feature is involved in priming, but analyses of the initial saccadic latencies showed the pattern of results associated with holistic priming effects. The next experiment was designed to test whether the same result patterns could be obtained with colour as target-defining feature.

5. Experiment 2

Experiment 2 was quite similar to the first experiment, with the deviation that now, participants searched for a colour singleton whose colour was randomly black or white. With this, Experiment 2 is more similar to Hillstrom's (2000) experiments, in which also colour and orientation varied between trials. The bottom row of Fig. 1 depicts an example of the displays in the separate and holistic presentation condition.

5.1. Methods

5.1.1. Participants

Eight students from the University of Bielefeld, Germany, took part in the experiment as paid volunteers (6€/h). Three of them were male, 5 female, and they had a mean age of 29. All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

5.1.2. Stimuli, design and procedure

These were exactly the same as in Experiment 1, with the only exception that in Experiment 2, the bars and squares were all of the smaller size (0.4° × 1.1° and 1.2° × 1.2°, respectively), and the target-defining feature was constituted by a colour singleton. In the separate presentation condition, the response-related bars were all red, and the target square was coloured either white or black while the remaining items were presented in the opposite colour. In the holistic presentation condition, one of the response-related bars itself was presented in white or black colour. As in the previous experiment, participants had to respond to the orientation of the bar in both conditions.

5.2. Results

5.2.1. Data

Excluding all data with manual RTs above 2000 ms and all data with target fixation latencies exceeding 2000 ms led to a loss of 4.20% of all data in Experiment 2.

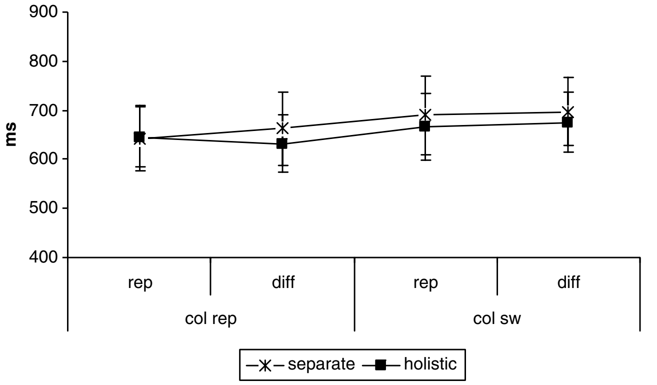

Fig. 4. Mean RTs of the colour singleton search condition of Exp. 2 depicted as a function of whether the task-relevant feature colour was repeated (col rep) or switched (col sw) and whether the response-related feature orientation was repeated (rep) or switched (diff). Error bars depict 1 SEM.

5.2.2. Manual responses

The mean RTs and error scores of Experiment 2 are depicted in Fig. 4 and Table 3, respectively. A first glance on the figures suggests that performance is visibly better than in the previous experiment, with shorter RTs and fewer errors. This suggests that the present task, to find a colour singleton, may be easier than search for the size singleton used in the previous experiment.

5.2.3. RTs

First of all, a two-tailed *t*-test calculated over the mean slopes from the set size 5 and 7 conditions showed a negative slope of -5 ms/item. This slope was also significantly different from zero, as tested by a two-tailed *t*-test ($t(7) = 4.6$; $p = .003$).

The ANOVA calculated over the mean RTs of Experiment 2 showed only a significant main effect of repeating the target-defining feature colour ($F(1,7) = 29.14$; $MS_e = 644.12$; $p = .001$). On average, RTs were 35 ms faster when the colour was repeated ($M = 643$ ms) than when it switched ($M = 677$ ms). The remaining effects and interactions were all nonsignificant (all $ps > .08$).

5.2.4. Errors

Preliminary analyses showed that the different set size conditions did not affect mean error scores ($p > .07$). Further statistical analyses did not yield any significant effects or interactions in the mean error scores. This indicates that the results were not due to a speed-accuracy trade-off.

5.2.5. Eye movement data

The mean proportions of first saccades on the target in all conditions are presented in Table 4, and the remaining eye movement data are depicted in Fig. 5, separately for each condition.

5.2.6. Target fixation latencies

The same analysis calculated over the mean target fixation latencies yielded only a significant main effect of repeating the target-defining feature ($F(1,7) = 32.77$; $MS_e = 770.68$; $p = .001$). On average, the target was fixated 40 ms earlier when the target colour was repeated

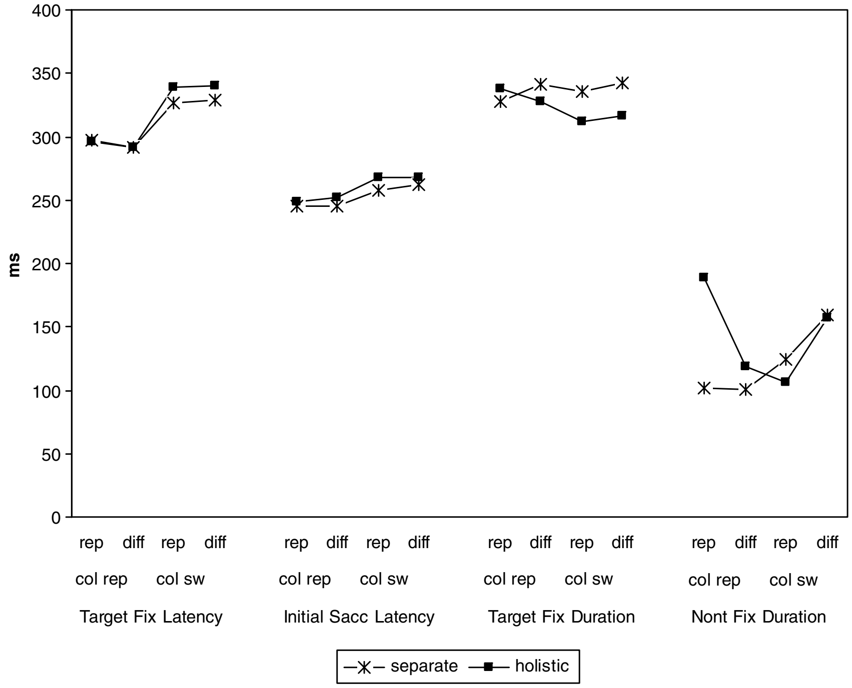

Fig. 5. Mean target fixation latencies (Target Fix Latency), initial saccadic latencies (Initial Sacc Latency), target fixation durations (Target Fix Duration), and nontarget fixation durations (Nont Fix Duration) of the size singleton search condition of Experiment 2. Means are depicted separately for repetitions and switches of the task-relevant feature colour (col rep, col sw) and the response (rep, diff).

