VISION
RESEARCH
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Computational Vision • Eye Movements & Visuomotor Control

ISSN 0042-6989 | Volume 49 | Number 14 | July 2009

Vision Research 49 (2009) 1738–1756

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Can intertrial priming account for the similarity effect in visual search?

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ARTICLE INFO

Article history:
Received 16 May 2008
Received in revised form 26 March 2009

Keywords:
Attention
Visual search
Distractor
Singleton
Similarity
Disengagement

ABSTRACT

In a visual search task, a salient distractor often elongates response times (RTs) even when it is task-irrelevant. These distraction costs are larger when the irrelevant distractor is similar than when dissimilar to the target. In the present study, we tested whether this similarity effect is mostly due to more frequent oculomotor capture by target-similar versus target-dissimilar distractors (*contingent capture hypothesis*), or to elongated dwell times on target-similar versus dissimilar distractors (*attentional disengagement hypothesis*), by measuring the eye movements of the observers during visual search. The results showed that similar distractors were both selected more frequently, and produced longer dwell times than dissimilar distractors. However, attentional capture contributed more to the similarity effect than disengagement. The results of a second experiment showed that stronger capture by similar than dissimilar distractors in part reflected intertrial priming effects: distractors which had the same colour as the target on the previous trial were selected more frequently than distractors with a different colour. These priming effects were however too small to account fully for the similarity effect. More importantly, the results indicated that allegedly stimulus-driven intertrial priming effects and allegedly top-down controlled similarity effects may be mediated by the same underlying mechanism.

1. Introduction

One fundamental and hotly debated issue in visual attention research concerns the extent to which attention is governed by top-down, goal-driven (endogenous) factors versus bottom-up, stimulus-driven (exogenous) factors. According to the *contingent capture hypothesis*, attention is ultimately guided by a top-down target template that specifies the properties of the relevant target (cf. Folk, Remington, & Johnston, 1992). Target feature(s) are represented in so-called attentional control settings. These guide attention in a goal-directed manner to regions matching the target template.

According to the *singleton capture hypothesis*, by contrast, attention is generally drawn to the most salient stimulus in the visual field, that is, to the stimulus that exhibits the largest feature contrast (e.g., Bergen & Julesz, 1983; Itti & Koch, 2001; Theeuwes, 1992). Moreover, initial stimulus-driven attentional capture is thought to be top-down impenetrable, that is, it cannot be modulated by the intentions or goals of the observer (e.g., Theeuwes, 1991, 1992).

The strongest evidence for the singleton capture hypothesis derives from the *distractor effect*: irrelevant salient distractors can produce interference in search, even when they are highly dissimilar from the target. Especially when observers search for a pop-out target which is itself salient, the presence of an irrelevant salient distractor in another dimension can interfere with search (e.g., Theeuwes, 1991, 1992). For instance, when observers search for a salient item in the shape dimension (e.g., a diamond presented amongst circles), search times are higher in the presence of a colour singleton distractor (e.g., a red circle amongst green circles) than when all distractors have the same colour (e.g., Theeuwes, 1991, 1992). The costs produced by such irrelevant salient distractors have been attributed to time-consuming attention shifts to the position of the irrelevant distractor (Theeuwes, 1991, 1992). Moreover, the finding that the distractor even captures attention when observers have instructions and good reasons to ignore it indicates that salient distractors capture attention even against the intentions of the observer, in a purely stimulus-driven manner (e.g., Theeuwes, 1992; Yantis, 1993; Yantis & Egeth, 1999; but see Bacon & Egeth, 1994; Leber & Egeth, 2006).

At a first glance, the finding that an irrelevant colour singleton interferes with search seems to be at odds with the contingent capture hypothesis: if the guidance of attention is generally under top-down control, attention should only be deployed to stimuli that match the attentional control settings, that is, that have the same or similar features as a target (e.g., Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk, Remington, & Johnston,

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doi:10.1016/j.visres.2009.04.001

1993; Folk et al., 1992). However, proponents of the contingent capture hypothesis have argued that the costs produced by an irrelevant distractor do not reflect attentional capture by the distractor, but instead spatially unspecific *filtering costs* (e.g., Folk & Remington, 1998; Folk et al., 1992, 1993). On this view, task-irrelevant features which are sufficiently dissimilar from the searched targets do not capture attention, but are filtered out (i.e., excluded from search) prior to the deployment of attention. Filtering of task-irrelevant features is however a time-consuming process, which accounts for the observation that mean RTs are elevated in the presence of a dissimilar distractor (Folk & Remington, 1998).

According to the contingent capture hypothesis, only distractors that are similar to the target-defining features can elicit involuntary attention shifts to their position. This view is supported by the observation that the distractor effect is much larger when the distractor is similar to the target than when it is dissimilar (e.g., Ansorge & Heumann, 2003; Ansorge & Horstmann, 2007; Ansorge, Horstmann, & Carbone, 2005; Folk & Remington, 1998, 2006; Folk et al., 1992, 1993; Lamy, Leber, & Egeth, 2004; Ludwig & Gilchrist, 2002, 2003a): for instance, when observers have to search for a red target amongst green non-targets, then a red distractor presented at an irrelevant position will produce larger RT costs than a green distractor (Ludwig & Gilchrist, 2002, 2003a). This *similarity effect* has usually been interpreted to show that similar distractors capture attention to a larger extent than dissimilar distractors, in line with the contingent capture hypothesis (e.g., Ansorge & Heumann, 2003; Folk et al., 1992, 1993, Folk & Remington, 1998; Ludwig & Gilchrist, 2002, 2003a).

1.1. The similarity effect: contingent capture or disengagement?

The contingent capture explanation of the distractor effect received its major support from *cuing experiments*, in which target and distractors are presented in distinct displays: in a typical experiment, half of the observers had to search for a green target embedded amongst red non-target stimuli, whilst the other half of the observers had to search for an onset target. In both conditions, the search display was always preceded by a cuing display, which contained either an irrelevant colour singleton or an irrelevant onset singleton. The results showed that irrelevant colour singletons in the pre-cueing display only captured attention when observers searched for the colour singleton target, but not when they searched for the onset singleton target. Similarly, irrelevant onset singletons in the pre-cueing display only captured attention when observers actively searched for an onset singleton, whereas onsets failed to capture attention when observers searched for the colour singleton target (Folk et al., 1992; see also Folk & Remington, 1998; Folk et al., 1993). These results were taken to indicate that the capture of spatial attention critically depends on the top-down controlled attentional control settings: obviously, irrelevant singletons only capture attention to their location when they are sufficiently similar to the pre-defined target template.

Subsequent studies additionally showed that dissimilar singletons can elongate mean RTs compared to a distractor-absent control condition, without capturing attention (Folk & Remington, 1998). For instance, when observers searched for a red target amongst green non-targets, then onset singletons in the pre-cueing display elongated RTs compared with a condition without any singletons in the pre-cueing display. However, in contrast to the distractor effect of similar distractors, the costs incurred by onset singletons were *spatially unspecific*: the distractor effect of the dissimilar distractor was generally not modulated by location congruence, that is, it did not make a difference whether the irrelevant singleton in the pre-cueing display was presented at the same position as the target or at a different position than the target (Ansorge & Heumann, 2003; Folk & Remington, 1998; Folk et al., 1992, 1993; but see Lamy et al., 2004). This result pattern is incompatible with the hypothesis that the dissimilar singleton captured spatial attention to its location (Folk & Remington, 1998). In contrast, location-specific capture effects were restricted to pre-cueing displays containing target-similar distractors. These results provide strong support for the hypothesis that only similar distractors capture attention (due to their matching the pre-defined attentional control settings), whereas dissimilar distractors are filtered out (Folk & Remington, 1998).

Theeuwes, Atchley, and Kramer (2000) however argued that these results were also compatible with a *disengagement view*: because previous studies used a cuing procedure in which the distractor display was shown 150 ms before the onset of the search display, it is possible that similar and dissimilar distractors initially captured attention to the same extent, but that quickly thereafter (i.e., within 150 ms), attention was disengaged from the dissimilar distractor and redirected to a neutral position. De-allocating attention from similar distractors in turn might be more difficult, because these distractors match the top-down attentional control settings (Theeuwes et al., 2000). On the disengagement view, the similarity effect is thus not due to more frequent attentional capture of similar distractors, but instead to elongated disengagement of attention, so that attention is still focused on the similar cue when the target has its onset. This disengagement explanation is consistent with the view that attention is first captured by stimulus saliency alone, whereas top-down control over the direction of attention can only be exerted after attention has been deployed to a stimulus.

To summarise, there are two different explanations both for the distractor effect and the similarity effect: first, according to the contingent capture hypothesis, the distractor effect (i.e., RT cost produced by dissimilar distractors) is due to spatially unspecific filtering costs, whereas the similarity effect (i.e., additional RT cost produced by similar distractors) is due to attention shifts to the similar distractor. According to saliency-based explanations, similar and dissimilar distractors initially capture attention to the same extent, and thus, the distractor effect is due to attentional capture by salient distractors. The similarity effect, on the other hand, is due to the fact that similar distractors produce a delay in disengaging attention from a once attended stimulus.

1.2. Evidence for capture versus disengagement of attention

When first proposing the disengagement hypothesis, Theeuwes et al. (2000) devised an experiment to test their hypothesis that attention can be disengaged quickly from distractors that are dissimilar to the target-defining feature. In their study, observers searched for a shape singleton target whilst on half of all trials, one of the non-target circles was coloured red and presented amongst homogeneously coloured grey items. To assess the time-course of attentional capture, the colour singleton distractor was presented at varying stimulus onset asynchronies (SOAs; 50, 100, 150, 200, 250, 300 ms) before the target. The results showed that the dissimilar colour singleton distractor interfered with search at short SOAs, but not when more than 150 ms had elapsed between the onset of the distractor and the target. These results indicated that after a time-span of 150–200 ms, attention can indeed be disengaged from the location of an irrelevant distractor.

Although Theeuwes et al.'s (2000) experiment demonstrates that disengagement of attention from dissimilar irrelevant distractors might be completed after 150 ms, it may be doubted whether it can be interpreted in support of the disengagement hypothesis. Critically, the study of Theeuwes et al. (2000) did not include comparisons between similar and dissimilar-distractor conditions and, thus, cannot shed any light on the origin of the similarity effect.

A much more direct test of the disengagement hypothesis was provided by Ansorge and Heumann (2003). In one of their experiments, they varied the SOA between a display containing an irrelevant singleton distractor and the target between 0, 17, and 34 ms. The irrelevant singleton distractor had either a similar or a dissimilar colour as the pre-defined target, and disengagement was encouraged by never presenting the target at the position of the distractor. On the disengagement view, we would expect target-dissimilar and target-similar distractors to capture attention to the same extent at the shortest SOA, and a fast decreasing interference from target-dissimilar distractors with increasing SOA. The results were clearly at odds with this prediction: only similar distractors significantly elongated mean RTs, whereas dissimilar distractors did not produce any significant costs. (Ansorge & Heumann, 2003; see also Folk & Remington, 2006). The same results were obtained in a study by Chen and Mordkoff (2007), who tested attentional capture of similar versus dissimilar colour and onset cues in a cueing experiment with irrelevant pre-cues at a short SOA: in their experiment, the cue display was shown for 35 ms, followed by the cue and target display which were simultaneously present for 15 ms, and the target display which was then presented alone for another 35 ms. The results showed that onset cues only captured attention when observers searched for an onset target, whereas colour cues only captured attention when observers had to search for the target of the same colour, despite the short SOA between cue and target displays. Taken together, the available evidence on the similarity effect is not in line with the disengagement hypothesis, but instead supports the contingent capture view, which proposes that similar distractors capture attention in virtue of matching the top-down settings for the target, whereas dissimilar distractors can be successfully filtered out (Ansorge & Heumann, 2003, 2004; Folk & Remington, 1998, 2006; Folk et al., 1992, 1993).

1.3. Oculomotor capture and dwell times

However, considerably less research has been devoted to the question whether similar distractors might cause elongated dwell times in overt eye movement behaviour. Previous eye movement studies primarily investigated whether similar distractors are visually selected more frequently than dissimilar distractors, and showed more frequent oculomotor capture by similar than dissimilar distractors (Ludwig & Gilchrist, 2002; Ludwig & Gilchrist, 2003a; Wu & Remington, 2003 but see Theeuwes, de Vries, & Godijn, 2004). However, so far, it has not been examined whether possible differences in dwell times between similar versus dissimilar distractors additionally contribute to the similarity effect. Therefore, it is still an open question whether disengagement of the eyes from the similar distractors additionally contributes to the similarity effect. In the present study, we attempted to close this empirical gap, by examining both the proportions of irrelevant fixations on each similar versus dissimilar distractors, and the mean dwell times, or fixation durations, on each distractor type.

Moreover, previous studies have examined the effect of irrelevant distractors on eye movement behaviour in a *saccade-task*, in which observers were instructed to respond by making a fast and precise eye movement to the target. In some studies, the results from this saccade-task were then compared to a covert attention task, in which observers had to maintain fixation on the centre and to respond to an additional feature of the target (e.g., Ludwig & Gilchrist, 2003a; Wu & Remington, 2003). Observing similar results in the covert attention task and saccade task, it was then concluded that similar versus dissimilar distractors exerted similar effects on covert shifts of attention and eye movements. However, the requirement to use eye movements as a response, to indicate the target position, is rather unusual and might itself change the eye movement pattern. It is, for instance, conceivable that observers exert more top-down control over their instructed saccades to avoid making mistakes, either by making their eye movements more strongly contingent on their top-down attentional control settings, or by delaying their saccades to ensure greater precision (e.g., Findlay, 1997). Thus, it is possible that capture by dissimilar distractors has been underestimated in previous studies using only a saccade-task, because top-down control over eye movements may be unusually strong when saccades are used as a response. (This is at least plausible when we assume that processes subserving actions (or responses) are generally more strongly top-down controlled than processes subserving perception.)

