Journal of Experimental Psychology:
Human Perception and Performance
2008, Vol. 34, No. 6, 1417–1440

0096-1523/08/$12.00 DOI: 10.1037/a0011386

Can Intertrial Effects of Features and Dimensions Be Explained by a Single Theory?

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This study investigated feature- and dimension-based intertrial effects in visual search for a pop-out target. The 2 prominent theories explaining intertrial effects, priming of pop-out and dimension weighting, both assume that repeating the target from the previous trial facilitates attention shifts to the target, whereas changing the target leads to attentional switch costs. In contrast, the results from the present study indicate that intertrial effects from changing features and dimensions involve different underlying mechanisms: Eye movement recordings showed that feature priming reliably modulates the speed of visually selecting the target, whereas changing the target dimension interferes only with processes after selection of the search target. Further experiments with a size and orientation singleton target showed that feature priming does not consist in carryover effects of target activation or nontarget inhibition, contrary to standard assumptions in visual search. Instead, priming effects critically depended on whether a coarse relation between target and nontarget features (e.g., smaller or larger) was repeated or reversed across trials. These results suggest the need to modify current models of priming in visual search.

Keywords: priming of pop-out, dimension weighting, linear separability, visual search, eye movement

The question of how people select relevant information and discard irrelevant information from a cluttered visual scene has occupied attention researchers for several decades now. Visual selective attention is often studied with the help of the visual search paradigm: In a typical visual search task, observers have to find a prespecified target among several nontarget items. Previous research suggests that response times are usually affected by the number of objects in the display or the overall set size. It is notable that when the target is similar to the nontarget items or when it is presented among a group of heterogeneous nontargets (Duncan & Humphreys, 1989), participants perform an inefficient or serial search (Treisman, 1982; Wolfe, 1994). The hallmark of such searches is that response times (RTs) increase linearly with an increasing number of objects in the display. In contrast, search is very efficient and independent of the number of nontargets when the target constitutes an odd-man-out or "singleton" that differs in a single feature from all nontarget items (e.g., Treisman, 1988). In singleton search tasks, the target can, for instance, be a red item presented among green nontarget items or a diamond shape among nontarget circles. Phenomenally, such a target appears to pop out from the display, which led to labeling efficient search in these displays as showing a *pop-out effect*.

Theoretically, efficient versus nonefficient search has been explained by a two-stage visual process (e.g., Itti & Koch, 2000; Treisman & Sato, 1990; Wolfe, 1994). According to this view, processes at the first, "preattentive" stage operate in parallel across the entire visual field and extract information about the position of single features differing from their surrounds. Because information about primitive features is available at a very early stage of processing, attention can be immediately deployed to the search target if it possesses a unique feature. Deploying attention to an item in the visual field is thought to gate the passage of information to higher stages of processing, including visual object recognition and response selection. Critically, processes at this second, "attentive" stage are capacity limited and integrate information from a limited part of the visual field in a time-consuming process. Thus, when the target is defined by a specific conjunction of features, time-consuming attentional processing is necessary to locally combine the information of the corresponding features, resulting in inefficient search.

Recently, several researchers have analyzed eye movements during visual search to supplement traditional RT and accuracy measures (e.g., Findlay, 1997; Williams, Reingold, Moscovitch, & Behrmann, 1997; Zelinsky, 1996; see Rayner, 1998, for a review). Although covert shifts of attention do not automatically lead to saccadic selection of the corresponding location (e.g., Juan, Shorter-Jacobi, & Schall, 2004; Wu & Remington, 2003), eye movements are usually preceded by shifts of attention (e.g., Deubel & Schneider, 1996; Hoffman & Subramian, 1995; Peterson, Kramer, & Irwin, 2004; Sheliga, Riggio, & Rizzolatti, 1995). As a consequence, eye movements can be taken as a valid indicator of covert attention shifts.

Results from eye movement studies support the view that pop-out targets can be selected as the first item in the display: In a pop-out search task, the number of fixations until selection of the target is very low and does not increase with increases in the number of nontarget items. In contrast, the number of fixations is higher and increases with increasing set size in conjunction search

This research was supported by German Research Council Grant HO3248/1 to Gernot Horstmann and Grant AN3931/1 to Ulrich Ansorge, Holk Cruse, and Odmar Neumann. I wish to thank Christine Broermann for conducting the experiments and collecting the data and Heike Hartwig-Jacobs for assisting in preparation of the manuscript.

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(e.g., Williams et al., 1997). These analyses may allow a more fine-grained analysis of the spatial and temporal aspects of search performance than analyses of RTs alone, which may be influenced by a variety of decision- and response-related processes unrelated to search (cf. Williams et al., 1997).

Intertrial Effects

Previously it has been thought that in pop-out displays, search is modulated only by the feature contrast between the target and nontargets (e.g., Theeuwes, 1991). However, recent research suggests that performance in pop-out search is modulated by the trial history, or more precisely, by the search display on the preceding trial: RTs are longer when the target is changed, compared to the previous, $n-1$ trial, than when it is repeated. This *intertrial effect* has been demonstrated in several different contexts, including changes of the target-defining dimension (Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; Müller, Reimann, & Krummenacher, 2003) and the target-defining feature (Found & Müller, 1996; Maljkovic & Nakayama, 1994; Pinto, Olivers, & Theeuwes, 2005). Intertrial effects also occur when the task-irrelevant dimensions are changed (Olivers & Humphreys, 2003) and when task-irrelevant features vary across trials (Becker, 2007; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Kristjansson, Wang, & Nakayama, 2002; Maljkovic & Nakayama, 1996).

Feature Priming and Dimension Change Effects

The present study is concerned with intertrial effects from changing both the target-defining feature and its dimension. Intertrial effects of the target feature were first discovered in a pop-out search task in which participants had to search for a diamond target that could be red or green, whereas the nontargets carried the other color (Maljkovic & Nakayama, 1994). Responses were impeded when the color assignment to target and nontargets changed relative to when the colors of the target and nontargets were repeated. This *feature priming effect* has also been observed for targets varying in size (e.g., Huang et al., 2004) and orientation (e.g., Hillstrom, 2000).

Effects of changing the target dimension were first discovered by Treisman (1988). In her experiment, participants had to search for a pop-out target in three blocked conditions: In the *control* condition, participants had to find a right-tilted target among vertically oriented nontargets. In the second, *within-dimension* condition, the target could be tilted left, right, or horizontally among vertically oriented nontargets. In the third, *across-dimension* condition, the target could be a singleton along the size, orientation, or color dimension. The results show, first, that mean RTs were longer in the across- than in the within-dimension condition. Second, intertrial effects occurred only in the across-dimension block, in which the target dimension varied. In contrast, there were no intertrial effects in the within-dimension condition, in which only the target feature value varied between trials. These results indicate that changing the target dimension across trials leads to *switch costs* that are absent when only the target feature changes, and this also accounts for the higher mean RTs in the across-dimension condition than in the within-dimension condition.

Here, intertrial effects are assigned to the target dimension when the target changes from being defined along the size, color, or orientation dimension (this is the dimension change effect). Intertrial effects are assigned to the target feature when search is modulated by a change in the target feature value within a dimension—for example, when there is a change from a red to a green target along the color dimension or a change from a small to a large target along the size dimension (this is the feature priming effect).

Visual Selection Versus Postselectional View

As outlined above, efficient search in pop-out search tasks can be attributed to processes located at the stage of preattentive processing. However, it is at present unclear whether intertrial contingencies modulate early, preattentive processes concerned with target selection or whether they influence later, postselectional processes concerned, for instance, with object identification or response selection. Previously, researchers have distinguished between a *visual selection view* and a *postselectional view* of intertrial effects in search (cf. Olivers & Meeter, 2006; Becker, 2008b). According to a visual selection view, changing the target feature between trials leads to attentional switch costs, whereas repeating it speeds search by facilitating processes concerned with target selection. Among the most prominent visual selection views are the *priming of pop-out* hypothesis (Maljkovic & Nakayama, 1994, 1996) and the *dimension weighting* account (Müller et al., 1995), which are described below.

Conversely, proponents of a postselectional view claim that priming does not affect processes involved with search, but that it modulates later, postselectional processes commencing after selection of the target. Such a view has been proposed to account for both dimension- and feature-based repetition effects. According to the dimensional action model (Cohen & Magen, 1999), dimension-based intertrial effects are due to response selection processes. On this account, there is one response selection mechanism for each stimulus dimension, and intertrial effects are due to competition between different dimension-specific modules when more than one target dimension is involved (Cohen & Magen, 1999).

With regard to feature-based intertrial effects, an *episodic retrieval* view has been proposed (Huang et al., 2004). On this view, performance in a visual search task is determined by three successive stages: (a) searching for the target, (b) deciding whether a selected candidate item is in fact the target, and (c) selecting and executing the response (cf. Huang et al., 2004). According to the episodic retrieval account, changing the target feature across trials interferes with decisional processes that verify whether an already selected item is indeed the search target (Huang et al., 2004). It is important to note that on the episodic retrieval view, the verification procedure is not supposed to affect the distribution of attentional resources (e.g., Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992). Instead, it is assumed that priming effects originate from processes located at the decisional stage: After selection of a candidate target, "the system does not always proceed directly to choosing the appropriate response. Rather, it seeks to verify that this element is indeed the target" (Huang et al., 2004, p. 20).

It is notable that the visual selection and postselectional views claim that intertrial effects affect RTs at two different points in

time. According to the visual selection view, changing the target affects processes before or until selection of the target. In contrast, according to the postselectional view, intertrial contingencies modulate RTs only after visual selection of the target. That is, intertrial effects are claimed to be effective in two different time windows, before versus after selection of the search target.

Two Different Visual Selection Views for Features and Dimensions

The cornerstone of the present study is that two different visual selection views have been proposed for intertrial effects from the target feature versus its dimension. According to the priming of pop-out hypothesis, selection of the target on a given trial primes attention shifts to the target-defining feature on subsequent trials, which leads to speeded selection of that feature on subsequent trials. As a consequence, selection of the target will be facilitated on repetition trials but hampered on switch trials. This priming effect is supposed to involve only the target-defining feature and to occur in a stimulus-driven, automatic fashion (Maljkovic & Nakayama, 1994, 1996).

Whereas the priming of pop-out hypothesis represents a visual selection account of feature-based intertrial effects, the dimension weighting hypothesis deals with dimension-based effects of changing the target dimension. According to this view, attentional selection of the target requires a certain preactivation or weighting of corresponding dimension-specific maps. Weights can be conceptualized as activation patterns that are necessary to detect pop-out items within a particular stimulus dimension. It is important to note that the weight settings from the current trial will transfer to the next trial and thus modulate search performance. If the target dimension is the same as on the previous trial, the weight settings will allow immediate detection of the target so that attention can be shifted to the target position without delay. If, however, the target dimension changes and the wrong dimension is preactivated from the previous trial, the attentional weights must be shifted to another stimulus dimension in a time-consuming process. This leads to the typical result pattern of facilitation when the target dimension is repeated and across-dimension switch costs when the target dimension changes (Müller et al., 1995).[1] The priming of pop-out and dimension weighting accounts are quite similar insofar as they share central assumptions about the mechanism underlying the intertrial effect: Both hypotheses assume that the trial history modulates performance by carryover effects of target activation. Moreover, both accounts subscribe to a visual selection view and deny that intertrial effects are caused by processes concerned with object identification or response selection (e.g., Maljkovic & Nakayama, 1996; Müller & Krummenacher, 2006).

Given that both the priming of pop-out hypothesis and the dimension weighting account explain feature and dimension repetition effects in a similar manner, it might be asked whether it is necessary to propose two distinct theories of intertrial facilitation effects. From a theoretical perspective, it would be more parsimonious to explain feature-based and dimension-based intertrial effects by a single theoretical account. An idea suggested by Olivers and Humphreys (2003) is that carryover effects of target activation and nontarget suppression might primarily pertain to dimensions and, to a lesser extent, also to features.

However, despite the theoretical merits, there are several problems that have to be addressed before this idea can be pursued further. In the next sections, I first briefly describe these problems and subsequently discuss a possible solution.

Three Arguments Against a Unified Theory

Despite the similarities between the priming of pop-out hypothesis and the dimension weighting account, the two accounts also differ in at least two important respects. Whereas the priming of pop-out hypothesis claims that intertrial effects reflect variations in the target feature value, the dimension weighting account asserts that intertrial effects reflect changes of the target dimension and not its feature value. Crucially, both hypotheses are also validated by different pieces of empirical evidence that are themselves contradictory. First, intertrial effects from changing the target feature are typically absent in the within-dimension condition, in which only the target feature can change. For instance, in a visual search task in which participants had to indicate the presence or absence of an orientation singleton target, search was not modulated by repeating or changing the target orientation across trials (e.g., Müller et al., 1995). On the other hand, in a study concerned with the feature priming effect in which the target was present on all trials, changing the target orientation resulted in large switch costs of 105 ms (Hillstrom, 2000). These contradictory results from feature priming and across-dimension search tasks need to be resolved before a unified account of feature priming and dimension change effects can be proposed.

A further difference between the two visual selection views concerns the top-down penetrability of intertrial effects. The dimension weighting view asserts that potential target dimensions can also be assigned weights according to the expectations and knowledge of the participants in a top-down controlled manner. Thus, intertrial effects of the target dimension should be modifiable by top-down attentional control settings (cf. Müller & Krummenacher, 2006; see also Wolfe, Butcher, Lee, & Hyle, 2003, for a more pronounced top-down view). Consistent with this, valid precuing of the target dimension significantly reduces intertrial effects compared with a neutral cue baseline condition (Müller et al., 2003; but see also Theeuwes, Reimann, & Mortier, 2006).