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($M = 294$ ms) than when it switched ($M = 334$ ms). None of the remaining effects approached significance (all $ps > .32$).

5.2.7. First saccades on target: proportion and latency

The ANOVA computed over the mean proportion of first saccades that directly went to the search target revealed that significantly more saccades directly went to the target when the target colour was repeated ($M = 96.17\%$) than when it switched ($M = 88.15\%$; $F(1,7) = 19.29$; $MS_e = 53.37$; $p = .003$). Additionally, the main effect of presentation type approached significance ($F(1,7) = 5.34$; $MS_e = 129.13$; $p = .054$), reflecting that more saccades directly went to the target in the holistic ($M = 95.44\%$) than in the separate presentation condition ($M = 88.87\%$).

Concerning, next, the latencies of these initially correct saccades, the analysis showed only a significant effect of repeating the target colour ($F(1,7) = 28.45$; $MS_e = 148.24$; $p = .001$), reflecting shorter latencies in feature repetition trials ($M = 248$ ms) than when the target feature switched ($M = 264$ ms). None of the remaining effects reached significance (all $ps > .13$).

5.2.8. Target fixation durations

The duration the eyes remained fixated on the target after first selecting it did not show any effects of repeating the target-defining or response-related feature (all $ps > .11$). The result pattern also did not change when the analysis was calculated over the summed durations of all target fixations in a trial (all $ps > .12$).

5.2.9. Nontarget fixation durations

In the mean nontarget fixation durations, the analysis did not reveal any statistically significant effects or interactions (all $ps > .08$). The reason that the rather large differences in the mean nontarget fixation durations (see Fig. 5) did not reach significance is presumably due to the fact that nontarget fixations occurred quite rarely in Experiment 2 (see Table 4), which produced a rather large variance in the data.

5.3. Discussion

Mean RTs were slightly lower in the set size 7 condition than in the set size 5 condition. Such an inverse set size effect is not unusual in pop-out search tasks in which the target defining feature varies (e.g., Bravo & Nakayama, 1992). It certainly does not give rise to any concerns, but is fully compatible with the contention that the colour singleton constituted a pop-out item.

The results from Experiment 2 also clearly support the view that feature priming operates on the attentional stage of target detection and selection: Repetition facilitation effects only occurred in the attentional measures, that is, the proportion of first saccades directed to the target, the respective latencies of these saccades and the target fixation latencies. In contrast, priming effects were absent in the post-selectional measures, indicating that post-selectional processes do not contribute to the feature priming effect. With regard to the attentional nature of the priming effect, Experiment 2 thus fully replicates the findings of Experiment 1.

With regard to the question which features are subject to priming, the present experiment clearly supports the feature-based view of the priming of pop-out account: Experiment 2 did not show any response-related priming effects, or interactions between feature priming and response repetition. This is at odds with the holistic and flexible priming views (see Table 2). Moreover, the results rule out that the failure to find such effects in Experiment 1 was related to size constituting the target-defining feature, or to the relative difficulty of the search task, when compared to colour singleton search.

Deviating from the first experiment, Experiment 2 failed to show any differences between the two presentation conditions: This is presumably due to the fact that the search task in Experiment 2 was easier than in Experiment 1: As can be seen in Table 4, erroneous selections of nontargets, which were responsible for this effect in Experiment 1, were generally quite rare in Experiment 2.

6. Experiment 3

The previous experiments clearly showed that feature priming operates on the attentional stage of target detection and selection. However, with respect to response priming effects, the experiments fail to replicate previous results, which showed significant interactions between feature and response priming effects (e.g., Hillstrom, 2000).

Closer inspection of the results of Hillstrom (2000) suggests that in her experiments, the holistic priming effect was quite weak when the target-defining feature varied randomly and unforeseeably, but became much stronger when the target-defining feature predictably alternated: When participants knew the target colour of the upcoming trial, the response-related effect was approximately twice as large compared to a condition in which the colour randomly switched. The same tendency for stronger effects also appeared in Hillstrom's Experiment 2 (Hillstrom, 2000), in which orientation constituted the target-defining feature. Thus, a possible reason for the failure to replicate the results of Hillstrom (2000) might be that with random variations of the target-defining feature, the effect size of the holistic priming effect is too small to be detectable (with the method invoked in the present experiments). Additionally, if the holistic priming effect is indeed stronger with predictable variations of the target-defining feature, this suggests that expectations of the participants regarding the target-defining feature might play a role for the holistic priming effect. This possibility was tested in Experiments 3 and 4.

Experiment 3 was closely modelled to the first experiment of the present study. Participants had to search for a size singleton and to indicate the orientation of the bar by pressing a key. Deviating from Experiment 1, the target size in Experiment 3 varied predictably. The trial sequence was a regularly alternating sequence of repetition and switch, yielding two trials in which the target was larger, followed by two trials in which it was smaller, and so forth.

If Experiments 1 and 2 indeed failed to show holistic priming because the effect size was too small, and invoking predictable variations amplifies the holistic priming effect, then we would expect holistic priming effects to occur in Experiments 3 and 4. Moreover, if priming of the response-related item also operates on the attentional stage, holistic priming effects should surface in the corresponding attentional eye movement measures (see Table 1). On the other hand, if repeating the response-related item facilitates processing on the decisional stage, holistic priming effects should obtain in the decisional measures, *viz.,* the target and nontarget fixation durations.