To assess whether previous failures to find oculomotor capture by dissimilar distractors might have been due to using a saccade-task, we examined the effects of similar versus dissimilar distractors in a saccade-task and in a *manual response-task*, in which observers did not receive any instructions about their eye movements, but eye movements were encouraged by presenting a small response-relevant item. We hypothesised that eye movements in this manual task might be used more naturally for the purpose of allowing fine-grained perception and identification, so that they were less shielded from stimulus-driven effects than eye movements in the saccade-task.

1.4. Problems of interpretation

Previous studies have commonly attributed more frequent attentional or oculomotor capture by similar than dissimilar distractors to top-down controlled processes of attention (e.g., Ansorge & Heumann, 2003; Ansorge & Horstmann, 2007; Folk & Remington, 1998; Folk et al., 1992, 1993; Ludwig & Gilchrist, 2002, 2003a). However, it is important to note that the similarity effect may also be due to stimulus-driven *intertrial priming effects*: feature priming effects were first discovered in a study of Maljkovic and Nakayama (1994), in which observers had to search for an oddly coloured target that could be red or green and was presented amongst a group of non-targets of the opposite colour. The results showed that RTs on trial *n* were shorter when the target and non-target colours from the previous, $n - 1$ trial were repeated than when they changed. Moreover, when the target colour was repeated over a sequence of trials, RTs successively decreased, indicating that priming is cumulative (Hillstrom, 2000; Kristjansson, Wang, & Nakayama, 2002; Maljkovic & Nakayama, 1994). Several subsequent studies demonstrated that this repetition facilitation effect reflects faster allocation of attention to the target on repetition trials (Becker, 2008a; Goolsby & Suzuki, 2001; McPeek, Maljkovic, & Nakayama, 1999), and that on switch trials, the first eye movement is more frequently made towards the non-targets (Becker, 2008a, 2008b, 2008c). Moreover, it has been argued that intertrial priming effects are based on stimulus-driven processes which cannot be modulated by top-down controlled processes: pre-knowledge of the upcoming target colour did neither eliminate nor even reduce the priming effect, which was generally taken to show that priming occurs automatically and is top-down impenetrable (Becker, 2008a; Maljkovic & Nakayama, 1994, 2000; but see also Becker, 2007; Folk & Remington, 2008; Leonard & Egeth, 2008).

In previous studies which investigated the effects of similar versus dissimilar distractors on search performance, the target-defining feature was generally held constant across a block of trials and thus, was always repeated across trials (Folk & Remington, 1998; Folk et al., 1992, 1993; but see Ansorge et al., 2005; Folk, Remington, & Wright, 1994; Leonard & Egeth, 2008). However, under these conditions, it is impossible to say whether the similar distractor is selected more frequently in virtue of matching a top-down defined target template, or because the features of the similar distractor correspond to the target feature on the previous trial, which have been primed for attentional selection in a stimulus-driven way. As a consequence, it is possible that effects that have previously been attributed to a capacity to filter out irrelevant dissimilar distractors are in fact due to stimulus-driven intertrial carry-over effects that bias attention shifts to the similar distractor.

1.5. The present study

The aim of the first experiment was two-fold. First, we investigated whether and to what extent the similarity effect is due to more frequent visual selection of the similar distractor (contingent capture) and elongated dwell times on the similar distractor (disengagement). To that aim, the eye movements of the observers were measured in three different conditions of a visual search task, (1) without any distractors, (2) in the presence of a similar distractor and (3) in the presence of a dissimilar distractor. In Experiment 1, observers were instructed to search for a diamond target, which was always red and presented amongst grey non-target circles. In the distractor-present condition, one of the circles could be either coloured green, constituting a dissimilar distractor, or it was red, constituting the similar distractor. Observers were instructed to ignore all colour differences, which rendered the distractors similar or dissimilar in an irrelevant but highly salient dimension.

Deviating from Ludwig and Gilchrist (2003a), the distractors were not presented at an irrelevant position, because this might have rendered the task more similar to a flanker task, which differs conceivably from the visual search tasks where irrelevant salient items were first discovered to capture attention (e.g., Theeuwes, 1992; see also Belopolsky, Zwaan, Theeuwes, & Kramer, 2007). Moreover, in such a flanker task, observers may attempt to exclude irrelevant distractors by changing the spatial distribution of attentional resources (e.g., “narrowing” of the attentional spotlight; Eriksen & St. James, 1986). However, since it is unclear how changes of the spatial distribution of attention relate to the feature-specific filtering mechanism described by Folk and Remington (1998), we chose the present method to investigate the effects of similar versus dissimilar distractors.

In Experiment 1, performance was moreover assessed in two different tasks; a saccade-task, in which observers had to make an eye movement to the target, and in a standard manual response-task, in which observers pressed a button to discriminate between small figures located inside the target. These different tasks were included to assess whether the saccade task, which artificially restricted the eye movements of the observers, would lead to higher levels of top-down control over eye movements than the manual task.

The main aim of Experiment 2 was to critically test whether the similarity effect is indeed due to top-down controlled factors, as proposed by the contingent capture hypothesis, or whether it is due to stimulus-driven processes. In particular, we investigated whether and to what extent oculomotor capture by similar distractors is mediated by automatic intertrial priming effects. To that aim, distractor effects in Experiment 2 were assessed under conditions where the target feature was either held constant or varied randomly across trials. Oculomotor capture which is mediated by priming can be inferred when distractors that are similar to the target feature on the previous trial are more frequently selected than distractors that are dissimilar to the target feature on the previous trial. By comparing the capture effects of target-similar distractors with priming-induced capture effects, we can then estimate the relative contributions of stimulus-driven and top-down controlled factors to the similarity effect.

2. Experiment 1

The primary aim of the present experiment was to explore whether and to what extent the similarity effect is due to more frequent oculomotor capture by the similar distractor or elongated dwell times on the similar distractor, compared with the dissimilar distractor (e.g., Theeuwes et al., 2000). To that aim, eye movements were assessed in a distractor-present condition and a distractor-absent control condition. In the distractor-absent condition, observers had to search for a diamond target which was consistently presented in red colour and surrounded by grey non-target circles. In the distractor-present condition, one of the non-target discs was presented either in the same colour (red) as the target, constituting the *similar-distractor condition*; or it was presented in green colour, constituting the *dissimilar-distractor condition*.

Eye movements were measured in two different visual search tasks, first, in a saccade-task, in which observers were instructed to respond by making a saccade toward a target, and secondly, in a conventional manual response-task, in which observers had to discriminate between two different response-indicative features located inside the target, by pressing a button. In the latter task, no instructions regarding eye movements were given, but these were encouraged by presenting small response-indicative features in the periphery. The response-indicative features were so small as to require foveation for discrimination and the eye movements were tracked in both the saccade-task and manual response-task.

Previous studies investigating the effect of similar versus dissimilar distractors in a saccade-task found that similar distractors (a) significantly elongated the mean target fixation latencies (i.e., the time from the onset of the search display until the eyes were first fixated on the target), (b) were more frequently selected, (c) elicited more initial saccades in their direction and (d) produced longer saccade latencies, compared to dissimilar distractors (Ludwig & Gilchrist, 2002, 2003a; Wu & Remington, 2003). Moreover, (e) the first saccades leaving the fixation area were more frequently directed to the similar than the dissimilar distractor, and (f) saccades that directly went to the target were more strongly curved away from the similar distractor than from the dissimilar distractor (Ludwig & Gilchrist, 2003b; Van der Stigchel, Meeter, & Theeuwes, 2006; Wu & Remington, 2003). Studies that investigated only the effects of dissimilar distractors moreover found that in some instances, the eyes start in the direction of the dissimilar distractor, but then change direction to the target in mid-flight (Godijn & Theeuwes, 2002, 2003; McPeek & Keller, 2001).

To assess possible differences in eye movement patterns between the saccade-task and the manual response-task, all of these variables were included in the present study. In addition, we also compared the distractor fixation durations separately for the similar and dissimilar distractor, to examine whether and to what extent elongated dwell times on the similar distractor can contribute to the similarity effect.

2.1. Method

2.1.1. Observers

Eight students at University of Bielefeld, Germany, took part in the experiment for small monetary exchange (4 €). All subjects had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

2.1.2. Materials

An Intel Pentium® four central processing unit 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. Observers were seated in a dimly lit room, with their head fixed by the eye tracker'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 RT measurement were controlled by the Presentation software (*Neurobehavioral Systems*).

2.1.3. Stimuli

The response-indicative stimuli consisted of seven black "x" or "+" stimuli of equal sizes ($0.2° \times 0.2°$; Arial, 10 pt). These were presented in the centre of the seven coloured diamond ($1.5° \times 1.5°$) or disc shapes (1.7° diameter). Red, green, and grey colours were matched for luminance (4.1 cd/m^2) with a Mavolux digital photometer, and the coloured diamond and discs were presented on a constantly white background (7.5 cd/m^2) together with a small black fixation cross. Beginning at the 12 o'clock position, all stimuli were placed equidistantly on the outline of an imaginary circle with a diameter of 7.1°. The distance between two adjacent stimuli measured 3.1° from centre to centre. Fig. 1A depicts an example of the display.

2.1.4. Design

The experiment had a $2 \times 2 \times 2$ within-subjects design, with "response type" (saccade-task versus manual response-task), "distractor presence" (present versus absent) and "distractor similarity" (similar versus dissimilar) as variables. Manual response-task and saccade-tasks were presented in separate blocks, and the order of blocks balanced across observers. Distractor-present and distractor-absent conditions were also blocked: in the distractor-absent condition, observers searched for a diamond target that was consistently coloured red, whilst the non-target discs were always presented in grey. In the distractor-present trials, one of the non-target discs was additionally coloured, constituting an irrelevant distractor. In the similar-distractor condition, the distractor was presented in the same colour as the target (red). In the dissimilar-distractor condition, the distractor was coloured green.

The positions of target and distractor were chosen randomly from trial to trial. In the distractor-present trials, the distractor was randomly presented either in the same colour as the search target, constituting a similar distractor, or in a different colour than the target, constituting a dissimilar distractor. The response-indicative stimulus of the manual response-task, which was task-irrelevant in the saccade task, was also chosen randomly on each trial, with the restriction that the non-targets contained an equal number of "+" and "x" stimuli.

The distractor-absent control condition comprised 120 trials in each manual response-task and saccade-task. In the distractor-present condition of both tasks, observers completed 240 trials. Observers were allowed a short rest after each experimental block.

2.1.5. Procedure

Each trial started with the presentation of a small black fixation cross and a fixation control: the stimulus display was only presented if the eye tracking was stable (no blinks) and the gaze was within 50 pixels of the centre of the fixation cross (i.e., deviation was <1°), for at least 350 ms (within a time-window of 3000 ms). Otherwise, observers were calibrated anew (5-point calibration) and the next trial started again with the fixation control.

Upon presentation of the stimulus display, observers were required to search the display for the diamond target. In the manual response-task, observers should then press the right mouse button if there was a "+" inside the target diamond, and the left button if it was an "x". In the saccade-task, observers made a saccade to the target and pressed the space bar of a keyboard when they fixated on the target.

The stimulus display remained on screen until response, and was immediately succeeded by a feedback display. The feedback were the black printed words "right" or "wrong" (in German, Arial 14 pt) which were presented centrally for 500 ms. After an inter-trial interval of 500 ms, in which a blank white screen was presented, the next trial started with the presentation of a fixation cross.

Before each block, observers were calibrated with a 5-point calibration and given written instruction about their task in the next block. With regard to the distractor-present block, observers were informed that one of the non-target discs would be coloured either red or green and they were instructed to ignore the odd-coloured distractor. Moreover, observers were instructed to respond to the target as fast as possible without making mistakes. On average, it took 40 min. to complete the experiment.

2.2. Results

2.2.1. Data

Data were excluded from all analyses when manual RTs in the manual response-task exceeded 1500 ms, or when the eyes did not fixate on the target within 1500 ms from the beginning of a trial. The eyes were counted as fixating on the target or on the distractor if the gaze was within a distance of 1° from the centre of the diamond or disc, and no saccade occurred (velocity smaller than 30°/sec). By this criterion 10.6% of all data were excluded. In the statistical analyses, we report the Greenhouse–Geisser-corrected *p* values were appropriate, together with the uncorrected degrees of freedom.

2.2.2. Manual response

2.2.2.1. RTs. In the manual response-task, there was a significant distractor effect: mean RTs were significantly faster in the distractor-absent control condition ($M = 801$ ms) than in both similar-distractor condition ($M = 961$ ms; $F[1,7] = 79.01$; $MS_e = 1133.36$; $p < .001$) and dissimilar-distractor condition ($M = 833$ ms; $F[1,7] = 70.06$; $MS_e = 57.74$; $p < .001$). More importantly, there was also a significant similarity effect, as mean RTs were elevated by 128 ms in the similar-distractor condition relative to the dissimilar-distractor condition ($F[1,7] = 73.27$; $MS_e = 757.79$; $p < .001$).