In contrast, the priming of pop-out hypothesis asserts that priming is based on stimulus-driven processes that are not penetrable by top-down processes. Thus, feature priming effects should not be modifiable by knowledge or expectations of the participants. In line with this assumption, several studies have demonstrated that feature priming effects are not reduced when the target-defining feature varies in predictably alternating sequences (Becker, 2008b; Hillstrom, 2000; Maljkovic & Nakayama, 1994; Müller et al., 2003). Preknowledge about the exact target feature does not even reduce priming effects when observers subvocally utter the target feature prior to its presentation (Maljkovic & Nakayama, 1994; but see also Folk, in press; Leonard & Egeth, in press). This difference in the top-down penetrability of feature priming and dimension

[1] It should be noted that repetition facilitation effects cannot in principle be distinguished from costs produced by changes of the target, because intertrial effects lack a neutral baseline (but see "memory kernel analysis"; Maljkovic & Nakayama, 1994).

change effects presents a second problem for a unified explanation of these effects.

A further problem for a unified account of feature priming and dimension change effects arises at a purely empirical level. The currently available evidence indicates that feature priming effects reflect processes located at the preattentive or selectional stage, whereas dimension change effects arise from processes at the postselectional stage. First, with regard to the feature priming effect, Goolsby and Suzuki (2001) demonstrated that both precuing the target position and presenting the target alone in the search display reduce or even eliminate the effect of the previous item. The absence of priming under these circumstances indicates that priming usually affects processes involved with search. Moreover, several eye tracking studies demonstrate that saccadic latencies to the target decrease as the number of feature repetition trials increases (Kowler, Martins, & Pavel, 1984; McPeek, Maljkovic, & Nakayama, 1999). Thus, intertrial contingencies based on the target feature apparently modulate processes concerned with target selection, supporting a visual selection view of feature priming (Goolsby & Suzuki, 2001; McPeek et al., 1999; but see also Huang & Pashler, 2005).

In contrast, dimension-based intertrial effects have been demonstrated to occur even on nonsearch trials when the target is presented alone (Mortier, Theeuwes, & Starreveld, 2005) and to be susceptible to modifications of response contingencies (Cohen & Magen, 1999; Kumada, 2001). These results are not in line with a visual selection view and favor a postselectional view of the dimension change effect, like the dimensional action model (Cohen & Magen, 1999; but see also Müller & Krummenacher, 2006).

In sum, the challenges a unified theory of intertrial effects of features and dimensions must meet are as follows. First, it must explain why feature priming effects often fail to occur in the within-dimension condition of studies designed to investigate the dimension change effect. Second, it has to account for the differences in the top-down penetrability of feature priming versus dimension change effects. Third, it has to account for different empirical results that favor a visual selection view for the feature priming effect and a postselectional view for the dimension change effect.

Resolving the Difficulties

Despite the differences between the priming of pop-out hypothesis and the dimension weighting account, it might still be possible to incorporate both into a single theoretical framework. It should be noted that feature priming and dimension change effects have been assessed in two different paradigms that employ different experimental methods. The most obvious difference is that in a typical feature priming search task, the features of target and nontargets typically exchange on switch trials, such that the target inherits the feature formerly associated with the nontargets and vice versa (e.g., displays containing a red target among green nontargets are followed by displays containing a green target among red nontargets). In across-dimension search tasks, on the other hand, only the target feature or dimension changes, whereas the nontarget features remain constant throughout the experiment (e.g., in the across-dimension condition, displays containing a red target among grey nontargets are followed by displays with a larger grey target among grey nontargets). A second major difference is that studies investigating the feature priming effect typically employ a *compound search task* in which the target is present on all trials, and the response is determined by an additional feature of the target. In contrast, studies examining dimension change effects typically employ a *simple search task* in which the target is present on only half of all trials, and participants have to indicate the presence or absence of the target in the display.

Taken together, these two differences between the experimental methods might explain why feature priming effects are typically absent in the within-dimension condition of simple search tasks. If it is assumed that intertrial effects primarily pertain to the target dimension and only to a lesser extent to the target feature (cf. Olivers & Humphreys, 2003), it is possible that the simple search task is not sensitive enough to detect feature priming effects. This conjecture might even seem more plausible when one considers that simple search tasks are generally regarded as suboptimal to examine effects of focal attention because the response can be elicited with minimal attentional involvement (e.g., Bravo & Nakayama, 1992).

Moreover, in simple search tasks, the target-defining and response-indicative features are bound together into a single object; participants respond to the presence of the target by pressing one button and to its absence by pressing a different button. Accordingly, it is possible that simple search tasks allow response-related processes to contribute more to intertrial effects than do compound search tasks, where the target-defining feature is present on all trials and a different feature determines the response (Bravo & Nakayama, 1992). This difference between the tasks might already account for the different contributions of selectional and postselectional processes to feature priming versus dimension change effects. If it is assumed that postselectional processes are to a larger extent top-down penetrable, this difference between the tasks may also account for the finding that dimension change effects are top-down penetrable to a greater extent than feature priming effects. The above discussion indicates that the differences between feature priming and dimension change effects might not be due to different mechanisms mediating feature priming versus dimension change effects, but to differences in the experimental design.

Deciding Between a Visual-Selection and a Postselectional View

To show that a single framework can account for both feature- and dimension-based intertrial effects, at least two challenges must be met. First, feature priming and dimension change effects must be tested in the same experimental settings, to demonstrate that the absence of feature priming effects in the within-dimension condition is due to specifics of the experimental design and does not signify a critical difference between feature priming and dimension change effects. Second, both feature priming effects and dimension change effects must demonstrably arise from the same stage of processing: either both reflect altered visual selection or both reflect postselectional processes. On an experimental level, it is quite difficult to distinguish between a visual selection and postselectional view. At first glance, eye movements might be regarded as the prime indicator for visual selection. However, at the same time, saccades are also motor responses. Specifically, in a saccade task, participants respond by executing a saccade to the

predefined search target. In such a task, a saccade might not be a good indicator for processes of visual selection; it might be more akin to executing a motor response, possibly involving conscious decisions on where to look and other processes typically related to response selection (e.g., Findlay, 1997). In a saccade task, it is thus unclear whether saccadic responses indicate visual selection processes or postselectional processes (cf. Becker, 2008a, 2008b).

To circumvent this problem, I measured both manual RTs and eye movements in a compound visual search task in which the to-be-selected target-defining feature is different from the response-indicative feature. Moreover, participants were given no explicit instructions about their eye movements, but the response-indicative feature was chosen so that it required foveation for discrimination. Responses were given manually by pressing one of two buttons. These conditions may allow a reasonably straightforward assessment of visual selection versus postselectional accounts, because the to-be-selected and response-indicative features are not confounded either on the stimulus level or on the response level. With this, saccades to the target should reliably indicate processes of visual selection (in short "selectional processes") without being contaminated by postselectional processes concerning, for instance, response selection.

Intertrial effects in the current study are regarded as selectional if repeating or changing the target affects the *target fixation latencies*, that is, the duration needed to fixate on the target (measured from the onset of the search display). Conversely, intertrial effects are classified as postselectional if repeating or changing the target modulates the *target fixation durations*, that is, the duration the eyes remain fixated on the target after visual selection in order to select a response. Naturally, it is also possible that both selectional and postselectional processes contribute to intertrial effects. In this case, the magnitude of intertrial effects in the target fixation latencies and target fixation durations show whether and to what extent priming effects observed in the mean RTs can be attributed to selectional or postselectional processes.

It is possible to criticize the proposed method for distinguishing between selectional and postselectional processes. For example, it may be argued that the target fixation latencies might include erroneous selections of nontargets and thus are not a reliable indicator of target selection. Indeed, prolonged target fixation latencies on trials where the target feature or its dimension changes may be due to extended fixations on nontargets. In this case, the target fixation latency measure may reflect postselection instead of selection processes. Even if this possibility is taken into account, however, it may be argued that target fixation latencies still reflect the most appropriate measure for processes of visual selection. Note that intertrial effects on the nontarget fixation durations can be compatible with the visual selection view, because both the priming of pop-out account and the dimension weighting account propose that on trials where the target feature or dimension changes, the "wrong" feature or dimension is prioritized for visual selection, which in turn leads to a higher probability of erroneously selecting one of the nontargets. Both accounts also leave unspecified whether weight-shifting processes that are necessary for target selection occur before or after selection of any nontargets. Hence, elongated fixation durations on nontargets might not reflect postselectional processes concerned with response selection, but might indicate time-consuming weight-shifting processes that are necessary for target selection (cf. Becker, 2008a, 2008b). Second, it is noteworthy that the target fixation durations also constitute the most straightforward measure for postselection processes. This holds because current postselectional accounts have little to say about selection of nontargets but instead explain feature- and dimension-based intertrial effects with reference to decisional or response-selection processes that only pertain to the target. Third, and most important, the question of whether feature priming is due to selectional or postselectional processes was recently investigated in a study using the same task as here (Becker, 2008b). The results indicated that when participants searched for a color or size singleton target, changing the target-defining feature led to a higher proportion of trials on which a nontarget was selected first but did not affect the fixation durations on the target or the nontargets (Becker, 2008b). As argued above, the finding that intertrial contingencies modulate the probability of selecting a nontarget is in line with a visual selection view (see also Becker, 2008a). This indicates that target fixation latencies can be used as an appropriate indicator for processes affecting selection in intertrial priming.

Overview of Experiments

To investigate whether feature priming and dimension change effects can be explained by a single theoretical account, I investigated the two effects using the same search task, and eye movements were measured to determine whether feature- and dimension based intertrial effects can be explained by a single mechanism. Experiments 1 and 2 tested feature priming and dimension change effects in a compound search task. If both feature- and dimension-based intertrial effects are due to attentional processes, then changing the target should lead to elongated target fixation latencies, compared with trials on which the target from the previous trial is repeated. On the other hand, if intertrial contingencies of the target feature and dimension both modulate postselectional processes, then repeating or changing the target should primarily modulate the target fixation durations, but not the target fixation latencies. If feature- and dimension-based intertrial effects require different explanations, then changing the target feature versus its dimension should affect the target fixation latencies and durations differently.

Experiment 3 was designed to explore why feature priming effects are typically absent in the within-dimension condition (e.g., when only the target feature changes but the nontarget features remain constant). More precisely, Experiment 3 examined whether changes in the target feature alone are sufficient to produce priming effects or whether target and nontarget have to exchange features on switch trials. Experiments 4 and 5 tested whether holding the nontargets constant across all trials is sufficient to eliminate priming effects and what kind of stimulus change is required to produce priming effects.

In all experiments, the intertrial contingencies of the target-defining feature and the response-indicative feature were varied independently of each other. The results of response-based intertrial effects are reported experiment by experiment; however, because these effects were found to be quite weak and unstable across experiments, a discussion of these results is deferred until later in the article.

Experiment 1

The aim of the first experiment was to investigate the feature priming effect. Participants had to search for a size singleton target that could be either smaller or larger than the nontargets and respond to a small *x* or + located inside the target. When the target constituted the larger item, the nontargets were all smaller; when the target was the smaller item, the nontargets were larger. Compared to the previous, $n-1$, trial, the target and nontarget features could thus either repeat or switch. On switch trials, the target inherited the features formerly associated with the nontargets and vice versa (see Figure 1A for an example of the displays).

Independently of this random variation of the target-defining feature, the response-indicative item inside the target could also either repeat or change compared to the previous, $n-1$, trial. This allows the intertrial effects of the target-defining and response-indicative feature to be assessed separately from each other.

Method

Participants

Sixteen students from the University of Bielefeld, Bielefeld, Germany, participated in the experiment as paid volunteers. Six of them were male, 10 female, and they had a mean age of 24. All participants had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Materials

An Intel Pentium 4 CPU 3.00 GHz computer with a 19-in. SVGA color monitor controlled the timing of events and generated the stimuli. Stimuli were presented with a resolution of 1,024 × 768 pixels and a refresh rate of 99.9 Hz. For recording of eye movements, I used a video-based infrared eye-tracking system (iViewX tracker; SensoMotoric Instruments, Teltow, Germany) with a spatial resolution of 0.1° and a temporal resolution of 240 Hz. Participants were seated in a dimly lit room with their head fixated by the eye tracker's chin rest and forehead support, and they viewed the screen from a distance of 92 cm. A standard USB optical mouse was used to register manual responses. Event scheduling and RT measurement were controlled by the Presentation software (Neurobehavioral Systems, 2006).

Stimuli

The response-indicative stimuli consisted of five black *x* or + stimuli (0.2° × 0.2°; font size = 14 pt) that had to be fixated in order to be discriminated from each other. They were located in the center of five green squares (21 cd/m^2). The squares could either be small (1.9° × 1.9°) or large (2.8° × 2.8°) and were located on the outlines of an imaginary circle with a diameter of 6.5°. All stimuli were equally spaced from each other, beginning at the 12 o'clock position, and were presented on a constantly white background (92 cd/m^2).

Design

The experiment consisted of the 2 × 2 within-subjects conditions $n-1$ *target-defining feature* and $n-1$ *response-indicative feature*. The intertrial contingencies of the target–nontarget features and response were varied in the following way: The target on Trial *n* could either be the same as in the previous, $n-1$ trial (same-target trial), or it could inherit the size previously associated with the nontargets (switch trial). Additionally, the response could be repeated (same response trial), or it could differ from the previous, $n-1$ trial (different response trial).

The position of the target and the combinations of each target type with each response-indicative item were controlled such that each response-indicative item appeared together with each target type (small vs. large) on each of the five possible locations equally. Moreover, the number of response-indicative items in the display was controlled such that it always included equal numbers of *x* and + stimuli (exempting the target).

The experiment also included a second block in which an irrelevant singleton distractor was presented. However, the results from this condition are not reported because they are irrelevant to the research question. In the relevant condition, participants completed 160 trials.

Procedure

Each trial started with the presentation of a small black fixation cross. Participants were instructed to fixate on the center of the cross. At the beginning of each trial, a fixation control was implemented: The stimulus display was only presented if the tracking was stable (no blinks) and the gaze was within 50 pixels (1°) of the center of the fixation cross for at least 350 ms (within a time window of 3,000 ms). Otherwise, participants were calibrated anew (five-point calibration) and the next trial started again with the fixation control.

