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Dimension-Specific Intertrial Priming Effects Are Task-Specific: Evidence for Multiple Weighting Systems

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Feature singleton search is faster when the target-defining dimension repeats across consecutive trials than when it changes (Found & Müller, 1996). However, this dimension repetition benefit (DRB) has also been demonstrated for the tasks with no search component (Mortier, Theeuwes, & Starreveld, 2005). If DRBs in the search and non-search tasks have the same origin, significant DRBs across trials of different tasks should rise. Two different tasks varied either in a predictable manner (Experiment 1) or randomly (Experiment 2) across trials. In detection task, search displays containing either color or orientation singletons were used. Discrimination task required identification of either color or orientation of a single presented item (non-search display). In Experiment 3, participants performed only the discrimination task, while the search and non-search displays varied randomly. There were significant DRBs for both tasks when the task repeated but not when the task changed (Experiments 1 and 2). DRBs were significant both when the display type repeated and when it changed (Experiment 3). Overall, the findings can be well explained by assuming multiple, independent dimension-weighting systems generating DRBs in different tasks.

Keywords: intertrial priming, dimension weighting, visual search, feature discrimination, task switching

Our senses provide us with abundant information about our environment. At the same time, our cognitive system is limited in its processing capacity (e.g., Broadbent, 1982; Pashler, 1984, 1994). Capacity limitations force the system to deal only with subsets of the sensory input at any given moment. How does the system select what information will be processed preferentially? What is selected is determined by properties of the current stimulation and the state of the cognitive system. However, prominent models of visual selection (e.g., Itti & Koch, 2000, 2001) describe the selection dynamics as being determined primarily by stimulus properties (i.e., by local feature contrast signals). In stimulus-driven accounts of visual selection, the role of previous experience had been largely ignored until a range of studies revealed intertrial effects that point to an important role of previous experience in visual selection processes (e.g., Found & Müller, 1996; Maljkovic & Nakayama, 1994, 1996, 2000; Müller, Heller, & Ziegler, 1995; Treisman, 1988). Although these effects have been firmly established, there is an ongoing debate about whether they have their locus on a stage before or after selection takes place. Implicit in this dichotomy is the assumption that previous experience modulates human performance via a single mechanism located at either a preselective or a postselective processing stage. Alternatively, however, one could envisage the existence of several mechanisms that influence cognitive processes at different processing stages. The present study was designed, in the main, to contrast the assumptions of single versus multiple mechanisms via which previous experience may affect human performance in visual search and non-search tasks.

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Dynamics of Visual Selection Processes

Mechanisms of visual selection are often investigated using the feature singleton detection paradigm, in which a target differs from homogeneous distractors in one or more visual features. Typically, response times (RTs) are fast and independent of set size (e.g., Treisman, 1982). Several functional processing architectures have been proposed to explain the finding of efficient search for feature singletons (e.g., Itti & Koch, 2000, 2001; Koch & Ullman, 1985; Wolfe, 1994; Wolfe, Butcher, Lee, & Hyle, 2003; Wolfe, Cave, & Franzel, 1989). According to these models, the visual scene is analyzed in terms of feature contrast across all locations in parallel. This parallel

processing stage gives rise to a map of feature-contrast signals that are proportional to the relative uniqueness of the stimuli at analyzed locations. The feature-contrast signals are first integrated into dimension-specific maps (e.g., for color and orientation) and then summed up into a (supradimensional) master map of saliencies. The locations producing the strongest signals on the master map are then selected by focal attention. In the singleton detection task, the location of the singleton target will always produce the strongest saliency signal, and therefore the target will be the first item to be selected, independently of the set size.

In these models, the strength of the signals on the master map of saliencies depends only on the current visual stimulation, independent of previous experience. However, Found and Müller (1996) found search performance for a given singleton (e.g., color) on trial n to depend on the target dimension of the previous trial ($n - 1$): singleton detection on the current trial (n) was faster when the previous trial ($n - 1$) contained a singleton defined in the *same dimension* (e.g., a color target followed by a color target) rather than one defined in a *different dimension* (an orientation followed by a color target). This effect was primarily dimension specific rather than feature specific: Significant priming was observed even across trials containing different targets (e.g., blue or green among yellow bars), provided that the dimension of distinction repeated (i.e., when it was color). If stimulus properties were the sole determinant of the selection dynamics, the same stimulation should always generate the same saliency signal, which in turn should produce comparable singleton detection RTs (whatever the singleton on the previous trial). Thus, the dimension repetition benefit (DRB) demonstrates that factors other than feature contrast signals also affect visual search dynamics.

Dimension Weighting Account

To account for the effects of dimensional repetition on singleton detection times, Müller and colleagues (Found & Müller, 1996; Müller et al., 1995; Müller & Krummenacher, 2006a; Müller & O'Grady, 2000) formulated the dimension-weighting account (DWA), according to which signal summation from different dimensional modules to the level of master map of saliencies is modulated by dimension-specific weights. Increased dimensional weights (e.g., for color) increase the speed or efficiency with which the signals from that dimension (e.g., color dimension map) are transferred to the master map. The weights themselves are sensitive to the recent trial history: A color singleton presented on a given trial leads to an increase of the color weight, which in turn facilitates processing of color signals on the subsequent trial, giving rise to the DRB.

Evidence in favor of a perceptual locus of dimensional weighting comes from investigations of the neural correlates of the DRB. Pollmann and colleagues (Pollmann, Weidner, Müller, & von Cramon, 2000; Pollmann, Weidner, Müller, Maertens, & von Cramon, 2006), in an event-related functional MRI (fMRI) study, reported a significant BOLD signal increase in visual sensory areas (V4 and hMT+), contingent on the repetition of the target-defining dimension (color and, respectively, motion) across consecutive trials.

Sensitivity of sensory visual areas to repetitions of the relevant dimensions argues in favour of a perceptual locus of dimensional weighting. That this perceptual locus is indeed pre-selective is supported by a study of Töllner, Gramann, Müller, Kiss, and Eimer (2008), who investigated ERP correlates of the DRB using a compound task (Bravo & Nakayama, 1992; Duncan, 1985), where the target- and the response-defining features were dissociated: participants had to respond to the orientation of a grating within a form- or a color-defined target. Analysis of the N2pc component (an ERP marker that is commonly assumed to reflect processes of attentional allocation; e.g., Eimer, 1996) revealed significant effects of dimension repetitions (vs. changes) on both N2pc amplitudes and peak latencies. This adds support to the notion that dimensional weighting modulates (pre-selective) signal coding processes that form the basis for the allocation of focal attention.

Alternative Explanation of Dimension Repetition Benefit

Instead of assuming that dimensional weights modulate saliency computation processes (as in the DWA), alternative accounts, suggested independently by different authors, assume that the DBRs originate from later, postselective stages of processing (e.g., Cohen & Magen, 1999; Cohen & Shoup, 1997, 2000; Feintuch & Cohen, 2002; Theeuwes, 1991, 1992, 2004). According to these authors, basic stimulus properties are the main determinants of the saliency computation processes and, consequently, the search dynamics, whereas the DRB effects arise at the postselective stage of response selection.

The assumption that dimension-specific intertrial effects originate from stages after the search took place implies that significant DRBs should arise even in tasks that do not require searching for the target. Mortier et al. (2005) tested this prediction in a study with two tasks that varied in their demands on target selection. In the *singleton search* task, participants had to discern the presence versus absence of a singleton target in displays with varying numbers of distractor items. Mortier et al. compared two blocked search conditions: (a) *within-dimension search*, in which the singleton, when present, always differed from distractors in color; and (b) *cross-dimension search*, in which the singleton differed in color, shape, or size.

