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Higher set sizes in pop-out search displays do not eliminate priming or enhance target selection

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ABSTRACT

Previous research shows that salient stimuli do not pop out solely in virtue of their feature contrast. Rather, visual selection of a pop-out target is strongly modulated by feature priming: Repeating the target feature (e.g., red) across trials primes attention shifts to the target but delays target selection when the target feature changes (e.g., from red to green). However, it has been argued that priming modulated target selection only because the stimuli were too sparsely packed, suggesting that pop-out is still mostly determined by the target's saliency (i.e., local feature contrast). Here, we tested these different views by measuring the observer's eye movements in search for a colour target (Exp. 1) or size target (Exp. 2), when the target was similar versus dissimilar to the target, and when the displays contained 6 or 12 search items. The results showed that making the target less similar to the nontargets indeed eliminated priming effects in search for colour, but not in search for size. Moreover, increasing the set size neither increased search efficiency nor eliminated feature priming effects. Taken together, the results indicated that priming can still modulate target selection even in search for salient targets.

1. Introduction

Attention determines which items in the visual field will be processed with priority. This has important implications for survival (e.g., foraging for food) and managing everyday tasks, like visual search (e.g., searching for a friend in a crowded cafeteria). One of the most important goals of attention research has been to determine the factors that drive attention and determine visual selection.

One factor that determines the deployment of attention is *saliency*, or *feature contrast*: In a visual search task, items with a high feature contrast appear to pop out from the display and can be found immediately (e.g., Itti & Koch, 2000; Li, 2002; Nothdurft, 1992; Wolfe, 1994, 1998a, 1998b). Originally, it has been thought that feature contrast completely determines the pop-out effect (cf. Koch & Ulman, 1985). However, Maljkovic and Nakayama (1994) found that search for a pop-out target is significantly faster when the features of the target and nontargets from the previous trial are repeated than when they change. For instance, when the target was randomly either red or green and presented among nontargets of the opposite colour, response times were about 30–50 ms faster when the colours of the target and nontargets were repeated than when they switched (Maljkovic & Nakayama, 1994). Since the original study, corresponding intertrial effects have been demonstrated in several different contexts, including inefficient search (e.g., conjunction search; e.g., Becker & Horstmann, 2009; Kristjansson, Wang, & Nakayama, 2002), changes of the target-defining dimension (Müller, Heller, & Ziegler, 1995; Müller, Reimann, & Krummenacher, 2003), and a variety of target-defining features, including colour (Found & Müller, 1996; Maljkovic & Nakayama, 1994), brightness (e.g., Becker, 2008b), size (e.g., Becker, 2008b; Hodsoll, Humphreys, & Braithwaite, 2006), shape (Becker, in press, 2010b; Pinto, Olivers, & Theeuwes, 2005), and orientation (e.g., Hillstrom, 2000). According to the *priming of pop-out hypothesis* of Maljkovic and Nakayama (1994), selection on a given trial *primes* or biases attention to the target-defining feature, and this attentional bias automatically transfers to subsequent trial(s), which facilitates search when the target feature is repeated and delays attention shifts to targets with different, non-repeated features (Maljkovic & Nakayama, 1994, 1996).

As pointed out by Müller, Reimann, and Krummenacher (2003), the finding that pop-out search is modulated by the features of the target and nontargets on the previous trials indicates that "the target does not simply 'pop out' of the field on the basis of some early, pre-attentive, detection mechanism, operating in a purely bottom-up fashion." [p. 1021]. Contrary to major visual search theories (e.g., Julesz, 1986; Koch & Ulman, 1985; Treisman, 1988; Wolfe, 1994) the priming effect indicates that there is an attentional,

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feature-based mechanism mediating detection and selection of a pop-out target.

However, the claim that feature priming modulates early attentional and perceptual processes has also been disputed. Of note, most studies investigated priming effects by measuring response times (RTs) in visual search (with unlimited display durations), so that the priming effect could have been due to processes operating at a late, post-selectional stage of visual processing (e.g., Becker, 2008a, 2008b). In fact, corresponding late-selection views have been proposed as alternative or additional explanations for the feature priming effect (Cohen & Magen, 1999; Huang, Holcombe, & Pashler, 2004; Lamy, Zivony, & Yahsar, 2011; Meeter & Olivers, 2005; Olivers & Meeter, 2006).

Subsequent studies measured eye movements to determine whether priming affects search at an early stage of visual selection. Eye movements can serve as a more direct indicator for early selection and of covert attention shifts because eye movements cannot be executed to unattended locations but require that covert attention is first allocated to the saccade target location. For instance, Deubel and Schneider (1996) found that subjects were unable to covertly attend to a particular location when they were asked to saccade to a different location, suggesting "an obligatory and selective coupling of saccade programming and visual attention..." (Deubel & Schneider, 1996, p. 1827 [abstract]; see also Hoffman & Subramaniam, 1995; Klein, 1980; Kowler et al., 1995; Rizzolatti, 1983; Sheliga, Riggio, & Rizzolatti, 1995; Shepherd, Findlay, & Hockey, 1986). The coupling is selective in the sense that it is possible to shift covert attention while the eyes remain fixated at a particular location (e.g., Posner, 1980). Yet, once an eye movement is observed, we can infer that attention was allocated to the location shortly before the start of the saccade. This renders eye movements a valid indicator for covert attention shifts. Eye movements can also be deemed to be a better indicator for covert attention shifts than button press RT, because an eye movement provides spatial information about attention shifts, and eye movements probe visual search performance at an earlier point in time and are thus less contaminated by later, post-selectional processes than button press RT (e.g., Becker, 2008a; Folk & Remington, 1998; McPeek, Maljkovic, & Nakayama, 1999; Yantis & Egeth, 1999).

In line with the priming of pop-out hypothesis, eye movement studies showed that repeating a high-contrast pop-out target across successive trials increased the proportion of initial eye movements to the target and decreased the latencies of these saccades. By comparison, switch trials led to more frequent selection of one of the nontargets prior to target selection and/or significantly delayed the first eye movement to the target, indicating that selection of the target feature on the previous trial indeed primed attention shifts and eye movements to select the same feature on the current trial (e.g., Becker, 2008a, 2008b, 2010a, 2010b; McPeek, Maljkovic, & Nakayama, 1999).

The finding that target selection was modulated by feature priming demonstrates that feature contrast does not completely determine pop-out (or our ability to select the target with the first glance) and seems to be at odds with the view that feature contrast alone is sufficient for pop-out. However, this apparent conflict can be resolved if one conceives of priming as modulating the pop-out effect only in conditions of low saliency or low feature contrast. For instance, Meeter and Olivers (2005) argued that, in previous studies, the target was not salient enough to support pop-out by saliency, because the search displays were too sparsely populated with stimuli, consisting sometimes of only 3 items. Such sparse displays do not allow high local feature contrasts and may not promote pop-out, because the same-colour non targets are too few and too far apart from one another to strongly inhibit one another. Of note, saliency-driven pop-out supposedly depends on a strong local feature gradient (e.g., Julesz, 1986), or local inhibitory connections that suppress the nontarget features (e.g., Koch & Ulman, 1985; Treisman, 1988; see also Desimone, 1998; Duncan, 1996), a view that is also supported by several neurophysiological studies (e.g., Beck & Kastner, 2005, 2009; Desimone, 1998; Desimone & Duncan, 1995; Kastner et al., 2001). Hence, it is possible that the target did not pop out from the background of other items in standard-priming experiments because of the sparsely populated displays and the resulting low saliency.