Upon presentation of the stimulus display, participants were required to search the display for the odd-sized square and to press the right mouse button if the item inside the square was a + and the left button if it was an *x*. The stimulus display remained on screen until response and was immediately succeeded by a feedback display. The feedback consisted of the black printed words *right* [*richtig*] or *wrong* [*falsch*] (in German, 14 pt.), which were presented centrally and remained on screen for 500 ms. After an intertrial interval of 500 ms in which a blank white screen was presented, the next trial started with the presentation of the fixation cross.

Before the experiment, participants were calibrated with a 5-point calibration and were given written instructions. Moreover, participants were instructed to respond to the target as fast as possible without making mistakes.

Results

Data

Manual responses and eye data were treated as separate measures to which different exclusion criteria apply. Note that the eye data remain valid even if the manual response is wrong, because a fixation can be made to a target but the wrong response may be selected.

Manual RTs above 2,000 ms were excluded from both RT and error analyses, which resulted in a loss of 2.77% of the data. Before analyses of the eye data, they were subjected to a drift

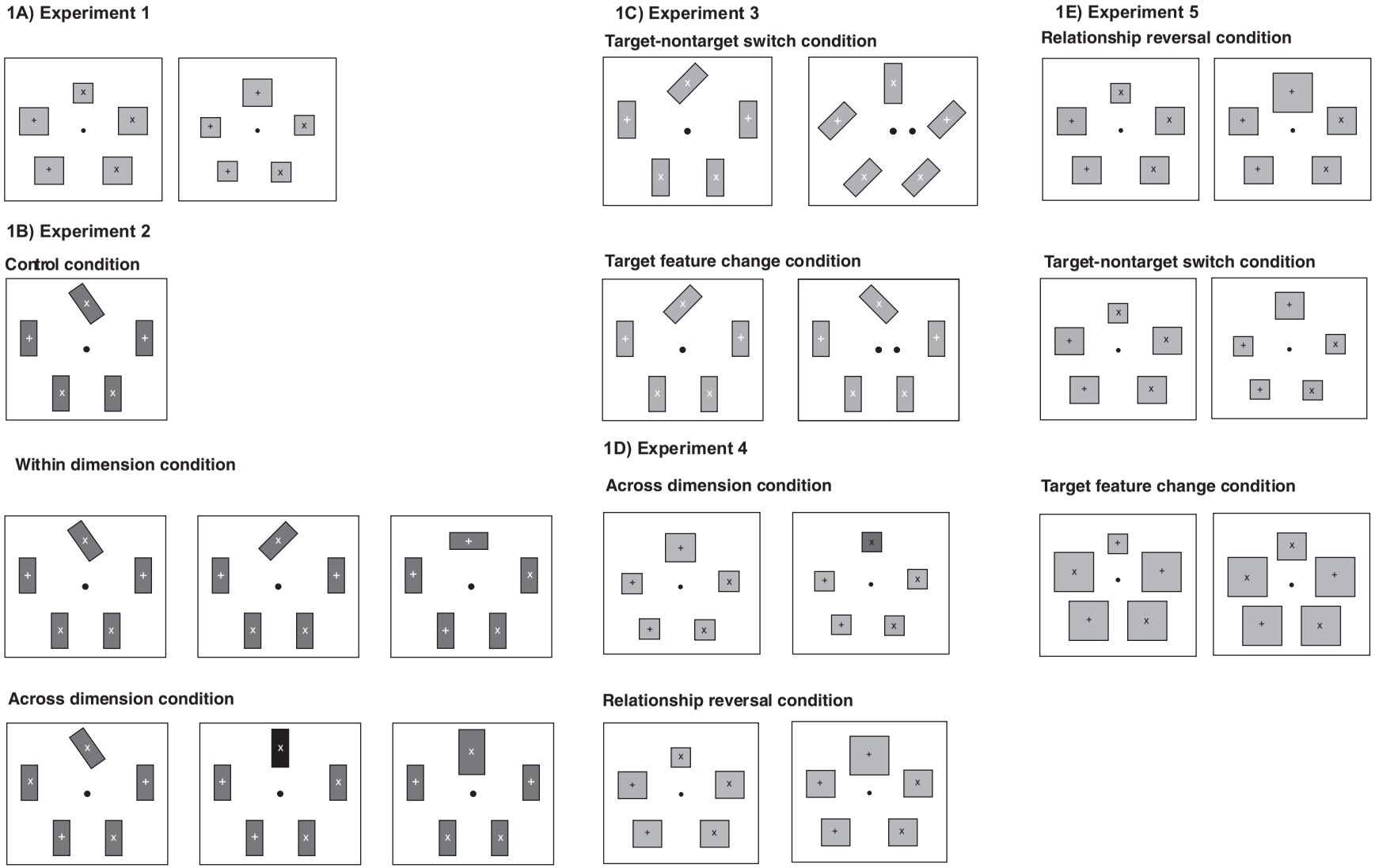

Figure 1. Examples of the stimulus displays in Experiments 1 to 5. In all example displays, the target is depicted at the 12 o'clock position, whereas in the experiments themselves, the target position varied.

correction: At the onset of the search display, the gaze was assumed to have rested in the center, with the deviation being subtracted from all subsequent eye position data of this trial. Eye data were then excluded from analyses if the gaze had not been on the target within 2,000 ms from the beginning of the trial. This resulted in a loss of 0.33% of the eye data. The eyes were counted as fixating on the target if the gaze was within a distance of 50 pixels (1°) from the center of the response-indicative *x* or + stimulus and no saccade occurred (velocity smaller than 30°/s).

The data were analyzed by analysis of variance (ANOVA), and all ANOVAs were subjected to Mauchly's test of sphericity. When violations of sphericity occurred, the Greenhouse-Geisser corrected *p* values were reported (together with the uncorrected degrees of freedom). For assessment of intertrial effects, partial eta-squared was also included as a measure of effect size.

Manual Responses

RTs. Figure 2 illustrates the mean RTs and error scores of Experiment 1. A 2 × 2 ANOVA comprising the variables $n-1$ target-defining feature (same target vs. different target) and $n-1$ response-indicative feature (same response vs. different response) calculated over the mean RTs yielded a main effect of changing the target-defining feature, $F(1, 15) = 27.47$, $MSE = 1{,}963.86$, $p < .001$, $\eta^2 = .65$. Mean RTs were on average 58 ms faster when the target size was repeated ($M = 1{,}090$ ms) than when it switched ($M = 1{,}148$ ms). Repeating the response-indicative item did not significantly influence RTs ($F < 1$; $\eta^2 < .01$), and the interaction was similarly nonsignificant ($F < 1$; $\eta^2 < .01$).

Errors. The same analyses calculated over the mean error scores did not yield any significant effects (all ps $> .13$). This indicates that the results were not due to a speed–accuracy tradeoff.

Eye Movement Data

Figure 3 illustrates the mean target fixation latencies and target fixation durations of Experiment 1.

Target fixation latencies. A 2 × 2 ANOVA yielded only a significant main effect of $n-1$ target size, $F(1, 15) = 29.59$, $MSE = 2{,}187.51$, $p < .001$, $\eta^2 = .66$. On average, target fixations occurred 63 ms earlier when the size of the target and nontargets was repeated ($M = 492$ ms) than when it switched ($M = 555$ ms; partial $\eta^2 = .66$). None of the remaining effects were reliable (all ps $> .20$; all η^2s $< .11$).

Target fixation durations. The same ANOVA was also computed over the mean durations that the eyes remained fixated on the target after visual selection. However, the analysis did not yield any significant main effects or interactions (all Fs ≤ 1; all η^2s $< .01$).

Discussion

The results from the first experiment support a visual selection view of the feature priming effect. First, the finding that priming effects occur only with respect to the target-defining feature size and not for repetitions of the response-indicative feature effectively rules out response-based or stimulus–response-based accounts as an explanation of the observed priming effect (Olivers & Humphreys, 2003). Second, the results from the eye movement measures also support the view that feature priming affects processes concerned with visual selection: Changing the target-defining feature across trials led to elongated target fixation latencies but did not affect the target fixation durations. This shows that intertrial contingencies modulate the time needed to visually select the target, without postselectional processes further contributing to priming effects. This is also further reflected in the fact that priming effects on manual RTs and on target fixation latencies were identical in magnitude (58 ms and 63 ms, respectively), leaving no room for later processes to contribute to priming.

Experiment 2

Experiment 2 was designed to investigate both feature- and dimension-based intertrial effects. It consisted of a control, a within-dimension condition, and an across-dimension condition. In

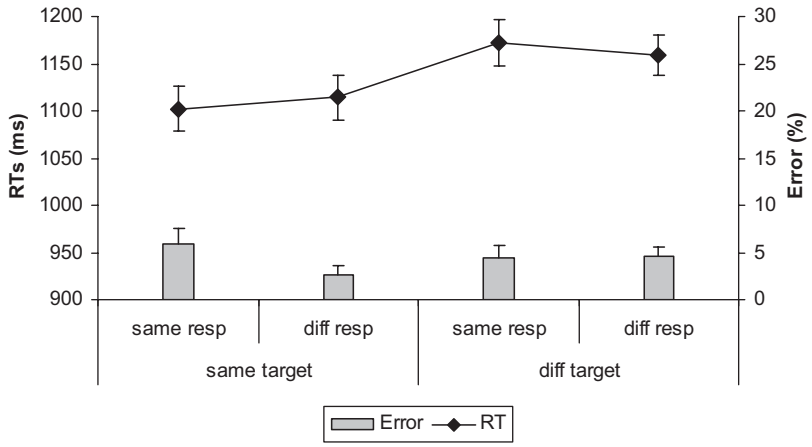

Figure 2. Mean response times (line graph, left *y* axis) and error scores (bar graph, right *y* axis) of Experiment 1, depicted as a function of whether the target-defining feature size was repeated (same target) or switched (diff target) and whether the response-indicative item was repeated (same resp) or changed (diff resp). Error bars represent plus or minus one standard error of the mean. RT = response time; resp = response; diff = different.

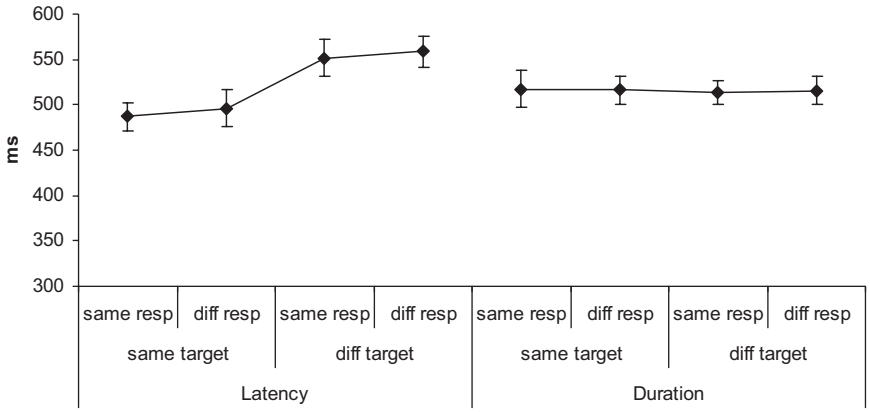

Figure 3. Mean target fixation latencies and target fixation durations of Experiment 1, depicted as a function of whether the target-defining feature size was repeated (same target) or switched (diff target) and whether the response-indicative item was repeated (same resp) or changed (diff resp). Error bars represent plus or minus one standard error of the mean. Resp = response; diff = different.

the across-dimension condition, the target changed randomly between the dimensions size, orientation, and color, whereas the nontargets always possessed the same feature (Müller et al., 1995). The target could be a larger sized bar, an odd-colored bar, or a bar tilted 45° to the right, whereas the nontargets were consistently constituted by grey, vertical nontargets of smaller size. In the within-dimension condition, the target dimension was held constant and only the orientation of the target varied randomly. Thus, the target was constituted by a bar oriented 45° to the right, 45° to the left, or horizontally. Finally, in the control condition, the target orientation was held constant throughout a block (tilted 45° to the right), representing a baseline condition against which performance from the other two conditions could be compared (see Figure 1B for an example of the displays used in Experiment 2). As is customary in these experiments, only trials containing the right-tilted target were submitted to analysis.

Experiment 2 was closely modeled on the typical visual search paradigms used to assess dimension change effects. The only deviation consisted in the fact that the compound search task from Experiment 1 was used. Thus, deviating from the commonly used simple search task, the target was present on all trials, and participants had to indicate whether the item located inside the target was an *x* or a +. Eye movements were measured in the same way as in Experiment 1.

Method

Participants

Eighteen participants from the University of Bielefeld, Bielefeld, Germany, took part in Experiment 2. Eleven of them were male, 7 were female, and they had a mean age of 25. All participants had normal or corrected-to-normal vision and were not informed about the purpose of the experiment.

Materials

The materials were the same as in Experiment 1.

Stimuli

The response-indicative stimuli consisted again of five *x* or + stimuli that were colored white and presented against the background of five grey or black bars. Across all conditions, the nontarget bars were consistently oriented in a vertical direction, were grey, and were relatively small (0.6° × 1.9°). In the within-dimension condition, the target bar could be either oriented 45° to the right, oriented 45° to the left, or presented horizontally (90°). In the across-dimension condition, the target bar either was of a larger size (0.9° × 3°) than the nontargets (0.6° × 1.9°), was black, or was oriented 45° to the right. The stimulus positions were the same as in Experiment 1.