The *non-search* task was designed to eliminate the search component from the task by presenting only one item on every trial. On some trials, the presented stimulus was a small gray circle, identical to distractor items from the search task. This circle was also treated as a distractor in the non-search task and required one ("target absent") response. If the presented item was different from the distractor (in whatever visual attribute), another ("target present") response was required. Analogously to the search task, for the non-search task there were two blocked conditions: (a) a *within-dimension* condition, in which the critical difference was always in color; and (b) a *cross-dimension* condition, in which the difference could be in color, shape, or size. Thus, in brief, Mortier et al. (2005) compared performance between two tasks in which the selection process was relatively difficult (search task) or the search component was minimized (non-search task).

Participants responded faster to the target stimulus in the within-dimension condition than in the cross-dimension condition, in both tasks. In the cross-dimension condition of both tasks, responses were faster when the relevant dimension repeated across consec-

utive trials than when the dimension changed (i.e., significant DRBs were observed in both search and non-search tasks).

In a further experiment (Experiment 5), Mortier et al. (2005) changed the response requirements in the non-search task: The presented stimulus contained a small line element, and participants had to discriminate its orientation. As before, the size, shape, or color features of the stimulus could either repeat or change across consecutive trials; they were, however, irrelevant for the required response. In contrast to the previous experiments, there were no significant dimension repetition benefits under these task conditions.[1] Given that the change in response requirements appeared to abolish DRBs in the non-search task, Mortier et al. argued for a postselective, response selection account of dimensional intertrial effects.

Single Versus Multiple Weighting Systems

The studies reviewed thus far show that processing speed in a variety of simple cognitive tasks is sensitive to the recent trial history. Dimension-specific intertrial effects were observed in both visual search tasks and tasks in which no search was necessary. The striking similarity of behavioral data from search and non-search tasks has been taken, by Mortier et al. (2005), to indicate that the dimension repetition benefits in both tasks originate from postselective processing stages. However, apart from this similarity, arguably, no direct empirical support for this hypothesis has been put forward thus far. Instead of assuming a single postselective dimension weighting system involved in search and non-search tasks, one could also assume the existence of two weighting mechanisms situated at different processing stages. One mechanism would modulate preselective saliency signal computations, as are elaborated in the DWA, and generate the DRBs in the search task. The other weighting mechanism would modulate postselective processes and produce the DRBs in the non-search task.

The idea of multiple sequence-sensitive mechanisms is not entirely new in the literature. For example, Huang and colleagues (Huang, Holcombe, & Pashler, 2004; Huang & Pashler, 2005) argued for multiple sources of intertrial effects in Maljkovic and Nakayama's (1994, 1996, 2000) "priming of pop-out (PoP)" paradigm: one mechanism presumably engaging preselective, perceptual processing stages, and the other modulating postperceptual, response-selection processes. Similarly, Kumada (2001) argued for existence of separate systems modulating performance in different tasks. In a variety of tasks, from singleton detection to a version of a non-search compound task, he compared two measures of dimensional facilitation: within-dimensional facilitation (WDF; Müller et al., 1995; Treisman, 1988)—that is, faster mean RTs in trial blocks in which the relevant dimension is fixed—in comparison with blocks in which the dimension is variable; and dimension repetition benefits across consecutive trials (in the variable-dimension trial blocks). Kumada (2001) found that in tasks requiring only target detection (e.g., singleton detection), both WDF and DRBs were significant, whereas in tasks demanding postselective processing (e.g., compound task), only the WDF was significant. This dissociation motivated Kumada to argue for separate mechanisms underlying WDF and DRBs, respectively.

The notion of multiple dimension-weighting systems is compatible with the DWA. In essence, the DWA assumes that at least part of the DRBs observed in the singleton detection (search) task stem from the weighting of dimension-specific feature contrast signals. This assumption does not a priori exclude the possibility that there may be other, dimension-specific postselective processes (see, e.g., Müller & Krumenacher, 2006a, who acknowledged this possibility, and Töllner et al., 2008, for an elaboration of a postselective mechanism sensitive to both dimension and response sequences). The two weighting systems would have a similar dimension-specific dynamic, producing similar data patterns of dimension repetition benefits in both search and non-search tasks. In contrast, postselective accounts of the DRBs have been very definite about the nature of the DRBs: They assume that, whatever the task (search or non-search), the observed DRBs all have a common source, namely, the response selection stage (e.g., Mortier et al., 2005).

Purpose of the Present Study

In summary, significant DRBs are observed in both search and non-search tasks. This pattern of findings could be explained either by a single weighting system operating at a postselective processing stage or by multiple weighting systems influencing different processes at preselective and, respectively, postselective processing stages. These two accounts give rise to differential predictions when the two tasks, search and non-search, are made to alternate within a block of trials. In such a situation, the task to be performed can either repeat or change across consecutive trials. Both the single and the multiple weighting systems hypotheses predict significant dimension repetition benefits when the task repeats across consecutive trials. The critical question, however, is what would happen when the task changes across trials. If there were only one weighting system, it should operate in both tasks; consequently, DRBs should be evident even across consecutive trials with different tasks. By contrast, if the DRBs observed within different tasks were generated by separate weighting systems, no dimension repetition benefit would be expected across trials with different tasks.

To test these differential predictions, two different tasks were mixed within the same block of trials: a search task and a non-search task similar to those examined, in separate trial blocks, by Mortier et al. (2005). The non-search task differed in one crucial respect from that used by Mortier et al., in that dimension repetitions were dissociated from response repetitions. If the DRBs were found to persist across response changes, this would argue against a strong response selection–based interpretation of the DRBs in non-search tasks (i.e., the interpretation favored by Mortier et al., 2005).

Experiment 1 examined whether the dimension repetition benefits would generalize across different tasks (A and B) with the task sequence fixed in an alternating-runs manner (AABBAA). Experiment 2 tested whether the pattern of effects observed in Experiment 1 could be replicated even when the task sequence is made unpredictable. In both Experiments 1 and 2, the stimulus display indicated the type of task to be performed, which led to a correlation between task and display sequences (i.e., when the

[1] As Mortier et al. (2005) did not report mean RTs per condition, it is hard to tell whether there was a trend towards a DRB; judging from their Figure 8, there appears to be a numerical benefit of some 5–6 ms.

display changed, the task changed as well). Given this, Experiment 3 assessed effects of display type change on DRBs, independently of task change effects.

General Method

All three experiments used a similar experimental setup and paradigm. Therefore, the shared methods are presented here, with differences between experiments noted in the Method section of the respective experiment.

Apparatus

The experiments were run on a Dell PC running under the Windows XP operating system. The stimuli were presented on a Fujitsu Siemens 21-inch CRT monitor, with a screen resolution of 1280 × 1024 pixels and a refresh rate of 85 Hz. The experimental software was custom written in C++. Participants performed the task in a dimly lit and acoustically isolated room, seated in front of the computer display. Head-to-monitor distance was 57 cm, controlled by means of a chin rest. Participants were to respond by pressing the left or the right button of a computer mouse, with their left or right index finger, respectively.

Stimuli

Two types of stimulus display were used, similar to the display types used by Mortier et al. (2005): (a) search and (b) non-search displays. The search display consisted of 28 bars organized in three concentric circles (around a central fixation mark) with 4, 8, and 16 elements, respectively. The individual bars were 0.4° of visual angle in width and 1.7° in height. The whole stimulus display subtended an area of 14° × 14° of visual angle. A search display either could contain (in 60% of the trials) a singleton item (=target present) or not (=target absent). In target-absent displays, all bars were yellow (CIE xyY 0.438, 0.475, 58.4) and tilted 45° counterclockwise from the vertical (=left tilted). When a target was present, it differed from distractors in either color (red, CIE xyY 0.486, 0.389, 50.2) or orientation (tilted 45° clockwise from the vertical = right tilted). A pilot experiment was performed to determine the color and orientation values of the singletons such that they yielded comparable singleton detection times.