In line with this view, Meeter and Olivers (2005) showed that, in search for colour, feature priming effects are much reduced or even eliminated when the target is presented in a densely packed display consisting of 12 items. These authors concluded that priming effects can only modulate search performance when the saliency of the target or its local feature contrast is low (Meeter & Olivers, 2005; Olivers & Meeter, 2006).[1] Consequently, from this perspective, it would be an error to claim that pop-out depends on priming. Rather, consistent with current models of visual search (e.g., Wolfe, 1994), pop-out would depend on the (relative) saliency of the target, and priming would only modulate performance when the target is not salient enough to immediately guide attention to the target.

1.1. Is pop-out mediated by saliency or priming?

To date, it is still an open question whether and to what extent pop-out is mediated by feature priming (across images) versus saliency (or local feature contrast within an image). So far, more densely packed search arrays have only been found to eliminate priming in search for colour (e.g., Meeter & Olivers, 2005; Olivers & Meeter, 2006). In other search tasks, priming effects could be reliably observed even with larger set sizes (i.e., larger numbers of items in the display). For instance, Hodsoll, Humphreys, and Braithwaite (2006) found large priming effects in search for size, despite the fact that the search displays contained 8 or 16 items. Similarly, in search for a shape target that was randomly a circle among diamonds or a diamond among circles, significant priming effects were found that were not modulated by set size (5 versus 9; Lamy et al., 2006; see also Asgeirsson & Kristjannson, 2011; Becker, 2008a, 2008b; Huang, Holcombe, & Pashler, 2004; Wolfe et al., 2003). Taken together, the currently available evidence does not unequivocally support the view that increasing the set size will typically eliminate or diminish priming effects. This has only been shown to occur with red and green stimuli, but it is currently unclear whether the principle generalises to other stimulus dimensions or colours.

There are also reasons to doubt that the findings from colour search will generalise to other stimulus dimensions: Firstly, increasing the number of nontargets (or the set size) can lead to shorter baseline RT in search for red-among-green when the target and nontarget colours switch randomly and unpredictably (e.g., Bacon & Egeth, 1991; Bravo & Nakayama, 1992; Meeter & Olivers, 2005). However, such an inverse set size effect has not been reported in analogous conditions for targets from other stimulus dimensions (e.g., size; Asgeirsson & Kristjannson, 2011; Hodsoll, Humphreys, & Braithwaite, 2006). Secondly, saliency as the local feature contrast is not always equally effective. For instance, search for a target with a unique colour can be equally efficient when the

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[1] It should be noted that this claim is only one part of a larger theoretical framework proposed by Meeter and Olivers (2005), labeled the ambiguity resolution account. Yet, they clearly state that "[i]t is known that in such tasks pop-out may be stronger when there are many distractor elements in the display, than when there are few (Bravo & Nakayama, 1992). The more distractors there are, the more unique and more salient the target becomes relative to these distractors, reducing competition. Our hypothesis would thus predict that as the number of distractor elements increases, and the ambiguity is reduced, intertrial priming effects will also be reduced." (p. 207).

colour target is a singleton versus when it is surrounded by nontargets with different colours (Duncan, 1989; see also Wolfe, 1998a, 1998b). These findings suggest that either, dense packing of homogenous nontargets does not always increase the saliency of a singleton target, or that an increase in saliency does not always facilitate search.

Even if an increase of set size can reduce priming effects, it is an open question whether this effect can be attributed to the increase in the local feature contrast of the target. Changing the set size is a rather indirect manipulation of feature contrast (e.g., Palmer, 1994, 1995), and corresponding effects can be subject to different explanations. For instance, McPeek, Maljkovic, and Nakayama (1999) found the saliency-predicted facilitation – that is, an "inverse set size effect" in a saccade task, where observers had to visually select a colour target that randomly varied between red and green: Increasing the set size in this task led to a higher proportion of first fixations on the target and shortened the latencies of these saccades (see also Bravo & Nakayama, 1992; Wolfe et al., 2003). However, McPeek and colleagues did not attribute this facilitation to an enhanced local feature contrast, but to the higher density of same-colour nontargets (or distractors) in large set size conditions, which facilitates target selection because it allows rejecting distractors as a group rather than individually (e.g., Julesz, 1986; Nakayama & Joseph, 1998; see also Duncan & Humphreys, 1989).

Other explanations for the inverse set size effect are also conceivable: It is, for example, possible that observers can use configurational cues in densely packed search arrays, to detect the target by searching for an irregularity in the pattern (e.g., Nakayama & Martini, 2011; Palmer, 1994). For instance, targets that deviate in their orientation from all nontargets can presumably be found by looking for a "gap" in the otherwise regular pattern. The degree to which this search strategy will be successful depends on the set size, not on feature contrast, but can provide an alternative explanation for reduced priming effects in higher set size conditions (see Bravo & Nakayama, 1992; Maljkovic & Nakayama, 1994; see also Nothdurft, 2000).

In sum, varying the set size does not seem to offer the most direct manipulation of feature contrast. The claim that priming does not contribute to the pop-out effect of salient targets would appear more convincing if feature contrast had been manipulated more directly, for instance, by varying the similarity between the target and the nontargets (e.g., comparing priming effects of a low-contrast red–orange search display with priming effects of a high-contrast red–green search display).

Another possible limitation of previous research is that it is not entirely clear whether the observed set size-on-priming effects were indeed due to processes at the level of early visual-attentional selection. Of note, in the studies of Meeter and Olivers, only RTs were measured and taken as an indicator for attentional processes. However, as mentioned above, RTs are also affected by later decisional processes that commence after the target has been selected. Hence, it is possible that priming effects occurring at the level of visual selection were compensated by an inverse effect in later processes concerned, for instance, with target identification or stimulus-to-response mappings. In this case, increasing the set size would not have reduced switch costs occurring at the level of early attention or visual selection of the target, but rather would have modulated RTs at a later post-perceptual stage of processing.

1.2. Aim of the present study

The aim of the present study was to investigate whether and to what extent priming can modulate pop-out for targets of high versus low feature contrast. Specifically, we investigated the set size-on-priming effect with regard to the questions (1) whether increases in set size will also reduce priming effects in other stimulus dimensions than colour (i.e., size); (2) whether reduced priming effects in higher set size conditions can indeed be attributed to processes at the level of visual-attentional selection, and specifically, (3) whether priming is reduced in higher set size conditions because the feature contrast of the target is enhanced.

To test whether increases in set size increase saliency and reduce priming also in other stimulus dimensions, we tested priming effects in pop-out search for colour (Exp. 1) and size (Exp. 2), when the target was presented either among 5 or 11 nontagets (set sizes 6 and 12). Importantly, if set size increases saliency, an inverse set size effect should be found. Also, to examine whether increasing the set size indeed reduces switch costs at the level of early visual selection, we measured the eye movements of the observers in both experiments. If increasing the set size increases target saliency and impacts early visual selection, then increasing the set size should facilitate target selection and lead to shorter target saccade latencies and/or a higher proportion of first eye movements to the target (e.g., Becker, 2008a, 2008b; Becker & Horstmann, 2009). In addition, if it is true that saliency decreases priming, then priming effects should be reduced with a larger set size. Note, however, that if increasing the set size only attenuates the priming effect without an leading to an inverse set size effect or if increasing the set size does not affect early visual selection but modulates only later processes (e.g., as reflected in fixation durations or manual RTs), we cannot conclude that the effects were due to an increase in saliency: Without an inverse set size effect we have no independent evidence for the assumed effect of set size on saliency. Moreover, if set size or set size-on-priming effects can only be found in the fixation durations but not in the proportion of first target fixations or their latencies, the saliency explanation would have to be refuted because set size would not affect early processes of visual selection, but only later processes (e.g., Becker, 2008a, 2008b; Becker & Horstmann, 2009).