Design

The experiment consisted of three within-subjects conditions that were presented blockwise. The order of blocks was balanced across participants. In the control condition, participants searched for a grey bar oriented to the right presented among vertically oriented nontarget bars. In the within-dimension condition, the task was to find a bar that could be oriented to the right, to the left, or horizontally and was presented among vertically oriented nontargets. Finally, in the across-dimension condition, participants searched for a target bar that could be either black, oriented to the right, or of larger size than the nontarget bars. In the within- and across-dimension conditions, the target could either be the same as in the previous, $n-1$ trial, constituting a same-target trial, or the target could differ from the previous target, which represents a different-target trial.

In the within-dimension and across-dimensions conditions, the number of trials for each target type was controlled to ensure that an equal number of trials were available for analysis across the conditions. Additionally, the target position, the number of each type of response-indicative item, and the combination between target position and the response-indicative item were controlled in the same way as in Experiment 1. In the control condition, participants completed 60 trials; in the within- and across-dimension conditions, they completed 180 trials.

Procedure

The procedure was the same as in the previous experiment. On average, it took 40 min to complete the experiment.

Results

Data

Across all conditions, the analyses included only trials in which the target was oriented to the right. This left 3,240 trials for analysis. As in Experiment 1, manual responses and eye movement data were separately cleared from outliers. Concerning the manual responses, RTs above 2,000 ms were excluded from both RT and error analyses, which resulted in a loss of 1.91% of the data. As in Experiment 1, eye data were excluded from analysis if the gaze had not been on the target within 2,000 ms from the beginning of the trial. This resulted in a loss of 0.22% of the eye movement data.

Manual Responses

Figure 4 illustrates the mean RTs and error scores in Experiment 2.

RTs. A one-way ANOVA calculated over the mean RTs of the control, within-dimension, and across-dimension conditions yielded a significant main effect of search condition, $F(2, 34) = 4.95$, $MSE = 10{,}425.34$, $p = .013$. Mean RTs were inflated by 37 ms in the across-dimension condition ($M = 1{,}013$ ms) when compared to the control condition, $M = 976$ ms, $F(1, 17) = 6.52$, $MSE = 5{,}130.19$, $p = .014$, and by 41 ms when compared to the within-dimension condition, $M = 971$ ms, $F(1, 17) = 6.77$, $MSE = 5{,}295.03$, $p = .011$. In contrast, performance in the within-dimension and control condition did not differ significantly, $F(1, 17) = 1.17$, $p = .26$.

Second, intertrial effects were examined in a 2×2 ANOVA with the variables $n - 1$ target-defining feature and $n - 1$ response-indicative feature calculated over the mean RTs. In the within-dimension condition, there were no effects of changing either the target-defining feature ($F < 1$) or the response-indicative feature, $F(1, 17) = 1.69$, $p = .21$. The interaction was not reliable ($F < 1$; all η^2s $< .10$).

The same analysis calculated over the mean RTs of the across-dimension condition conversely showed a significant main effect of the $n - 1$ target dimension, $F(1, 17) = 7.7$, $MSE = 4{,}172.95$, $p = .013$, $\eta^2 = .31$, with participants responding 42 ms more slowly when the target dimension changed ($M = 1{,}028$ ms) than when it was repeated ($M = 986$ ms). In contrast, repeating or changing the response-indicative feature did not affect performance, $F(1, 17) = 1.81$, $p = .2$, $\eta^2 < .10$, and did not interact with the dimension change effect ($F < 1$; $\eta^2 < .01$). In the control condition, RTs were slower on response repetition trials ($M = 990$ ms) than on different response trials, $M = 957$ ms, $MSE = 1{,}375.44$, $F(1, 17) = 7.25$, $p = .015$, $\eta^2 = .29$.

Errors. The one-way ANOVA calculated over the mean error scores yielded a significant main effect of the search condition, $F(2, 34) = 4.25$, $MSE = 12.71$, $p = .023$, reflecting that more errors were committed in the across-dimension condition ($M = 7.0\%$) than in the control condition, $M = 3.5\%$, $F(1, 17) = 8.31$, $MSE = 12.98$, $p = .01$. In the within-dimension condition, intermediate error scores occurred ($M = 5.2\%$), which did not differ significantly from the control, $F(1, 17) = 1.82$, $p = .2$, or the across-dimension condition, $F(1, 17) = 2.57$, $p = .13$.

The intertrial analysis for the within-dimension condition yielded only a significant main effect of response repetition, $F(1, 17) = 8.05$, $MSE = 56.10$, $p = .011$, with participants committing 7.6% errors on response repetition trials and 2.6% on different

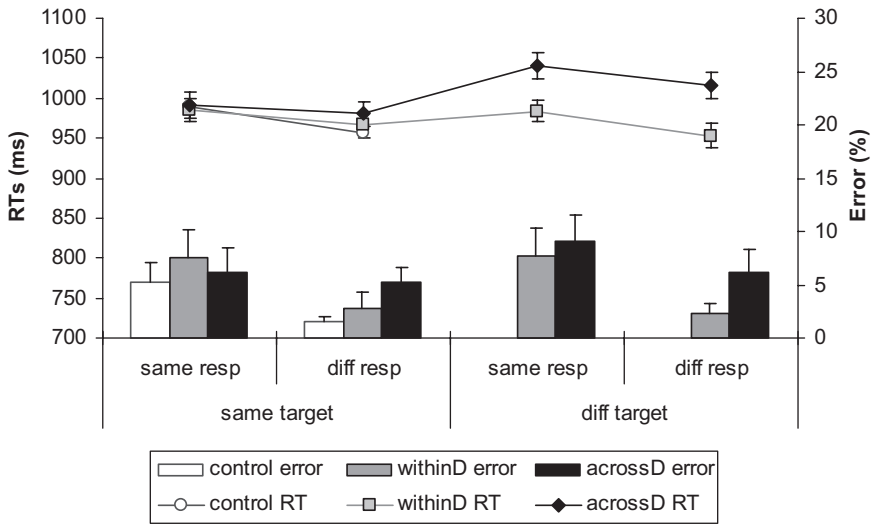

Figure 4. Mean response times and error scores of the control, within-dimension, and across-dimension conditions of Experiment 2, depicted as a function of whether the target-defining feature or dimension was repeated (same target) or changed (diff target) and whether the response-indicative item was repeated (same resp) or changed (diff resp). Error bars represent plus or minus one standard error of the mean. RT = response time; resp = response; diff = different; withinD = within-dimension; acrossD = across-dimension.

response trials. In the across-dimension condition, mean error scores were conversely affected neither by repetitions of the target-defining feature nor by the response-indicative feature (all $ps > .3$). Finally, in the control condition, participants on average committed 5.3% errors when the response-defining feature was repeated and 1.6% errors when it differed from the previous response, which just failed to reach significance, $F(1, 17) = 3.94$, $MSE = 31.12$, $p = .063$.

Eye Movement Data

The mean target fixation latencies and target fixation durations of Experiment 2 are illustrated in Figure 5.

Target fixation latencies. A one-way ANOVA calculated over the mean target fixation latencies in the control, within-dimension, and across-dimension conditions did not show any significant differences across the search conditions ($F < 1$). Moreover, the target fixation latencies did not show any significant intertrial effects, either in the within-dimension condition (all $ps > .28$; all $\eta^2 s < .02$) or in the across-dimension condition (all $ps > .44$; all $\eta^2 s < .04$).

Target fixation durations. A one-way ANOVA computed over the mean target fixation durations showed marginally significant differences between the control, within-dimension, and across-dimension conditions, $F(2, 34) = 2.72$, $MSE = 4{,}935.83$, $p = .080$. Target fixation durations were significantly longer in the across-dimension condition ($M = 624$ ms) than in the control condition, $M = 581$ ms, $F(1, 17) = 6.08$, $MSE = 2{,}794.95$, $p = .025$, and in the within-dimension condition, $M = 574$ ms, $F(1, 17) = 2.98$, $MSE = 7{,}692.62$, $p = .103$. The mean fixation durations in the within-dimension condition did not differ significantly from the control condition ($F < 1$). Furthermore, fixation durations in the within-dimension condition were not modulated by intertrial contingencies of either the target-defining feature or the response-indicative item (all $ps > .3$). However, in the across-dimension condition, target fixation durations were significantly longer when the target dimension was changed ($M = 641$ ms) relative to when it was repeated, $M = 597$ ms, $F(1, 17) = 7.14$, $MSE = 4{,}781.79$, $p = .016$, $\eta^2 = .30$. Repeating or changing the response-indicative feature did not have an effect, $F(1, 17) = 1.71$, $p = .21$, $\eta^2 < .10$, and did not interact with the dimension change effect ($F < 1$; $\eta^2 < .01$).

Discussion

Unlike Experiment 1, Experiment 2 did not show any signs of feature-based intertrial effects. In contrast, the results showed a significant dimension change effect, with longer RTs when the target dimension changed than when it was repeated, compared to the previous, $n-1$ trial. Apparently, changing the target dimension led to significant costs, indicated by longer response times in the across-dimension condition than in the control and the within-dimension conditions.

However, inspection of Figure 5 reveals that the target fixation latencies are obviously not modulated by repetitions or changes of the target dimension. Instead, the dimension change effect can be seen only in the mean target fixation durations. At first glance, these results do not seem to be in line with the hypothesis of the dimension weighting account that the dimension change effect arises from a process of attentional weight shifting that guides attention to the target. In this case, intertrial contingencies based on changes in the target dimension should have modulated only processes that precede target selection (e.g., Müller et al., 1995; Müller & Krummenacher, 2006). In contrast, the present results suggest that intertrial changes in the target dimension modulate processes only after target selection. This may be taken to show that changing the target dimension interferes with later postselectional processes concerning, for example, processes of perceptual

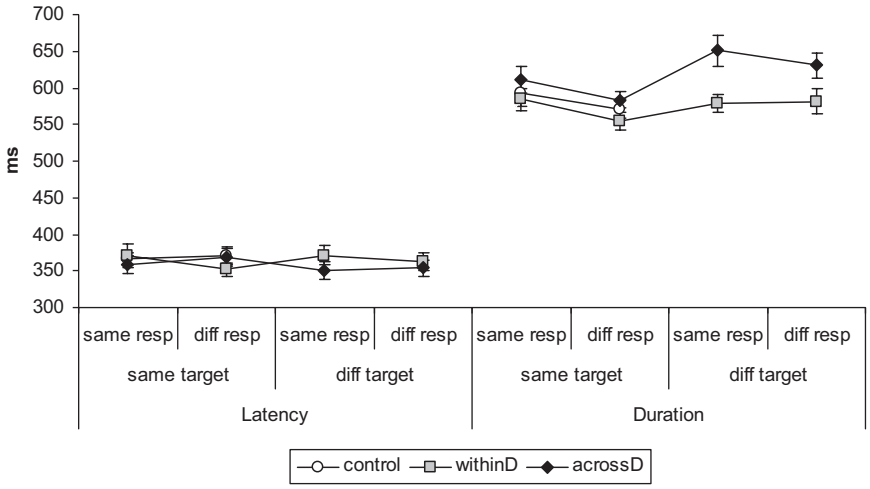

Figure 5. Mean target fixation latencies and target fixation durations of the control, within-dimension, and across-dimension conditions of Experiment 2, depicted as a function of whether the target-defining feature size was repeated (same target) or switched (diff target) and whether the response-indicative item was repeated (same resp) or switched (diff resp). Error bars represent plus or minus one standard error of the mean and may be smaller than the plotting symbol. Resp = response; diff = different; withinD = within-dimension; acrossD = across-dimension.

identification and decision- or response-related processes, in line with previous findings (e.g., Mortier et al., 2005; Theeuwes et al., 2006). However, the compatibility of these results with the dimension weighting account is discussed in more detail in the General Discussion.

More important, the results of the dimension change effect are directly contrary to the results for feature priming (see Experiment 1), where changing the target feature was found to modulate only target fixation latencies but not target fixation durations (see Figure 3). This dissociation indicates that feature priming and dimension change effects are not mediated by the same underlying mechanism.

Intriguingly, the results of Experiment 2 are also at odds with the priming of pop-out hypothesis. On this account, feature-based intertrial effects should have occured in the within-dimension condition, where that target orientation varied across trials. Repeating versus changing the target orientation across trials should have led to significant priming effects because, on the priming of pop-out account, intertrial effects are mainly due to target activation carrying over to the next trial(s) (Maljkovic & Nakayama, 1994). On this *target activation view*, repeating or changing the target feature alone should always result in priming effects, notwithstanding whether the nontarget features remain constant, as in Experiment 2, or whether target and nontarget features switch, as in Experiment 1 (Maljkovic & Nakayama, 1994).

Several different explanations can conceivably account for the fact that feature priming effects occurred only in Experiment 1, but not in the within-dimension condition of Experiment 2. First, it is possible that changing the target-defining feature only results in significant switch costs on trials in which target and nontarget exchange features on switch trials, when the target inherits the features formerly associated with the nontargets and vice versa. In contrast, when the nontargets remain constant, effects may be small, as in Experiment 2. Second, it is possible to attribute the diverging results to differences in variations in the features used—a size singleton target in Experiment 1 and an orientation singleton target in Experiment 2.

The next two experiments were designed to investigate which of the conjectures delineated above might account for the finding that feature priming effects occurred only in Experiment 1 but not in Experiment 2.

Experiment 3

The aim of Experiment 3 was to find out whether feature priming effects critically depend on switches between target and nontarget features. To investigate feature priming effects under similar conditions, participants had to search for an orientation singleton, as in the within-dimension condition of Experiment 2.

To test effects of target–nontarget switches, I implemented two conditions: In the first, *target change* condition, only the target-defining feature varied across trials, whereas the nontargets remained constant, replicating the condition from the previous experiment. In the second, *target–nontarget switch* condition, the target and nontargets exchanged features on switch trials (as in Experiment 1). Thus, in the target change condition, the target could be oriented to either the left or the right and was presented among consistently vertically oriented nontargets. In the target–nontarget switch condition, the target could be oriented either to the right or in a vertical direction, with the nontargets assuming the opposite orientation (see Figure 1C for an example of one of the displays).