Non-search displays consisted of a single bar presented in the center of the screen. There were four possible bars: vertical or horizontal yellow bars (*orientation* targets), and blue or green left-tilted bars (*color* targets). Note that for orientation targets, the irrelevant (color) feature was the same as the color of distractors in the search displays (yellow). Likewise, for color targets, the irrelevant (orientation) feature matched the orientation of distractors in the search displays (leftward tilt). A pilot experiment using heterochromatic flicker photometry was performed to determine individual blue-green isoluminance. The group mean isoluminance coordinates were then used as color values for blue (CIE xyY 0.235, 0.280, 85.5) and green (CIE xyY 0.288, 0.486, 85.4), respectively. An illustration of both search and non-search stimulus displays is given in Figure 1.

Design

There were two tasks: (a) singleton detection (search task) and (b) feature discrimination (non-search task). Search displays were used for the singleton detection task, and non-search displays for the feature discrimination task. This way, information about what task was to be performed was provided by the type of stimulus display. In the singleton detection (search) task, participants had to discern the presence or absence of a singleton target in the display and respond by pressing the corresponding mouse button as fast as possible. In the feature discrimination (non-search) task, participants had to discriminate either the color (blue vs. green) or the orientation feature (horizontal vs. vertical) of a presented target bar. Different features within a given dimension of discrimination were mapped to different responses (e.g., for color discrimination, right button for green and left button for blue target bars). Different stimulus-response mappings for either task were balanced across participants.

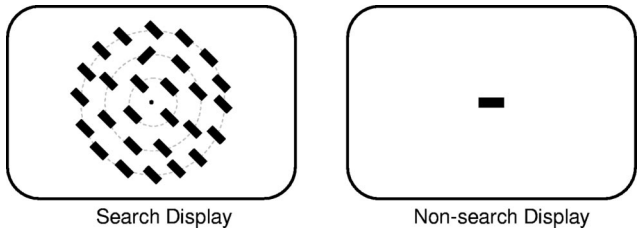

Figure 1. Illustration of the stimulus displays used in the present experiments. Original stimuli were plotted on a black background and were of different colors. See the text for more details.

The feature discrimination (non-search) task in the present experiments differed from the non-search task used by Mortier et al. (2005) in that the sequence of dimensions on consecutive trials (same vs. different) was dissociated from the sequence of responses. Thus, for example, participants may have had to discriminate color on both trial $n - 1$ and trial n, but the required response could either repeat or change. This was done to permit the DRBs in the present feature discrimination task to be assessed independently of the response sequence. Nevertheless, as in the non-search task of Mortier et al., the targets were the only items in display and presented at a fixed (central) location, which minimized the search component of the task performance.

A given trial in the present experiments was defined by the task to be performed (detection vs. discrimination) and by the task-relevant dimension (color vs. orientation). In the singleton detection task, *relevant dimension* refers to the dimensional module from which the informative feature contrast signal originates; in the feature discrimination task, it refers to the dimension of feature discrimination. The task, dimension, and response could (independently) either repeat or change across a pair of consecutive trials. Combining the experimental factors produced the following design: (a) task (detection vs. discrimination), (b) dimension (color vs. orientation), (c) task sequence across pairs of trials (same vs. different), (d) dimension sequence (same vs. different), and (e) response sequence (same vs. different).

Procedure

Given that participants had to memorize and simultaneously maintain the stimulus–response mappings for two tasks (detection and discrimination), and for two separate dimensions in the discrimination task (color and orientation discrimination), the exper-

iments required a time-consuming learning stage. For this reason, each experiment was split into two sessions. The first session, of 600 trials (which took about 20 min to complete), was dedicated to practice. The second, experimental session consisted of 1800 trials (which took about 1 hr to complete). A large number of trials were necessary to assure enough observations for analyzing the various intertrial sequences. The two sessions were separated by a short break (of 5–10 min) for participants to get some rest and for the experimenter to check whether the stimulus–response mappings had been learned.

Participants were to respond on every trial. Stimuli were presented either until a response was made or for 3 s if meanwhile no response was given. Trials were separated by a variable interstimulus interval. After a correct response, only a fixation point was visible on the screen during this interval (200 to 700 ms). Erroneous responses were followed by an empty (black) screen of variable duration (1000 to 2000 ms). An example of the trial sequence with timing details is provided in Figure 2.

Experiment 1

In Experiment 1, participants performed both the singleton detection and the feature discrimination task within the same blocks of trials. The aim was to examine whether similar dimension repetition benefits (DRBs) could be observed for both tasks. The critical analysis concerned whether or not the DRBs would persist across trials with different tasks. Significant DRBs across such trials would argue in favor of postselective accounts of dimensional weighting. Conversely, the absence of intertrial effects across different tasks would be consistent with the hypothesis of multiple weighting systems.

Method

Participants. Eleven university students (3 women, mean age of 25 years) with normal or corrected-to-normal vision took part in the experiment in return for monetary compensation (8€ per hour). All of them were naïve with respect to the purpose of the experiment, though they all had previous experience with psychophysical experiments and visual search tasks.

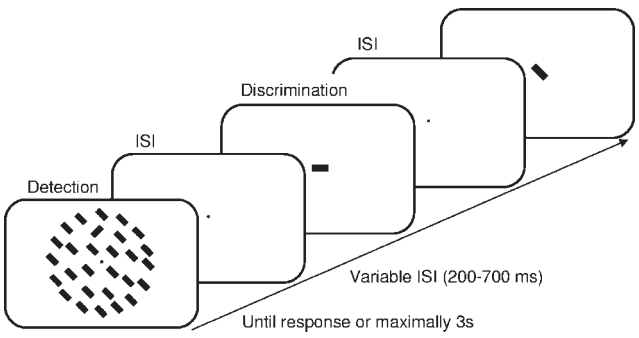

Figure 2. Illustration of trial sequence used in the present experiments. Participants performed the singleton detection task when presented with a search display and the feature discrimination task when presented with a non-search display. ISI = interstimulus interval. See the text for more details.

Procedure. Participants performed the two tasks mixed within the same blocks of trials. The task sequence (same/different) was fixed, with two trials of one task (Task A) followed by two trials of the other task (Task B). This alternating-runs sequence (AABB) was used for two reasons. One was to make the paradigm (in particular, task changes) easier for participants. The other was to have an equal number of trials for each task sequence condition. All other methodological details were as described in the General Method section.

Results

The recorded response data were first filtered for errors and extreme reaction times (outside ± 3 standard deviations, SD, of the RT distribution). About 1% of trials per participant were excluded because of extreme RTs. Participants made response errors in approximately 4% of all trials, on average, with most participants' error rates varying between 3% and 5%. One participant made more than 5% errors and was excluded from subsequent analyses. Data inspection revealed no indications of speed–accuracy trade-offs. Because of the generally low error rates, no further analyses were performed on the error data.

The remaining trials were then sorted into 16 experimental conditions: task (detection vs. discrimination) × dimension (color vs. orientation) × task sequence (same vs. different task across consecutive trials) × dimension sequence (same vs. different dimension across trials). On average, for each experimental condition there were around 52 trials (range of 30 to 89 trials). For the detection task, only target-present trials were analyzed. This resulted in only one response type for the detection task, so that the sequence of responses across consecutive trials was not taken into account in the analyses.