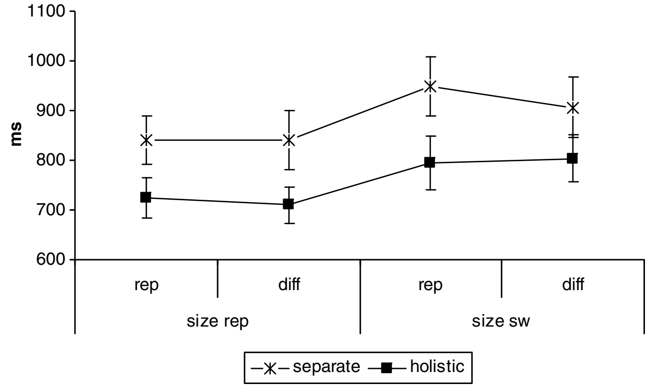

Fig. 6. Mean RTs of the size singleton search condition of Exp. 3, depicted as a function of whether the task-relevant feature size was repeated (size rep) or switched (size sw) and whether the response-related feature orientation was repeated (rep) or switched (diff). Error bars depict 1 SEM.

6.1. Methods

6.1.1. Participants

Twelve students from the University of Bielefeld were paid 6 Euro for participation in Experiment 3. Half of them were male, half female and they had a mean age of 31. Two participants had to be excluded due to a data saving error in the eye tracking software. One more participant had to be excluded because he did not follow the instructions which resulted in a loss of over 50% of his data.

6.1.2. Stimuli, design and procedure

These were exactly the same as in Experiment 1, with the only exception that in Experiment 3, the target-defining feature varied in a regularly alternating sequence: The target was twice presented as the larger item, then again twice as the smaller item, then again twice as the larger item, and so forth, such that the number of repetition and switch trials was equal. The participants were explicitly told that the size change of the target was completely predictable, and instructed to use this information.

6.2. Results

6.2.1. Data

Excluding all data with manual RTs or target fixation latencies above 2000 ms resulted in a loss of 5.5% of the data.

6.2.2. Manual responses

The mean RTs and error scores are depicted in Fig. 6 and Table 3, respectively. A first glance on Fig. 6 suggests that the results of Experiment 3 closely resemble the data obtained in Experiment 1, in which the target size varied randomly (see Fig. 2).

6.2.3. RTs

For analysis of a set size effect, a two-tailed t-test was calculated over the mean slopes from the set size 5 and 7 conditions. The results showed a mean slope of 9.9 ms/item which did not differ significantly from zero ($t(8) = 1.63$; $p = .14$). Further statistical analyses revealed, first, a significant main effect of the presentation condition ($F(1,8) = 12.38$; $MS_e = 23{,}002.78$; $p = .008$), reflecting that RTs were 126 ms faster in the holistic condition ($M = 758$ ms) than in the separate presentation condition ($M = 884$ ms). Second, the main effect of repeating the target-defining feature reached significance ($F(1,8) = 33.91$; $MS_e = 3844.58$; $p < .001$). On average, RTs were 85 ms faster when the target size was repeated ($M = 779$ ms) than when it switched ($M = 864$ ms). However, these effects were qualified by a significant three way interaction between the presentation condition and priming of the target-defining and response-related feature ($F(1,8) = 6.05$; $MS_e = 719.34$; $p = .039$). The interaction was due to the fact that repeating the response significantly affected mean RTs only in the separate presentation condition when the target-defining feature switched ($t(9) = 2.83$; $p = .022$). In this condition, repeating the response slowed mean RTs by 41 ms, whereas the response-related effects did not reach significance in any of the remaining conditions (all ps $> .45$).

6.2.4. Errors

A preliminary analysis showed that the mean error scores did not significantly differ between the two set size conditions ($p > .71$). Further statistical analyses yielded a significant main effect of repeating the target-defining feature ($F(1,8) = 5.52$; $MS_e = 21.87$; $p = .047$), with lower error scores when the target size was repeated ($M = 3.04\%$) than when it switched ($M = 5.63\%$). Moreover, there was a significant main effect of response repetition ($F(1,11) = 23.23$; $MS_e = 5.71$; $p = .008$), reflecting that repeating the response increased mean errors by 1.98% ($M = 5.32\%$) compared with changing the response ($M = 3.35\%$).

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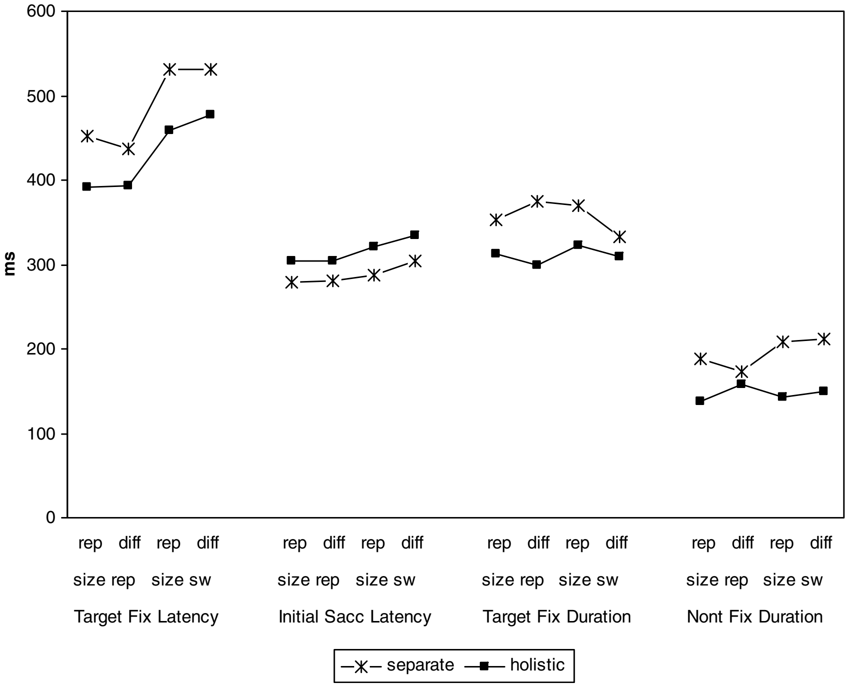

Fig. 7. Mean target fixation latencies (Target Fix Latency), initial saccadic latencies (Initial Sacc Latency), target fixation durations (Target Fix Duration), and nontarget fixation durations (Nont Fix Duration) of the size singleton search condition of Experiment 3. Means are depicted separately for repetitions and switches of the task-relevant feature size (size rep, size sw) and the response (rep, diff).