The present study also examined whether set size-on-priming effects can be attributed to the differences in the feature contrast of the target, by additionally manipulating the feature contrast of the target more directly: In different blocks, the target features were construed such that they were either featurally similar or featurally dissimilar to the nontargets. If increasing the set size reduces priming effects by increasing the saliency of the target, then increasing the set size and the feature contrast between target and nontarget features should have similar effects on visual selection. Specifically, increasing featural dissimilarity between target and nontargets should facilitate early visual selection of the target, that is, increase the proportion of first target fixations and/or shorten the latencies of first eye movements directed to the target.

2. Experiment 1

Experiment 1 assessed feature priming effects in a discrimination task, where observers had to search for a unique colour-target and responded to an additional item located inside the target (an "o" or "="). Feature priming effects were assessed in two different set size conditions (6 and 12), and when the target was similar versus dissimilar to the nontargets. The nontargets were always orange. In the similar (or less salient target) condition, the target could be either red or yellow–orange, and in the dissimilar (or salient target) condition, the target colour randomly varied between green and blue. All stimuli were presented in the periphery, and the response-defining features were kept small to encourage observers to foveate the target and to prevent saccadic undershoot (which otherwise complicates the assignment of eye movements to objects; e.g., Troost, Weber, & Daroff, 1974).

Eye movements were measured and assessed in a similar way as in earlier studies (e.g., Becker, 2008a, 2008b, 2010a, 2010b; Becker, Ansorge, & Horstmann, 2009; Becker & Horstmann, 2009; see also Geyer, Müeller, & Krummenacher, 2008; Williams & Reingold, 2001). First, to assess whether early processes are affected by priming effects and set size-on-priming effects, we assessed (1) the proportion of first eye movements to the target, and (2) the latencies of first saccades to the targets. [Here, the proportion of first fixations on the nontargets is reported instead of the proportion of first fixations on the target because this permits comparing the priming effect more easily to the remaining measures, e.g., of latencies, fixation durations, RTs, and errors.]

To further distinguish between processes that are versus are not response- or decision-related, we also report (3) the mean target fixation latencies (which should be less response-related), and (4) the mean fixation durations on the target (which are more response-related). Target fixation latency is the time needed to direct the gaze to the target, measured from the onset of the search display. The target fixation latencies comprise costs of erroneously looking at a nontarget and re-directing the gaze to the target, and thus, represent a mixed measure that can contain both early and relatively late processes (e.g., of distractor rejection). However, the target fixation latencies probably do not include processes of response selection, because in fine-grained discrimination tasks, observers usually fixate on the target prior to executing the response (e.g., Posner, 1980). Thus, if effects observed in the mean RT can be fully accounted for by effects in the target fixation latencies, we can be reasonably confident that the effect was due to processes preceding response selection proper.

The target fixation duration (or dwell time) is the duration from the onset of the first target fixation to the end of the fixation, or until the response, whichever occurred earlier. Although dwell times may not strictly depend on the time needed to identify an item, and/or the time needed to initiate the response, they often reflect such processes (e.g., Becker, 2011). Target fixation durations included to examine whether and to what extent late processes of target identification, decision, and response selection may contribute to the observed effects.

If priming affects early processes of visual selection, then we would expect a higher proportion of first target fixations on repetition trials than on switch trials (e.g., Becker, 2008a, 2008b, 2010a, 2010b). Moreover, if increasing the set size reduces priming by facilitating visual selection of the target (via increases of the target's local feature contrast), then we would expect that increasing the set size enhances the proportion of first eye movements to the target, and that priming effects should be eliminated in the set size 12 condition. Similarly, priming effects should be reduced or eliminated with the dissimilar target, because this target has a higher local feature contrast and is more salient than the similar target.

If, on the other hand, increasing the set size eliminates priming at the level of later processes, concerned, for instance, with decision making or response selection, then differences in set size should not affect the proportion of initial nontarget fixations or the initial target fixation latencies, but should be observed only in the mean RT or in the duration that the eyes remain fixated on the target.

2.1. Method

2.1.1. Participants

Twelve volunteers from the University of Queensland, Australia, participated in the experiment and were paid $10 for their time. The participants all had normal or corrected-to-normal vision. Seven of them were female, 5 male, and they had a mean age of 26.7.

2.1.2. Materials

An Intel Duo 2 CPU 2.4 GHz computer with a 17″ FP92E colour monitor was used to produce and display the stimuli. Stimuli were presented with a resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. For eye tracking, a video-based infra-red eye tracker with a spatial resolution of 0.1 and a temporal resolution of 500 Hz was used (Eyelink 1000, SR Research, Ontario, Canada). Participants were seated in a well-lit room, with their head fixated by the eye trackeŕs chin rest and forehead support, and viewed the screen from a distance of 63 cm. For registration of manual responses, a standard USB optical mouse was used. Event scheduling and RT measurement were controlled by the Presentation software (*Neurobehavioral Systems*).

2.1.3. Stimuli

The response-indicative stimuli consisted of small black "o" or "=" characters (0.2° × 0.2°; Arial Black, 12 pt) which were located at the centre of different coloured squares (2.2° × 2.2°). The squares were placed equidistantly on the outlines of an imaginary circle centred on the screen with a diameter of 18.2°, beginning at the 12 o'clock position, and presented against a white background. The nontargets were always orange, across all conditions. In the similar condition, the target was randomly either yellowish-orange or red. In the dissimilar condition, the target was either blue or green. Fig. 1 depicts an example of the stimulus displays.

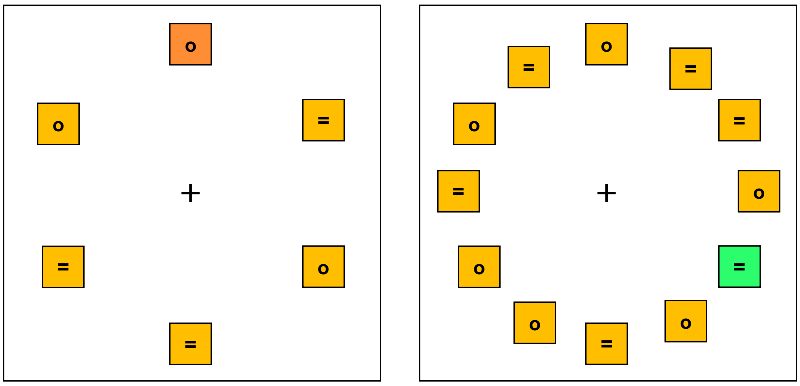

Fig. 1. Example displays of Experiment 1, where observers searched for a colour pop-out target and responded to the o- and =-characters inside the target. The target could be either similar to the nontargets (left panel), or dissimilar from the nontargets (right panel), and the set size varied between 6 and 12 items (left and right panels, respectively).