A four-way repeated-measures analysis of variance (ANOVA) of the RTs was carried out with main terms for (a) task, (b) dimension, (c) task sequence, and (d) dimension sequence. There were significant main effects of task, $F(1, 9) = 9.70$, $p < .01$, $\eta_p^2 = .52$; task sequence, $F(1, 9) = 62.18$, $p < .01$, $\eta_p^2 = .87$; and dimension sequence, $F(1, 9) = 25.45$, $p < .01$, $\eta_p^2 = .74$. Participants were faster to detect than to discriminate a target item (476 vs. 509 ms), faster when the current task was the same rather than different from the preceding task (474 vs. 510 ms), and faster when the relevant dimension was repeated, rather than changed, across trials (482 vs. 503 ms). Furthermore, the Task Sequence × Dimension Sequence interaction, $F(1, 9) = 62.69$, $p < .01$, $\eta_p^2 = .87$, and the Task × Task Sequence × Dimension Sequence interaction, $F(1, 9) = 10.14$, $p < .01$, $\eta_p^2 = .53$, were significant. Neither the main effect of dimension (color vs. orientation) nor its interactions with any other factor reached significance (all Fs < 4.94, $p > .05$). Thus, effects of dimension are not further discussed, and the data presented here are collapsed across color and orientation targets. The distribution of mean RTs across different tasks, task sequences, and dimension sequences is presented in Figure 3.

Figure 3 shows that there was a difference in mean RTs between different dimension sequences (same vs. different dimension) in both tasks, when the task repeated across consecutive trials (squares). However, no such difference was evident when the task changed (circles). To examine exactly for which tasks and task sequences the dimension sequence produced significant effects (i.e., DRBs), we performed a post-hoc analysis (two-sided Tukey

HSD, critical alpha level of .05) for the Task × Task Sequence × Dimension Sequence interaction. There were significant dimension sequence effects for both detection and discrimination tasks. Participants detected targets faster, by 32 ms, when the relevant dimension was the same as that on the previous trial in comparison with when it was different. Similarly, discrimination was faster, by 60 ms, when the dimension repeated than when it changed. However, the DRBs were significant only when the task stayed the same across consecutive trials; no significant DRBs were observed when the tasks changed (0 and −6 ms for detection and discrimination, respectively).

In a second analysis, planned comparisons (two-sided *t* tests, critical alpha level of .05) were carried out for pairs of nonconsecutive trials. Maljkovic and Nakayama (1994, 1996, 2000) had shown significant priming of pop-out effects on the current trial (n) by stimulus properties on trials up to five trials before (trial $n - 5$). Thus, in general, intertrial priming effects can be tested between the current trial n and any previous trial $n - i$. For Experiment 1, the second analysis focused on the DRBs between nonconsecutive trials n and $n - 3$ (due to the AABBAA sequence of tasks, it was not possible to assess DRBs across same tasks between trials n and $n - 2$). Mean RTs were compared for different dimension sequences (same vs. different) separately for different tasks (detection and discrimination) and different task sequences (same or different). The results of the planned comparisons are summarized in Table 1. As can be seen, the analysis of DRBs across nonconsecutive trials yielded no significant effects for the detection task. By contrast, for the discrimination task, there was a significant DRB, provided that participants performed the same task (discrimination) on both trials n and $n - 3$.[2]

Thus, the above comparisons revealed significant DRBs across both consecutive and nonconsecutive trials of the same task, but not across trials of different tasks. One could object, though, that the (true) magnitude of DRBs across trials of different tasks was underestimated in these comparisons: Such intertrial transitions involved a change in both task and (potentially) response, which may have been associated with costs that could have masked any benefits due to dimensional repetition. However, the finding that at least for the discrimination task, the DRBs persist across two task changes (from discrimination on trial $n - 3$ to detection on trials $n - 2$ and $n - 1$, back to discrimination on trial n) argues that task change costs were unlikely to have masked potential DRBs across consecutive trials of different tasks (involving only one task change). To examine the role of response change costs, an additional ANOVA was carried out with main terms for (a) task, (b) dimension, (c) dimension sequence, and (d) response sequence, across consecutive trials of different tasks. If response change costs did mask potential DRBs across different tasks, then it should be possible to observe significant DRBs across different tasks when the response repeats (in which case there cannot be a response change cost). The ANOVA revealed only the main effect of task to be significant, $F(1, 9) = 8.36$, $p < .05$, $\eta_p^2 = .48$, with detection being performed faster than feature discrimination (496 vs. 527 ms). No other effects reached significance (all Fs < 3, $p > .11$). Most importantly, there was neither a main effect of response sequence, $F(1, 9) = .38$, $p = .55$, $\eta_p^2 = .04$, nor an interaction with task and dimension sequence, $F(1, 9) = .99$, $p = .35$, $\eta_p^2 = .01$, arguing against response change costs being responsible for the absence of DRBs across consecutive trials of different tasks.

Table 1
Mean Reaction Times (RTs, in Milliseconds), Standard Errors of the Means (M_{RT}; SE_M in Parentheses), as Well as Magnitudes of the DRBs and Corresponding Student's T Values for Different Dimension Sequences (Same vs. Different) Across Nonconsecutive Pairs of Trials in Experiments 1 and 2

Task sequence	Dimension sequence: Same	Dimension sequence: Different	DRB	*T*
Experiment 1, df = 9				
Detection on trial n				
Same task on trial $n - 3$	489 (25)	491 (23)	2	0.49*
Different task	473 (22)	469 (25)	−4	0.80*
Discrimination on trial n				
Same task on trial $n - 3$	520 (26)	530 (25)	10	3.22**
Different task	493 (19)	488 (21)	−5	1.37*
Experiment 2, df = 10				
Detection on trial n				
Same task on trial $n - 2$	475 (30)	490 (31)	15	3.57*
Different task	496 (33)	500 (31)	4	1.41*
Discrimination on trial n				
Same on trial $n - 2$	524 (32)	542 (32)	18	4.78**
Different task	541 (33)	539 (35)	−2	0.54*

Note. These findings are presented separately for different tasks (detection and discrimination) and different task sequences (same vs. different). DRB = $M_{\text{RT different dimension}} - M_{\text{RT same dimension}}$; *df* = degrees of freedom. * Not significant. ** $p < .01$.

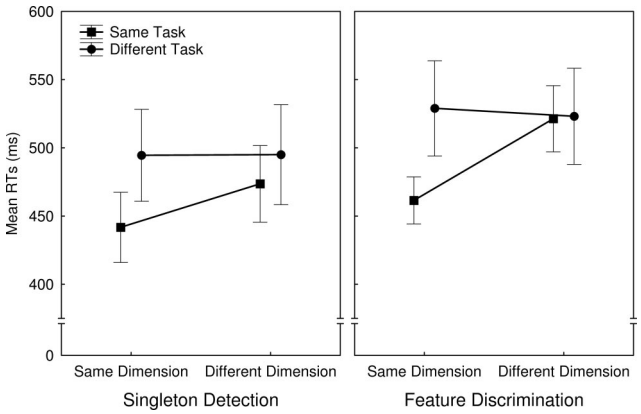

Figure 3. Mean reaction times (RTs; in milliseconds) across different tasks (detection and discrimination), task sequences (same task in both trial n and trial $n - 1$ = squares; different task = circles), and dimension sequences (same vs. different) in Experiment 1. Vertical bars denote standard errors of the means.