6.2.5. Eye movement data

The mean eye movement data are depicted in Fig. 7 and Table 4. At a first glance, the results seem to be quite similar to those obtained with the random variation of the size singleton in Experiment 1 (see Fig. 3).

6.2.6. Target fixation latencies

Statistical analysis of the target fixation latencies yielded, first, a significant main effect of the presentation condition ($F(1,8) = 13.85$; $MS_e = 4314.16$; $p = .006$), reflecting that the target fixation latencies were 49 ms shorter in the holistic presentation condition ($M = 439$ ms) than in the separate presentation condition ($M = 488$ ms). Secondly, there was also a significant main effect of priming of the target-defining feature ($F(1,8) = 40.69$; $MS_e = 2908.65$; $p < .001$): On average, mean target fixation latencies were 81 ms shorter when the target size was repeated ($M = 418$ ms) than when it switched ($M = 499$ ms). None of the remaining effects approached significance (all ps > .21).

6.2.7. First saccades on target: proportion and latency

The ANOVA computed over the mean proportion of initial saccades on the target revealed, first, a significant main effect of the presentation condition ($F(1,8) = 27.07$; $MS_e = 135.14$; $p = .001$), reflecting that in the holistic presentation, significantly more saccades directly went to the target ($M = 75.1\%$) than in the separate presentation condition ($M = 60.8\%$). Second, the main effect of repeating the target size was also significant ($F(1,8) = 26.81$; $MS_e = 174.81$; $p = .001$), with a higher portion of correct saccades in repetition trials ($M = 76.0\%$) than in switch trials ($M = 59.9\%$).

Statistical analysis of the mean saccadic latencies showed a significant main effect of the presentation condition ($F(1,8) = 6.96$; $MS_e = 2027.20$; $p = .030$), with shorter initial saccadic latencies in the separate presentation condition ($M = 288$ ms) than in the holistic presentation condition ($M = 316$ ms). Moreover, there was a main effect of repeating the target-defining feature ($F(1,8) = 12.15$; $MS_e = 543.48$; $p = .008$), with shorter saccadic latencies at repetition trials ($M = 293$ ms) than at switch trials ($M = 312$ ms).

Comparing the effect of presentation condition across the proportion and latency of correct initial saccades suggests the possibility of a speed-accuracy trade-off: apparently, in the separate presentation condition, saccadic latencies were shorter at the cost of being less accurate. However, this speed–accuracy trade-off obviously only affects differences between the two presentation conditions, but leaves the priming effect unaffected.

6.2.8. Target fixation durations

Statistical analysis of the target fixation durations showed a significant main effect of the presentation condition ($F(1,8) = 11.20$; $MS_e = 3542.50$; $p = .010$), indicating that fixation durations were 47 ms shorter in the holistic presentation condition ($M = 311$ ms) than in the separate presentation condition ($M = 358$ ms). Moreover, the three-way interaction between presentation condition and

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priming of the target-defining feature and the response reached significance ($F(1,8) = 8.01$; $MS_e = 462.94$; $p = .022$), reflecting that repeating the target size and the response only significantly interacted in the separate presentation condition ($F(1,8) = 5.77$; $MS_e = 1332.54$; $p = .043$), but not in the holistic presentation condition ($p > .9$).

Repeating the response only elongated fixation durations in the separate presentation condition when the target size switched ($t(9) = 3{,}54$; $p = .008$), whereas response repetition did not affect mean target fixation durations in any of the other conditions (all $ps > .31$).

6.2.9. Nontarget fixation durations

The mean duration the eyes were fixated on a nontarget was significantly affected by the presentation condition ($F(1,8) = 15.10$; $MS_e = 3{,}803.12$; $p = .005$), with longer nontarget fixation durations in the separate presentation condition ($M = 195$ ms) than in the holistic presentation condition ($M = 139$ ms). Additionally, mean nontarget fixation durations also showed a significant priming effect ($F(1,8) = 10.35$; $MS_e = 339.81$; $p = .012$), reflecting that the nontarget fixation durations were 14 ms shorter when the target size was repeated ($M = 160$ ms) than when it switched ($M = 174$ ms). This priming effect only occurred in the separate presentation condition, where it amounted to 28 ms, but not in the holistic presentation condition, where it only amounted to 1 ms ($F(1,8) = 4.71$; $p = .062$).

6.3. Discussion

In Experiment 3, priming effects of the target-defining feature were not restricted to the attentional measures, but also occurred in the nontarget fixation durations. With this, the present experiment provided the first evidence that feature priming might also affect processes on the post-selectional stage. However, the priming effect in the nontarget fixation durations only amounted to 14 ms, which is insufficient to account for the 81 ms effect in the target fixation latencies or the 85 ms priming effect found in the RTs. Therefore, priming effects must still be regarded as primarily operating at the stage of attentional guidance, with possible contributions from post-selectional effects.

Experiment 3 also provides the first evidence for the hypothesis that priming is not restricted to the target-defining feature, but also applies to the response-related items. Moreover, intertrial effects of the response-related feature also interacted with priming of the target-defining feature, such that repeating the response led to significant RT costs when simultaneously, the target size switched. This result pattern occurred both in the RTs and in the target fixation durations, that is, in the durations the eyes remained fixated on the target after selection. At first, these results might be viewed as supporting the holistic priming view. However, this interpretation is complicated by the observation that the interaction was not straightforward between the target-defining and response-related feature, as predicted by the holistic priming account, but was modulated by the presentation condition as well. Feature and response priming effects only interacted significantly with each other in the separate presentation condition, contrary to the expectations of the flexible view.

Although the evidence for holistic priming effects in Experiment 3 is certainly stronger than in the twin Experiment 1, the observed result pattern does not strictly conform to the predicted results of the holistic or flexible priming view. Thus, before discussing these matters in more detail, the presence of holistic priming effects shall be further ascertained by the next experiment.