2.2.2.2. Errors. In the manual response-task, observers committed slightly fewer errors in the dissimilar-distractor condition ($M = 2.6\%$) than in the distractor-absent condition ($M = 3.4\%$) and in the similar-distractor conditions ($M = 3.9\%$), but these differences did not reach significance (all ps > 0.23, see Table 1). The RT effects are thus not due to a speed–accuracy trade-off.

2.2.3. Eye movement data

2.2.3.1. Target fixation latencies. The mean target fixation latencies (i.e., the time from the onset of the search display until the eyes were first fixated on the target) were also analysed by a 2×3 analysis of variance comprising the variables "task" (manual response-task versus saccade-task) and "distractor conditions" (distractor absent versus similar distractor versus dissimilar distractor). The results showed only a significant main effect of the distractor condition ($F[2,14] = 93.71$; $MS_e = 377.20$; $p < .001$). Separate ANOVAs revealed that mean latencies were longest in the similar-distractor condition ($M = 340$ ms), and differed significantly both from the dissimilar-distractor condition ($M = 271$ ms; $F[1,7] = 149.84$; $MS_e = 258.57$; $p < .001$) and the distractor-absent control condition ($M = 251$ ms; $F[1,7] = 140.49$; $MS_e = 456.37$; $p < .001$). Additionally,

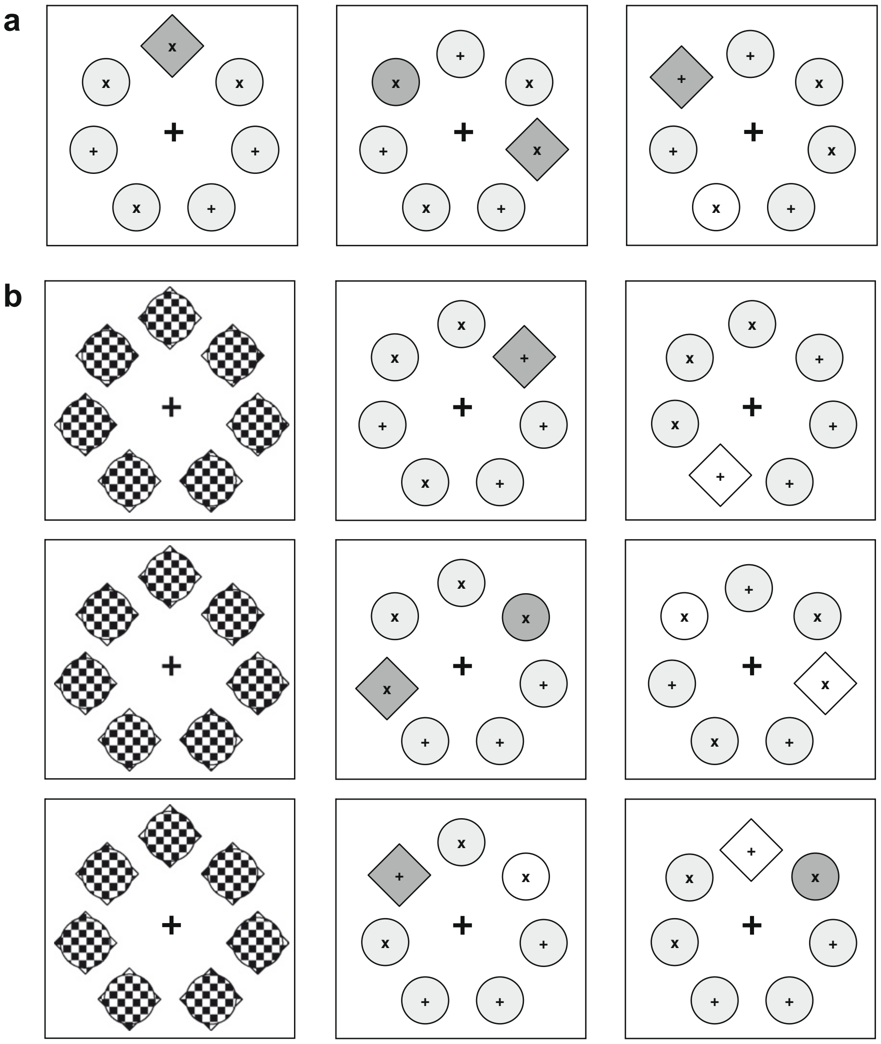

Fig. 1. (a) Example displays of Experiment 1, in which search performance was tested in a saccade-task and in a standard manual response-task. The target was a red diamond presented among grey nontarget circles. In the distractor-present trials, one of the nontarget circles was coloured red (similar distractor; depicted in dark grey) or green (dissimilar distractor; depicted in white. (b) Example displays of the single-target and two-targets condition of Experiment 2. In the single-target condition of Experiment 2, the target was either red or green across the whole block, whereas in the two-targets condition, the target colour varied randomly between red and green within blocks (red = dark grey; green = white). The left row illustrates the checkerboard pre-masks. In the examples, the target is displayed at the top position, whereas in the experiment, the target position varied. (Stimuli not drawn to scale.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

target fixation latencies were also significantly longer in the dissimilar-distractor condition than in the distractor-absent control condition ($F[1,7] = 7.63$; $MS_e = 416.65$; $p = .028$).

The target fixation latencies did not differ between the saccade-task and the manual response-task across the different distractor conditions, indicating that in terms of the target fixation latencies, the two tasks yield comparable performance. It is also noteworthy that the results from the mean target fixation latencies exactly mimicked the results found in the mean RTs. This indicates that the requirement to respond to the item located inside the target does not alter the time-course of visually selecting the target.

2.2.3.2. Proportion of first fixations on the target. To test whether distractor similarity affects early processes concerned with guiding attention to the target, the proportion of first fixations on the target was analysed. The 2 × 3 ANOVA yielded only a significant main effect of distractor condition ($F[1,7] = 33.13$; $MS_e = 84.37$; $p < .001$): the mean proportion of first fixations on the target was lowest in the similar-distractor condition ($M = 62.2\%$), which was significantly different both from the distractor-absent control condition ($M = 86.5\%$; $F[1,7] = 76.23$; $MS_e = 61.78$; $p < .001$) and the dissimilar-distractor condition ($M = 81.4\%$; $F[1,7] = 37.67$; $MS_e = 77.95$; $p < .001$). However, the mean proportion of first fixa-

Table 1
Mean proportion of error in Experiments 1 and 2, presented separately for the distinct conditions. SME, standard error of the mean.

		Mean error (%)	SME
Exp. 1			
Distractor absent		3.37	0.71
Distractor present	Similar	3.93	1.11
	Dissimilar	2.59	0.74
Exp. 2			
Single target			
Distractor absent		3.25	1.31
Distractor present	Similar	2.56	0.58
	Dissimilar	3.10	0.82
Two targets			
Distractor absent		2.65	1.10
(A) Distractor present	Homogeneous	2.49	0.81
	Heterogeneous	3.64	1.21
(B) Distractor present	$n - 1$ similar	4.28	1.21
	$n - 1$ dissimilar	2.86	0.88

tions on the target was not lower in the dissimilar-distractor condition than in the distractor-absent control condition ($F[1, 7] = 2.14$; $MS_e = 97.33$; $p = .19$).

2.2.3.3. Proportion of fixations on the distractor. A 2 × 2 ANOVA calculated over the mean proportion of fixations on the similar versus dissimilar distractor revealed a significant main effect of task ($F[1, 7] = 7.43$; $MS_e = 39.12$; $p = .003$), reflecting a higher proportion of distractor fixations in the manual response-task ($M = 20.8\%$) than in the saccade-task ($M = 15\%$). Moreover, the main effect of distractor similarity was significant ($F[1, 7] = 45.65$; $MS_e = 113.79$; $p < .001$). In both the manual response and the saccade-task, the similar distractor was fixated significantly more frequently than the dissimilar distractor ($F[1, 7] = 39.70$; $MS_e = 88.50$; $p < .001$ and $F[1, 7] = 31.81$; $MS_e = 57.21$; $p = .001$, respectively). The interaction between task and distractor similarity just failed to reach significance ($F[1, 7] = 4.33$; $MS_e = 31.91$; $p = .076$). The trend for this interaction reflected that the proportion of fixations on the similar distractor was significantly higher in the manual response-task ($M = 35.7\%$) than in the saccade-task ($M = 25.5\%$; $F[1, 7] = 10.06$; $MS_e = 41.19$; $p = .016$), whereas the dissimilar distractor was selected equally infrequently in the manual response-task ($M = 6.0\%$) and saccade-task ($M = 4.1\%$; $F < 1$).

The inconspicuous grey non-targets were selected very infrequently across all conditions. A 2 × 3 ANOVA on the proportion of non-target fixations yielded only a marginally significant main effect of task, reflecting that in the manual response task, non-targets were fixated on a higher proportion of trials ($M = 1.12\%$) than in the saccade-task ($M = 0.62\%$; $F[1, 7] = 5.54$; $MS_e = 0.45$; $p = .051$). Moreover, there was a trend for more frequent non-target fixations in the similar-distractor condition ($M = 1.28\%$) than in the dissimilar-distractor condition ($M = 0.78\%$) and the distractor-absent condition ($M = 0.54\%$; $F[1, 7] = 3.01$; $MS_e = 24.79$; $MS_e = 0.74$; $p = .081$), but no interaction with task ($F < 1$).

To determine whether the salient distractors had been fixated more frequently than one of the inconspicuous grey non-targets, the proportion of fixations on each salient distractor was also compared to the mean proportion of fixations on the non-targets. The results showed that the salient distractor was selected more often than the inconspicuous grey non-targets, both when the distractor was dissimilar to the target (*mean difference* = 4.5%; $F[1, 7] = 6.65$, $MS_e = 24.79$; $p = .037$) and when it was similar to the target (*mean difference* = 30.0%; $F[1, 7] = 57.51$, $MS_e = 125.38$; $p < .001$).

2.2.3.4. Latencies of first saccades to the target and the distractor. To control for possible speed–accuracy trade-offs in the first saccades that directly went to the target, we also assessed the mean latencies of saccades that first went to the target and the distractors. Concerning, first, the latencies of saccades directed to the target, the results of a 2 × 3 ANOVA showed a significant main effect of task, reflecting that saccade latencies were shorter in the manual response-task ($M = 203$ ms) than in the saccade-task ($M = 225$ ms; $F[1, 7] = 17.51$; $MS_e = 337.52$; $p = .004$). Moreover, the main effect of distractor condition reached significance ($F[2, 14] = 24.97$; $MS_e = 71.65$; $p = .001$), reflecting that saccade latencies were significantly higher in the similar-distractor condition ($M = 223$ ms) than in the distractor-absent control condition ($M = 208$ ms; $F[1, 7] = 23.48$; $MS_e = 76.48$; $p = .002$) and in the dissimilar-distractor condition ($M = 211$ ms; $F[1, 7] = 73.90$; $MS_e = 17.98$; $p < .001$). By contrast, mean saccade latencies did not differ significantly between the dissimilar-distractor condition and the distractor-absent control condition ($F[1, 7] = 1.10$; $MS_e = 32.06$; $p = .33$).

Saccades that went to a distractor had shorter latencies than saccades directed to the target ($M = 214$ ms; $F[1, 7] = 10.65$; $MS_e = 230.78$; $p = .003$). However, saccade latencies of saccades directed towards the dissimilar distractor ($M = 218$ ms) did not differ significantly from latencies of saccades directed towards the similar distractor ($M = 212$ ms; $F < 1$).

2.2.3.5. Proportion of first fixations on target as a function of saccade latency. To determine whether the time-course of capture by similar versus dissimilar distractors differ, we computed quartiles for the proportion of first fixations on the target depending on the latencies of the saccade.[1] Thus, the first quartile comprised the proportion of first fixations on the target when the saccade latencies were very short, whereas the last, fourth quartile included the proportion of first fixations on the target when the saccade latencies were very long. The results of a 2 × 2 × 4 ANOVA comprising the variables "task", "similarity" and "quartile" showed a significant main effect of similarity ($F[1, 7] = 29.21$; $MS_e = 249.56$; $p = .001$) and of quartile ($F[1, 7] = 4.43$; $MS_e = 116.12$; $p = .29$), but no significant interaction between the two variables (all other $Fs < 1.5$; $ps > .33$). Separate ANOVAs showed that in the dissimilar-distractor condition, quartile had a marginally significant main effect ($F[3, 21] = 3.01$; $MS_e = 78.77$; $p = .053$), reflecting that the proportion of first fixations on the target was most greatly reduced in the first quartil ($M = 80.2\%$), and less reduced in the second to fourth quartil ($M = 86.7\%$, 88.7% and 87.7%, respectively). Although the similar-distractor condition showed similar numerical trends, with less first fixations on the target in the first quartile ($M = 66.3\%$) than in the following quartiles ($M = 73.8\%$, 70.8%, and 71.9%, respectively), there was no main effect of quartile ($F = 1.76$; $p = .18$). These results indicate that saccade errors are more likely to occur when the saccade latency is short, specifically with large saccadic errors such as selecting a dissimilar distractor, and thus, reflect the well-known speed–accuracy trade-off in saccade programming (Findlay, 1997; Theeuwes et al., 2000; Van Zoest, Donk, & Theeuwes, 2004).