[2] Analysis of DRBs across nonconsecutive trials also showed that mean RTs were slower for trials with the same task than for trials with different tasks. This result is due to the fixed task sequence in Experiment 1: When n and $n - 3$ were trials of the same task, the task on the immediately preceding trial ($n - 1$) was always different from the task on the current trial (n). Thus, higher mean RTs reflect task change costs between trials $n - 1$ and n.

Discussion

The results of Experiment 1 showed that dimension repetition benefits are task specific. When the task repeated across the pair of analyzed trials, significant dimension repetition benefits were observed for both detection and discrimination tasks. However, there were no significant DRBs when the task changed across the pair of analyzed trials. The absence of a dimension repetition benefit across trials with different tasks argues against the hypothesis of a single weighting system. On the other hand, this (non) finding can easily be explained by assuming that separate weighting systems modulate intertrial effects in different tasks.

Other explanations, besides invoking multiple weighting systems, could possibly also account for the task specificity of the DRBs. For example, one alternative explanation could be that when the task changes, the (complete) dimensional weight set that has evolved over the trial history is erased or, respectively, the weights reset to some default value. If this were the case, then there should be dimension repetition benefits only in cases in which the task repeats across a pair of consecutive trials. That is, accounts assuming the existence of (only) one weighting system would predict, by invoking the weight-resetting hypothesis, significant DRBs only when the task remains the same on consecutive trials. In contrast, the results of Experiment 1 showed that there was a significant dimension repetition benefit for the discrimination task even between nonconsecutive pairs of trials. This finding shows that the task-specific dimensional weight set can survive across several task switches, which seriously challenges the weight-resetting hypothesis.

However, the significant DRBs for nonconsecutive trials of the discrimination task do not permit the resetting hypothesis to be rejected completely, because this finding does not generalize to the detection task. The (seeming) dissociation between detection and discrimination tasks might have several reasons. For example, the DRBs across nonconsecutive trials of the discrimination task may be due to some specific strategy that participants adopted for performing the discrimination task. In Experiment 1, the task change sequence was predictable. To exploit this, participants may have invested additional effort to maintain the weight settings for the (more difficult) discrimination task, being aware that the same task would repeat after the next two trials. This strategy might not have been necessary for performing the detection task, which was much easier to solve than was the discrimination task. Accordingly, the dissociation between the two tasks may reflect differential strategies that participants used in the two tasks.

The multiple-weighting-systems hypothesis could provide a different explanation. The DRBs deriving from the immediately preceding trial $n - 1$ were smaller, in the first instance, for the detection task (≈30 ms) than for the discrimination task (≈60 ms). Because the $n - 3$ effects were smaller than were the $n - 1$ effects in the discrimination task, such a reduction would also be expected for the detection task (see, e.g., Maljkovic & Nakayama, 1994, who also found smaller repetition effects arising from trial $n - 3$ than from trial $n - 1$). As a consequence, in the detection task, this benefit might have decreased to a statistically nonreliable value over the course of three trials.

In summary, the results of Experiment 1 can be interpreted in at least two ways. One is that separate weighting systems modulated performance in search and non-search tasks. Favoring this interpretation is the evidence for significant DRBs across nonconsecutive trials of the discrimination task. That there was no such effect for the detection task could then be explained by assuming that accumulated weight settings decayed over the course of two to three trials, so that potential DRBs across nonconsecutive trials of the detection task could no longer be discerned statistically. On the other hand, one could also assume that there is only one weighting system, but that weight settings are reset to some initial (default) value with every task change. Along these lines, the finding of significant DRBs across nonconsecutive trials of the discrimination task could be explained by assuming that, given a predictable task sequence, participants adopted a special (effortful) strategy to improve performance in the (more difficult) discrimination task. No such strategy was necessary for performing the easier detection task. Experiment 2 was designed to assess the multiple-weighting-systems versus the weight-resetting account of the findings of Experiment 1.

Experiment 2

The weight-resetting and multiple-weighting-systems hypotheses make different predictions regarding random task change sequences: If the task varies in an unpredictable manner within a block of trials, adoption of a special (effortful) strategy for the discrimination task would yield little benefit for overall performance; in fact, arguably, active maintenance of the weight setting for one particular task across an unpredictable number of trials would interfere with performance on the intervening trials, harming overall performance. Accordingly, for such situations, the weight-resetting hypothesis would predict no (or at least reduced) DRBs across nonconsecutive trials of the discrimination task. By contrast, the multiple-weighting-systems hypothesis assumes that the weight settings persist across task switches, regardless of the task sequence. Consequently, there would be a DRB across nonconsecutive trials even when the task sequence is unpredictable.

An additional prediction deriving from the multiple-weighting-systems hypothesis is that the DRBs should increase with a decrease in the temporal distance between analyzed pairs of trials, that is, intertrial (DRB) effects should be stronger between trials n and $n - 2$ than between trials n and $n - 3$. For the (easier) detection task (in which the effects of the weighting are generally reduced), analysis of dimension-specific intertrial effects might reveal the DRBs to be significant between trials n and $n - 2$ (which could not be assessed in Experiment 1). In contrast, the weight-resetting hypothesis would not predict such a pattern of effects, because the weights are assumed to be reset with every task change.

The particular task sequence used in Experiment 1 did not allow direct testing of the different predictions regarding intertrial effects between trials n and $n - 2$. Because of the alternating-runs sequence (AABB) of tasks in Experiment 1, there were no n and $n - 2$ trials of the same task. For this reason, a random task change sequence was used in Experiment 2, which also rendered any strategy of actively maintaining the settings for the more effortful task less beneficial for overall performance. Thus, within a single paradigm, predictions regarding the role of strategy and intertrial distance in generating DBRs across nonconsecutive trials could be tested.

Method

Participants. Twelve university students (4 women, mean age 25 years) with normal or corrected-to-normal vision took part in Experiment 2 for monetary compensation. All of them were naïve with respect to the purpose of the experiment. All of them had previous experience with psychophysical experiments and visual search tasks.

Procedure. Participants performed both the singleton detection and the feature discrimination task within the same block of trials, with the task sequence varying unpredictably across trials. All other parameters were as described in the General Method.

Results

Trials with extreme RTs (out of ±3 SD range) and trials with response errors were first filtered out. About 2% of trials per participant were excluded because of the extreme RTs. Participants made about 4% errors, on average. One participant made more than 5% errors and was excluded from the subsequent analyses. Inspection of the error pattern revealed no evidence of speed–accuracy trade-offs. Because of the low error rates, these were not analyzed further.

The remaining trials were then sorted according to the task (detection or discrimination), relevant dimension (color or orientation), task sequence across consecutive trials (same or different tasks on trials n and $n - 1$), and dimension sequence (same or different). On average, there were about 51 trials per condition (ranging between 29 and 77 trials). A repeated-measures ANOVA was performed with the main terms for (a) task, (b) dimension, (c) task sequence, and (d) dimension sequence. This ANOVA revealed the main effects of task, $F(1, 10) = 151.88$, $p < .01$, $\eta_p^2 = .94$, task sequence, $F(1, 10) = 59.34$, $p < .01$, $\eta_p^2 = .86$, and dimension sequence, $F(1, 10) = 40.57$, $p < .01$, $\eta_p^2 = .80$, to be significant. Participants were, on average, faster to detect targets (489 ms) than to discriminate them (537 ms), faster when the task repeated (491 ms) than when it changed (535 ms), and faster when the dimension repeated (500 ms) than when it changed (526 ms). The Task × Dimension Sequence, $F(1, 10) = 32.50$, $p < .01$, $\eta_p^2 = .76$, Task Sequence × Dimension Sequence, $F(1, 10) = 57.55$, $p < .01$, $\eta_p^2 = .85$, and Task × Task Sequence ×Dimension Sequence, $F(1, 10) = 16.92$, $p < .01$, $\eta_p^2 = .63$, interactions were also significant. No other main effects or interactions reached significance (all Fs < 3.22, all ps $> .10$). The mean RTs for the different tasks, task sequences, and dimension sequences are shown in Figure 4.