7. Experiment 4

The fourth experiment was designed along the lines of the previous two experiments: As in Experiment 2, participants had to search for a colour singleton target which changed its colour from black to white and *vice versa*. Similar to the previous experiment, the variations in the target-defining feature were completely predictable, with the target changing its colour on every second trial.

7.1. Methods

7.1.1. Participants

Twelve students from the University of Bielefeld, Germany, took part in the experiment, for small monetary exchange (6€/h). Four of them were male, 8 were female, and they had a mean age of 28.

7.1.2. Stimuli, design and procedure

These were exactly the same as in Experiment 2, with the only exception that the target-defining feature predictably alternated between trials. Variations of the target colour occurred in regular sequences of two trials in which the target was coloured white, followed by two trials in which it was black, and so forth.

7.2. Results

7.2.1. Data

Excluding all data with manual RTs or target fixation latencies above 2000 ms resulted in a loss of 2.43% of the data.

7.2.2. Manual responses

Fig. 8 presents the mean RTs of Experiment 4, and Table 3 presents the mean errors, as a function of repetition and presentation condition.

7.2.3. RTs

First of all, a two-tailed t-test calculated over the mean slopes from the set size 5 and 7 conditions yielded a negative slope of -2 ms/item which did not differ significantly from zero ($t(7) = 1.2$; $p = .27$). Further statistical analyses showed only a significant main effect of repeating the tar-

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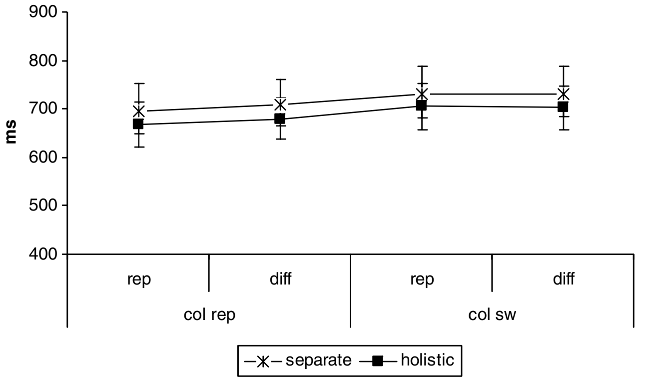

Fig. 8. Mean RTs of the colour singleton search condition of Experiment 4 depicted as a function of whether the task-relevant feature colour was repeated (col rep) or switched (col sw) and whether the response-related feature orientation was repeated (rep) or switched (diff). Error bars depict 1 SEM.

get-defining feature colour ($F(1,11) = 40.55$; $MS_e = 514.25$; $p < .001$). On average, RTs were 30 ms faster when the colour was repeated ($M = 687$ ms) than when it switched ($M = 717$ ms). None of the remaining effects or interactions reached significance (all *p*s > .17).

7.2.4. Errors

A preliminary analysis of the mean error scores showed that the two set size conditions did not differ in accuracy ($p > .36$)—an ANOVA calculated over the mean error scores yielded a significant two-way interaction between the presentation type and response repetition ($F(1,11) = 6.24$; $MS_e = 1.69$; $p = .030$), reflecting that in the holistic presentation condition, repeating the response increased mean errors by 1.11%, whereas response repetition did not affect accuracy in the separate presentation condition (*mean difference* = 0.21%). None of the remaining effects approached significance (all $p > .14$), which indicates that the results were not due to a speed–accuracy trade-off.

7.2.5. Eye movement data

The mean eye movement data of Experiment 4 are depicted in Fig. 9 and Table 4.

7.2.6. Target fixation latencies

The same ANOVA computed over the mean latencies until the eyes fixated the target showed a significant main effect of repeating the target-defining feature ($F(1,11) = 87.06$; $MS_e = 202.06$; $p < .001$). On average, the target was selected 27 ms earlier at colour repetition trials ($M = 308$ ms) than when the target colour switched ($M = 334$ ms), whereas none of the remaining effects approached significance (all *p*s > .10).

7.2.7. First saccades on target: Proportion and latency

Analysing the mean proportion of first saccades that directly went to the search target revealed, first, a significant main effect of the presentation condition ($F(1,11) = 8.44$; $MS_e = 100.77$; $p = .014$), reflecting that in the holistic presentation, significantly more saccades directly went to the target ($M = 93.5\%$) than in the sepa-

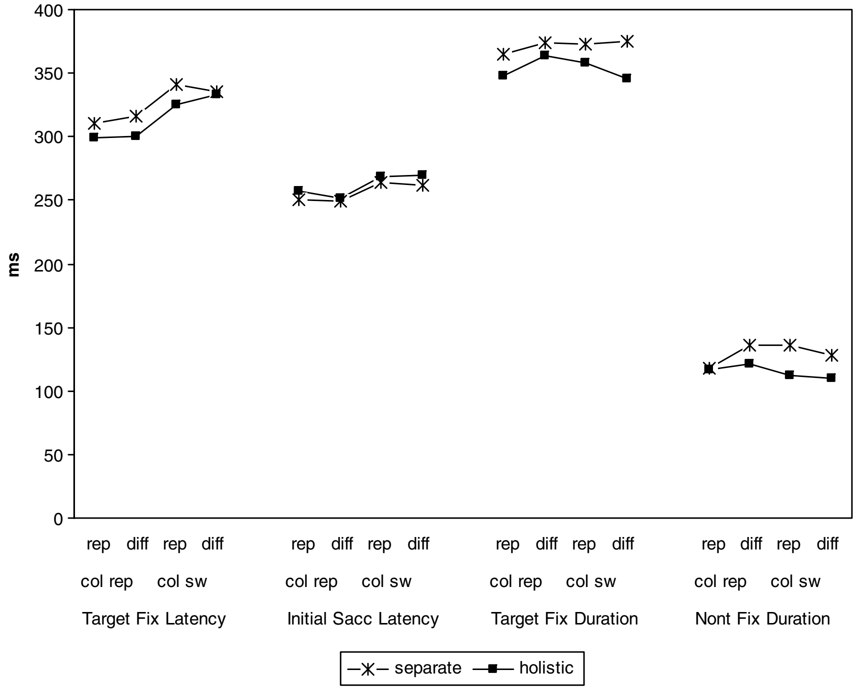

Fig. 9. Mean target fixation latencies (Target Fix Latency), initial saccadic latencies (Initial Sacc Latency), target fixation durations (Target Fix Duration) and nontarget fixation durations (Nont Fix Duration) of the size singleton search condition of Experiment 4. Means are depicted separately for repetitions and switches of the task-relevant feature colour (col rep, col sw) and the response (rep, diff).