2.2.3.6. Distractor fixation durations. To determine whether and to what extent disengagement processes contribute to the similarity effect, the same analysis was also conducted over the mean durations of fixations on each irrelevant distractor type. The analysis showed only a significant main effect of similarity: on average, the fixations were longer on the similar distractor ($M = 171$ ms) than on the dissimilar distractor ($M = 97$ ms; $F[1, 7] = 13.94$; $MS_e = 3176.88$; $p = .007$).[2]

2.2.3.7. Proportion of first saccades to similar and dissimilar distractors. For an analysis of the proportion of saccades which were directed towards the distractor and the target, we first identified the first saccade leaving the fixation area by its velocity (velocity > 30°/s) and the fact that its endpoint deviated more than 1° from the centre of the display. The saccade was then assigned to the target or distractor when it was directed plus or minus 25 degrees of angle towards the position of the target or the distractor. The *initial direction* of the saccade was computed by calculating the angle based on the starting position and the position of the eyes after three time points of the saccade (approximately 15 ms after the start of a saccade; see Ludwig & Gilchrist, 2002). Saccades were then included in the analyses if they belonged to one of four categories: they were clearly directed (a) to the target during the initial phase and on the whole (TT), (b) to the target initially but

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[1] A more straightforward way to analyse the data would be to compute the number of fixations of the similar vs. dissimilar distractor for each quartile, instead of the proportion of first fixations on the target. However, this was not possible with the data of the present study because fixations on the dissimilar distractor were too rare.

[2] Fixations on the inconspicuous grey nontargets were too infrequent to analyse their mean fixation durations or latencies.

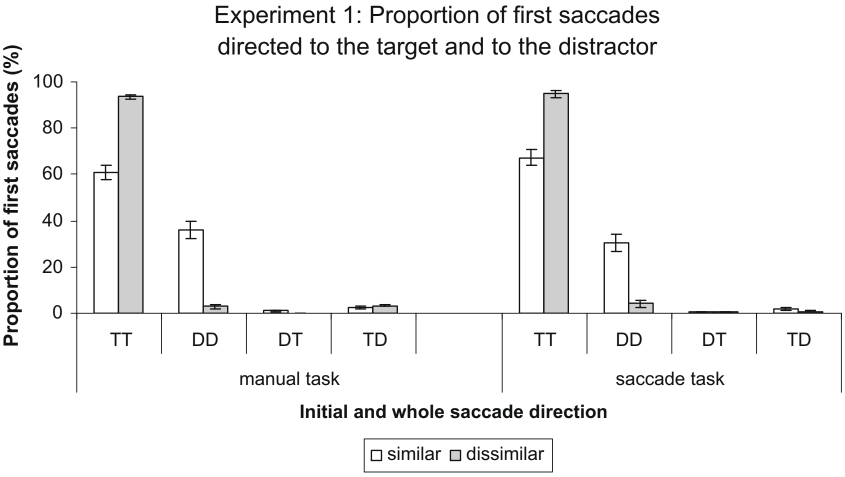

Fig. 2. Mean proportion of first saccades that were both initially and on the whole directed towards the target (TT) or towards the distractor (DD), and saccades that were initially directed towards the distractor, but then went to the target (DT) and saccades that were initially directed towards the target and then went to the distractor (TD), depicted separately for the manual response-task and for the saccade-task of Experiment 1.

to a distractor on the whole (TD), to a distractor initially and on the whole (DD), and to a distractor initially and to the target on the whole (DT). Fig. 2 depicts the mean proportion of these saccades. Initial analyses showed only a significant interaction between the direction of the saccades and similarity, reflecting that a significantly higher proportion of saccades was directed to the distractor when it was similar than when it was dissimilar, both in the saccade-task ($t[7] = 8.22$; $p < .001$) and in the manual response-task ($t[7] = 10.35$; $p < .001$). In the saccade-task, instances where the eyes were initially directed to the distractor but then landed on the target or vice versa were rare and did not differ between similar and dissimilar distractors. However, in the manual response-task, the proportion of saccades that were initially directed to the distractor but finally ended at the target location was significantly higher in the similar-distractor condition than in the dissimilar-distractor condition ($t[7] = 3.00$; $p = .020$).

2.2.3.8. Saccade curvature. To assess whether similar versus dissimilar distractors affected the curvature of saccades, we computed the angular deviation of saccades that directly went to the target, by taking the endpoint of the 3rd time point of the saccades as a reference (see above), and coding deviations towards the distractor as positive, and deviations away from the distractor as negative. Moreover, saccade curvature was separately assessed for conditions in which the (similar or dissimilar) distractor was located at ±51°, 102° and 135° from the target. A $2 \times 2 \times 3$ ANOVA comprising the variables task (saccade-task versus manual-response task), similarity (similar versus dissimilar distractor), and position (±51°, ±102° and ±135°) calculated over the mean angular deviations of saccades directed to the target showed a significant main effect of similarity ($F[1,7] = 6.44$; $p = .039$), and a significant three-way interaction ($F[2,14] = 4.40$; $p = .033$). The interaction was due to the fact that, in the saccade task, saccades were generally more strongly curved away from the similar than from the dissimilar distractors, regardless of the relative target–distractor positions ($F[1,7] = 9.32$; $p = .019$; differences between similar and dissimilar distractors at ±51°: −2.35°; at ±102°: −2.35°; and at ±154°: −2.46°). In contrast, in the manual response task, saccades were only more strongly curved away from similar than dissimilar distractors when the distractor was located at ±102° from the target ($F[2,14] = 5.36$; $p = .019$; differences between similar and dissimilar distractors at ±51°: +1.29°; at ±102°: −2.19°; and at ±154°: −0.28°).

2.3. Discussion

Experiment 1 produced several interesting results. First, the results tentatively support the view that eye movements might be subject to more top-down control in saccade-tasks than in manual response-tasks: distractor fixations were generally more frequent in the manual response-task than in the saccade-task, in which saccades to the target position were the instructed responses. Simultaneously, saccade latencies were 22 ms longer in the saccade-task than in the manual response-task, suggesting that observers in the saccade-task delayed their saccades on a portion of trials to prevent erroneous fixations on the distractor (e.g., Findlay, 1997). This probably also resulted in more saccades being curved away from the distractor in the saccade-task than in the manual response-task. In previous studies, the finding that saccade trajectories curved away from the distractor has been taken to show that covert attention was deployed to this position (e.g., Godijn & Theeuwes, 2002; Van der Stigchel et al., 2006; Wu & Remington, 2003). Following this rationale, we can infer that covert attention was more frequently deployed to the similar than to the dissimilar distractor. The fact that covert attention shifts are also time-consuming might thus account both for the elongated saccade latencies and for more curved saccade trajectories in the saccade-task than in the manual response-task. Contrary to previously voiced concerns, selection of the dissimilar distractor was not more frequent in the manual response-task than in the saccade-task. This indicates that observers did not make their eye movements more strongly contingent on the top-down attentional control settings in the saccade-task. In contrast, the finding that similar and dissimilar distractors alike were more frequently selected in the manual response-task indicates that differences in controlling eye movements during saccade and manual response-tasks do not modulate the vulnerability of the eye movement system for interference by dissimilar distractors.

With regard to the similarity effect, Experiment 1 showed that similar distractors are visually selected much more frequently than dissimilar distractors. This replicates previous findings showing more frequent fixations on similar than dissimilar distractors (e.g., Ludwig & Gilchrist, 2003a). The results corroborate the view that colour information was used to detect the target and for the purpose of programming the first saccade to the tentative target location, and shows that similarity can be manipulated successfully on a nominally irrelevant dimension.

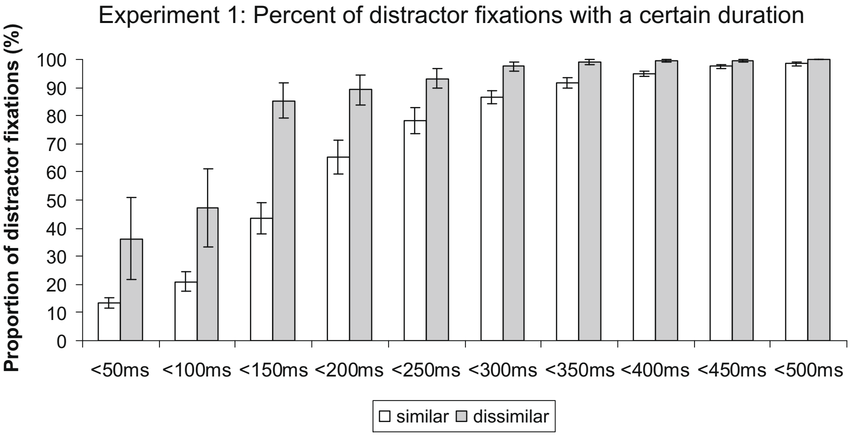

Fig. 3. The mean proportion of distractor fixations (*y*-axis) with certain fixation durations (specified on the *x*-axis) in Experiment 1. Error bars represent ±1 SEM.

Moreover, the similar distractor was also found to be prioritised for selection at a very early stage of the search process, with significantly more saccades being initially (during the first three time points of the saccade) directed towards the similar than the dissimilar distractor. These results demonstrate that oculomotor capture by similar distractors and filtering of dissimilar distractors occurs at a very early stage of the search process, corroborating the contingent capture view.

However, similar distractors also produced longer fixation durations than dissimilar distractors. At a first glance, this may suggest that disengagement from the similar distractor was more difficult and time-consuming than disengagement from the dissimilar distractor, corroborating the disengagement hypothesis for eye movements. On the other hand, it should be noted that the mean fixation duration of 180 ms on similar distractors were not unusually long, but rather in the range of the expected fixation duration. Previous studies estimated that it typically takes between 150 and 250 ms to program and execute a new saccade to an object (e.g., Findlay, 1997). Hence, the mean fixation duration of 180 ms for the similar distractor is well within the expected range, whereas the mean fixation duration of 96 ms on the dissimilar distractors is suspiciously short. Thus, contrary to the disengagement hypothesis, it does not seem to be the case that the fixation duration on similar distractors is unusually long, but instead, that the fixation duration on dissimilar distractors is unusually short.

To further evaluate this possibility, we separately computed the mean proportion of fixations on each distractor with distractor fixation durations below 50–500 ms, in steps of 50 ms. Relative rates are depicted in Fig. 3. The results show that a relatively large proportion of fixations on the dissimilar distractor (36%) was very short, amounting only to 50 ms, whereas this was the case for only 13% of fixations on the similar distractor. Almost half of all fixations on the dissimilar distractor (47%) had durations below 100 ms, and 85% of all fixations were below 150 ms, which is still a relatively short fixation. This compares with only 21% of all fixations on the similar distractor having durations below 100 ms, and only about half of all fixations (44%) being below 150 ms. Although these results are merely descriptive, they do suggest that – contrary to the disengagement hypothesis – fixation durations on similar distractors are not unusually long. Corresponding results of extremely short fixation durations on dissimilar distractors have also been observed in a different visual search study, where 63% of all fixations on dissimilar distractors were found to have durations below 150 ms (Theeuwes et al., 2004).

Since programming and execution of a new saccade usually takes at least 150 ms, the unusually short fixation durations on dissimilar distractors indicate that eye movements to the dissimilar distractor and the target were frequently programmed in parallel (e.g., Findlay, 1997; Theeuwes et al., 2004), or that the saccade to the target was programmed whilst the saccade to the dissimilar distractor was executed. Since subsequent saccades to the target could already be pre-programmed, the dissimilar distractor was only fixated for a very short time. As pointed out above, colour information is presumably available in the visual system at a very early point in time, so that erroneous saccade targets can be identified earlier in the dissimilar-distractor condition than in the similar-distractor condition. This in turn allows immediate programming of the target-directed saccade, accounting for the unusually short fixation durations. In conclusion, the differences in the fixation durations are presumably not due to difficulties in disengaging attention from distractors that match the top-down attentional control settings, but instead to the fact that the target can be identified more easily in the dissimilar condition, which allows the attention-guiding mechanism to select the target more quickly as the correct object after the first saccade has been erroneously directed to a dissimilar distractor. In other words, the disengagement hypothesis is supported in so far as the similar distractor cannot be rejected as quickly as the dissimilar distractor. However, elongated dwell times are probably not due to difficulties in disengaging attention, but to difficulties in detecting saccade errors whilst planning or executing saccades to a distractor. Therefore, saccades to the similar distractor and target are also usually not programmed in parallel, with serial saccade programming probably leading to longer fixation durations on similar than dissimilar distractors. Further research is necessary to shed light on the origin of the short fixation durations on dissimilar distractors.

In this respect, it should also be noted that the results of Experiment 1 are equivocal with respect to the origin of the effect of the dissimilar distractor: although mean RTs and target fixation latencies were significantly higher in the dissimilar-distractor condition than in the distractor-absent condition, the presence of a dissimilar distractor did not reduce the mean proportion of first fixations on the target or the latencies of these saccades. This suggests that the dissimilar distractor was not more frequently selected than one of the inconspicuous grey non-targets in the distractor-absent condition. Presumably, dissimilar distractors produced costs originating later in the search process, for instance, by their being actively inhibited (Lamy et al., 2004) or by their salience leading to still longer fixation durations in comparison to the less salient non-singletons. This hypothesis could not be evaluated in the present experiment, because the inconspicuous grey non-singletons were not selected often enough to be formally compared with dwell times on the dissimilar distractor.