As is depicted in Figure 4, when the task was the same across the trials (squares), participants were 30 ms faster to detect targets, and 67 ms faster to discriminate target features when the relevant dimension was the same on both trials n and $n - 1$, relative to when the dimension was different between these trials. No such effect was apparent when the tasks differed across trials (circles). To test for significance of the dimension sequence effects across different tasks and task sequences, post hoc comparisons (Tukey HSD, with a two-sided alpha level of .05) were performed for the Task × Task Sequence × Dimension Sequence interaction. Similar to Experiment 1, there was a significant effect of dimension sequence (i.e., significant DRBs) for both tasks, provided the task stayed the same; there were no significant DRBs when the task changed.

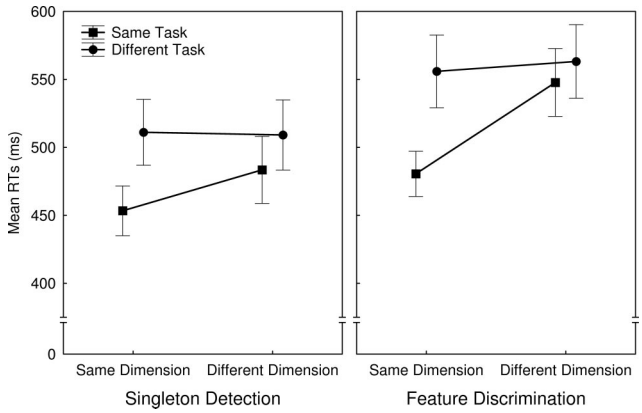

Figure 4. Mean reaction times (RTs; in milliseconds) across different tasks (detection and discrimination), task sequences (same task in both trial n and trial $n - 1$ = squares; different task = circles), and dimension sequences (same vs. different) in Experiment 2. Vertical bars denote standard errors of the means.

To test whether dimension repetitions across nonconsecutive trials generated significant DRBs, planned t tests (with a two-sided alpha level of .05) were performed between different dimension sequences (same vs. different) for trial pairs n and $n - 2$, separately for different tasks and task sequences. The results are summarized in Table 1. Planned comparisons revealed significant DRBs for both detection and discrimination tasks between nonconsecutive trials, provided the task stayed the same across these trials. No DRBs reached significance levels when the task on the current trial was different from that on trial $n - 2$.

Similar to Experiment 1, an ANOVA was performed with (a) task, (b) dimension, (c) dimension sequence, and (d) response sequence as main terms, across consecutive trials of different tasks. The analysis revealed only a significant main effect of task, $F(1, 10) = 44.06$, $p < .01$, $\eta_p^2 = .81$, with the detection task permitting faster responses than did the discrimination task (510 vs. 561 ms). No other main effects or interactions reached significance (all Fs < 2.27, $p > .16$). Importantly, as in Experiment 1, there was neither a main effect of response sequence, $F(1, 10) = .55$, $p = .47$, $\eta_p^2 = .05$, nor an interaction of this factor with task and dimension sequence, $F(1, 10) = .15$, $p = .70$, $\eta_p^2 = .01$. These (non) findings argue against response change costs masking potential DRBs across trials of different tasks.

Discussion

As in Experiment 1, the DRBs observed in Experiment 2 were also task specific, that is, they were significant only across trials of the same task, but not trials of different tasks. Moreover, Experiment 2 demonstrated significant DRBs across nonconsecutive trials for both detection and discrimination tasks. Taken together, results of Experiments 1 and 2 argue strongly against the weight-resetting hypothesis, while being in accordance with predictions derived from the multiple-weighting-systems hypothesis.

With regard to the question of whether the finding of a DRB observed within one task automatically generalizes across tasks, the answer is negative. The results of Experiments 1 and 2 are in close agreement with the findings of Mortier et al. (2005), in that

they show significant DRBs for both search and non-search tasks, as long as the task repeats across the analyzed pair of trials. However, going beyond Mortier et al., the present findings demonstrate for the first time (to our knowledge) that the intertrial effects do not generalize across search and non-search tasks.[3] Thus, while a postselective origin of dimension-specific intertrial effects may be true for one task, this is not necessarily the case for another task (if it were the case, then there should have been intertrial effects across different tasks). In contrast, the multiple-weighting-systems hypothesis can account for this pattern of findings: Performance in different tasks depends on different weighting systems. The feature contrast weighting system assumed by the DWA for singleton detection tasks would not contribute to the feature discrimination task, because there is no search component in this task. By contrast, postselective weighting mechanisms would play little role for performance in the singleton detection task, because this task can, in principle, be performed on the basis of the master saliency map representation (see, e.g., Krummenacher, Müller, & Heller, 2002a, 2002b). Assuming that different tasks involve different weighting mechanisms, no dimension-specific intertrial effects would be expected to arise between trials of different tasks.

In summary, Experiments 1 and 2 showed significant DRBs across consecutive and nonconsecutive trials of the same task, but not across trials of different tasks. On the multiple-weighting-systems hypothesis, this might be interpreted as a consequence of different sequence-sensitive mechanisms operating in the different tasks. However, alternative explanations remain possible. This is because the design used in Experiments 1 and 2 confounded task sequence and display type sequence: Search displays were presented for the detection task, and non-search displays for the feature discrimination task. Consequently, the DRBs may be stimulus display specific rather than task specific. Experiment 3 was designed to discriminate between these alternative explanations of the results of Experiments 1 and 2.

Experiment 3

In order to assess the role of stimulus changes separately from those of task changes, only the feature discrimination task, with two possible display types, was used in Experiment 3. Displays containing multiple items (as in the singleton detection task in Experiments 1 and 2), were mixed randomly with single-item displays (as in the discrimination task of the previous experiments). Irrespective of the display (multiple vs. single item), the target was always presented in the center of the screen. Participants were to perform only one, the feature discrimination task. Thus, Experiment 3 was similar to Experiments 1 and 2 in that it contained both multiple- and single-item displays, whereas, unlike Experiments 1 and 2, there was only one task to perform: the feature discrimination task. If the DRBs are task specific, rather than stimulus specific, then by virtue of having only one task, the DRBs should persist even across stimulus display changes in Experiment 3. Alternatively, if the DRBs are stimulus specific, no DRBs would be expected across different displays.

Experiment 3 also permitted the properties of the presumed postselective dimension weighting system (involved in the discrimination task) to be tested. From Experiments 1 and 2, it was unclear whether the DRBs in the discrimination task originate from response selection processes or from processes that are response independent and occur prior to the stage of response selection. If the selection of a particular response was facilitated, then significant DRBs should arise only contingent on a response repetition. However, if the intertrial effects originate from processes prior to response selection, then DRBs should occur even when the response changes across the pair of analyzed trials.

Method

Participants. Eleven university students (4 women, mean age 25 years) with normal or corrected-to-normal vision took part in the experiment for monetary compensation. All of them were naïve with respect to the purpose of the experiment. All of them had previous experience with psychophysical experiments and visual search tasks.