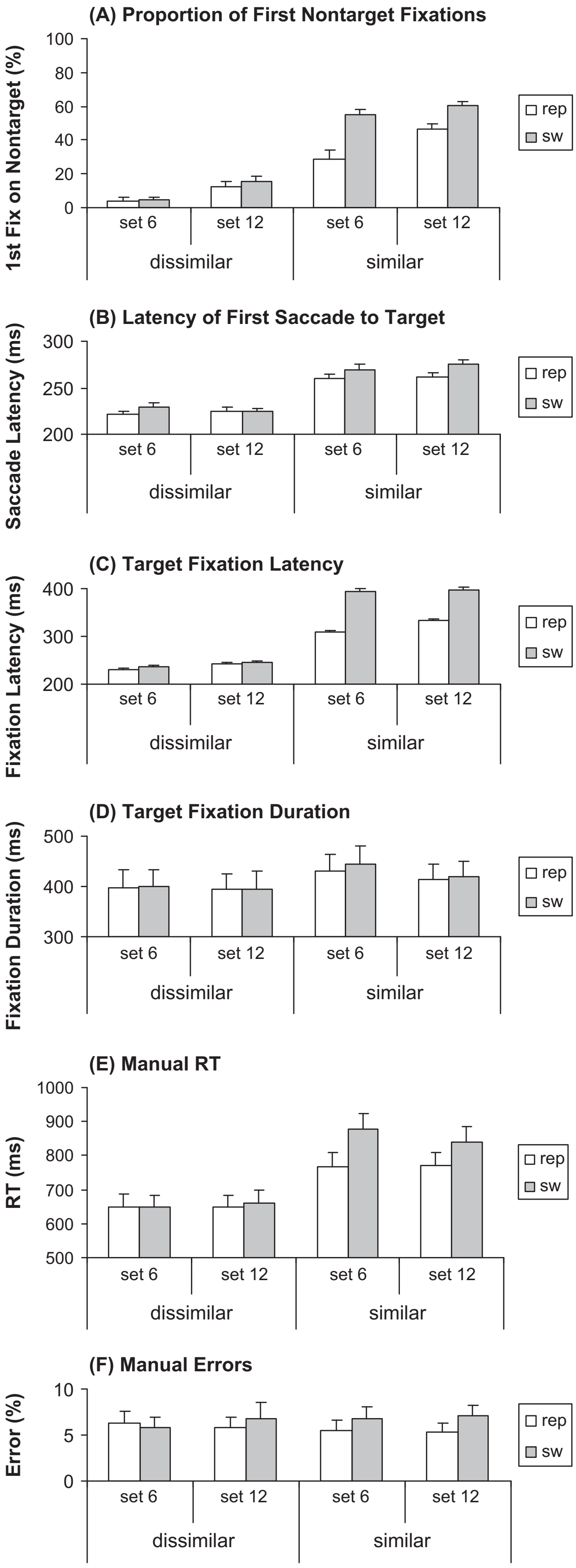

Fig. 2. Results of the colour-search task of Experiment 1, depicted separately for the different dependent measures. The priming effect is the difference between repetition trials (rep; white histograms) and switch trials (sw; grey histograms), and is depicted separately for the similar versus dissimilar target condition and the two different set size conditions. Error bars depict the standard error of the mean.

2.1.4. Design

The experiment consisted of the $2 \times 2 \times 2$ within-subjects design, with the conditions "target similarity", "set size", and "priming". The similarity variable was blocked and the order of blocks counterbalanced across participants. The set size, target colour, target position, and the response-indicative item were all determined randomly on each trial, with the restriction that the number of "o" and "=" characters in the display was always equal. Participants completed 240 trials in the similar and dissimilar condition, yielding 480 trials per participant.

2.1.5. Procedure

Each trial started with the presentation of a small black fixation cross and a fixation control: Participants were instructed to fixate on the centre of the cross. The search display was only presented if the tracking was stable (no blinks) and the gaze was within 50 pixels (1.2°) of the centre of the fixation cross, for at least 500 ms (within a time-window of 3000 ms). Otherwise, participants were calibrated anew (9-point calibration) and the next trial started again with the fixation control.

Upon presentation of the stimulus display, the fixation cross disappeared and participants were required to search the display for the pre-defined target, and to press the right mouse button if the response-indicative item located inside the target square was an "o", and the left mouse button when it was an "=". 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' (Arial, 12 pt.) which were presented centrally against a white background and remained on screen for 500 ms. After an intertrial interval of 250 ms, in which a blank white screen was presented, the next trial started with the presentation of the fixation cross.

Before each block, participants were calibrated with a 9-point calibration, and were given written instructions about the next block. Participants were instructed to search for the pre-defined target and to manually respond to the item inside the target as fast as possible without making mistakes. Participants were not explicitly instructed to make eye movements to the target, as this may prompt them to exert more top-down control over their eye movements, with the corresponding decision-related processes delaying the saccade and rendering the eye movement measures more noisy (Becker, Ansorge, & Horstmann, 2009). Eye movements were however made on >99% of the trials, indicating that the response-related items were sufficiently small to encourage eye movements. On average, it took 40 min to complete the experiment.

2.2. Results

2.2.1. Data

Eye movement data were parsed into saccades and fixations using the standard parser configuration of the Eyelink 1000, with thresholds set at 30°/s for saccade velocity and $8000°/s^2$ for saccade acceleration. Fixations were assigned to a particular stimulus when the gaze was within 2.35° of the centre of the response-related item. Data were excluded from all analyses when RT was below 200 ms or above 3000 ms (0.28% of all data) or when the gaze was not fixated on the target within 3000 ms from the onset of the search display (0.88% of all trials). Only trials with a correct manual response were included in the analysis of eye movements and RT.

2.2.2. Proportion of first saccades to the nontargets

In the analysis of the proportion of first saccades to the target, eye movements were assigned to the target when the first fixation on a trial was within 2.35° of the centre of the target, and otherwise counted as a nontarget fixation, to prevent that the results are skewed by the higher *a priori* probability of selecting a nontarget in the set size 12 condition (e.g., in the case of imprecise saccadic selection). The results of Experiment 1 are depicted in Fig. 2. The mean proportion of first eye movements directed to the target was analysed by a $2 \times 2 \times 2$ ANOVA comprising the within-subject variables "similarity" (similar versus. dissimilar"), "set size" (set size 6 versus 12), and "feature priming" (repetition versus switch trial). The analysis showed significant main effects of similarity [$F(1,11) = 298.88$; $MSE = 120.34$; $p < .001$; $\eta^2 = 0.97$], set size [$F(1,11) = 56.94$; $MSE = 49.09$; $p < .001$; $\eta^2 = 0.84$], and feature priming [$F(1,11) = 52.50$; $MSE = 56.17$; $p < .001$; $\eta^2 = 0.83$]. The first saccades landed less often on the nontargets when the target feature was repeated/primed ($P = 43.1\%$) than when it was switched/unprimed ($P = 23.0\%$). More initial saccades were directed to the nontargets in the similar condition ($P = 47.8\%$) than in the dissimilar condition ($P = 9.2\%$), and with a set size of 12 ($P = 33.9\%$) than with a set size of 6 items ($P = 23.1\%$). There was a significant interaction between similarity and priming [$F(1,11) = 53.45$; MSE = 38.77; $p < .001$; $\eta^2 = 0.83$], reflecting that priming effects were larger in the similar condition (proportion of saccades to the nontargets in switched/unprimed trials minus proportion of saccades in repeated/primed trials: 20.0%) than in the dissimilar condition (proportion of saccades to the nontargets in switched/unprimed trials minus proportion of saccades in repeated/primed trials: 1.8%). The interaction between set size and priming was also significant [$F(1,11) = 6.81$; MSE = 19.87; $p = .024$; $\eta^2 = 0.38$], indicating that priming effects were larger in the set size 6 condition (proportion of saccades to the nontargets in switched/unprimed trials minus proportion of saccades in repeated/primed trials: 13.4%) than the set size 12 condition (proportion of saccades to the nontargets in switched/unprimed trials minus proportion of saccades in repeated/primed trials: 8.6%). The three-way interaction between similarity, set size, and priming was also significant [$F(1,11) = 13.01$; $MSE = 24.80$; $p = .004$; $\eta^2 = 0.54$]. The three-way interaction was due to the fact that the similar condition showed strong priming effects [proportion of saccades to the nontargets in switched/unprimed trials minus proportion of saccades in repeated/primed trials: 38.6%; $F(1,11) = 57.98$; $MSE = 85.92$; $p < .001$; $\eta^2 = 0.84$] which also were significantly stronger in the set size 6 condition (priming effect: 26.4%) than in the set size 12 condition [priming effect: $P = 14.2\%$; $F(1,11) = 10.73$; $MSE = 40.79$; $p = .007$; $\eta^2 = 0.49$]. By contrast, priming effects were non-significant in the dissimilar condition [$P = 1.8\%$; $F(1,11) = 4.27$; $MSE = 9.02$; $p = .062$; $\eta^2 = 0.28$], and the effect was in the opposite direction, with stronger priming effects in the set size 12 condition ($P = 3.1\%$) than the set size 6 condition [$P = 0.4\%$; $F(1,11) = 5.15$; $MSE = 3.88$; $p = .044$; $\eta^2 = 0.32$].