Finally, comparing the initial direction of the first saccades away from fixation showed that only a very small proportion of saccades were initially (during the first three points in time) directed to a different location. Moreover, in the distractor-present condition, a substantial proportion of saccades was directed towards the similar distractor, whereas only few saccades were directed towards the dissimilar distractor. In addition, saccade latencies to the target were slightly longer when a similar distractor was present than when a dissimilar distractor was present. As described above, these elongated saccade latencies could reflect difficulties in disengaging covert attention from the similar distractor, when covert attention shifts are not followed by an eye movement. However, the difference in the saccade latencies was very small, amounting to only 11 ms. Thus, the elongated saccade latencies are too small to account for the similarity effect of 76 ms (in the mean RTs). Hence, the results of the present study are only weak support for the disengagement view, according to which (a) dissimilar distractors frequently capture covert attention and (b) attention can be quickly disengaged from the position of the dissimilar distractors. In conclusion, the present results are better in line with the contingent capture view that similar distractors capture attention more frequently, whereas dissimilar distractors can be filtered out.

However, the claim of the contingent capture view, that the similarity effect is primarily driven by top-down controlled settings for directing attention is less certain. Strictly speaking, the results of Experiment 1 do not allow inferences about whether the observed similarity effects are due to top-down or bottom-up controlled factors. As was described in the Introduction, selection of the target can bias attention and eye movements to similar stimuli on subsequent trials (e.g., Becker, 2008a, 2008b; McPeek et al., 1999). Since in Experiment 1, the target was consistently coloured red, it is possible that cumulative priming of the target colour led to the more frequent selection of the similar distractor than the dissimilar distractor. In this case, more frequent selection of the similar than the dissimilar distractor would not be due to the similarity or dissimilarity of the distractor features to a pre-defined top-down target template, but instead to intertrial priming effects, that automatically transfer information about the target feature to the next trial (e.g., Maljkovic & Nakayama, 1994).

3. Experiment 2

Experiment 2 was primarily designed to assess possible contributions of intertrial priming effects to the similarity effect. To that aim, search performance was assessed in two different conditions; in the *single-target condition*, half of the observers searched for a diamond target that was consistently red, and the other half searched for diamonds that were consistently green. In the distractor-present block, one of the grey non-target circles was presented either in red or green. Depending on the colour of the diamond target, the irrelevant distractor was thus either similar or dissimilar to the target, replicating the conditions of Experiment 1. In the *two-targets condition*, the target diamond was randomly coloured red or green, and in the distractor-present block, one of the grey non-target circles was also randomly presented in red or green.

The two-targets condition allows assessing the contribution of intertrial priming effects to the distractor effect. If selection of the target feature biases attention towards the identically coloured distractors on subsequent trials (i.e., target-distractor feature priming effects), then distractors that have the same colour as the target on the preceding trial ("$n-1$ similar distractors"), should capture attention to a larger extent than distractors that have a different colour than the target on the preceding trial ("$n-1$ dissimilar distractors"). Furthermore, by comparing the priming-induced distractor effect to the similarity effect obtained in the single-target condition, we can assess the relative contribution of intertrial priming to the similarity effect. If the similarity effect is entirely due to automatic carry-over effects of the target colour, then the priming-induced distractor effect in the two-targets condition should be of approximately the same magnitude as the similarity effect observed in the single-target condition.

Although the majority of studies on the priming effect used comparisons between single target and two-target conditions to assess the contribution of repeated presentations to search performance (e.g., Geyer, Mueller, & Krummenacher, 2008; Kristjansson et al., 2002), the method of comparing two different effects (similarity effect versus priming-induced distractor effects) across different blocks is probably not ideal. More direct evidence for the view that top-down controlled processes cause the similarity effect could be obtained if it were possible to eliminate priming effects and to show that similarity effects could still be obtained. Hence, in Experiment 2, we tried to eliminate intertrial priming, by using *pre-mask displays* (see Fig. 1B). Previous research indicates that pre-masking (or backward masking) of the search stimuli can reduce or even eliminate intertrial priming effects (Ansorge & Horstmann, 2007; Huang & Pashler, 2005). In the present experiment, we used checkerboard figures as pre-trial masks. To test whether this procedure could eliminate intertrial priming effects, we additionally assessed priming effects pertaining exclusively to the target (i.e., target–target feature priming effects), and effects of repeating and changing the distractor (i.e., distractor–distractor feature priming effects, which may be contingent on repetitions versus changes of the target feature).

If pre-masking completely eliminates the intertrial priming effect, then the difference between similar and dissimilar distractors in the single-target condition can be directly interpreted in terms of top-down controlled processes (provided that contributions from the other possible stimulus-driven factors described above can be ruled out). However, if intertrial priming persists despite pre-masking, some more detailed analyses are required to estimate the relative contributions of priming-induced distractor effects to the similarity effect. In particular, a number of pre-conditions must be met before intertrial priming effects can be considered as fully accounting for the similarity effect. First, the priming-induced capture effect should be either of the same magnitude as the similarity effect, or (if the priming-induced capture effect is smaller than the similarity effect), priming must be demonstrably cumulative, so that differences between $n-1$ similar and $n-1$ dissimilar distractors increase with increasing repetitions of the target colour to eventually make up for the full similarity effect under the ideal conditions of the one-target blocks. Second, for priming to account for the similarity effect, priming-induced capture must also modulate the same dependent variables as distractor similarity. In assessing this correspondence, we concentrated on those dependent variables that have an impact on RTs (i.e., the proportion of erroneous fixations on distractors, distractor fixation durations, and the proportion and latencies of first saccade to the target), and did not assess dependent variables such as saccade curvature, or the initial direction of saccades.

Finally, the design of Experiment 2 also eliminates two possible confounds from Experiment 1: first, it should be noted that in Experiment 1, the similar distractor was consistently coloured red, whilst the dissimilar distractor was always coloured green. Thus, it is possible that larger distraction costs for similar than dissimilar distractors were due to the fact that red items capture attention more than green items. In the single-target condition of Experiment 2, the similar distractor was green for half of all observers, whereas it was red for the other half of observers, which eliminates the previous confound.

Secondly, in Experiment 1, the displays in the dissimilar and similar-distractor condition differed on a purely perceptual level as well, because displays in the similar-distractor condition always included two identically coloured stimuli, whereas displays in the dissimilar-distractor condition always contained two differently coloured stimuli. Presenting two similarly coloured stimuli in turn might have caused interference in purely perceptual or decisional processes that are unrelated to attention, but or create delays in deploying attention to any stimulus (e.g., by increasing the difficulty of decisional processes, cf. Remington, Folk, & McLean, 2001). To assess whether the presence of two same-coloured items might account for the similarity effect, homogeneous (same-coloured) and heterogeneous (differently-coloured) displays from the two-targets condition were examined separately. If the similarity effect is indeed driven by perceptual factors arising from presenting two identically coloured stimuli, then the distractor effect should be larger in *homogeneous displays*, which comprised two identically coloured stimuli (e.g., a red target and a red distractor) than in *heterogeneous displays*, where the target and the distractor had a different colour (e.g., a red target and a green distractor).

3.1. Method

3.1.1. Observers

Eight paid volunteers from the University of Bielefeld, Germany, participated in Experiment 2. Three of them were female, five male, and they had a mean age of 31.

3.1.2. Material

The materials were the same as in Experiment 1.

3.1.3. Stimuli, design and procedure

These were the same as in Experiment 1, with the following exceptions. Search performance was only assessed in the manual response-task, in which attentional capture by irrelevant distractors occurred more frequently. Moreover, Experiment 2 comprised two blocked search conditions, each including a distractor-absent and a distractor-present block. In the single-target condition, observers searched for a diamond target that was consistently red for one half of the observers, and consistently green for the other half of the observers. In the distractor-present block, one of the grey non-target circles was presented either in red or green. Depending on the colour of the diamond target, the irrelevant distractor was thus either similar or dissimilar to the target. In the two-targets condition, the target diamond was randomly coloured red or green. In the distractor-present block, one of the grey non-target circles was also randomly presented in red or green.

Before each trial, a pre-mask display consisting of seven black-and-white checkerboard masks was presented. The shapes of the masks were derived by superimposing the diamond and circle shapes, and the luminance of the masks was matched to the luminance of the grey, red and green coloured stimuli (4.0–4.1 cd/m^2). The pre-mask display was shown during the fixation control, for at least 1000 ms (up to 3000 ms), and observers were required to fixate on the fixation cross during this time (see Fig. 1B for an example of the displays).

Observers completed 120 trials in the distractor-absent blocks of both single and two-targets conditions, and 240 trials in the distractor-present blocks of both conditions, yielding 720 trials per subject. On average, it took 90 min to complete the experiment.

3.2. Results

3.2.1. Data

Data were excluded from all analyses when manual RT exceeded 1500 ms, or when the eyes were not fixated on the target within 1500 ms. Application of this exclusion criterion resulted in a loss of 3.5% of all data.

3.2.2. Manual response: similarity and distractor effects

3.2.2.1. RTs. The results from the single-target condition replicated the results of the first experiment: mean RTs were significantly faster in the distractor-absent control condition ($M = 707$ ms) than in both the similar-distractor condition ($M = 884$ ms; $F[1, 7] = 58.76$; $MS_e = 2131.26$; $p < .001$) and the dissimilar-distractor condition ($M = 808$ ms; $F[1, 7] = 15.30$; $MS_e = 2664.87$; $p = .006$). Moreover, there was a significant similarity effect, with RTs being 76 ms slower in the presence of a similar distractor than in the presence of a dissimilar distractor ($F[1, 7] = 20.63$; $MS_e = 1119.45$; $p = .003$).

3.2.2.2. Errors. None of these effects approached significance in the mean error scores (all Fs < 1), indicating that the RT results are not due to a speed–accuracy trade-off (see Table 1).

3.2.3. Homogeneous versus heterogeneous displays in the two-target condition

To examine whether the similarity effect is due to larger interference when two same coloured stimuli are present in the display than when two heterogeneously coloured stimuli are presented, we compared mean RTs in *homogeneous* displays (in which target and distractor were both coloured green or both coloured red) with mean RTs in *heterogeneous* displays (in which the target possessed a different colour than the distractor). Statistical analysis showed, however, that mean RTs were comparable in homogeneous ($M = 892$ ms) and heterogeneous ($M = 910$ ms) displays ($F[1, 7] = 2.4$; $p = .17$). Thus, the similarity effect cannot be attributed to differences between homogeneous and heterogeneous displays affecting purely perceptual processes.

3.2.4. Priming effects

To test whether the similarity effect in Experiment 1 and the single-target condition of Experiment 2 might be due to cumulative priming effects prioritising similarly coloured distractors for selection, we first analysed distractor-present and distractor-absent trials of the two-target condition separately for *target feature priming* effects. In the distractor-absent condition, mean RTs were not affected by whether the target feature was a repetition from the previous trial ($M = 721$ ms) or whether it was changed ($M = 733$ ms; $F[1, 7] = 1.6$; $p = .25$). However, in the distractor-present condition there was a significant priming effect, with RTs being 42 ms faster on repetition trials ($M = 880$ ms) than on trials in which the target colour was changed ($M = 922$ ms; $F[1, 7] = 8.64$; $MS_e = 797.63$; $p = .022$).

To further explore the scope of the priming effect, data from the distractor-present condition were additionally analysed for *distractor priming* effects and possible interactions with target feature priming effects. A 2 × 2 ANOVA comprising the variables "$n - 1$ target feature" (same target versus different target as in previous trial) and "$n - 1$ distractor feature" (same distractor versus different distractor as in previous trial), however, showed that repeating the distractor colour across trials did not modulate performance. Mean RTs did not differ between trials in which the distractor colour was repeated ($M = 904$ ms) and trials in which it changed ($M = 899$ ms; $F < 1$) and distractor repetition also did not interact with changes of the target colour ($F < 1$).

To clarify whether capture by the similar distractors could be due to priming, it is necessary to evaluate whether distraction costs vary as a function of the similarity versus dissimilarity of the distractor to the previous target (n–1 similarity). To that aim, trials from the distractor-present condition were separated according to whether the target in the previous, $n - 1$ trial had the same colour as the distractor on the current, nth trial ($n - 1$ similar distractor), or whether it possessed a different colour ($n - 1$ dissimilar distractor). In line with the view that intertrial priming modulates the distraction costs, mean RTs were 28 ms slower on trials in which the distractor had the same colour as the target in the previous trial ($M = 915$ ms) than on trials in which the distractor possessed a different colour ($M = 887$ ms; $F[1, 7] = 7.62$; $MS_e = 362.47$; $p = .028$).

At a first glance, these results may be taken to indicate that the similarity effect has to be attributed to bottom-up intertrial priming effects instead of top-down controlled factors of attention. However, for the intertrial priming effect to fully account for the similarity effect, at least two pre-conditions must be met: first, priming-induced distractor effects should have the same *signature* as the similarity effect (i.e., they should modulate the same dependent variables of the eye movement measures). Second, it has to be demonstrated that priming can produce differences between $n-1$-similar and $n-1$-dissimilar-distractor conditions that are of the same magnitude as the similarity effect in the single-target condition. So far, the similarity effect in the single-target condition amounted to 76 ms, and, thus, was considerably larger than the increase of 28 ms for $n-1$-similar distractors. This difference between the magnitude of the respective effects was significant, as assessed by a 2 × 2 ANOVA ($F[1, 7] = 13.93$; $MS_e = 355.21$; $p = .007$). Still, intertrial priming effects may be responsible for similarity effects, if these intertrial effects are cumulative across successive repetitions, that is, if distractor effects generally become stronger when the target is repeated over a successive number of trials (e.g., Maljkovic & Nakayama, 1994). In the next two sections, we critically assessed first, the signature of similarity effects and priming-induced distractor effects, respectively. Second, we examined whether cumulative priming effects may lead to successively larger distraction costs with repeating the target feature on successive trials.