Stimuli. Two types of stimulus display were used: (a) search display and (b) non-search display. The search displays closely resembled those in Experiments 1 and 2. It consisted of 28 left-tilted yellow bars, arranged in three concentric circles of 4, 8, and 16 items, respectively. The non-search display was identical to the non-search display used in Experiments 1 and 2. However, in both search and non-search displays, the target item always appeared in the center of the screen. It could be green or blue (left tilted), or horizontal or vertical (yellow) bar. The color and orientation values were the same as those used in the non-search displays of Experiments 1 and 2. In the search display, the target item appeared surrounded by distractor items; in the non-search display, the target was the only item presented on the screen.

Because the location of the target item was fixed throughout the sequence of display types, no search was strictly necessary to localize the targets even in "search"-type, multi-item displays. However, to emphasize the parallels between the search displays presented in (the detection tasks of) Experiments 1 and 2 and "search"-type displays used in (the feature discrimination task of) Experiment 3, we preserved this terminology, that is, multi-item displays are referred to as *search displays* and single-item displays as *non-search displays*.

Procedure. Search and non-search types of display were varied randomly across trials, with the target item always presented in the center of the screen. Whatever the display type, participants had to perform the feature discrimination task, that is, they had to indicate either the color (green vs. blue) or the orientation (vertical vs. horizontal) feature of the central target item. All other parameters were as described in the General Method.

Results

Trials with erroneous response and extreme response latencies were first filtered out. About 1% of trials per participant were excluded because of extreme RTs. Error rates were less than 4% on average. Because of a small number of errors, error rates were not analyzed further. Inspection of the error patterns revealed no indication of speed–accuracy trade-offs.

[3] Olivers and Meeter (2006) demonstrated a similar lack of carry-over effects across two search tasks, specifically, singleton detection and compound-search tasks.

The RT data were examined by a repeated-measures ANOVA with main terms for (a) display (search vs. non-search), (b) relevant dimension (color vs. orientation), (c) display sequence (same vs. different display in relation to the $n - 1$ trial), (d) dimension sequence (same vs. different dimension in relation the to previous trial), and (e) response sequence (same or different response in relation the to previous trial). This ANOVA revealed the main effects of display, $F(1, 10) = 174.47$, $p < .01$, $\eta_p^2 = .95$, display sequence, $F(1, 10) = 50.34$, $p < .01$, $\eta_p^2 = .83$, dimension sequence, $F(1, 10) = 37.64$, $p < .01$, $\eta_p^2 = .79$, and response sequence, $F(1, 10) = 18.56$, $p < .01$, $\eta_p^2 = .65$, to be significant. Participants were faster to discriminate features in the non-search display than in the search display (500 vs. 529 ms), and faster when the display repeated than when it changed across a pair of trials (510 vs. 519 ms). Additionally, participants were faster when the dimension to be discriminated repeated than when it changed (484 vs. 545 ms), and faster when the required response repeated than when it changed (501 vs. 527 ms). The Dimension × Response Sequence interaction, $F(1, 10) = 6.35$, $p < .05$, $\eta_p^2 = .39$, also proved significant. Post hoc analysis (Tukey HSD, two-sided alpha = .05) revealed a significant difference in RTs between color and orientation targets when the response changed across trials (535 and 519 ms for color and orientation targets, respectively), whereas there was no RT difference between color and orientation targets when the required response repeated across trials (502 and 500 ms for color and orientation targets). Additionally, the following interactions were significant: Display Sequence × Dimension Sequence, $F(1, 10) = 20.98$, $p < .01$, $\eta_p^2 = .68$, Display Sequence × Response Sequence, $F(1, 10) = 10.13$, $p < .01$, $\eta_p^2 = .50$, Dimension Sequence × Response Sequence, $F(1, 10) = 35.43$, $p < .01$, $\eta_p^2 = .78$, and Display Sequence × Dimension Sequence × Response Sequence, $F(1, 10) = 20.16$, $p < .01$, $\eta_p^2 = .67$. No other main effects or interactions proved significant (all Fs < 3.39, $p > .10$). The mean RTs for the different dimension sequences (same vs. different dimension across consecutive trials), across different display sequences and response sequences, are illustrated in Figure 5.

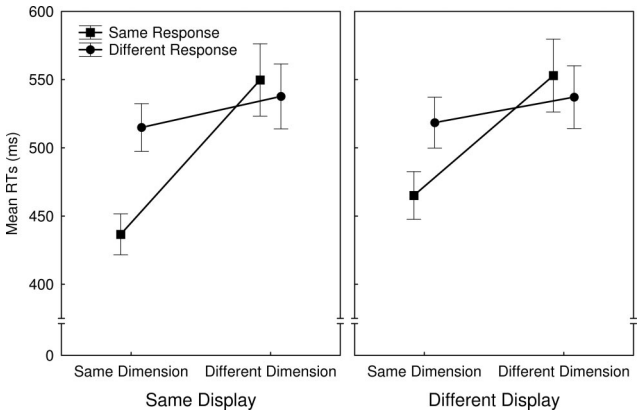

Figure 5. Mean reaction times (RTs; in milliseconds) across different display sequences (same vs. different display type across trials n and $n - 1$), dimension sequences (same vs. different), and response sequences (same = squares; different = circles) in Experiment 3. Vertical bars denote standard errors of the means.

As can be seen from Figure 5, participants were always faster to discriminate the target when the dimension repeated than when it changed across consecutive trials. To determine the significance of the DRBs across different display and response sequences, a post hoc analysis (Tukey HSD, two-sided $\alpha = .05$) was performed for the Display Sequence × Dimension Sequence × Response Sequence interaction. This analysis revealed the DRBs to be significant for all combinations of display sequence and response sequence. However, the magnitude of the DRBs was dependent on the experimental condition: When the display type repeated, the DRBs were 113 and 23 ms for sequences of the same and of different responses, respectively; when the displays differed across consecutive trials, the respective DRBs were 88 and 19 ms. In summary, DRBs, although considerably weaker, did persist across display and response changes.

Discussion

The main goal of Experiment 3 was to examine the role of display changes in dimension-specific intertrial effects, independently of task changes. The results showed significant DRBs for both search and non-search displays. Most importantly, a significant and very substantial DRB was observed across consecutive trials with different displays (≈50 ms). In contrast, no DRB was observed in Experiments 1 and 2 when both the display and, associated with it, the task changed across trials. Against this background (of Experiments 1 and 2), the findings of Experiment 3 support the hypothesis that dimension-specific weights are task, rather than display, specific.

Analysis of the modulation of the DRBs by the response sequence showed that intertrial effects survive response changes. However, DRBs were considerably larger when the required response repeated than when it changed (≈100 ms in comparison with ≈20 ms). This discrepancy stems from the fact that when both the dimension of discrimination and the required response repeated across a pair of trials, participants actually performed the identical discrimination twice (e.g., green–green). In such cases, there were actually three separate aspects of the task that repeated: (a) the dimension of discrimination, (b) the feature to be discriminated, and (c) the required response. In contrast, in sequences of trials in which the required response changed (e.g., green–blue), only the dimension of discrimination could repeat across trials. Thus, intertrial effects were generated by three types of repetition in one case, in comparison with only one type of repetition in the other case. Given this, it is not surprising that the intertrial effects were larger when multiple aspects of the task repeated across trials. Most importantly, the DRBs were still significant even when the particular feature and the required response changed. This finding suggests that the dimension-weighting mechanism involved in performing the discrimination task operates at a stage prior to response selection.