2.2.3. Latencies of first saccades to the target

The same ANOVA computed over the mean saccade latencies showed significant main effects of similarity [$F(1,11) = 108.01$; $MSE = 386.94$; $p < .001$; $\eta^2 = 0.91$] and priming [$F(1,11) = 27.80$; $MSE = 51.58$; $p < .001$; $\eta^2 = 0.72$]. Mean latency of the first target fixation was shorter in dissimilar conditions (225 ms) than in similar conditions (267 ms) and it was also shorter on primed trials (242 ms) than on switched/unprimed trials (250 ms). Moreover, priming interacted significantly with similarity, reflecting that priming effects (switched/unprimed latency minus repeated/primed latency) were significantly stronger in the similar condition (12 ms) than in the dissimilar condition [3 ms; $F(1,11) = 7.09$; $MSE = 52.50$; $p = .022$; $\eta^2 = 0.39$].

2.2.4. Target fixation latencies

The same analysis computed over the target-fixation latencies (i.e., the time needed to fixate the target) revealed significant main effects of similarity [$F(1,11) = 128.15$; $MSE = 2691.74$; $p < .001$; $\eta^2 = 0.92$], set size [$F(1,11) = 15.48$; $MSE = 237.35$; $p = .002$; $\eta^2 = 0.59$], and feature priming [$F(1,11) = 41.09$; $MSE = 942.46$; $p < .001$; $\eta^2 = 0.79$]. Target fixation latencies were shorter with dissimilar (238 ms) than with similar (358 ms) nontargets, and they were shorter in the set size 6 condition (292 ms) than the set size 12 condition (302 ms). Latencies were also shorter on primed trials (278 ms) than on switched/unprimed (318 ms) trials. Similarity interacted significantly with priming [$F(1,11) = 38.76$; $MSE = 780.25$; $p < .001$; $\eta^2 = 0.78$], indicating that priming effects (switched/unprimed latency minus primed latency) were stronger in the similar condition (81 ms) than in the dissimilar condition (5 ms). Set size also interacted significantly with priming [$F(1,11) = 8.66$; $MSE = 96.67$; $p = .013$; $\eta^2 = 0.44$], with larger priming effects in the set size 6 condition (46 ms) than in the set size 12 condition (34 ms).

2.2.5. Target fixation durations

The durations that the eyes remained fixated on the target were modulated by similarity [$F(1,11) = 4.84$; $MSE = 4474.97$; $p = .050$; $\eta^2 = 0.31$], and set size [$F(1,11) = 12.09$; $MSE = 346.20$; $p = .005$; $\eta^2 = 0.52$]. However, the trend was in the opposite direction, with target fixation durations being 13 ms shorter in the set size 12 condition (405 ms), resulting in an inverse set size effect. Of the interactions, only the set size × similarity interaction reached significance [$F(1,11) = 6.71$; $MSE = 243.39$; $p = .025$; $\eta^2 = 0.38$], reflecting that the inverse set size effect was stronger in the similar condition (−22 ms) than in the dissimilar condition (−5 ms).

2.2.6. Manual RT

Analysis of the mean correct RTs showed significant main effects of similarity [$F(1,11) = 40.75$; $MSE = 15270.15$; $p < .001$; $\eta^2 = 0.79$] and feature priming [$F(1,11) = 45.09$; $MSE = 1252.97$; $p < .001$; $\eta^2 = 0.80$]. RT was longer in the similar (815 ms) than the dissimilar condition (652 ms), and responses were faster on primed trials (709 ms) as compared to switched/unprimed (758 ms) trials. The main effect of set size failed to reach significance [$F(1,11) = 3.10$; $MSE = 259.96$; $p = .11$] but the trends were in the direction of an inverse set size effect. The similarity × set size interaction was significant [$F(1,11) = 9.27$; $MSE = 345.00$; $p = .011$; $\eta^2 = 0.46$], reflecting that the similar condition showed an inverse set size effect (RT in 12 items conditions minus RT in 6 items conditions) which was significant [−17 ms, $F(1,11) = 7.78$; $MSE = 456.98$; $p = .018$; $\eta^2 = 0.41$], whereas the dissimilar condition showed only non-significant trends for a positive set size effect (6 ms).

More importantly, similarity interacted significantly with priming [$F(1,11) = 62.48$; $MSE = 718.48$; $p < .001$; $\eta^2 = 0.85$], reflecting that priming effects (switched/unprimed RT minus primed RT) were much stronger in the similar condition [92 ms; $F(1,11) = 56.57$; $MSE = 1786.13$; $p < .001$; $\eta^2 = 0.84$] than in the dissimilar condition, where they also did not reach significance [5 ms; $F(1,11) = 1.8$; $MSE = 185.31$; $p = .20$]. The interaction between set size and priming just failed to reach significance [$F(1,11) = 4.57$; $MSE = 318.72$; $p = .056$], with a trend for larger priming effects in the set size 6 condition (56 ms) than in the set size 12 condition (40 ms).

2.2.7. Errors

The same analysis computed over the mean error scores did not show any significant effects or interactions.

2.3. Discussion

The results of the first experiment corroborate results of previous studies in showing that priming effects are due to processes of early visual selection: Changing the target feature across trials significantly reduced the proportion of first fixations on the target.

Moreover, later processes concerned with response selection (that were reflected in target fixation durations) did not contribute to priming effects (e.g., Becker, 2008a, 2008b; Goolsby & Suzuki, 2001; McPeek, Maljkovic, & Nakayama, 1999).

Importantly, priming of early visual selection only modulated pop-out in the similar condition, but not in the dissimilar condition. This would be in line with the assumption that priming only impacts on search performance where local saliency is weak because the similar target is less salient than the dissimilar target. However, our results do not unequivocally support the hypothesis that increasing the set size increases the saliency of the target. First, increasing the set size led to shorter mean RT. Importantly, however, this inverse set size effect was restricted to dependent variables reflecting late processes (such as response-selection or decisions) because effects analogous to the RTs were only found in the target fixation durations. By contrast, our dependent variables that indicated early attentional effects, that is, the proportion of first target fixations and the target fixation latencies, showed an opposite trend, as selection of the target was impaired by increases of the set size, especially in the similar condition. This result appears to be inconsistent with the saliency explanation: If set size increments had affected priming via saliency, an inverse set size effect should have been found during early visual selection, too. During early visual selection, however, there was no inverse set size effect. Hence, the inverse set size effect found in the RT and the target fixation durations is presumably due to later processes that commence after the target has been selected (e.g., decisional or response-related processes).