As in the last experiment, only trials with identical search displays were compared, thus restricting the analyses to trials in which the target was tilted to the right and presented among vertically oriented nontargets.

Method

Participants

Eight participants with normal or corrected-to-normal vision took part in Experiment 3 for a small amount of money. Half of them were female, half were male, and they had a mean age of 25. None were informed about the purpose of the experiment.

Materials

The materials were the same as in the first two experiments.

Stimuli

The response-indicative stimuli consisted again of five *x* or + stimuli that were black and presented against the background of five green bars (0.6° × 1.9°). In the target change condition, the nontarget bars were consistently oriented in a vertical direction with the target being oriented 45° to either the right or the left. In the target–nontarget switch condition, either the target bar was oriented to the right and presented among vertically oriented nontargets or it was oriented vertically, whereas all nontargets were oriented 45° to the right. The number and position of the stimuli were the same as in Experiments 1 and 2.

Design

The experiment consisted of the following 2 × 2 × 2 within-subjects conditions: trial type, intertrial contingency of the target-defining feature, and intertrial contingency of the response-indicative feature. The target change and target–nontarget switch conditions were presented blockwise, and the order of blocks was balanced across participants. Otherwise, the design closely resembled that of Experiments 1 and 2.

In the target change condition, the participants searched for a right- or left-oriented green bar among vertically oriented green nontarget bars. In the target–nontarget switch condition, target and nontarget features exchanged on switch trials. Thus, the target could either be tilted to the right while all nontargets were oriented vertically, or vice versa. Each condition comprised 220 trials so that each participant completed 440 trials. On average, it took 1 hr to complete the experiment.

Procedure

The procedure was the same as in the previous experiment.

Results

Data

As in Experiment 2, only trials in which the target was tilted to the right were subjected to analysis. This left 1,760 trials for

statistical analysis. Concerning the manual responses, reaction times above 2,000 ms were excluded from both RT and error analyses, which resulted in a loss of 4.43% of the data. Excluding all eye data from analyses in which the gaze had not been on the target within 2,000 ms from the beginning of the trial resulted in a loss of 1.99% of the eye data.

Manual Responses

Figure 6 illustrates the mean RTs and error scores of the target–nontarget switch condition and target change condition of Experiment 3.

RTs. A 2 × 2 × 2 ANOVA comprising the variables search condition (target change vs. target–nontarget switch condition), *n* −1 target-defining feature (same target vs. different target), and *n* −1 response-indicative feature (same response vs. different response) calculated over the mean RTs showed a significant main effect of search condition, $F(1, 7) = 25.03$, $MSE = 34{,}612.79$, $p = .002$, with faster responses in the target change condition (M = 936 ms) than in the target–nontarget switch condition (M = 1,168 ms). Second, the main effect of changing the target-defining feature was significant, $F(1, 11) = 10.87$, $MSE = 2{,}941.04$, $p = .013$, but this was qualified by a significant two-way interaction between the search condition and the effect of changing the target feature, $F(1, 7) = 17.88$, $MSE = 2{,}496.19$, $p = .004$.

To disentangle the effects, I calculated two separate ANOVAs over the mean RTs in the target change and target–nontarget switch conditions. For the target–nontarget switch condition, the intertrial analysis yielded a main effect of changing the orientation of the target, $F(1, 7) = 15.28$, $MSE = 4{,}978.83$, $p = .006$, $\eta^2 = .69$; mean RTs were increased on switch trials (M = 1,217 ms) when compared to repetition trials (M = 1,119 ms). However, intertrial contingencies of the response-indicative feature did not significantly affect mean RTs, $F(1, 7) = 1.3$, $p = .29$, $\eta^2 < .16$, nor did it interact significantly with the priming effect ($F < 1$; $\eta^2 < .02$). The same ANOVA calculated over the mean RTs of the target change condition did not yield any significant effects (all ps $> .3$; all η^2s $< .04$).

Errors. The same analyses calculated over the mean errors showed that participants committed significantly more errors in the target–nontarget switch condition (M = 4.6%) than in the target change condition, $M = 0.8\%$, $F(1, 7) = 18.70$, $MSE = 11.87$, $p = .003$. Moreover, repeating the response-indicative feature led to worse performance (M = 3.8%) compared with different response trials, $M = 1.7\%$, $F(1, 7) = 8.08$, $MSE = 8.73$, $p = .025$. Additionally, the interaction between both variables was significant, $F(1, 7) = 22.27$, $MSE = 5.37$, $p = .002$, reflecting that repeating the response-indicative feature increased errors only in the target–nontarget switch condition, $MD = 2.8\%$, $F(1, 7) = 21.58$, $MSE = 8.67$, $p = .002$, but not in the target change condition (all ps $> .29$).

Eye Movement Data

Figure 7 depicts the mean target fixation latencies and target fixation durations in the target change and target–nontarget switch conditions of Experiment 3.

Target fixation latencies. A one-way ANOVA computed over the mean target fixation latencies showed significant differences between the target change and switch conditions, $F(1, 7) = 41.44$, $MSE = 15{,}105.70$, $p < .001$; there were longer fixation latencies in the target–nontarget switch condition (M = 541 ms) than in the target change condition (M = 344 ms). Second, the main effect of changing the target-defining feature reached significance, $F(1, 7) = 15.39$, $MSE = 1{,}987.77$, $p = .006$, but this was qualified by a significant two-way interaction between the two variables, $F(1, 7) = 15.55$, $MSE = 2{,}332.45$, $p = .006$.

Two ANOVAs calculated separately over the data from each search condition showed that in the target–nontarget switch condition, switching the target-defining feature significantly elongated mean target fixation latencies, M = 587 ms, $F(1, 7) = 16.42$, $MSE = 5{,}057.32$, $p = .005$, $\eta^2 = .70$, compared with feature

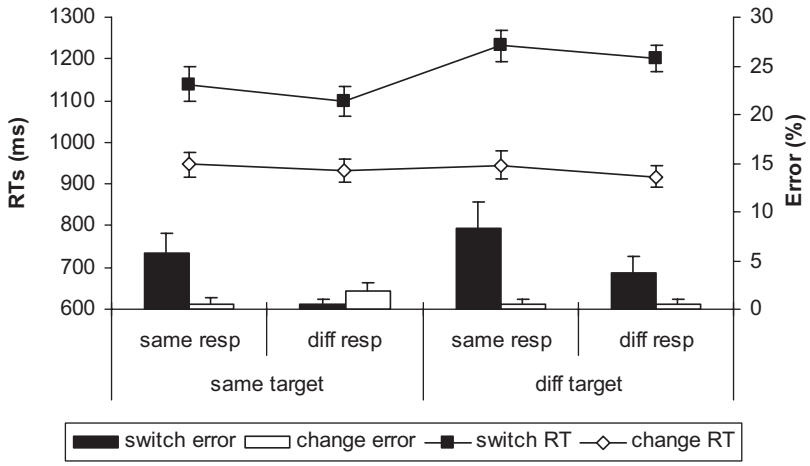

Figure 6. Mean response times and error scores of the target feature change and target–nontarget switch conditions of Experiment 3, as a function of whether the target feature from the previous trial is repeated (same target) or changed (diff target) and whether the response is repeated (same resp) or changed (diff resp). Error bars represent plus or minus one standard error of the mean. RT = response time; resp = response; diff = different.

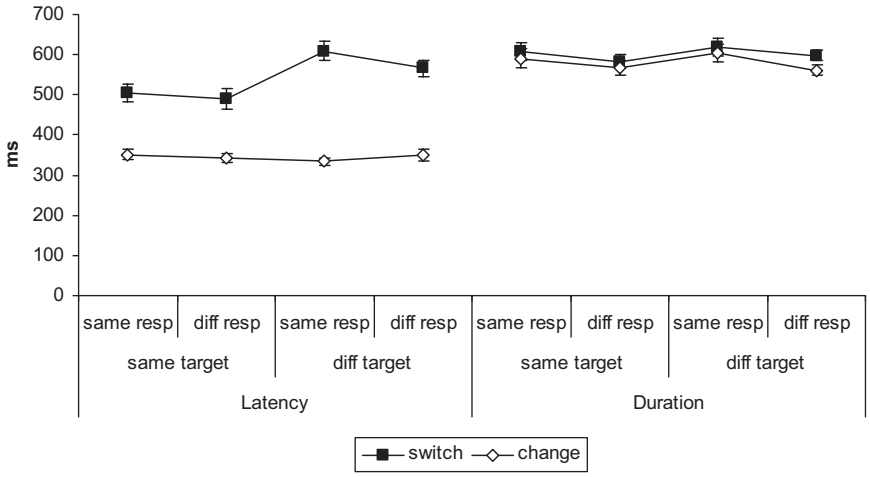

Figure 7. Mean target fixation latencies and target fixation durations in the target feature change and target-nontarget switch conditions of Experiment 3, depicted separately for trials in which the target feature is repeated (same target) or changed (diff target) and whether the response-indicative item was repeated (same resp) or changed (diff resp). Error bars represent plus or minus one standard error of the mean and may be smaller than the plotting symbol. Resp = response; diff = different.

repetition trials ($M = 496$ ms). Changes in the response-indicative feature did not significantly influence target fixation latencies, $F(1, 7) = 1.0$, $p = .38$, $\eta^2 < .12$, nor did it interact with the feature priming effect ($F < 1$; $\eta^2 < .11$). The same analysis conducted over the mean target fixation latencies of the target change condition did not yield any significant intertrial effects (all ps $> .25$; all η^2s $< .19$).

Target fixation durations. The same overall ANOVA was also computed over the mean target fixation durations to assess possible contributions of decision-related effects. However, the analysis did not yield any significant effects (all ps $> .16$; all η^2s $< .23$).

Discussion

In Experiment 3, significant feature priming effects were obtained even though the target-defining feature was constituted by orientation. This effectively rules out that the failure to obtain feature priming effects in the within-dimension condition of Experiment 2 was due to the use of the specific target feature.

Instead, the results of Experiment 2 suggest that for priming effects, it is crucial that target and nontarget features exchange on switch trials: Feature priming effects occurred only in the target–nontarget switch condition, in which the target inherits the features formerly associated with the nontargets and vice versa. This result pattern is at odds with a target activation view of the feature priming effect: As indicated by the absence of significant priming effects in the target change condition, priming obviously does not depend solely on carryover effects of target activation. On this account, merely repeating and changing the target feature across trials should have been sufficient to produce priming effects. Instead, the results suggest that intertrial changes in nontarget features are crucial to produce priming effects (e.g., Geyer, Müller, & Krummenacher, 2006; Kristjansson et al., 2002).

With this, the results of Experiment 3 can help to clarify why feature priming effects often fail to occur in the within-dimension condition of experiments used to explore the dimension change effect (e.g., Müller et al., 1995; Treisman, 1988). In these experiments, it is typical that only the target feature or dimension is repeated or changed, whereas nontargets remain constant across trials (e.g., Found & Müller, 1996; Müller et al., 1995, 2003; Treisman, 1988). In contrast, experiments on feature priming reliably show intertrial effects, presumably because target and nontargets typically exchange their features in these experiments (Becker, 2008a, 2008b; Hillstrom, 2000; Huang et al., 2004; Maljkovic & Nakayama, 1994). Thus, it seems safe to conclude that the absence of feature priming effects in Experiment 2 was because the nontarget features remained constant.

The question now arises of how to interpret the absence of priming effects in the target change condition: Does it mean that there were no intertrial transfers of feature-specific information in the target change condition? In my view, it is more probable that intertrial transfers of feature-specific information did occur, but that changing only the target feature was insufficient to incur any switch costs. Even when the target feature changed between trials, the information transferred across trials apparently facilitated search in a way similar to repeating the target-defining feature. This interpretation is supported by the observation that the mean RTs and target fixation latencies were generally shorter in the target change condition than in the target–nontarget switch condition (see Figure 6). Shorter RTs in the target change condition may be due to constant facilitation occurring on both repetition trials and trials where the target feature changed between trials. If this interpretation is correct, then the question arises as to what kinds of information are transferred across trials, leading to switch costs when the target and nontarget features exchange across trials and to facilitation when only the target feature changes. As indicated above, the findings are incompatible with a target activation view of priming, according to which mainly information about the target feature is transferred across trials and produces intertrial effects.

Ad hoc, two explanations seem plausible: First, according to a *nontarget suppression* hypothesis, priming would primarily per-

tain to nontarget features and not to features of the target. According to this view, nontarget rejection or suppression processes carrying over to the next trial are responsible for the typical pattern of repetition facilitation and switch costs in feature priming (e.g., Geyer et al., 2006; Kristjansson et al., 2002).

Second, it is possible that priming pertains neither directly to the target nor to the nontarget features, but to whatever distinguishes the target from the nontargets. According to this view, feature priming effects would critically depend on whether the target can be consistently distinguished from the nontargets on all trials or whether switch trials make this impossible: If it is possible to form a target template or representation that will consistently favor selection of the target over selection of the nontargets, then changing the target across trials should not result in switch costs (i.e., priming effects should be absent). Conversely, when target and nontargets exchange features, the relation that distinguished between target and nontarget features on the previous trial reverses, which may lead to switch costs. On this view, priming effects emerged in Experiment 1 because on switch trials, the relation that delineated the target from the nontargets reversed (e.g., the target on Trial $n-1$ was smaller than the nontargets, whereas that on Trial n was larger than the nontargets). In contrast, switch costs failed to occur in the target change condition of Experiment 3 because the relation between targets and nontargets did not reverse on change trials. In the following, this view is called the *relational priming hypothesis*, reflecting that priming pertains to the relational feature that distinguishes target from nontarget features, not directly to the target or nontarget features themselves.