3.2.5. I. Signatures of the similarity effect and the priming-induced distractor effect

To explore whether the similarity effect and the priming-induced distractor effect both modulate the same dependent variables, we compared the impact of these effects in the single target and two-targets conditions, respectively, on the target fixation latencies, the mean proportion of fixations on the distractor, the mean distractor fixation durations, and the proportion and latencies of first fixations on the target.

3.2.5.1. Target fixation latencies. The mean target fixation latencies for similar versus dissimilar distractors in the single-target condition, and for $n-1$-similar and $n-1$-dissimilar distractors (i.e., for distractors possessing the same colour as versus a different colour from the target in the previous trial) are depicted in Fig. 4. Statistical analyses of the target fixation latencies revealed a significant similarity effect in the single-target condition: target selection commenced 76 ms later when a similar distractor was present ($M = 399$ ms) than in the presence of a dissimilar distractor ($M = 323$ ms; $F[1, 7] = 32.23$; $MS_e = 702.32$; $p = .001$). Similarly, target selection commenced later in the two-targets condition when the distractor possessed the same colour as the target in the previous, $n-1$ trial ($M = 411$ ms) than when it had a different colour ($M = 382$ ms; $F[1, 7] = 7.78$; $MS_e = 429.82$; $p = .027$). However, this effect was only of a magnitude of 29 ms, and, thus, was significantly smaller than the similarity effect ($F[1, 7] = 19.84$; $MS_e = 216.20$; $p = .003$).

3.2.5.2. Proportion of first fixations on the target. To explore whether priming modulates early processes concerned with guiding attention to the target, the mean proportion of first saccades directed to the target were committed to the same analysis (see Fig. 5). Distractor similarity in the single-target condition significantly modulated the mean proportion of first fixations on the target, which were significantly reduced in the similar-distractor condition ($M = 70\%$) when compared to the dissimilar distractor ($M = 88\%$; $F[1, 7] = 21.62$; $MS_e = 56.26$; $p = .002$). Deviating from Experiment 1, the dissimilar distractor also significantly reduced the mean proportion of first fixations on the target compared with the distractor-absent control condition ($M = 100\%$; $F[1, 7] = 5.65$; $MS_e = 109.61$; $p = .05$). In the two-targets condition, $n-1$ similar distractors (that had the same colour as the previous target) also significantly reduced the mean proportion of first fixations on the target ($M = 63\%$) when compared to $n-1$ dissimilar distractors (that were of a different colour; $M = 76\%$; $F[1, 7] = 18.05$; $MS_e = 36.64$; $p = .004$). Additionally, the proportion of first fixations on the target was significantly lower in the presence of an $n-1$ dissimilar distractor than in its absence ($M = 99\%$; $F[1, 7] = 31.76$; $MS_e = 66.13$; $p = .001$).

Comparing the distractor effects in the single-target and two-targets condition by a 2 × 2 ANOVA showed that first saccades were generally more precise in the single-target condition ($M = 79\%$) than in the two-targets condition ($M = 69\%$; $F[1, 7] = 10.43$; $MS_e = 72.39$; $p = .014$). However, the differences between similarity effects in the single-target condition and priming-induced $n-1$ similarity effects in the two-targets condition just failed to reach significance ($F[1, 7] = 3.38$; $p = .108$).

3.2.5.3. Proportion of fixations on the distractor. The same ANOVAs were also calculated over the mean proportion of fixations on the

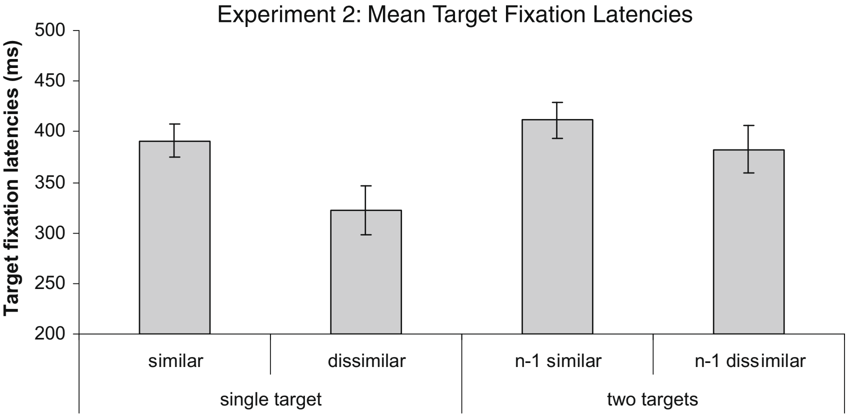

Fig. 4. Comparing the similarity effect in single-target conditions to distractor effects mediated by intertrial contingencies of the target in the two-targets condition of Experiment 2: the mean target fixation latencies are depicted separately for similar and dissimilar-distractor trials in the single-target condition, and separately for $n-1$ similar distractors (that had the same colour as the target on the previous trial) and $n-1$ dissimilar distractors (that had a different colour from the target on the previous trial) in the two-targets condition. Error bars represent ±1 SEM.

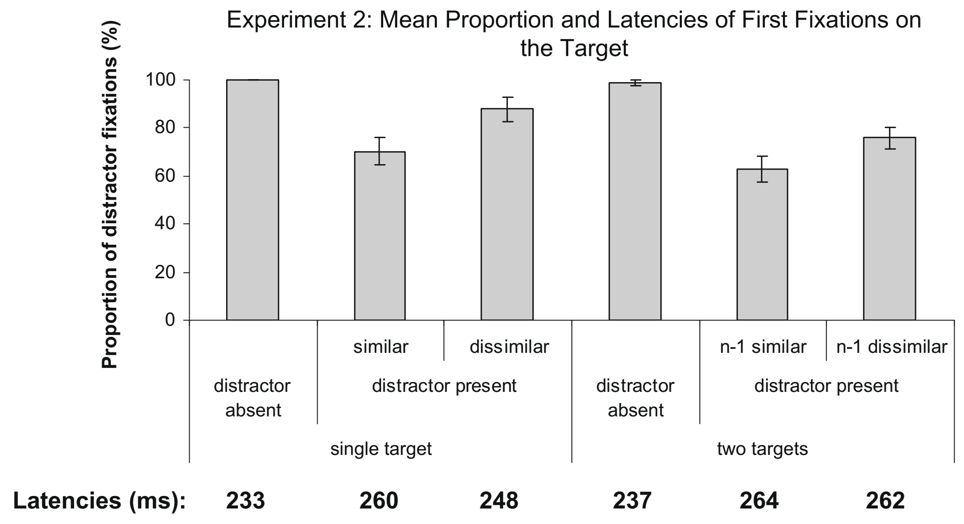

Fig. 5. The effect of distractor similarity and $n-1$ distractor similarity on the mean proportions and latencies of first saccades to the target in Experiment 2: the mean proportion of trials where the target was selected as the first item is depicted separately for similar and dissimilar-distractor trials in the single-target condition, and for $n-1$ similar versus $n-1$ dissimilar distractors in the two-targets condition. Latencies are depicted below the histograms. Error bars represent ±1 SEM.

irrelevant distractor (see Fig. 6). The analysis revealed a significant main effect of similarity in the single-target condition: on average, the similar distractor was fixated on 29.3% of all trials, whereas the dissimilar distractor was selected on only 11.9% of all trials ($F[1,7] = 21.62$; $MS_e = 56.26$; $p = .002$). In the two-targets condition, a higher proportion of distractor fixations occurred when the distractor had the same colour as the previous target ($M = 37.0\%$) than when the distractor was colour-dissimilar to the target in the previous trial ($M = 23.9\%$; $F[1,7] = 18.25$; $MS_e = 37.54$; $p = .004$). Although similarity between target and distractor produced a larger increase in distractor fixations (*mean difference* = 17%) than priming (*mean difference* = 13%), the difference between the two effects failed to reach significance ($F[1,7] = 2.83$; $p = .136$).

3.2.5.4. Latencies of first fixations on the target and on the distractor. Next, the mean latencies of these saccades were submitted to the same analysis (see Figs. 5 and 6). In the single-target condition, mean latencies of saccades to the target were significantly longer when the distractor was similar to the target than when it was dissimilar ($F[1,7] = 15.90$; $MS_e = 40.32$; $p = .005$). Moreover, saccade latencies in the dissimilar-distractor condition were longer than mean latencies in the distractor-absent control condition ($F[1,7] = 10.79$; $MS_e = 81.58$; $p = .013$). Conversely, in the two-target condition, saccade latencies did not differ between distractors that had the same colour as the target in the previous trial and distractors of a different colour ($F < 1$). However, saccade latencies were higher in both $n-1$ similar-distractor and $n-1$ dissimilar-distractor conditions than in the distractor-absent control condition ($F[1,7] = 13.46$; $MS_e = 183.74$; $p = .008$). These differences between the similarity effect in the single-target condition, and the $n-1$-similarity effect in the two-targets condition also proved to be significant ($F[1,7] = 8.28$; $MS_e = 27.76$; $p = .024$).

Comparing the latencies of saccades directed towards the distractors versus the target showed that saccades to the distractor had significantly shorter latencies ($F[1,7] = 17.57$; $MS_e = 97.37$; $p = .004$).

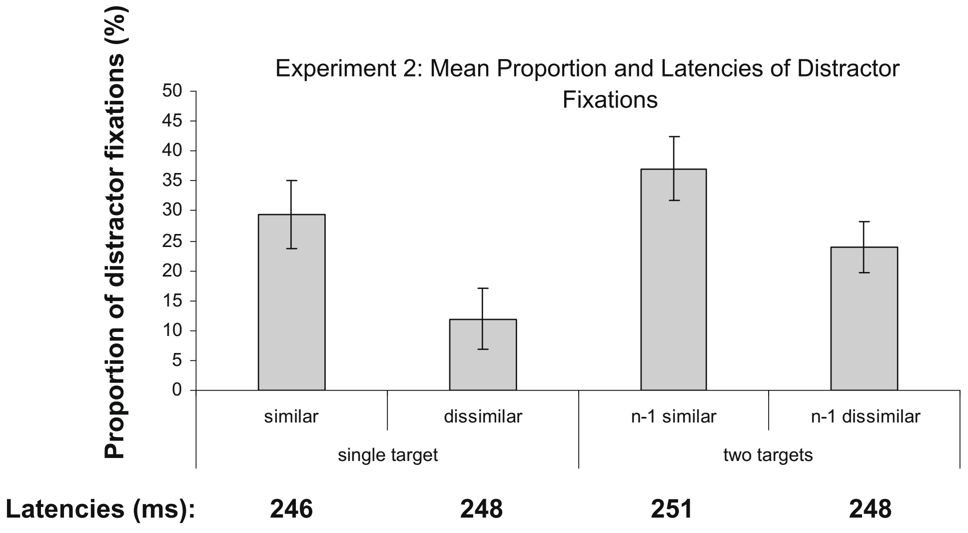

Fig. 6. Comparing the effect of distractor similarity and $n-1$ distractor similarity on the mean proportion and latencies of first saccades to the distractor in Experiment 2: the mean proportion of trials on which a distractor was selected first is depicted separately for similar and dissimilar-distractor trials in the single-target condition, and for $n-1$ similar versus $n-1$ dissimilar distractors in the two-targets condition. The latencies of these saccades are depicted below the histograms. Error bars represent ±1 SEM.

Fig. 7. The effect of distractor similarity and $n-1$ distractor similarity on the mean distractor fixation durations in Experiment 2: the mean distractor fixation durations are depicted separately for similar and dissimilar-distractor trials in the single-target condition, and for $n-1$ similar versus $n-1$ dissimilar distractors in the two-targets condition. Error bars represent ±1 SEM.

However, latencies of saccades directed to the similar and dissimilar distractor, or to the $n-1$-similar versus $n-1$-dissimilar distractor did not differ significantly from one another ($F < 1$).

3.2.5.5. Distractor fixation durations. Concerning next, the durations the eyes remained fixated on a distractor, these were slightly longer when the distractor was similar to the target ($M = 201$ ms) than when it was dissimilar ($M = 180$ ms), but this difference was not significant ($F < 1$; see Fig. 7). In the two-target condition, the distractor fixation durations were longer when the distractor was similar to the previous target ($M = 214$ ms) than when it was dissimilar ($M = 194$ ms), but this difference just failed to reach significance ($F[1,7] = 4.53$; $p = .071$). Moreover, there were no differences between similarity effects in the single-target condition and $n-1$ similarity effects in the two-targets condition on dwell times ($F < 1$).

3.2.6. Cumulative priming

The results of the analyses show striking correspondences between the similarity effect in the single-target condition and the priming-induced $n-1$ similarity effect in the two-target condition: this indicates that priming effects can account for at least a portion of the similarity effect in the single-target condition. However, in order to fully account for the similarity effect, intertrial effects would have to be cumulative – that is, they should lead to increasingly stronger distractor effects with each successive target repetition. To assess whether the similarity effect might be due to such a cumulative *priming effect*, we tested the effect of repeated target presentations on the distraction costs (see Fig. 8).