Secondly, the set size-on-priming effect was also not in the expected direction: According to a saliency account, we would have expected intertrial priming effects or switch costs to be reduced in the higher set size condition because a higher proportion of first fixations can be directed to the target in the high set size condition, both on repetition trials and switch trials. By contrast, the results from the similar condition showed that the proportion of first fixations to the target was reduced in the higher set size condition [and two-tailed *t*-tests confirmed that target selection was significantly reduced in the higher set size condition, both on repetition trials, $t(11) = 5.7$, $p < .001$, and on switch trials, $t(11) = 2.4$, $p = .036$]. Fig. 2 moreover suggests that the priming effect was reduced in the higher set size condition because benefits of repeating the target colour were reduced in the higher set size condition. Although the cause of the priming × set size interaction cannot be determined with certainty, it seems that increasing the set size led to a higher proportion of nontarget fixations on repetition trials, not to a lower proportion of nontarget fixations on switch trials (see similar condition of Fig. 2). Moreover, in the dissimilar condition, a significant priming effect on the proportion of first target fixations was found only in the set size 12 condition, but not in the set size 6 condition. These results would also appear to be inconsistent with the prediction that priming effects should be reduced in higher set size conditions.

Taken together, the RT results of Experiment 1 were in line with previous results, as priming effects in the mean RT were reduced with higher set sizes, and with increasing the dissimilarity between target and nontargets. However, the results for the first fixations on the target did not unequivocally support the view that increasing the set size increases the saliency of the target and thereby decreases priming.

3. Experiment 2

The aim of Experiment 2 was to test whether the effects observed in search for colour apply generally and can also be observed in search for a size-pop-out target, or whether they may be specific to colour search. To that aim, the effects of set size and similarity-effects on priming were examined in search for size. In Experiment 2, observers were asked to search for a target singleton with a unique size. As in Experiment 1, priming effects were assessed in two different similarity conditions (similar versus dissimilar target) and in two set size conditions (6 versus 12 items).

3.1. Method

3.1.1. Participants

Twelve new volunteers participated in the experiment for $10. Two of them were male, 10 female and their mean age was 31.

3.1.2. Materials, stimuli, design and procedure

These were the same as in the previous experiment, with the exceptions that the squares were all coloured green, and that observers were instructed to search for a target with a unique size. Across all conditions, the nontargets were always of medium size (2.4° × 2.4°). In the similar condition, the target could be either small (1.9° × 1.9°) or large (2.9° × 2.9°), and in the dissimilar condition, the target was randomly either supersmall (1.3° × 1.3°) or superlarge (3.7° × 3.7°).

3.2. Results

3.2.1. Data

Excluding trials with RT below 200 ms or above 3000 ms led to a loss of 2.63% of all data. Additionally removing trials where the gaze had not been at the target location within 3000 ms led to further loss of 2.53% of all data.

3.2.2. Proportion of first fixations on a nontarget

The results of Experiment 2 are depicted in Fig. 3. Analysis of the proportion of first fixations on a nontarget revealed significant main effects of similarity [$F(1,11) = 53.96$; $MSE = 218.57$; $p < .001$; $\eta^2 = 0.83$], set size [$F(1,11) = 9.40$; $MSE = 119.47$; $p = .011$; $\eta^2 = 0.46$), and of feature priming [$F(1,11) = 25.50$; $MSE = 140.16$; $p < .001$; $\eta^2 = 0.70$]. The proportion of first fixations on a nontarget was higher in similar ($P = 68.6\%$) than in dissimilar ($P = 46.4\%$) conditions and it was higher on switch trials ($P = 63.6\%$) than on repeated target trials ($P = 51.4\%$). Priming was not significantly affected by differences in the set size ($F < 1$). There was a significant interaction between similarity and priming [$F(1,11) = 19.49$; $MSE = 21.75$; $p = .001$; $\eta^2 = 0.64$]. Contrary to expectations based on a saliency explanation, the priming effect (proportion of nontarget fixations on switched/unprimed trials minus proportion of nontarget fixations on repeated/primed trials) was stronger in the dissimilar condition [16%; $F(1,11) = 38.99$; $MSE = 82.83$; $p < .001$; $\eta^2 = 0.78$] than in the similar condition [8%; $F(1,11) = 9.71$; $MSE = 79.08$; $p = .010$; $\eta^2 = 0.47$].

3.2.3. Latencies of first saccades to the target

For the analysis of the saccade latencies, two observers who had failed to select the target as the first item in one condition had to be excluded. The analysis computed over the mean saccade latencies of the remaining observers showed a significant main effect of priming only [$F(1,9) = 7.15$; $MSE = 813.77$; $p = .025$; $\eta^2 = 0.44$], with shorter latencies on repetition trials (329 ms) than on switch trials (346 ms). The similarity × set size interaction also approached significance [$F(1,9) = 4.31$; $MSE = 536.18$; $p = .067$], with a trend for stronger set size effects (latency in set size 12 minus latency in set size 6 condition) in the similar condition (16 ms) than the dissimilar condition (−5 ms). The remaining effects were all non-significant (all *ps* > .20).

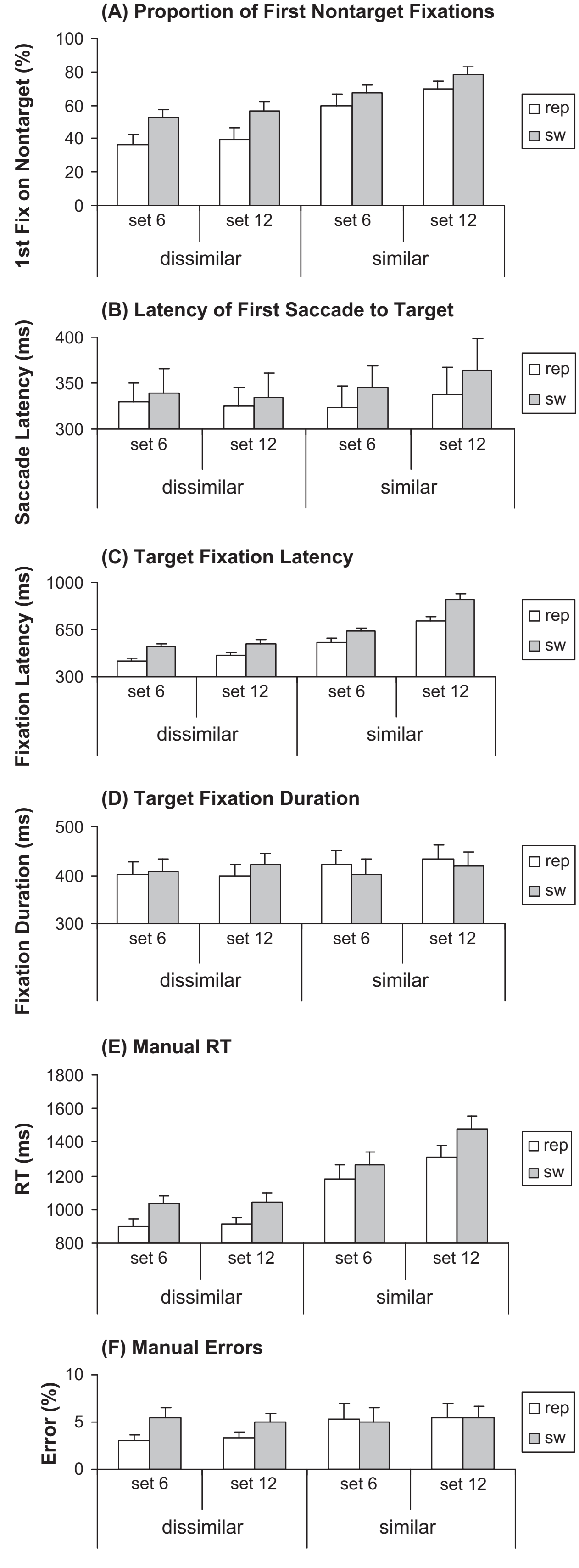

Fig. 3. Results of the size-search task of Experiment 2, listed separately for the different dependent measures of interest. Priming effects are depicted as the difference between repetition trials (rep; white histograms) and switch trials (sw; grey histograms) and are shown for the different similarity and set size conditions. Deviating from Experiment 1, priming effects were reduced in the similar condition, and mostly unaffected by manipulations of the set size. Error bars depict the standard error of the mean.