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rate presentation condition ($M = 87.5\%$). Second, the main effect of repeating the target colour was also significant ($F(1,11) = 11.69$; $MS_e = 83.50$; $p = .006$), reflecting that significantly more saccades were initially directed to the target at repetition trials ($M = 93.7\%$) than when the target colour switched ($M = 87.3\%$). However, none of the remaining effects reached significance (all $ps > .43$).

Concerning the mean saccadic latencies, the ANOVA showed only a significant main effect of repeating the target colour ($F(1,11) = 37.75$; $MS_e = 120.30$; $p = .000$), with shorter saccadic latencies when the target colour was repeated ($M = 252$ ms) than when it switched ($M = 266$ ms).

7.2.8. Target fixation durations

Statistical analysis of the target fixation durations resulted only in a marginally significant two way-interaction between repeating the target-defining feature and the response ($F(1,11) = 4.38$; $MS_e = 417.54$; $p = .060$). This interaction reached significance when the analysis was calculated over the summed fixation durations ($F(1,11) = 5.64$; $MS_e = 483.90$; $p = .037$), reflecting that response repetition shortened mean target fixation duration by 16 ms when the target-defining feature was also repeated, whereas repeating the response elongated fixation durations by 14 ms, when the target-defining feature switched. None of the remaining effects approached significance (all $ps > .18$).

7.2.9. Nontarget fixation durations

In the nontarget fixation durations, none of the main effects or interactions reached significance (all $ps > .15$).

7.3. Discussion

In the present experiment, priming effects of the target-defining feature were again restricted to the attentional measures. With this, Experiment 4 clearly supports the view of the priming of pop-out account, that feature priming affects the attentional stage of target detection and selection. In turn, the results do not indicate that post-selectional processes contribute to priming effects of the target-defining feature.

With respect to the question whether priming is feature-based or holistic, the results of Experiment 4 were again not clear-cut: Although no traces of holistic priming could be discerned in the manual RTs, such an effect occurred in the target fixation durations. The duration the eyes remained fixated on the target after selecting it showed an interaction between intertrial effects of the target-defining and response-related feature, which was in the direction proposed by the holistic priming account. This interaction was also slightly stronger in the holistic presentation condition than in the separate presentation condition.

In sum, the results of Experiment 4 in part resemble the result pattern of previous studies which interpreted this as support for the holistic priming view. However, the failure to obtain a similar result pattern in the manual RTs complicates interpretation of the results in terms of holistic priming effects. Thus, the results again call for tentative conclusions, which will be discussed in further detail in the next section.

8. General discussion

The present study was designed to investigate two issues concerning intertrial priming effects in visual search: The first and foremost question was whether intertrial facilitation effects operate on the attentional or the decisional stage. A second goal of this study was to find out whether intertrial carry-over effects exclusively pertain to the target-defining feature, or might also include the response-related feature, possibly depending on the way of presenting target-defining and response-related features. In the following, I will discuss the implications of the present results and possible interpretations separately for each topic.

8.1. The stage of priming

Concerning the question whether feature priming effects are based on attentional or post-selectional processes, the results of the present study clearly favour an attentional view of priming: Results from altogether four experiments invoking eye movement measurements consistently show priming effects in the target fixation latencies. This supports the priming of pop-out account, which proposes that repeating the target-defining feature reduces the time needed to visually select the target. The attentional view of priming can also be maintained in the more general framework of two stage theories of visual search. In all experiments, priming effects clearly modulated the precision and time-course of the first saccade of each trial, with more accurate and faster saccades on the target on repetition trials than in switch trials. This shows that priming already affects search at an early stage of attentional guidance, or at least at a point in time before selection of the first item in the display.

Conversely, the decisional view on priming does not receive support. The results of the present study suggest that priming effects in the target and nontarget fixation durations are either absent or of negligible magnitude, when compared to the priming effect in the manual RTs. This indicates that later, post-selectional stages of search do not contribute substantially to the priming effect. Thus, it can be ruled out that feature priming effects are mainly due to post-selectional processes (see Table 1).

With this, the present results are also in line with previous eye tracking studies. Using a saccade task, McPeek et al. (1999) similarly found that colour priming effects affect the attentional stage. The present study corroborates and extends on these findings; by showing, first, that the same results occur with priming of the target size; and second, by showing that post-selectional processes do not further contribute to feature priming effects. Unlike the

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saccade-task used in previous studies, the present eye movement measures allowed assessments of the possible contributions of post-selectional processes to feature priming. Despite the differences between the studies, the conclusions are very similar. This undermines previously voiced concerns that the standard visual search task and saccade task might yield priming effects of a different kind or origin.

However, the results of the present study appear to be incompatible with the study of Huang and Pashler (2005). In their study, intertrial facilitation effects could only be found in a speeded reaction time task, with long display durations. However, priming failed to occur in an accuracy task, in which the display durations were very short. This in turn indicates that intertrial facilitation effects do not modulate effects at the attentional level, but operate on a later, post-selectional level (Huang & Pashler, 2005; see also Prinzmetal et al., 2005). However, a possible methodological problem of the study might consist in the fact that a post-mask display was used only in the brief display condition, but not in the reaction time task with the longer display durations. There is much evidence that masks can erase memory traces which are, *ex hypothesi*, crucial for intertrial priming effects. Specifically, in a study of Maljkovic and Nakayama (2000), deploying attention to visually different stimuli between trials greatly reduced or even eliminated intertrial facilitation effects. This led the authors to conclude that the decreasing influence of a trial to its successors is not due to passive decay of memory traces, but to active interference.