Experiment 4

Experiment 4 was primarily designed to test the two different hypotheses of nontarget suppression versus relational priming of target–nontarget differences. To that aim, the nontarget features were held constant throughout the experiment, and two different target change conditions were included. In the dimension change condition, the target changed between two different dimensions, size and color. Thus, there were two target–nontarget differences, *smaller* and *red(der)*, which were never reversed. In the second, *relationship reversal* condition, the target could be either smaller or larger than the consistently sized nontargets. The size singleton targets were deemed to be better suited than orientation targets, because in the orientation dimension, it cannot be said a priori which changes will lead to reversals of target–nontarget differences. Conversely, in the size dimension, the target–nontarget relation will be reversed whenever the target feature changes between its larger and smaller size (see Figure 1D for an example of the displays in each condition).

Thus, if priming consists in carryover effects of relational information that distinguishes the target from the nontargets, then in the relationship reversal condition, changing the target feature should lead to priming effects because changing the target implies a reversal of the target–nontarget differences with respect to the previous trial. However, priming effects should be absent in the dimension change condition in which the relation between target and nontargets does not reverse but remains constant throughout a block.

On the other hand, if priming consists in carryover effects of nontarget suppression, then repeating or changing the target should modulate performance neither in the dimension change condition nor in the relationship reversal condition. This holds because in both conditions, the nontarget features remain constant across all trials.

Method

Participants

Four male and 8 female students from the University of Bielefeld, Bielefeld, Germany, took part in the experiment. Their mean age was 25. The last participant was excluded because more than 20% of his response data was classified as outliers or errors.

Materials

These were identical to those of the previous experiments.

Stimuli, Design, and Procedure

The conditions in Experiment 4 strongly resemble the control, within-dimension, and across-dimension conditions of Experiment 2. In the control condition, the target consisted of a green square that was consistently smaller ($0.9° \times 0.9°$) than the equally green nontarget squares ($1.9° \times 1.9°$). In the relationship reversal (within-dimension) condition, the target could be either smaller ($0.9° \times 0.9°$) or larger ($2.8° \times 2.8°$) than the nontargets, whose size remained constant ($1.9° \times 1.9°$). Finally, in the dimension change (across-dimension) condition, either the target was smaller than the nontargets or it was of the same size as the nontargets and colored red.

The task and procedure were the same as in the previous experiment. In the relationship reversal and dimension change conditions, 160 trials each were completed, whereas the control condition comprised 80 trials. As in Experiment 2, only trials featuring the smaller sized target were analyzed, yielding 80 valid trials per search condition and participant.

Results

Data

Evaluating only trials in which the target was smaller left 2,640 trials for analysis. Removing RTs greater than 2,000 ms resulted in a loss of 1.33% of all data. Removing all trials in which the eyes had not been on the target within 2,000 ms resulted in a loss of 0.15% of all eye movement data.

Manual Responses

Figure 8 depicts the mean RTs and error scores of Experiment 4.

RTs. An ANOVA calculated over the mean RTs of the control, relationship reversal, and dimension change conditions yielded a significant main effect of the search condition, $F(2, 20) = 18.64$, $MSE = 5{,}010.61$, $p = .002$. RTs in the relationship reversal condition were slowest ($M = 1{,}090$ ms) and were significantly different from both the control condition, $M = 919$ ms, $F(1, 10) = 23.53$, $MSE = 6{,}858.83$, $p = .001$, and the dimension change condition, $M = 946$ ms, $F(1, 10) = 25.68$, $MSE = 4{,}471.20$, $p <$

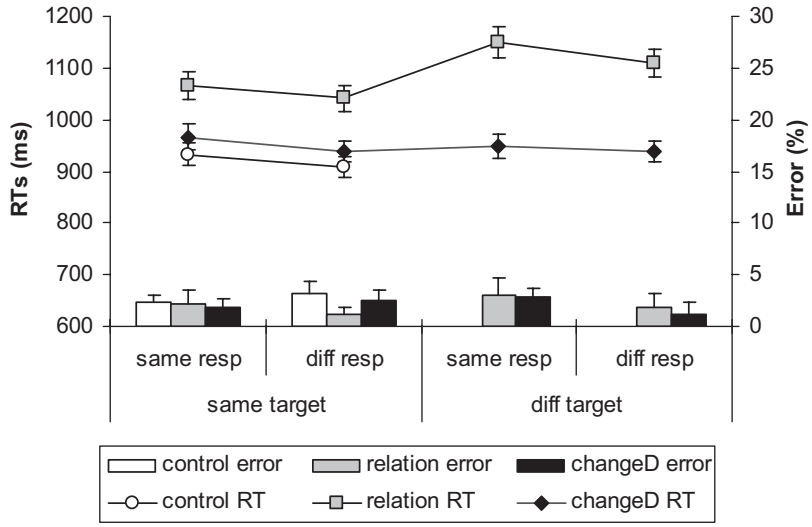

Figure 8. Mean response times and error scores of the control, relationship reversal, and dimension change conditions of Experiment 5. Mean response times and errors in each condition are depicted as a function of whether the target from the previous trial was repeated (same target) or changed (diff target) and whether the required response was the same as (same resp) or different from (diff resp) in the previous trial. Error bars represent plus or minus one standard error of the mean. RT = response time; resp = response; diff = different; relation = relationship reversal; changeD = dimension change.

.001. In contrast, the control and dimension change conditions did not differ significantly from each other, $F(1, 10) = 1.07$, $p = .33$.

Intertrial analysis of the mean RTs in the relationship reversal condition yielded a significant priming effect, $F(1, 10) = 56.06$, $MSE = 1{,}137.22$, $p < .001$, $\eta^2 = .85$, with faster responses when the target-defining feature was repeated ($M = 1{,}054$ ms) than when it changed ($M = 1{,}130$ ms). Moreover, the main effect of response repetition approached significance, $F(1, 10) = 4.12$, $MSE = 2{,}721.71$, $p = .07$, $\eta^2 = .29$, and showed the inverse trend: On average, responses were slower on response repetition trials ($M = 1{,}076$ ms) than on different response trials ($M = 1{,}108$ ms), but this effect did not interact with the priming effect ($F < 1$; $\eta^2 < .02$).

The same analysis calculated over the mean RTs of the dimension change condition did not show any significant effects. Mean RTs were very similar in different-dimension trials ($M = 943$ ms) and same-dimension trials ($M = 953$ ms, $F < 1$, $\eta^2 < .06$), and also did not differ between response repetition ($M = 957$ ms; $\eta^2 < .09$) and different response trials, $M = 939$ ms, $F(1, 10) = 1.0$, $p = .35$, $\eta^2 < .06$. Equally, the interaction between the two variables was nonsignificant ($F < 1$; $\eta^2 < .07$).

Finally, in the control condition, performance at response repetition trials was worse ($M = 933$ ms) than at different response trials ($M = 908$ ms), and this difference approached significance, $F(1, 10) = 3.42$, $MSE = 1{,}014.01$, $p = .094$, $\eta^2 = .26$.

Errors. The overall ANOVA showed that there were no significant differences between the control, relationship reversal, and dimension change conditions for mean errors, $F(2, 20) = 1.0$, $p = .39$. Moreover, the intertrial analyses showed that repeating the response-indicative feature in the relationship reversal condition just failed to reach significance, $F(1, 10) = 3.85$, $MSE = 3.68$, $p = .078$, with more errors on response repetition trials ($M = 2.6\%$) than at different response trials ($M = 1.5\%$; all other Fs < 1). In the dimension change condition, the mean error scores were not modulated by changes in either the target-defining or response-indicative feature (both Fs < 1), and these two variables also did not interact, $F(1, 10) = 1.39$, $p = .27$. Finally, mean errors in the control condition also did not differ between response repetition ($M = 2.3\%$) and different response trials ($M = 3.2\%$; $F < 1$).

Eye Movement Data

The mean target fixation latencies and target fixation durations of Experiment 4 are illustrated in Figure 9.

Target fixation latencies. First of all, an ANOVA computed over the mean target fixation latencies of the relationship reversal condition, the dimension change condition, and the control yielded significant differences between the conditions, $F(2, 20) = 33.1$, $MSE = 1{,}855.79$, $p < .001$, reflecting significantly longer latencies in the relationship reversal condition ($M = 447$ ms) than in both the dimension change condition, $M = 336$ ms, $F(1, 10) = 38.72$, $MSE = 1{,}769.78$, $p < .001$, and in the control condition, $M = 305$ ms, $F(1, 10) = 84.61$, $MSE = 1{,}308.52$, $p < .001$. The control and dimension change conditions did not differ significantly from each other, $F(1, 10) = 2.0$, $p = .19$.

The intertrial analysis showed that in the relationship reversal condition, mean target fixation latencies were larger when the target feature changed ($M = 489$ ms) than when it was repeated, $M = 408$ ms, $F(1, 10) = 24.64$, $MSE = 2{,}952.34$, $p = .001$, $\eta^2 = .71$. In contrast, variations in the response-indicative feature did not modulate fixation latencies of the target, $F(1, 10) = 1.78$, $p = .21$, $\eta^2 < .15$, nor did it interact with intertrial contingencies of the target-defining feature, $F(1, 10) = 2.05$, $p = .18$, $\eta^2 < .17$.

The dimension change condition showed the reverse trend, with slightly longer target fixation latencies for same dimension trials ($M = 348$ ms) than for different dimension trials, $M = 327$ ms,

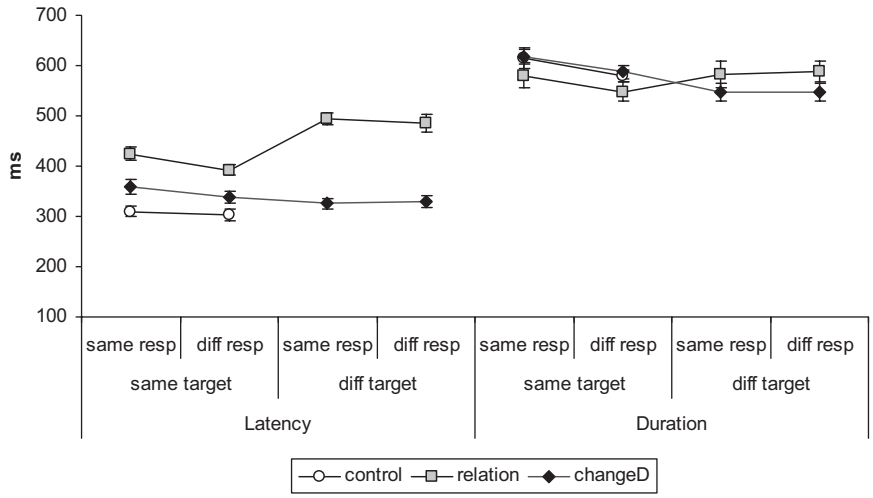

Figure 9. Mean target fixation latencies and target fixation durations in the control, relationship reversal, and dimension change conditions of Experiment 5, depicted separately for trials in which the target is repeated (same target) or changed (diff target) and whether the response-indicative item is repeated (same resp) or changed (diff resp). The data points representing the fixation durations of the control condition are partly hidden behind the data points of the dimension change condition. Error bars represent plus or minus one standard error of the mean and may be smaller than the plotting symbol. Resp = response; diff = different; relation = relationship reversal; changeD = dimension change.

$F(1, 10) = 5.16$, $MSE = 940.56$, $p = .046$, $\eta^2 = .34$. Repeating the response-indicative feature did not modulate mean fixation latencies ($F < 1$; $\eta^2 < .09$), nor did it interact significantly with changes of the target dimension, $F(1, 10) = 2.57$, $p = .14$, $\eta^2 < .21$.

Target fixation durations. The ANOVA computed over the mean target fixation durations did not show any significant differences between the conditions, $F(2, 20) = 1.48$, $p = .25$. Further intertrial analyses showed that the mean target fixation durations were not significantly affected by intertrial contingencies of the target-defining or the response-indicative item, neither in the relationship reversal condition (all ps $> .1$; all η^2s $< .24$), nor in the dimension change condition (all ps $> .3$; all η^2s $< .10$), nor in the control ($p > .13$; $\eta^2 < .03$).

Discussion

In Experiment 4, repeating or changing the target-defining feature significantly modulated search performance, although the nontargets always remained constant. This finding effectively rules out that constancy of nontargets is sufficient to eliminate feature priming effects. Consequently, the hypothesis that priming consists mainly in carryover effects of nontarget suppression must be rejected.

Instead, the present results provide support for the relational priming hypothesis, which asserts that priming pertains to target–nontarget differences or to whatever distinguishes a target from the nontarget features: When the target could be either larger or smaller than consistently sized nontargets and the relational property *larger* (or *smaller*) was reversed across trials, significant priming effects occurred. On the other hand, changes in the target dimension did not produce priming effects, because the involved target–nontarget relations delineating the target did not reverse in the course of the experiment.

However, there are some difficulties in the design of Experiment 4 that complicate interpretation of the results. First of all, the feature and dimension change conditions were confounded with the intended differences between the relationship reversal and no-reversal conditions: The relationship reversal condition included only changes between two target features within the size dimension but not across dimensions, whereas the across-dimension condition did not include changes in the target feature values but only between the dimensions size and color. Thus, the results could also be taken to indicate the absence of intertrial effects in any across-dimension condition when compared to a within-dimension condition. Second, and even more important, the design of Experiment 4 does not allow comparisons between the typical feature priming effect that can be observed when target and nontarget features exchange (see Experiments 1 and 3) and intertrial effects that occur at reversals of target–nontarget relations. Accordingly, one cannot be sure that the intertrial effect observed in the relationship reversal condition of Experiment 4 is identical to the priming effect observed in the classical experimental settings in which target and nontarget features exchange on switch trials.