3.2.4. Target fixation latencies

The same analysis computed over the mean target fixation latencies showed significant main effects of similarity [$F(1,11) = 118.79$; $MSE = 8630.66$; $p < .001$; $\eta^2 = 0.92$], set size [$F(1,11) = 64.50$; $MSE = 4794.97$; $p < .001$; $\eta^2 = 0.85$], and of feature priming [$F(1,11) = 89.83$; $MSE = 3375.82$; $p < .001$; $\eta^2 = 0.89$]. Target fixation latency was longer in similar (694 ms) than dissimilar (487 ms) conditions, longer in set size 12 (647 ms) than set size 6 (533 ms) conditions, and longer on switched/unprimed trials (646 ms) than on repeated/primed trials (534 ms). Moreover, the similarity × set size interaction was significant [$F(1,11) = 50.01$; $MSE = 3159.97$; $p < .001$; $\eta^2 = 0.82$], reflecting that set size effects (latency in set size 12 minus latency in set size 6 condition) were stronger in the similar condition (194 ms) than in the dissimilar condition (32 ms). The three-way interaction was also significant [$F(1,11) = 7.79$; $MSE = 1340.65$; $p = .018$; $\eta^2 = 0.41$], reflecting that set size-on-priming effects were different in the similar and dissimilar condition: In the similar condition, priming effects (switched/unprimed latency minus primed latency) were significantly larger in the set size 12 condition (160 ms) than in the set size 6 condition [92 ms; $F(1,11) = 7.35$; $MSE = 1878.13$; $p = .020$; $\eta^2 = 0.40$], whereas in the dissimilar condition, priming was equally strong in both set size conditions ($F < 1$).

3.2.5. Target fixation durations

Analysis of the target-fixation durations showed only a significant two-way interaction between similarity and priming [$F(1,11) = 12.43$; $MSE = 495.65$; $p = .005$; $\eta^2 = 0.53$]. The interaction was due to the fact that priming effects (switched/unprimed fixation duration minus primed fixation duration) on dwell times were observed only in the similar condition [14 ms; $F(1,11) = 7.27$; $\mathrm{MSE} = 322.58$; $p = .021$; $\eta^2 = 0.40$], whereas, in the dissimilar condition, fixation durations were non-significantly shorter on switch trials than on repetition trials [−18 ms; $F(1,11) = 4.12$; $\mathrm{MSE} = 942.99$; $p = .067$].

3.2.6. Manual RT

The analysis of the mean RTs showed significant main effects of similarity [$F(1,11) = 61.32$; $MSE = 43835.77$; $p < .001$; $\eta^2 = 0.85$], set size [$F(1,11) = 18.21$; $MSE = 11126.92$; $p = .001$; $\eta^2 = 0.62$], and feature priming [$F(1,11) = 97.71$; $MSE = 4083.63$; $p < .001$; $\eta^2 = 0.90$], reflecting that mean RTs were longer with similar distractors (1308 ms) than dissimilar nontargets (973 ms), and longer in the set size 12 condition (1187 ms) than the set size 6 condition (1095 ms). Mean RTs were also longer on switched/unprimed trials (1206 ms) than on primed trials (1077 ms). There was a significant similarity × set size interaction [$F(1,11) = 37.62$; $MSE = 4056.90$; $p < .001$; $\eta^2 = 0.77$], reflecting that set size effects (RT in set size 12 minus RT in set size 6 condition) were restricted to the similar condition [172 ms; $F(1,11) = 31.49$; $MSE = 11223.51$; $p < .001$; $\eta^2 = 0.74$] and did not occur in the dissimilar condition (12 ms; $F < 1$). However, priming effects were not affected by differences in set size or target similarity.

3.2.7. Errors

The same analysis computed over the mean error scores did not show any significant effects or interactions.

3.3. Discussion

The results of Experiment 2 show that repeating versus switching the target size also modulates visual selection of the target. This is similar to colour priming effects. Apart from this, the results for the size-search task were very different from the earlier colour-search results: First, rendering the target more dissimilar from the nontargets did neither eliminate nor significantly reduce priming effects, contrary to the findings of Experiment 1. Second, set size-on-priming effects were either absent or in the reverse direction, with larger priming effects in the set size 12 condition than in the set size 6 condition. These differences in the priming effect in the mean proportion of first nontarget fixations were also significant between the experiments, as shown by a significant priming × experiment interaction, $F(1,22) = 6.0$, $p < .023$, and a significant priming × set size × experiment interaction, $F(1,22) = 7.4$, $p = .013$.

The failure to replicate the findings of Experiment 1 cannot be attributed to differences in search efficiency: In the dissimilar condition of Experiment 2, search was efficient and did not differ significantly from performance in the similar condition of the colour-search task, as shown by non-significant differences in the set size effects between the experiments (set size × experiment interaction: $F < 1$ for the proportion of first fixations and latencies of first target fixations, $F < 1.76$, $ps > .19$, for the target fixation latencies). This indicates that the magnitude of priming effects can be independent of the set size.

Another interesting finding was that priming effects in Experiment 2 were equally large in search for the similar target and the dissimilar target – despite the fact that search became inefficient in the similar-target condition. This indicates that priming effects can also be largely independent of search efficiency, or of the ability to select the target as the first item on a trial. These results render it doubtful that strong intertrial priming of target selection is the flip side of weak within-trial target saliency.

4. General discussion

The present study investigated whether pop-out depends on between-trial priming of features, as claimed by the priming of pop-out hypothesis, or whether pop-out depends on feature contrast within a trial and between target and nontargets, so that priming only modulates pop-out when the target does not have a high feature contrast (or saliency). The latter, saliency-based hypothesis was mainly supported by the past finding that RT-priming effects are reduced or eliminated when the set size is increased (e.g., Meeter & Olivers, 2005).

The present study replicated these results for colour search: In the similar condition of Experiment 1, priming effects in the mean manual RTs were reduced when the set size was increased. However, this finding does not clearly support the view that intertrial priming only modulates pop-out when the target is not salient: First, the results from a size-search task showed even stronger priming effects when the target was less similar to the nontargets than when it was more similar to the nontargets, and priming effects were also not reduced by increases of the set size. This indicates that priming can be largely independent of the feature contrast of the target. Secondly, in the colour-search task, priming effects occurred only in the higher set size condition of the dissimilar condition and did not occur in the lower set size condition. Moreover, in the similar condition, reduced priming effects in higher set size conditions were not due to improved target selection in the higher set size conditions. To the contrary, target selection was significantly impaired by increasing the set size, both on repetition trials and on switch trials. These results are inconsistent with the view that increasing the set size enhances the local feature contrast of the target and promotes pop-out. If the salience-based pop-out effect of the target had been stronger under these conditions, more certainty about the target location should have increased the likelihood of rapid target selection and should therefore have led to a higher proportion of first fixations on the pop-out target (e.g., Duncan, 1989; Koch & Ulman, 1985; Meeter & Olivers, 2005). Contrary to this prediction, we found that, at the earliest level of visual selection, increasing the set size harmed search performance. Taken together, the results do not support the view that increases in the set size enhance the pop-out effect of the target (due to an increased target saliency) and in turn reduce priming.