Since in the study of Huang and Pashler (2005), interference arising from masking only occurred in the accuracy task with the short display durations, but not in the reaction time task, this difference in the experimental settings might be sufficient to explain the elimination of intertrial facilitation in the accuracy task.

In sum, the present study seems to be well in line with previous studies, and presents additional evidence for the hypothesis that feature priming effects of the target-defining feature are primarily due to processes concerned with guidance of attention. Although these results were consistently interpreted as supporting the priming of pop-out account, it is important to realise that the finding of attentional feature priming effects is also compatible with the attentional version of the episodic retrieval view (Hillstrom, 2000). As will be more elaborately argued below, the episodic retrieval account proposes that priming modulates the time-course with which attentional prioritisation rules can be retrieved from short-term memory. Although the proposed mechanism of priming differs largely from the mechanism proposed by the priming of pop-out account, it is well compatible with the observation that priming affects attentional guidance. Therefore, the present results should not be interpreted as unequivocally supporting the priming of pop-out account; further research is necessary to distinguish between these two different attentional views.

8.2. The object of priming

The second goal of the present investigation was to find out whether priming effects are feature-based, as proposed by the priming of pop-out account, or whether they might be holistic, as proposed by the episodic retrieval account. Another possibility taken into account was that priming could be flexibly tuned to be either feature-based or holistic, depending on whether the presentation condition promotes holistic encoding of all target features or not (see Table 2).

The results generally favour the feature-based view of the priming of pop-out account: Although intertrial facilitation effects were not always strictly confined to the target-defining feature, the main effect of feature priming was very reliable. Intertrial facilitation effects of the target-defining feature occurred in all experiments, not regarding whether it was constituted by size or colour.

Conversely, intertrial contingencies of the target across trials did not in general lead to holistic priming effects: Interactions between the target-defining and response-related features which are indicative of holistic priming only occurred in the manual responses of Experiment 3, and in other dependent measures in Experiments 1 and 4. Even in Experiment 3, the results do not unequivocally favour a holistic priming view: In this experiment, the interaction between feature and response priming effects was not straightforward, but was additionally modulated by the presentation condition. Contrary to the expectations of a flexible priming account, holistic priming effects were stronger in the separate presentation condition than in the holistic presentation condition. The findings of similar interactions in the eye movement measures equally do not show a systematic result pattern. In Experiments 3 and 4, trends for holistic priming could only be found in the post-selectional measures, whereas, in Experiment 1, this interaction appeared in the target fixation latencies (see Figs. 3, 7 and 9).

In sum, the evidence for holistic priming effects was generally weaker in the present study than in previous investigations (Hillstrom, 2000; Huang et al., 2004). Therefore, it is uncertain whether the rather weak effects found in the present study are comparable to the holistic priming effects obtained in previous studies.

The tentative conclusion to be drawn from these results is probably the following: *If* the present result pattern can be interpreted along the lines of a holistic priming view, then the results indicate, first, that the holistic priming effect is due to decisional and post-selectional processes pertaining to the target (and not to nontarget-rejection processes), as was originally proposed by the episodic retrieval view (Huang et al., 2004). This at least is suggested by recurring holistic result patterns in the target fixation durations, and the absence of such patterns in the nontarget fixation durations as well as in all attentional measures (with the exception of the initial saccadic latencies in Experiment 1; see Fig. 3). Second, the present study also indicates that the expectations of the participants might play a role for holistic priming. This might be derived from the fact that holistic result patterns were apparently stronger in Experiments 3 and 4, in which the target-defining feature varied predictably, than in the first two experiments, with random variations. Support for this hypothesis also derives from the observation that holistic priming effects in other studies appear to be stronger when the target-defining feature alternates predictably than when it varies randomly (Hillstrom, 2000).[2] Taken together, the results suggest that the holistic priming might emerge as an *expectation–repetition effect*, that critically depends on the participants' expectations (cf. Huang & Pashler, 2005).

Another factor that might modulate holistic priming effects is task difficulty. In the present study, holistic priming effects were stronger when the task was more difficult: for instance, holistic priming effects prominently surfaced in the separate presentation condition, and specifically when performance in this condition was significantly worse than in the separate presentation condition (see Experiments 1 and 3). Differences in task difficulty might also explain why holistic priming effects were stronger in other studies. In the present study, the feature differences between target and nontargets were very large, which probably rendered discrimination and target identification processes quite easy. In other studies, this might have been more difficult: For instance, in the study of Hillstrom (2000), the colours red and pink were used to distinguish between target and nontargets, which might be harder to discriminate from each other. Similarly, in the study of Huang et al. (2004), target identification might have been more difficult than in the present study, because participants had to distinguish a size singleton target from nontargets in a much bigger search array, while all items additionally differed in colour and orientation from each other. The increased task difficulty might have bolstered holistic priming effects by making perceptual decisions harder, so that decisional processes also exert a larger influence on search performance. However, further research is necessary to explore this possibility in a systematic way.

Apart from these considerations, it seems to be important to note that even the findings of strong and reliable interactions between priming of the target-defining and response-related features do not necessitate a holistic priming view. All results are also compatible with the view that the features are all processed independently of each other and in parallel, but that the target defining feature gains the capability to *bias* processes of the response-related feature. According to such a *biasing* explanation, the visual system identifies recurring features by comparing them to the target features from the previous trial(s). In this process, the current target features are automatically judged to be identical with the previous target features, or different. Since processing of the target-defining feature is given priority, the corresponding judgments are available faster and can bias processing of the response-related feature. Facilitation then only occurs when both target-defining and response-related feature were repeated or switched together than when this applied to only one of them. Such a biasing mechanism can also account for the observed interactions between priming of the target-defining and response-related feature, without assuming that all target features are necessarily holistically represented (see also Becker, 2007; Müller & Krummenacher, 2006).