Analysis of the mean RTs however showed that the $n-1$ similarity effect did not increase with increasing repetitions of same target colour displays ($F[3,21] = 1.47$; $p = .255$). In contrast, mean RTs for distractors sharing the preceding target's colour initially decreased for the first repetition and increased only when the target colour was repeated three times or more (913, 884, 913, and 937 ms; $F[3,21] = 2.71$; $p = .071$; see Fig. 8). For displays containing $n-1$ dissimilar distractors, mean RTs initially decreased with increasing repetitions of the target feature, but this was far from significant (886, 884, 882, and 910 ms; $F < 1$).

This indicates that the similarity effect cannot be fully attributed to intertrial carry-over effects, which automatically bias attention towards the distractor which is similar to the target on the previous trial(s). Thus, the similarity effect cannot be explained by solely reverting to automatic or stimulus-driven processes. In-

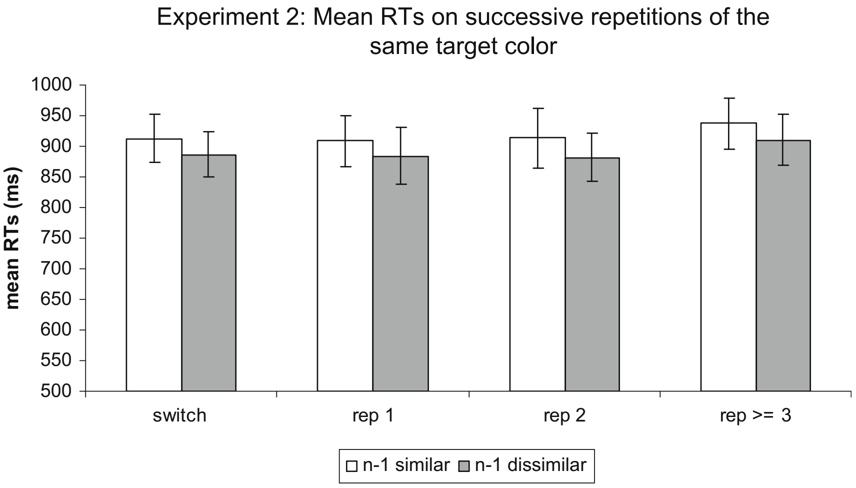

Fig. 8. The distractor-present trials of the two-targets condition of Experiment 2 were probed for cumulative priming effects: mean RTs are separated according to whether the distractor possessed the same colour as a target, which had been successively repeated for one, two, or three and more times ("rep 1", "rep 2", and "rep ⩾3", respectively), or whether the distractor had a different colour ("switch"). Error bars represent ±1 SEM.

stead, a large portion of the similarity effect is probably due to the fact that similar distractors match the top-down attentional control settings.

3.3. Discussion

Experiment 2 yielded several interesting results: first, the distractor effect and the similarity-dependent capture effect observed in Experiment 1 could be replicated in the single-target condition of Experiment 2 in which half of the observers searched for a red coloured target and the other half searched for a green coloured target. This indicates that the observed effects in Experiment 1 were not due to the use of a red coloured target. Secondly, the results of Experiment 2 effectively rule out that the similarity effect is due to differences underlying homogeneous displays versus heterogeneous displays: in the two-targets condition, a green distractor presented together with a red target or a red distractor presented together with a green target produced the same distraction costs as a red distractor presented together with a red target, or a green distractor presented together with a green target. This demonstrates that the similarity effect is not due to perceptual or decision-level processes that are impaired by presenting two same-coloured items in the display (cf. Ansorge & Heumann, 2004; Remington et al., 2001).

Moreover, the second experiment also supports the view that the similarity effect is not due to elongated disengagement of attention from similar distractors, but instead to more frequent attentional selection of the similar distractor: in Experiment 2, the duration of fixations on similar distractors was not significantly higher than that on dissimilar distractors. This finding is incompatible with the claim of the disengagement hypothesis that the similarity effect is mainly due to elongated disengagement from similar distractors (Theeuwes et al., 2000). Instead, the results support the claim of the contingent capture hypothesis, that similar distractors capture attention to a larger extent than dissimilar distractors (e.g., Folk & Remington, 1998).

However, Experiment 2 also revealed that intertrial priming effects modulated the same processes as were pinpointed by the similarity-dependent capture effect. In the two-target condition, presenting a distractor that had the same colour as the target in the preceding trial significantly reduced the proportion of first saccades on the target and led to significantly more selections of the irrelevant distractor. This indicates that the carry-over effects involved in trial-by-trial priming can guide attention to objects that possess the same colour as the target in the previous trial. Therefore, trial-by-trial priming can at least account for a portion of the similarity-dependent capture effect in the present study.

However, as argued above, the present results render it unlikely that the similarity-dependent capture effect is solely due to stimulus-driven intertrial priming effects. Comparing the magnitude of priming-induced increases in the distractor effect of the two-target condition and similarity-induced increases in the distractor effect of the single-target condition reveals that the former is significantly smaller than the latter. Therefore, trial-by-trial priming can hardly account for the entire similarity-dependent capture effect. This is all the more so, since the priming effect in the present study turned out not to be cumulative with respect to the distraction costs: the difference between similar distractors that share the preceding target's colour and the dissimilar distractors did not further increase as a function of repeating the target colour several times successively. Hence, it seems to be safe to conclude that top-down controlled processes of guiding attention still contributed to the similarity-dependent capture effect.

Finally, it should be observed that the results of Experiment 2 also shed some light on the origin of the dissimilar distractor effect: deviating from Experiment 1, we found that the presence of a dissimilar distractor significantly reduced the proportion of first saccades on the target and also significantly elongated the latencies of these saccades. Presumably, the failure to detect these effects in Experiment 1 was due to the fact that the dissimilar distractor was only selected on a small portion of all trials, especially in the saccade-task which was not used in the present experiment. With this, the results of Experiment 2 indicate that dissimilar distractors are not always filtered out prior to allocating attention to any items in the display. Instead, dissimilar distractors can apparently also capture attention; albeit to a lesser extent than similar distractors (see Experiment 1).

4. General discussion

Our multi-faceted approach yielded a number of insights into quite different research questions. First, we assessed eye movements control in saccade-tasks versus manual response-tasks, to clarify whether the two different tasks differed in the amount of top-down control. Second, we examined possible contributions of elongated disengagement from similar distractors to the similarity effect. Third, we investigated the role of intertrial priming effects in the similarity effect, to see whether similarity effects could be due to the fact that the target is presented with the same feature over a number of consecutive trials. In a nutshell, the results showed that in a manual response-task, saccade latencies are shorter and irrelevant distractors are selected more frequently than in a saccade-task, where eye movements are used as a response. Secondly, dwell times on similar distractors were indeed elongated compared to dissimilar distractors in some conditions (i.e., Experiment 1), but these results could not be interpreted as straightforward support for the disengagement hypothesis. Moreover, as will be discussed in further detail below, the contribution of disengagement to the similarity effect was rather small. Third, we found that intertrial effects may play a role in mediating the similarity effect, but that intertrial effects were too small to fully account for the similarity effect. Since intertrial effects are commonly regarded as bottom-up effects, whereas the similarity effect is commonly regarded as a top-down effect, the results can be interpreted to show that there are top-down effects that cannot be completely explained by bottom-up priming – contrary to what has been argued, for instance, by Kristjansson et al. (2002) with respect to search efficiency. Intriguingly, we also found that manipulating intertrial contingencies had exactly the same effects as manipulations of target similarity, which calls into question that intertrial effects and similarity effects are based on different processes (i.e., bottom-up versus top-down).

In the following, we will describe and explain the results and possible interpretations of them in more detail, by relating them to other studies. Moreover, we will propose an account of intertrial priming effects ("contingent priming"; Becker, 2007) that describes similarity effects and priming-induced distractor effects are based on the basis of the same underlying mechanism.

4.1. Top-down control over eye movements in saccade-tasks and manual response-tasks

In the past, it has been implicitly assumed that eye movements do not differ between tasks where saccades are used as a response (saccade task), and standard manual response-tasks, where eye movements are encouraged by presenting a small feature in the periphery (e.g., Geyer et al., 2008). The present study showed that observers apparently exert more control over their saccades in the saccade-task (in which an instructed saccade toward the target is required) than in the standard manual response-task (in which responses are made by button presses and observers could have used any strategy or criterion for moving their eyes). Erroneous saccades toward the irrelevant distractor were more frequent in the manual response-task than in the saccade-task. Moreover, the saccade latencies of first saccades to the target were significantly longer, and the trajectory of these saccades was significantly more curved away from the position of the similar distractor in the saccade-task than in the manual response-task. Contrary to our initial suggestion that observers might make their saccades more strongly contingent on the top-down attentional settings, more controlled eye movement behaviour in the saccade-task did not reduce selection of the dissimilar distractor. Rather, in the saccade-task, observers apparently delayed their initial saccades in order to enhance their precision and to avoid mistakes (see Findlay, 1997). This indicates that, in the saccade-task, eye movements were more decoupled from the preceding covert attention shifts than in the manual response-task. Thus, studies investigating eye movements as a successor to covert attention shifts might benefit from using a manual response-task instead of a saccade-task.

4.2. Contingent capture versus disengagement

A more important goal of our investigation was to test two possible explanations of the similarity effect, *viz.* the contingent capture view and the disengagement view. Previous studies investigating similarity effects on covert attention shifts have already ruled out that the similarity effect is completely due to elongated de-allocation or disengagement of attention from similar items (Ansorge & Heumann, 2003; Chen & Mordkoff, 2007; Folk & Remington, 2006). However, in the present study, we tested the disengagement hypothesis with regard to eye movements, and examined whether and to what extent elongated dwell times on similar distractors can contribute to the similarity effect. The results of Experiment 1 showed that fixation durations were significantly longer on similar distractors (180 ms) than on dissimilar distractors (97 ms), consistent with the disengagement hypothesis. However, these differences were too small to account for the similarity effect, which amounted to 128 ms in the mean RTs: since the dissimilar distractor was only selected on 5% of all trials, the differences in dwell times cannot explain the rather large difference between the similar and dissimilar-distractor conditions. Thus, it is safe to conclude that the similarity effect is primarily due to more frequent selection of the similar distractor (30%) than the dissimilar distractor (5%), whereas differences in dwell times play only a minor role.

Moreover, it may be doubted whether elongated dwell times on similar distractors can be interpreted in support of the disengagement hypothesis: contrary to the predictions of the disengagement hypothesis, fixation durations on similar distractors were not unusually long (180 ms), but rather, the fixation durations on dissimilar distractors were found to be unusually short (97 ms). This result pattern is inconsistent with the assumption that it is especially difficult to de-allocate attention from similar distractors. Instead, the results were interpreted in favour of a somewhat leaky filtering of dissimilar distractors, which did not always reliably suppress activation signals from the salient dissimilar distractor (e.g., Folk & Remington, 2008). As a consequence, saccades to the target and to the dissimilar distractor were occasionally programmed in parallel, leading to very short fixations on the dissimilar distractor (e.g., Findlay, 1997; Theeuwes et al., 2004). However, further research is necessary to clarify this issue. This is all the more so, since evidence for parallel programming of saccades to the target and the distractor could only be obtained in Experiment 1, whereas in the single-target condition of Experiment 2, the fixation durations on dissimilar distractors did not differ significantly from the fixation durations on similar distractors. This may be due to the use of the pre-mask displays in Experiment 2: possibly, the sudden onset of the search display in Experiment 1 produced a tendency to program saccades in parallel to several onset stimuli, prioritizing specifically salient onsets (e.g., Ludwig & Gilchrist, 2002, 2003a), whereas presenting the pre-mask displays before each trial eliminated this onset-dependent influence on saccade target selection. However, this cannot be ascertained and has to be investigated more thoroughly by future research.

Although we employed a slightly different design in the present study, where the distractor was made irrelevant by its shape (instead of its position; e.g., Ludwig & Gilchrist, 2003a), the results of previous studies could be mostly replicated. As in previous studies, similar distractors were selected much more frequently than dissimilar distractors, and interfered with very early processes of visual search. A substantial proportion of first saccades were initially directed towards the similar distractor, leading to a large reduction in the proportion of first saccades that were directed towards the target. Moreover, similar distractors significantly elongated the latencies of these saccades (see Experiment 1 and the single-target condition of Experiment 2), and caused the saccades to be more strongly curved away from the distractor. These results replicate the findings of previous studies (e.g., Ludwig & Gilchrist, 2002, 2003a) and rule out that similarity affects visual processes only after selection of a salient item, making de-allocation more difficult. Instead, consistent with the contingent capture explanation, the results suggest that similarity affects processes at an early stage of visual search. The finding that saccades were curved away from the distractor position has sometimes been taken to indicate that covert attention had been first shifted to the distractor location, and that subsequently, the distractor had been rejected by inhibiting the corresponding location, akin to inhibition of return (e.g., Van der Stigchel et al., 2006). If this were the case, then we would have to conclude that covert attention has actually been deployed to the dissimilar distractor prior to an eye movement, whereby the deployment of covert attention was less frequent than with the similar distractor (leading to stronger curvature on similar than dissimilar-distractor trials). However, the majority of previous studies failed to find evidence for attentional capture by distractors that were dissimilar in the colour dimension (e.g., Ansorge & Heumann, 2003; Becker, 2007; Folk & Remington, 2006). Hence, it seems more likely that, in the present study, curvature of saccades away from the dissimilar distractor location reflect that the distractor location was inhibited prior to any attention shifts. In fact, filtering of irrelevant features might well consist in inhibiting the corresponding locations containing such features prior to the deployment of attention, which can lead to the same result pattern as IOR. (e.g., Becker, 2007; Folk & Remington, 1998; Folk et al., 1993). One advantage of this view is that it can easily explain why saccades were more strongly curved away from similar than dissimilar distractors: the feature of the dissimilar distractor could be inhibited prior to each trial, whereas filtering of the similar distractor was not feasible, because it had the same colour as the target. Thus, the feature of the similar distractor could only be inhibited after erroneously selecting it (as reflected also in the more frequent selection of the similar distractor), resulting in more pronounced curvature for similar than dissimilar distractors. However, further research is necessary to clarify whether curvature in the trajectory of saccades reflects the deployment of attention to that location and subsequent inhibition (e.g., van der Stigchel et al., 2006) or inhibition that occurred prior to any attention shifts (e.g., Becker, 2007).