This is all the more so, since inverse set size effects in colour search were not due to early processes of visual selection but seemed to occur very late during visual search: In Experiment 1, inverse set size effects were found only in the dependent measure of target fixation durations, but not in the proportion of first target fixations or the initial target fixation latencies. Thus, the present results indicate that increasing the set size modulates late processes of visual selection concerned, for instance, with target identification or response selection (e.g., the choice of a response according to stimulus-to-response mappings). For example, after visually selecting the target for fixation, additional processes may be necessary to verify what kind of response is required and that the selected item is indeed the target. This verification process may be faster with a higher set size because a reduced distance to other stimuli might make it easier to compare the response-relevant features of the selected stimulus to those of other stimuli, thus shortening response selection or verification times (e.g., Becker, 2010a, 2010b, Huang, Holcombe, & Pashler, 2004; Huang & Pashler, 2005).

It should be noted, however, that McPeek, Maljkovic, and Nakayama (1999) did find facilitation of visual selection with increases of the set size: In their study, increasing the set size led to a higher proportion of first fixations on the target and to a shortening of the latencies of these fixations. There are a number of differences between the present study and McPeek et al.'s study that can potentially account for the differences in the results: First, the task in the study of McPeek, Maljkovic, and Nakayama (1999) was a saccade task, where the only required response was an eye movement itself. Since visual selection of a nontarget would have counted as an error in this task, it is possible that observers delayed execution of the first saccade until they were certain that the selected item was in fact the target (e.g., Findlay, 1997). In other words, target selection in McPeek, Maljkovic, and Nakayama (1999) may have reflected early as well as late selection processes. According to this explanation, inverse set size effects were due to decisional or target-verification processes also in McPeek et al.'s study; however, inverse set size effects were found in the saccade latencies instead of the target dwell times, because eye movements were delayed until after verification was completed (e.g., Becker, Ansorge, & Horstmann, 2009).

Another difference between the present study and the study of McPeek, Maljkovic, and Nakayama (1999) pertains to the stimuli: Different from the present study, not only the target feature changed on their switch trials, but the target and nontarget features directly swapped – that is, displays contained either a red target among green nontargets or vice versa, a green target among red nontargets. Several researchers have proposed that the direct swapping of target and nontarget features may be special in that it taps into processes different from changing only the target or nontargets feature across trials (e.g., Eimer, Kiss, & Cheung, 2010; Kristjansson & Driver, 2006; Kristjansson, Wang, & Nakayama, 2002; Wolfe et al., 2003). With respect to the present findings, it is possible that early processes of target–background discrimination can profit from direct swaps and facilitate selection of the target, for instance, because both the target and nontarget features were viewed on the previous trial and can be quickly retrieved to facilitate target–background discrimination. By contrast, when only the target feature changes as in the present experiments, a switch trial would contain one "new" feature that was not viewed on the previous trial. This may slow down figure–ground segmentation (e.g., Eimer, Kiss, & Cheung, 2010). According to this explanation, increasing the set size indeed affected early processes of visual selection in the study of McPeek, Maljkovic, and Nakayama

(1999), and these effects were not detected in the present study because target and nontarget features were not directly swapped on switch trials.

However, the explanation that increasing the set size aids early visual processes seems to be difficult to reconcile with the finding that inverse set size effects typically fail to occur in simple detection tasks, where the target is absent on half of all trials and observers respond to target presence (e.g., Bravo & Nakayama, 1992; Wolfe et al., 2003). If increasing the set size enhances the feature contrast of the target or facilitates grouping of nontargets or target–background segregation, then why is performance in a simple detection task typically unaffected by set size variations? Performance in a detection task is typically affected by differences in feature contrast, and/or the difficulty of target–background discrimination (e.g., Nothdurft, 2006). Hence, if increasing the set size indeed affects the saliency of a target, detection tasks should show similar inverse set size effects (and set size-on-priming effects) – contrary to the observed results (but see Bravo & Nakayama, 1992).

Viewed from this perspective, the interpretation that inverse set size effects are due to late post-selectional visual processing that is concerned with target identification seems more plausible. However, this hypothesis is at present speculative and certainly requires further research.

The above comments should not be taken to mean however that increasing the feature contrast cannot facilitate visual selection and thereby eliminate priming effects: In the colour-search task of Experiment 1, we found near-perfect visual selection for the dissimilar target. These results are certainly consistent with the view that increasing the feature contrast of the target can eliminate priming effects by increasing certainty about the target location (e.g., Meeter & Olivers, 2005; Olivers & Meeter, 2006). However, the results did not generalise to the size search task of Experiment 2. Priming effects were not reduced by enhancing the feature contrast in search for size. This indicates that increasing the feature contrast does not generally reduce priming effects. Second, in Experiment 1, set size-on-priming effects could not be attributed to facilitated target selection at higher set size conditions: In Experiment 1, inverse set size effects suggestive of saliency's influence on fixation latencies occurred too late to account for the set size-on-priming effect observed during initial visual selection. In addition, it should be noted that the dissimilar target condition failed to show priming effects even in the low, set size 6 condition. This result is at odds with previous studies showing significant priming effects for high-contrast targets in comparable, low set size conditions (e.g., Becker, 2008a, 2010a).

Again, studies reporting significant switch costs for high-contrast targets have mostly swapped the target and nontarget features on switch trials. Hence, the absence of priming effects in the present study could alternatively be due to the fact that only the target colour changed. The targets in the dissimilar condition were blue or green and were presented among consistently orange nontargets. It is possible that the blue and green target colours were sufficiently similar to one another to allow searching for both simultaneously, for instance, by grouping the colours together (e.g., Duncan & Humphreys, 1989). In this instance, switching between the targets would not have led to switch costs, because the attentional bias that allowed selecting one of the targets (e.g., green) also facilitated selection of the other target (e.g., blue), leading to constant repetition-facilitation effects even when the target colour changed (see also the relational priming hypothesis, Becker, 2008a, 2010a, 2010b; the feature-divider account, Huang, Holcombe, & Pashler, 2004; and the decision-boundary principle, Hodsoll, Humphreys, & Braithwaite, 2006).

Grouping was not possible in the similar target condition, because the red–orange and yellow–orange targets were more similar to the orange nontargets than to one other. Similarly, grouping was presumably not possible in the size-search task, because one target was always smaller and the other always larger than the nontargets, which rendered it impossible to form a coherent attentional set for both targets that linearly separated all conceivable targets from the nontargets. Further research is needed to distinguish between the saliency explanations and the grouping by similarity explanation.

What seems to be clear from the present study is that much more research is needed to answer the question whether and to what extent pop-out is mediated by between-trial feature priming versus within-trial feature contrast. The results from the present experiments so far contradict two standard explanations with respect to priming effects in visual search: First, the inverse set size effect in the present study was not due to processes that mediate initial visual-attentional selection, but to later, post-perceptual decisional processes. Second, set size-on-priming effects were not due to the fact that target selection was facilitated at a larger set size; rather, it seems that increasing the set size impaired target selection on repetition trials. Third, the results from the size-search task (Experiment 2) clearly showed that priming can be independent of the feature contrast of the target. Hence, the view that priming can only modulate pop-out when the target is non-salient needs to be rejected for size search, but can possibly account for reduced priming effects in search for high-contrast colour targets.

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