In the context of the present experiments, the biasing explanation might even appear to be preferable to a holistic view on priming: First, a biasing mechanism seems to be better compatible with the finding that holistic priming effects were not stronger in the holistic presentation condition than in the separate presentation condition. Secondly, the biasing explanation can also explain why the interaction between priming of the target-defining and response-related feature is sometimes feeble and often even fails to occur: According to the biasing explanation, the occurrence of such interactions critically depends on the time-course of each ongoing feature identification processes: Interactions are only possible in a small time-window, in which parallel identification processes of two features are still in progress, with one of these processes slightly leading the other. Only then can the output from the earlier one of these processes intersect the processing stream of the other feature at the sensitive point in time, where this information will have an effect—otherwise, there will be no interaction. According to the biasing explanation, interactions between intertrial effects of the target-defining and response-related feature would therefore predicted to be rather rare and generally unstable.

Last, but not least, the biasing explanation also seems to be a viable alternative to the holistic priming view on a theoretical level. One problem of the episodic retrieval account of Huang et al. (2004) is that the benefits of the proposed verification procedure are not entirely clear: A verification mechanism resting solely on the target from the previous, $n-1$ trial would not be a true verification procedure because the target-defining features are given by the task and not by the trial history. Benefits of such a procedure would be confined to cases in which the target exactly matches the target from the last trial. Considering that in Huang et al.'s (2004) study, the features colour, orientation, and size were all randomly varied, it follows that, in the majority of cases (5/6), the verification procedure could not help decide the question whether a candidate target was in fact the target. This slightly implausible implication of the episodic retrieval account emerges as a direct consequence of proposing a holistic verification mechanism.

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[2] An alternative explanation for stronger holistic priming effects in Experiments 3 and 4 than in Experiments 1 and 2 might be to claim that cumulative priming effects can somehow neutralise priming of the response-related features. In this case, holistic priming would be due to the fact that cumulative priming effects were only possible in Experiments 1 and 2, and not in Experiments 3 and 4. Since there seems to be *ad hoc* no reason for such a connection between holistic and cumulative priming effects, this is more a theoretical possibility than an explanation.

Therefore, the biasing explanation which asserts that the interaction is due to occasional interference of multiple independent parallel processes, might seem an attractive alternative to the holistic priming view.

8.3. Implications for pop-out

One of the results of the present study is that repeating the target-defining feature leads to more efficient selection of the target. In turn, switch trials consistently led to more erroneous selections of nontarget items. Although such an effect is to be expected on the priming of pop-out account, it might be asked whether and how this finding can be integrated into current models of visual search.

As mentioned in the introduction, most models of visual search assume that the visual field is initially represented in parallel as a set of basic stimulus attributes in different feature- or dimensions-specific maps. Maps of these saliency signals are computed in parallel in all modules, and are then summed onto the master map of locations. This overall saliency map indicates the locations of the highest activation, and this information can be used to guide focal attention to the pop-out item.

Intertrial facilitation effects might be incorporated into current models of visual search by assuming that memory traces from previous trial(s) can selectively activate and de-activate output from one of the feature- or dimension-specific maps (e.g., Wolfe, 1998; see also Müller & Krummenacher, 2006; Müller, Reimann, & Krummenacher, 2003). For example, if the previous target has been a large item among smaller nontargets, the visual system can pre-activate the map(s) coding for size, and thus enhance the output from size-specific maps before it is integrated into the overall saliency map. As a consequence, size differences between the items will pop out stronger than differences in other stimulus dimensions, like colour, or form. Allocation of attentional resources can in this way be tuned or biased towards the feature or dimension of the previous target-defining property (cf. Müller & Krummenacher, 2006).

Such a mechanism also seems to be in line with the priming of pop-out hypothesis, which asserts that intertrial carry-over processes enhance the pop-out effect, or saliency, of the target-defining feature (Maljkovic & Nakayama, 1994, 1996).

However, as was argued above, the results of the present study are also compatible with an attentional retrieval mechanism of priming (Hillstrom, 2000). According to this view, priming does not change the saliency of features, or the activation levels of certain feature maps on a trial-by-trial basis. Instead, attention is guided by prioritisation rules that can either be retrieved from previous trials, or have to be created anew in a time-consuming process. Whether an old prioritisation rule can be retrieved depends on whether memory traces from recent trials match the features in the current display. Repetition facilitation effects are due to the fact that memory traces specifying the target can be retrieved quickly, whereas the same information is difficult to retrieve when corresponding trials are too far back in history. According to the retrieval account of Hillstrom (2000), priming thus modulates the time-course of target selection without changing the attentional priorities or saliency of the respective features.

Such a retrieval mechanism is probably not so easily reconcilable with current models of visual selection. Moreover, previous results indicate that repeating and changing the target-defining feature across trials modulates its saliency on a trial-by-trial basis, consistent with the feature weighting mechanism proposed by the priming of pop-out account (Becker, in press). In a task similar to the present one, switch trials led to more frequent visual selection of nontargets, whereas precision was increased on repetition trials (Becker, in press). Such a result pattern is not predicted on the episodic retrieval account. On the retrieval view, priming should only modulate the time-course of visual selection (i.e., saccadic latency), but the precision of selection (i.e. proportion of first correct saccades). Thus, the present results provide converging evidence for the priming of pop-out account. However, further research is required to test the implications of the attentional view of the episodic retrieval account in a more direct way.

9. Conclusions

The present study yielded several interesting results concerning intertrial facilitation effects. Eye movement measurements indicate that priming modulates processes operating on the attentional level, of target detection and selection. Conversely, intertrial contingencies apparently do not affect post-selectional processes like, for instance, nontarget rejection processes, or de-allocating attention from already selected objects. Contrary to the episodic retrieval view of Huang et al. (2004), feature priming effects also do not affect decisional processes of target identification that come into play after attention has been allocated to the search target. The second question investigated in the present study was whether priming pertains only to the target-defining feature, or to all target features in a holistic fashion. Another possibility taken into account was that priming might flexibly change between these two possibilities. The results of the present study do not provide any support for such a flexible view, and at best weak support for the holistic view. Such holistic priming effects were most pronounced when the target-defining feature was predictable, suggesting that the corresponding result pattern is probably due to an expectation–repetition effect.

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