Experiment 5

Experiment 5 was conducted to overcome these difficulties. In Experiment 5, only features within the size dimension were varied, to exclude the possibility that differences between feature-based and dimension-based intertrial effects can account for differences between the relationship reversal and no-reversal conditions. Moreover, Experiment 5 included conditions that allowed compar-

isons between costs occurring at reversals of the target–nontarget relation and costs occurring when target and nontarget features exchange across trials. Experiment 5 included three conditions to test whether reversals in the relationship between target and nontarget features can fully account for switch costs observed in the typical settings. The *target–nontarget switch* condition reinstated the classical arrangement in which the target and nontarget features directly exchange on switch trials, such that the nontargets inherit the size formerly associated with the target and vice versa. In the remaining two conditions, the size of the nontargets always remained constant throughout a block, which again served as a test for the nontarget suppression view on priming. In the *target feature change condition*, the target size varied in the same way as in the target–nontarget switch condition, but the nontargets were always consistently larger sized items. In the *relationship reversal condition*, the target could be either smaller or larger than constantly middle-sized nontargets, replicating the condition of the previous experiment (see Figure 1E for an example of the displays in each condition).

The predictions were as follows: If the results of Experiment 4 were due to differences in the varied feature versus dimension of the target, then priming effects should also occur in the target feature change condition, because in Experiment 5, this condition involved a feature change instead of a dimension change.

Furthermore, if priming consists in carryover effects of nontarget suppression processes, then priming effects should be confined to the target–nontarget switch condition but should not occur in the target feature change or relationship reversal condition in which the nontargets remained constant.

Conversely, if priming depends critically on reversals of the relationship between target and nontarget features, then priming should be absent in the target feature change condition, but it should occur in both the relationship reversal condition and the target–nontarget switch condition. Moreover, if reversals of the relationship between target and nontarget features can fully account for the typical feature priming effect, then the priming effect should be of comparable magnitude in the relationship reversal condition and the target–nontarget switch condition.

Method

Participants

Three male and 3 female students from the University of Bielefeld, took part in the experiment. Their mean age was 26.5 years.

Materials

These were the same as in the previous experiment, with the exception that the monitor to head distance was increased to 100 cm.

Stimuli, Design, and Procedure

Experiment 5 comprised three blocked search conditions, which were balanced across participants. In the target–nontarget switch condition, participants searched for a square that was either larger (1.7° × 1.7°) or smaller (0.9° × 0.9°) than the nontargets, which assumed the opposite size. In the other two conditions, the size of the nontargets always remained constant throughout a block. In the target feature change condition, the target could be of two different sizes, measuring either 0.9° × 0.9 or 1.7° × 1.7°, and it was presented among consistently larger nontarget squares (2.8° × 2.8°). The target in the relationship reversal condition could be either smaller (0.9° × 0.9°) or larger (2.8° × 2.8°) than the middle-sized nontargets (1.7° × 1.7°). In each of the three conditions, 220 trials were completed. It took approximately 1 hr to complete the experiment.

Results

Data

Removing RTs greater than 3,000 ms resulted in a loss of 0.23% of the RT data. Removing eye data in which the eyes had not focused on the target within 3,000 ms equally resulted in a loss of 0.23% of all data.

Manual Responses

Figure 10 depicts the mean RTs and error scores separately for each of the three search conditions of Experiment 5.

RTs. For an analysis of RTs, a 3 × 2 × 2 ANOVA comprising the variables search condition (target–nontarget switch vs. target feature change vs. relationship reversal), $n-1$ target-defining feature (same target vs. different target), and $n-1$ response-indicative feature (same response vs. different response) was calculated over the mean response times. The ANOVA yielded a significant main effect of search condition, $F(2, 10) = 20.0$, $MSE = 10{,}984.39$, $p < .000$, indicating that RTs were faster in the target feature change condition ($M = 931$ ms) than in both the target–nontarget switch condition, $M = 1{,}058$ ms, $F(1, 5) = 12.17$, $MSE = 3{,}875.52$, $p = .018$, and the relationship reversal condition, $M = 1{,}118$ ms, $F(1, 5) = 187.84$, $MSE = 545.10$, $p < .000$, whereas the last two conditions did not differ significantly from each other, $F(1, 5) = 2.65$, $p = .16$.

Secondly, there was a significant priming effect, $F(1, 5) = 15.10$, $MSE = 12{,}593.57$, $p = .012$, reflecting that responses were on average 103 ms faster when the target size was repeated ($M = 984$) than when it changed ($M = 1{,}087$ ms). However, this effect was qualified by a significant two-way interaction between the search condition and the intertrial effect of the target-defining feature, $F(2, 10) = 11.32$, $MSE = 4{,}420.48$, $p = .003$.

Separate intertrial analyses showed that changing the target-defining feature significantly elongated RTs in the target–nontarget switch condition, mean difference = 96 ms, $F(1, 5) = 15.03$, $MSE = 3{,}719.57$, $p = .012$, $\eta^2 = .75$, and in the relationship reversal condition, mean difference = 197 ms, $F(1, 5) = 14.11$, $MSE = 16{,}512.44$, $p = .013$, $\eta^2 = .74$, but not in the target feature change condition, mean difference = 14 ms, $F(1, 5) = 1.08$, $p = .35$, $\eta^2 < .15$. None of the remaining effects or interactions reached significance.

Errors. The same analysis computed over the mean error scores showed significant differences between the three search conditions, $F(2, 10) = 5.18$, $MSE = 5.56$, $p = .029$, reflecting that, on average, more errors were committed in the relationship reversal condition ($M = 4.9\%$) than in the target–nontarget switch, $M = 2.9\%$, $F(1, 5) = 21.97$, $MSE = 0.47$, $p = .005$, and target feature

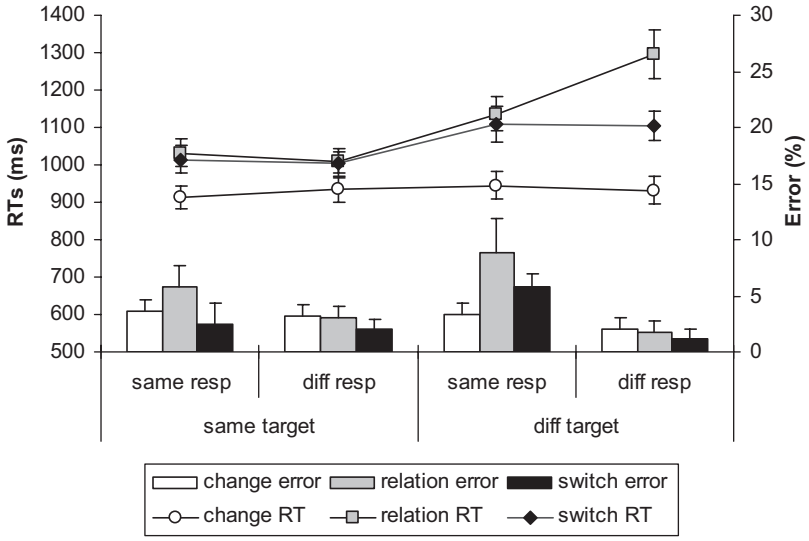

Figure 10. Mean response times and error scores of the control, relationship reversal, and target–nontarget switch conditions of Experiment 5. Mean response times and errors are depicted as a function of whether the target from the previous trial was repeated (same target) or changed (diff target) and whether the required response was the same (same resp) or different (diff resp) as in the previous trial. Error bars represent plus or minus one standard error of the mean and may be smaller than the plotting symbol. RT = response time; resp = response; diff = different; relation = relationship reversal.

change conditions, $M = 3.1\%$, $F(1, 5) = 4.65$, $MSE = 2.03$, $p = .083$. In turn, the target–nontarget switch condition and target feature change conditions did not differ significantly from each other ($F < 1$).

The analysis moreover showed a significant interaction between the search condition and repeating the response-indicative item, $F(2, 10) = 14.16$, $MSE = 1.76$, $p = .001$. Repeating the response led to more errors than changing it in the relationship reversal condition (mean difference = 1.8%) and the feature reversal condition (mean difference = 2.6%), but not in the target feature change condition (mean difference = 0.9%). Finally, the interaction between changing the target size and the response reached significance, $F(1, 5) = 7.54$, $MSE = 6.13$, $p = .04$, reflecting that errors at different response trials were reduced when the target size changed (mean difference = 4.3%), whereas only small differences occurred when the target size was repeated (mean difference = 1.1%).

Eye Movement Data

The mean target fixation latencies and target fixation durations of Experiment 5 are illustrated in Figure 11.

Target fixation latencies. A 3 × 2 × 2 ANOVA calculated over the mean target fixation latencies accordingly showed that latencies differed significantly between the three search conditions, $F(2, 10) = 34.78$, $MSE = 4{,}081.11$, $p < .000$, reflecting shorter target fixation latencies in the target feature change condition ($M = 292$ ms) than in both the relationship reversal condition $M = 424$ ms, $F(1, 5) = 43.87$, $MSE = 1{,}284.62$, $p = .001$, and the target–nontarget switch condition, $M = 429$ ms, $F(1, 5) = 68.13$, $MSE = 776.75$, $p < .000$. However, mean target fixation latencies did not differ significantly between the relationship reversal and target–nontarget switch conditions ($F < 1$).

Secondly, changing the target size led to significantly longer target fixation latencies ($M = 407$ ms) than repeating it, $M = 355$ ms, $F(1, 5) = 92.60$, $MSE = 528.79$, $p < .000$, but this effect was qualified by a significant interaction between search condition and intertrial effect, $F(2, 10) = 13.93$, $MSE = 1{,}261.34$, $p = .006$. The interaction was due to the fact that changing the target size significantly elongated target fixation latencies in the target–nontarget switch condition, mean difference = 98 ms, $F(1, 5) = 33.29$, $MSE = 1{,}718.72$, $p = .002$, $\eta^2 = .87$, and the relationship reversal condition, mean difference = 67 ms, $F(1, 5) = 31.71$, $MSE = 837.09$, $p = .002$, $\eta^2 = .84$, but not in the target feature change condition (mean difference = 8 ms, $F < 1$, $\eta^2 < .13$).

Target fixation durations. The same 3 × 2 × 2 ANOVA computed over the mean target fixation durations did not show any significant effects or interactions (all ps $> .12$). Mean fixation durations were quite similar in the target–nontarget switch condition ($M = 589$ ms), relationship reversal condition ($M = 591$ ms), and target feature change conditions ($M = 586$ ms) and also did not differ significantly between repetition trials ($M = 581$ ms) and trials in which the target-defining feature changed ($M = 596$ ms).

Discussion

The results from the present experiment provide converging evidence for the hypothesis that priming does not consist in carryover processes of target activation or nontarget inhibition, but instead critically depends on the relationship between target and nontarget features. In line with this hypothesis, priming occurred only in the target–nontarget switch condition, in which the target and nontarget features exchanged, and in the relationship reversal condition, in which the target–nontarget differences were reversed on switch trials. Conversely, target feature changes did not result

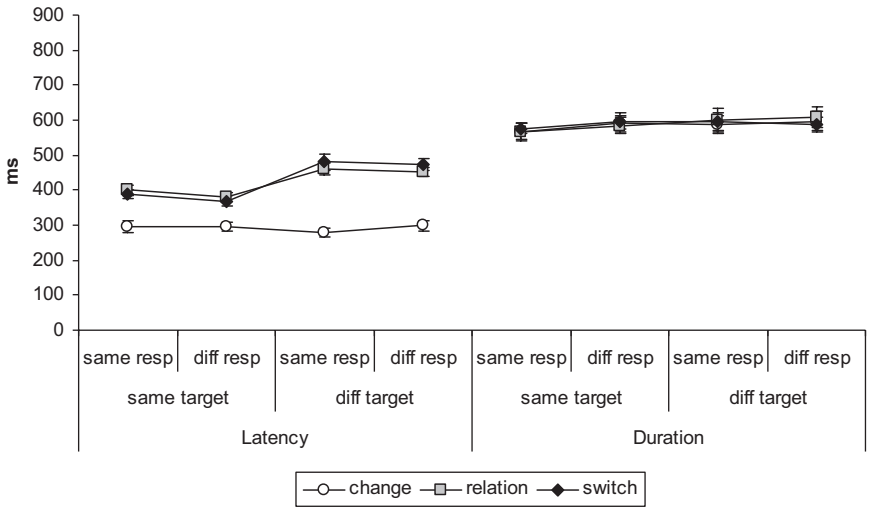

Figure 11. Mean target fixation latencies and target fixation durations of the control, relationship reversal, and target–nontarget switch conditions of Experiment 5, depicted as a function of whether the target from the previous trial was repeated (same target) or changed (diff target) and whether the required response was the same (same resp) or different (diff resp) as in the previous trial. Error bars represent plus or minus one standard error of the mean and may be smaller than the plotting symbol. Resp = response; diff = different; relation = relationship reversal.

in switch costs when the relation between target and nontargets remained constant (smaller).

This demonstrates that switch costs cannot be eliminated by simply holding the nontargets constant, contrary to the nontarget suppression hypothesis. The present findings also do not fit a target activation view, such as the priming of pop-out account: The changes in the target feature were exactly the same in the target feature change and target–nontarget switch condition. However, despite the fact that the target underwent the same changes in both conditions, switch costs were observed only in the target–nontarget switch condition.

The last result also rules out the hypothesis that priming is due to carryover effects of target activation or nontarget suppression. Instead, the results provide compelling evidence for the hypothesis that the target representation subject to priming contains information about the relationship between target and nontarget features.

Importantly, Experiment 5 indicates that this mechanism can also account for the switch costs that occur when target and nontarget features directly exchange. As can be seen in Figure 11, the result patterns for the feature reversal and relationship reversal conditions in Experiment 5 were virtually identical. The only difference between the conditions can be seen in the manual RTs when both the target-defining feature and the response differed from the previous trial (see Figure 10). However, close inspection of the error scores suggests the possibility that a speed–accuracy trade-off accounts for this deviation, so that this does not signify an important difference between the conditions. This interpretation is supported by the fact that this difference did not occur in the target fixation latencies (see Figure 11).