The results of the present study deviate slightly from previous research, in that previous studies have sometimes reported faster latencies for saccades to the dissimilar distractor than for saccades to the similar distractor (e.g., Mulckhuyse, Van Zoest, & Theeuwes, 2008). This finding has been taken to show that feature contrast information is available significantly earlier than information about the specific feature values, so that attention is initially completely controlled by bottom-up, feature contrast information. In the present study, we found that saccades to the distractors were initiated faster than saccades initiated to the target – a finding that has also been cited in support for the early saliency-based selection mechanism (e.g., Van Zoest et al., 2004) – but we did not find that saccades to the dissimilar distractor were initiated earlier than saccades to the similar distractor. So, how do the present results relate to the view that attention is initially controlled by bottom-up, feature contrast information? First of all, as mentioned above, the observation that saccades to the distractor(s) were initiated earlier than saccades that went to the target cannot be regarded as support of this view, because any such argument would rest on comparing erroneous saccades to correct saccades, and faster latencies for erroneous than correct saccades may simply reflect a speed–accuracy trade-off (e.g., Findlay, 1997). Secondly, it should be observed that Mulckhuyse et al., 2008 used onset distractors that could either have the same colour as the target (similar onset) or a different colour than the target (dissimilar onset). It is undisputable that information about *onsets* is available earlier to the visual system than information about particular feature values: prior to allocating attention to the visual field, we know the number of objects in the display and their positions (by figure-ground segmentation processes), but we do not know *what is where* (e.g., Treisman & Sato, 1990). It is not completely clear how the visual system extracts information about the location of a particular feature, but it is clear that any such process will cost time. Whereas it is undisputable that information about a sudden onset is available earlier in time than feature-specific information, this can hardly be interpreted as showing that attention is initially guided by *feature contrast* (e.g., Theeuwes, 1991, 1992) – that is, unless we want to claim that the existence or sudden appearance is a feature of an object, similar to, for instance its colour or shape (but see Yantis & Hillstrom, 1994). In the present study, we used distractors that were similar versus dissimilar in the colour dimension, which allows a more stringent test of the view that feature contrast information is available at an earlier point in time than feature-specific information. However, contrary to this view, we did not find any differences in the time-course of erroneous saccades towards the similar versus dissimilar distractors.

This result replicates the results of Ludwig and Gilchrist (2003a), who paramatrically varied the onset and colour similarity of their distractors. In line with the results of the present study, their study did *not* show that erroneous saccades to dissimilar no-onset distractors were faster (269 ms) than to similar no-onset distractors (233 ms), but just the opposite. In contrast, erroneous saccades to onset distractors were generally faster (range: 196–189 ms) than erroneous saccades to no-onset distractors (range: 233–269 ms), and this was especially the case when only similar onsets were compared to similar no-onset distractors (Ludwig & Gilchrist, 2003a). In another study, Ludwig and Gilchrist (2002) also found that saccades to dissimilar onset distractors were initiated faster than saccades to similar onset distractors, but they did not interpret their findings in terms of feature contrast, but in the same way as in the present study, that is, as showing the impact of onsets on the guidance of attention (Ludwig & Gilchrist, 2002).[3]

4.3. The similarity effect and priming-induced distractor effects: top-down or bottom-up?

The main aim of Experiment 2 was to test whether and to what extent similarity effects might be based on top-down knowledge about the target colour, and to what extent similarity effects might be based on intertrial priming effects, that is, on the fact that the target colour is constantly repeated across trials. Attending to the target on one trial could automatically bias attention towards selecting a stimulus with the same feature(s) on a subsequent trial, leading to more frequent selection of the similar distractor. Although the question whether these intertrial priming effects are stimulus-driven or top-down controlled is controversial in its own, it is clear that the role of the top-down attentional control settings would be dramatically different if similarity effects were wholly due to intertrial priming effects. Assessing possible contributions from intertrial priming effects to the similarity effect showed that distractors which were similar to the previous target were selected more frequently than distractors of a different colour, consistent with the hypothesis that intertrial priming effects can modulate attentional capture by irrelevant distractors (see Experiment 2).

Although the present results support the view that the similarity effect is in part due to intertrial carry-over effects, it is unlikely that the similarity effect is completely due to intertrial priming effects: whereas intertrial effects only produced a 29 ms difference between the distractor types, the similarity effect was 76 ms and thus, significantly greater than the priming-induced distractor effect. This indicates that similar distractors were not only selected in virtue of the previously selected target feature, but because their colours matched the top-down attentional control settings (e.g., Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk et al., 1992, 1993). These results are in line with prior studies showing that intertrial priming cannot account for stronger capture by similar than dissimilar distractors in manual discrimination experiments in which targets varied from trial to trial (Ansorge & Horstmann, 2007; Ansorge et al., 2005; Folk & Remington, 2008). On the other hand, the finding that allegedly bottom-up intertrial priming effects and allegedly top-down controlled effects modulated exactly the same variables in the present study (i.e., RTs, target fixation latencies, proportion of first saccades to the target and to the distractor, saccade latencies, etc.) indicates that both effects might rely on the same mechanism, and that there might be not such a strict distinction between bottom-up priming effects and top-down similarity effects as commonly assumed

However, the view that priming effects and top-down controlled factors guide attention in a similar way, from the same level and possibly sharing the underlying mechanism is at odds with the standard view that priming effects are mediated by stimulus-driven processes. In the pioneering studies of Maljkovic and Nakayama (1994, 2000), the observers' expectancy and intertrial effects were systematically varied. In one of their experiments, they changed the target and distractor colours in a predictable sequence (e.g., two red targets, followed by two green targets, followed again by two red targets etc.). This ensures maximum certainty, because observers always know the upcoming colour of the target. Despite this, priming effects prevailed. Moreover, the effect of the previous trial's target colour was not visibly reduced compared to a condition where the target colour varied randomly and observers did not have any information about the colour of the target on the next trial. These results were also be replicated in later studies, (e.g., Becker, 2008a; Hillstrom, 2000; Leonard & Egeth, 2008; Maljkovic & Nakayama, 1994, 2000), and were mostly taken to show that priming effects are top-down impenetrable, that is, that they cannot be modulated by knowledge about the target feature on the upcoming trial (but see Becker,

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[3] Other studies that found shorter saccade latencies to targets than to distractors (or shorter saccade latencies to dissimilar distractors) used targets and distractors that differed in their orientation from an array of nontargets (e.g., Van Zoest & Donk, 2004; Van Zoest & Donk, 2006; Van Zoest et al., 2004). One problem of these studies is that the target and distractor were often mirror images of one another (e.g., tilted 45° to the right or left), which rendered the target pre-attentively indistinguishable from the distractor (e.g., Wolfe, 2001). This is also reflected in the unusually high proportion of first saccades to the distractor ($\geqslant 50\%$; i.e., selection of the target at or below chance level). A second problem is that in none of these studies, search asymmetries between differently tilted items were taken into account, which can have a strong effect in the orientation dimension (e.g., Treisman & Souther, 1985; Wolfe, 2001; Wolfe, Butcher, Lee, & Hyle, 2003).

2007, 2008a, 2008b). On the basis of these findings, Maljkovic and Nakayama (1994) proposed that priming is a purely stimulus-driven process.

Contrary to this bottom-up view on priming, some more recent evidence suggests that priming effects depend on the top-down attentional control settings. Multiple studies have found that priming effects are confined to the target-defining feature, that is, to the feature that distinguishes the target from the non-targets, whereas priming effects for task-irrelevant features or response-related features are either absent or much weaker (e.g., Becker, 2007, 2008a, 2008b; Maljkovic & Nakayama, 1994). More precisely, priming effects of task-irrelevant features only occur when the task-irrelevant feature is correlated with the target-defining feature, whereas priming is usually eliminated when a given feature of the target is not correlated with the target-defining feature (Becker, 2007; Goolsby & Suzuki, 2001; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Maljkovic & Martini, 2005; see also Ansorge & Horstmann, 2007; Ansorge et al., 2005). The finding that priming effects selectively pertain to the target-defining feature is inconsistent with the view that priming effects are purely bottom-up: if priming effects were purely stimulus-driven, then they should apply indiscriminately to all features of the target, including task-irrelevant features of the target, and irrespective of whether they are predictive of the target location or not. The finding that priming effects pertain selectively to the target-defining feature in turn indicates that priming effects are contingent on top-down controlled processes that strictly distinguish between task-relevant and task-irrelevant features of the target (Becker, 2008a; see also Olivers & Humphreys, 2003).

On the *contingent priming view* (Becker, 2007), the feature(s) that are subject to priming are determined by top-down controlled processes that select the kind of information that is transferred across trials (Becker, 2007; see also Mueller, Heller, & Ziegler, 1995; Olivers & Humphreys, 2003). Selection and intertrial transfers are however supposed to occur automatically, in a reactive way, which accounts for the finding that priming effects cannot be eliminated by presenting advance information about the particular target feature on the upcoming trial (Becker, 2007, 2008a; see also Olivers & Humphreys, 2003, for a similar account). Note that this account is akin to the central claim of the contingent capture hypothesis, that attention is set in advance or “offline” to the target-defining feature, which restricts the “automatic” selection process (which proceeds in a fast reactive mode) to features that are similar to the target-defining feature (e.g., Folk & Remington, 1998; Folk et al., 1992, 1993). On the contingent capture and the contingent priming hypothesis, it is therefore possible that visual selection is simultaneously contingent on top-down controlled processes but proceeds automatically, that is, without continuous assistance from top-down control. “online” impenetrable to top-down control.

The hypothesis that priming depends on top-down controlled settings is also supported by a recent study of Folk and Remington (2008). The results from this study showed that, when the target colour is specified in advance in a go/no-go-task, priming effects only pertain to the target-matching colour, but not to the non-matching colour. Folk and Remington (2008) argued that the preceding trial can obviously only exert an effect on the current trial when observers are uncertain about the colour of the target. In contrast, when the target-defining feature is specified in advance, observers are well able to restrict the deployment of attention to task-relevant features. In addition to that, the results of the present study indicate that attention can also be set to two different target features: note that, in the distractor absent condition of Experiment 2, changing the target colour across trials did not produce priming effects, whereas priming effects of 42 ms occurred in the distractor-present condition. These results replicate earlier findings (e.g., Becker, 2007) and show that intertrial priming effects depend on the task and the stimulus conditions: presumably, in the distractor absent control condition, attention was set towards both red and green items, so that changing the target feature did not produce switch costs. However, in the presence of an irrelevant distractor, priming effects emerged – presumably because the feature(s) of the distractor had to be filtered out (in the single target condition, this was presumably done by inhibiting only the feature of the dissimilar distractor, whereas in the two-targets condition, inhibition of the distractor feature occurred on a trial-by-trial basis).

Taken together, the results suggest that feature priming effects are contingent on top-down controlled processes. Moreover, a recent study by Fecteau (2007) suggests that this contingency can also affect priming effects “on-line”. In this study, observers had to search either for a shape or colour singleton, which were both present in all displays. Information about whether the colour singleton was the target and the shape singleton was the distractor, or vice versa, was given directly prior to each trial by a cue specifying the target-defining dimension. Moreover, the shape and colour of the singleton and the remaining stimuli randomly changed across trials. The results showed that repeating the target and distractor features across trials only led to benefits when observers had to search for a singleton in the same dimension as on the previous trial. In contrast, when the target dimension changed, repeating or changing the singleton features did not affect response times (Fecteau, 2007). These results indicate that priming effects are eliminated when observers are forced to re-configure their attentional control settings, showing that priming effects are contingent on top-down processes.

Taken together, the results of the present study are commensurate with the contingent priming hypothesis: the finding that priming effects were demonstrated to modulate exactly the same dependent variables as allegedly top-down controlled processes that bring about the similarity effect indicates that there is no need to postulate different processes to account for similarity effects and intertrial priming effects. The contingent priming hypothesis reconciles the automatic nature of intertrial priming effects with a top-down contingent capture mechanism and shows that both similarity effects and priming effects can be explained by the same underlying mechanism. Hence, the contingent priming hypothesis presents a more parsimonious explanation, which is also in line with numerous recent findings about intertrial priming effects (Becker, 2007; Fecteau, 2007; Folk & Remington, 2008; Maljkovic & Martini, 2005; Olivers & Humphreys, 2003). Hopefully, the present account will spark further interest in examining the mechanism that mediates intertrial priming effects and similarity effects.

Acknowledgment

This research was supported by the German Research Council, Grant AN 3931/1 to Ulrich Ansorge, Holk Cruse, and Odmar Neumann.

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