Thus, there is no reason to believe that the priming effect in the relationship reversal condition is in any way different from the priming effect in more typical settings in which target and nontarget features exchange on switch trials. This is further corroborated by the eye movement measurements, which show that intertrial contingencies in the feature reversal and relationship reversal conditions affected the target fixation latencies and target fixation durations in the same way: Changing the target-defining feature in both the target–nontarget switch condition and the relationship reversal condition led to delayed selection of the target. In contrast, mean target fixation durations were not affected at all by intertrial contingencies, replicating the previous results (see Experiments 1 and 3). Taken together, the results indicate that switch costs in the target–nontarget switch condition are also due to reversals of the target–nontarget relation and not carryover effects of target activation or nontarget rejection processes.

Summary of Results and Discussion: Response-Indicative Effects—Experiments 1–6

In addition to the intertrial effects of the target-defining feature, the effects of response repetition were as follows. First of all, concerning the mean RTs, repeating the response-indicative item significantly prolonged manual response times in Experiments 2 and 4. This inverse response repetition effect did not interact with any of the other variables, and it was not systematically related to the conditions: Inverse response repetition effects occurred in the control condition of Experiment 2 and in the relationship reversal condition of Experiment 4. Second, inverse response priming effects were even more frequent in the manual error scores, where they occurred in all experiments. In most experiments, the effect straightforwardly led to increased errors at response repetition trials. This inverse response priming effect was again nonsystematically distributed over different conditions, occurring in the control and within-dimension conditions of Experiment 2, in the target–nontarget switch condition of Experiment 3, in the relationship reversal condition of Experiment 4, and in the target–

nontarget switch condition of Experiment 5. In the first and last experiment, repeating the response also interacted with repetitions of the target-defining feature, leading to decreased error scores when both features switched, but increased error scores when only the target-defining feature switched and the response was repeated.

In sum, intertrial effects from the response-indicative item were generally very small and did not show a systematic result pattern across experiments. In contrast, repeating and changing the target-defining feature or dimension reliably and systematically modulated the speed of manual responses and eye movements. This rules out the possibility that a response-selection account like the dimensional action model (Cohen & Magen, 1999) can account for the feature priming or dimension change effects found in the present study.

General Discussion

The visual search experiments reported in the present article provide new insights into the mechanisms that drive intertrial effects of features and dimensions. The primary aim of the present investigation was to explore whether feature priming and dimension change effects can be parsimoniously explained by a single theory. However, the results from the first two experiments demonstrate that intertrial effects of the target feature and the target dimension are mediated by different mechanisms. The results from the eye movement measurements clearly indicate a dissociation between feature- and dimension-based intertrial effects when both are tested under the same experimental conditions: Intertrial contingencies of the target feature reliably modulate the duration needed to select the target (target fixation latency) but do not modulate postselectional processes after target selection (target fixation duration; see Experiments 1, 3, 4, and 5). In contrast, repeating or changing the target dimension did not affect the time needed to select the target but modulated only processes commencing after selection of the target (see Experiment 2). The finding that variations in the target feature modulate only processes before selection of the search target, whereas variations in the target dimension modulate only processes after target selection, indicates a clear dissociation between feature priming and dimension change effects. This effectively frustrates any attempts to explain intertrial effects of features and dimensions by a single theory.

The second important finding of the present study concerns the feature priming effect: Current models of intertrial effects maintain that intertrial contingencies modulate search performance by carryover effects of target activation (e.g., Maljkovic & Nakayama, 1994) or nontarget suppression (e.g., Geyer et al., 2006; Kristjansson et al., 2002). The experiments from the present study, however, demonstrate that neither the target activation view nor the nontarget suppression view can account for priming effects. First, repeating or changing the target feature alone is not sufficient to produce priming effects (see Experiments 1, 3, 4, and 5). This result is inconsistent with a target activation view of the feature priming effect. Second, keeping the nontarget features constant across all trials also does not reliably eliminate the feature priming effect. The results from Experiments 4 and 5 demonstrate that priming effects occur even when only the target feature varies between two different sizes, whereas the nontarget features remain constant. These data effectively rule out a nontarget suppression view of priming.

The finding that priming does not consist in carryover effects of either target activation or nontarget inhibition provides clear difficulties for some current models of carryover effects in search, such as the dimension weighting account and the priming of pop-out hypothesis. The relational priming hypothesis was proposed to account for the findings of the present study. In this view, priming is mediated by carryover effects of information about the relationship between target and nontargets or by information capturing the target–nontarget differences (e.g., whatever distinguishes the target from the nontarget features). From this account it follows that carryover effects will lead to constant facilitation (i.e., no intertrial effects) when the relation between target and nontarget features is repeated across trials (e.g., when the target is consistently smaller than the nontargets; see Experiment 5). Switch costs—and with this, intertrial effects—arise only when the target feature changes such that the relation between target and nontargets reverses between trials (e.g., when the target is larger, and then smaller, than the nontargets; see Experiment 5). In the next section, the underlying mechanism for priming is described in more detail.

Relational Priming and Linear Separability

The proposed relational priming mechanism is closely related to the concept of *linear separability*. The linear separability account (D'Zmura, 1991) was originally developed to explain why some searches (e.g., search for a yellow target among orange and red nontargets, or search for a red target among yellow and orange nontargets) commence efficiently, whereas search in very similar tasks (e.g., search for an orange target among yellow and red nontargets) becomes inefficient. D'Zmura (1991) explained these differences in search performance with discrimination mechanisms that are linear in feature space. Thus, the target can only be detected efficiently when it is possible to draw a single straight line through color space, so that the target color occupies one side and the nontarget colors are located on the other side. The linear mechanism operates on all items of the visual field at once, in parallel, but the visual system can employ only one of these linear mechanisms at one time: Thus, if target and nontarget features are collinear in color space, so that they cannot be separated by a single line, then the target cannot be detected efficiently, and serial inspection of every item is necessary to find the target (D'Zmura, 1991; see also Bauer, Jolicoeur, & Cowan, 1995; and the feature divider account, Huang & Pashler, 2005).

In typical pop-out displays, target and nontarget features are of course always linearly separable—however, the results of Experiments 4 and 5 indicate that a linear separator mechanism can also account for intertrial priming effects (see also Hodsoll & Humphreys, 2001; Wolfe & Bose, 1991). The relationship reversal condition of Experiment 5 demonstrates that participants obviously cannot simultaneously search for linearly nonseparable targets that can be either larger or smaller than nontargets possessing a fixed size. On the other hand, simultaneous search for different target features is possible if both targets are smaller and thus linearly separable from the nontarget features, as indicated by the absence of any intertrial effects in the target feature change condition of Experiment 5.

If the relational priming and linear separability accounts are indeed as closely related to each other as suggested here, then an interesting possibility arises. It should be possible to predict search efficiency from pop-out search tasks and vice versa, to predict the occurrence of priming effects from standard visual search experiments measuring search efficiency. In a pop-out search task, changes in the target feature should only result in intertrial effects when the targets are not conjointly linearly separable from the nontargets. For instance, based on the findings from the linear separability experiments, intertrial effects should occur when the target changes between yellow and red color among consistently orange-colored nontargets. In contrast, intertrial effects should be reduced or absent when the task is to find a red or orange target among consistently yellow nontargets. Further research is needed to explore whether search performance in pop-out and feature search tasks can indeed be explained by a single mechanism that operates on relational properties.

Features Priming and Dimension Change Effects in Simple and Compound Search

Remarkably, previous research suggests a double dissociation between feature priming and dimension change effects in simple search tasks and compound search tasks. First, feature priming effects can regularly be observed in compound search tasks, but are mostly absent in simple search tasks. Feature priming effects in compound search tasks were on the order of 43–100 ms for color singletons (Maljkovic & Nakayama, 1994; Experiments 3, 4, 5, and 7), amounted to 105 ms for both color and orientation singletons (Hillstrom, 2000; Experiments 1 and 2), and reached 137 ms in search for size singletons (Huang et al., 2004). In contrast, changing the target feature in a simple search task either did not result in significant priming effects (Mortier et al., 2005; Müller et al., 1995, Experiments 1 and 2; Müller & Krummenacher, 2006), or the resulting switch costs were small in magnitude, reaching only 10–13 ms (Found & Müller, 1996, Experiments 1 and 2; Mortier et al., 2005, Experiment 1).

Secondly, dimension change effects can regularly be observed in simple search tasks but are equally regularly absent in compound search tasks. Dimension change effects in simple search tasks were in the order of 28–49 ms (Kumada, 2001, Experiment 1A; Mortier et al., 2005, Experiments 1 and 2; Müller et al., 1995, Experiments 1 and 2; Theeuwes et al., 2006, Experiment 1), and changing the target dimension resulted in additional costs of 35 ms and 27 ms even when the target feature changed compared to the previous trial (Found & Müller, 1996, Experiments 1 and 2). In contrast, in compound search tasks, changing the target dimension between size and orientation or between size, shape, and color either remained nonsignificant (Kumada, 2001; Mortier et al., 2005, Experiment 5; Müller & Krummenacher, 2006; Theeuwes et al., 2006, Experiments 4 and 5), or the effect was on the order of 10 ms (Theeuwes et al., 2006, Experiment 2). Thus, feature priming and dimension change effects seem to be doubly dissociated insofar as feature priming effects are prevalent in compound search tasks, but do not occur in simple search tasks; whereas the dimension change effect can be predominantly found in simple search tasks, but not in compound search tasks.

Feature Priming Effects

The results of the present study can help to clarify this apparent double dissociation between simple versus compound search tasks and variations of the target dimension versus the target feature: At least with respect to the feature priming effect, it is fairly clear that the different results are not due to differences between simple and compound search tasks. Instead, the differences in the feature priming effect are presumably due to the fact that in all simple search tasks cited above, the original paradigm of Treisman (1988) was used, in which only the target feature or dimension varies, whereas the nontarget features always remain constant. In turn, studies reporting results from compound search tasks usually employ the paradigm of Maljkovic and Nakayama (1994), in which target and nontarget features exchange on switch trials.

The results of the present study indicate that it is this difference between the switch trials in the respective paradigms that accounts for the different outcomes and not differences between the tasks per se. Feature priming effects are mostly absent when the nontargets are held constant throughout a block, even in a compound search task and probably not regarding whether a compound or simple search task is used. This interpretation is consistent with the results of a recent study by Kristjansson (2006): When the target and nontarget features exchanged on switch trials, the magnitude of feature priming effects was equally large in a compound search task, where they amounted to approximately 24 ms (Kristjansson, 2006, Experiment 1), and a simple search task, where they amounted to approximately 22 ms (Kristjansson, 2006, Experiment 4). This indicates that differences between the tasks cannot fully account for the dissociation of feature priming effects in simple and compound search tasks. Instead, what appears to be critical for priming is that target and nontarget features exchange on switch trials, because this renders the target features linearly nonseparable from the nontarget features in feature space.

Dimension Change Effects

Previous research has commonly explained the prevalence of dimension change effects in simple search tasks and their absence in compound search tasks by differences between the tasks. Specifically, it has been argued that only simple search tasks allow for consistent stimulus-to-response mappings and that changing the target dimension leads to interference in response selection processes (e.g., Meeter & Olivers, 2005; Mortier et al., 2005).

However, the present results are not entirely consistent with this line of reasoning. In the present study, significant dimension change effects were observed in a compound search task, that is, in the absence of stimulus-to-response mappings (see Experiment 2). This indicates that dimension-based intertrial effects cannot be solely based on response selection processes, as was proposed by the dimension action model (Cohen & Magen, 1999).

On the other hand, the results from the eye movement measures are also not compatible with the view that changing the target dimension leads to a delayed deployment of attention to the target, as was proposed by the dimension weighting hypothesis (e.g., Müller et al., 1995). In Experiment 2, changing the target dimension clearly did not delay visual selection of the target but only affected the target fixation durations. This suggests that the dimension change effect may be based on perceptual identification

processes of the target. Effects in the target fixation duration might, for instance, be identifiable with sustained attention effects that gate access to consciousness (e.g., Most, Scholl, Clifford, & Simons, 2005; Müller & Krummenacher, 2006; Treisman, 1988).

This can also help to explain why in the present study, dimension change effects could be found despite the use of a compound search task. First, a potentially important difference between the present study and previous studies is that all experiments of the present study included eye movement recordings, and the response-indicative features were constructed so as to require foveation for discrimination. The requirement to move the eyes during search and the fact that feature discrimination processes could begin only after the eyes had focused on the target might in turn have funneled perceptual processes that are responsible for the dimension change effect. Second, the search displays in the present study were also rather sparse, containing only five items, which might have bolstered processing of perceptual information.

However, it should be observed that significant dimension change effects could be found only in Experiment 2 (see Figures 4 and 5) but not in Experiment 4 (see Figures 8 and 9). The absence of dimension change effects in Experiment 4 is probably due to the fact that in Experiment 4, the target varied only between two different stimulus dimensions, whereas in Experiment 2, three different target dimensions were involved. Such an effect of the number of target dimensions on the dimension change effect would be expected if the target dimension is determined by a serial process, as was originally proposed by Treisman (1988). A serial checking procedure would result in a linear increase of the dimension change effect with the number of possible target dimensions and could account for the absence of dimension change effects when only two targets are involved: In this case, the effect size of the dimension change effect might be simply too small to be detected.

However, in the present study, the dimension change effect was not as systematically investigated as the feature priming effect. Hence, further research is necessary to clarify the underpinnings of the dimension change effect in simple and compound search tasks in more detail.

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Received November 12, 2006
Revision received November 10, 2007
Accepted December 9, 2007 ■

Correction to Roberts et al. (2008)

On the first page of the article "Effects of the Build-Up and Resetting of Auditory Stream Segregation on Temporal Discrimination" by Brian Roberts, Brian R. Glasberg, and Brian C. J. Moore (*Journal of Experimental Psychology: Human Perception and Performance*, 2008, Vol. 34, No. 4, pp. 992–1006), the year listed is incorrect. The article should have been dated 2008.

DOI: 10.1037/a0014237