General Discussion

The focus of the present study was on alternative, to some extent mutually exclusive, explanations of dimension-specific intertrial effects in a number of tasks. In singleton search tasks, dimension-specific intertrial effects can be accounted for in at least two ways. According to the dimension-weighting account (DWA), dimen-

sional weights modulate search processes by preferentially boosting feature contrast signals from previously relevant dimensions. The alternative set of explanations assumes that dimensional weights modulate processing after selection took place (Cohen & Magen, 1999; Feintuch & Cohen, 2002; Mortier et al., 2005; Theeuwes, 2004). Interestingly, both approaches typically used one type of task in their paradigms. Because the DWA assumes the efficiency of selection to be modulated by dimension-specific weights, the work carried out within the DWA framework typically used tasks that entailed a search component (see Müller & O'Grady, 2000, for an exception). These tasks could require simple singleton detection (Found & Müller, 1996), singleton dimension and feature discrimination (Found & Müller, 1996; Müller, Krummenacher, & Heller, 2004), singleton conjunction search (Weidner & Müller, 2009; Weidner, Pollmann, Müller, & von Cramon, 2002), or singleton localization (Zehetleitner, Krummenacher, Geyer, & Müller, 2009). By contrast, postselective approaches used tasks that demanded additional, postselective processing and more complicated stimulus-to-response mappings. These tasks included compound search (Theeuwes, 1991, 1992), the flanker task (Cohen & Shoup, 1997), or the non-search task of Mortier et al. (2005).

To account for the observed DRBs in a variety of tasks, both search and non-search, one may assume that there is only one dimensional weighting system that underlies DRBs in all tasks. The alternative is that there are several weighting mechanisms that affect different processes. Accordingly, depending on the processing required by a particular task, one or more weighting mechanisms might modulate task performance. If two tasks share a weighting mechanism (e.g., when both tasks entail feature contrast computation), then intertrial effects should be observed even across different tasks. By contrast, if the tasks involve different weighting mechanisms (such as detection and discrimination in the present study), there should be no carry-over of effects from one to the other task. Three experiments reported here tested the predictions derived from the single- and multiple-weighting-systems conceptions.

Experiments 1 and 2 tested whether DRBs would persist across trials of different tasks in which performance was presumed to be modulated by different weighting systems. The general finding was that significant DRBs persist across both consecutive and nonconsecutive trials of the same task, while there are no DRBs across trials of different tasks. Experiment 3 demonstrated that the DRB effects generalize across different types of display (search and non-search) as long as the task to be performed remains the same. Taken together, all three experiments show that DRBs are indeed task, rather than stimulus, specific and that they can survive several task switches.

Properties of the Multiple Weighting Systems

Both the present study and that of Mortier et al. (2005) demonstrated significant DRBs across trials of tasks that either did or did not require search for the target item. On the basis of their results, Mortier et al. concluded that a search component is not necessary in the task for DRBs to arise. This appears to be at odds with the findings of Goolsby and Suzuki (2001), who found that precuing of the singleton's location in a "priming of pop-out" paradigm (e.g., Maljkovic & Nakayama, 1994) abolished any intertrial effects. Goolsby and Suzuki's (non) finding argues that intertrial effects reflect, at least to some extent, facilitated singleton search processes. On the other hand, the finding of reliable DRBs in the non-search task (originally by Mortier et al. and replicated in the present study) suggests that these effects originate from processes other than facilitation of search processes. These seemingly contradictory findings are most readily reconciled if one assumes multiple weighting systems that have similar dynamics but operate at different pre- and postselective, processing stages. This assumption is similar to Meeter and Olivers' (2006; Olivers & Meeter, 2006) "ambiguity resolution" account of cross-trial "priming" effects in visual search. On this account, the presence of both perceptual and response-related ambiguity can give rise to intertrial effects, which by implication would be originating from either early (preselective) or late (postselective) stages of the processing system.[4] However, the difference between this account and the multiple-weighting-systems hypothesis is that the latter attempts to offer a more precise description of which stages and processes are influenced by trial sequences.

Concerning the nature of the multiple weighting systems, it is plausible to assume that the weighting system in the singleton search task modulated target selection processes. The dynamics of this preselective weighting system is described by the DWA (for a recent review, see Müller & Krummenacher, 2006b). The singleton detection task required the detection of a singleton target in a field of homogeneous distractor items (target present/absent decision). Solving this task is thought to involve the computation of feature contrast signals and their integration into an overall saliency map, whose activity guides the deployment of focal attention. According to the DWA, the computation of overall saliency is modulated by a preselective weighting system that tracks (weights) the search-critical dimension on a given trial and biases the system toward processing targets defined in the same, rather than a different, dimension on the next trial. Arguably, the target present/absent decision to be made in the search task requires no or little postselective processing, so that other (later) weighting mechanisms are presumably not contributing to performance in the search task (e.g., Müller et al., 2004; Töllner, Zehetleitner, Gramann, & Müller, in press).

The second weighting system underlies the intertrial effects in the discrimination task. Because this task makes minimal demands on target selection, the second weighting system is likely to influence later, postselective processes. Experiment 3 revealed the DRB effect to persist across different responses. This finding demonstrates that the DRBs are not response specific, but rather related to the repetition of the task-relevant perceptual dimension.

Consistent with a perceptual locus of the DRBs in the non-search task are the results of a study by Müller and O'Grady (2000), in which observers were presented with two superimposed outline rectangles at a fixed location (no-search task), for a limited period of time. The boxes were defined by their form (line texture:

[4] More precisely, according to Olivers and Meeter (2006), their ambiguity resolution account states that "intertrial priming becomes functional, and therefore measurable, only under circumstances of ambiguity. Ambiguity refers to the presence of uncertainty, conflict, or competition at any level between stimulus and response," including "the relationship between stimulus and response" (pp. 3–4).

dashed vs. dotted; size: small vs. large) and color attributes (hue: red vs. yellow; saturation: low vs. high). Overall, participants were more accurate when instructed to report dual attributes of one object, rather than of both objects (cf. Duncan, 1984). In addition to this object-based selection effect, there was also a dimension-based effect: participants were more accurate when instructed to report dual attributes from the same domain (e.g., both from color or both from form) than when they were to report attributes from different domains (e.g., one from color and one from form). The latter, dimension-based effect was evident even when participants were presented with one object only (Experiment 3). Note that this pattern of accuracy effects was obtained under conditions in which accuracy, rather than response speed, was emphasized. Given that effects on accuracy measures under time-limited stimulus presentation conditions (and non-limited response conditions) are assumed to reflect perceptual processing (e.g., Santee & Egeth, 1982), Müller and O'Grady's study suggests that DRBs observed in non-search tasks can also originate from postselective perceptual processes. One possibility is a dimension-based limitation in transferring instruction-appropriate object properties into visual short-term memory, that is, a format available for explicit report (e.g., Bundesen, 1990).

Relation to Previous Studies

There are a number of parallels between the paradigms used in the present experiments and those in previous studies. For example, both Kumada (2001) and Mortier et al. (2005) used a non-search variant of a compound task and failed to observe (significant) DRBs. By contrast, in Experiments 1 and 2 of Mortier et al. (2005), there were significant DRBs in a non-search version of the detection task. Mortier et al. attributed the disparate findings between non-search versions of compound and detection tasks to the differential response sets between the tasks; that is, they advocated a response-based account of DRBs. However, Experiment 3 of the present study showed that DRBs persisted even across different responses, which casts doubt on the response-based origin of DRBs in non-search paradigms.

In contrast to the findings of Kumada (2001) and Mortier et al. (2005), a number of more recent studies have reported significant DRBs even for compound tasks (Olivers & Meeter, 2006; Theeuwes, Reimann, & Mortier, 2006). Additionally, it is often reported that the effects of dimensional intertrial transition interact with those of response transition: Significant DRBs are observed only for response repetitions, but not for response changes, with the latter sometimes even being associated with a (tendency toward a) dimension repetition cost (Krummenacher, Müller, & Heller, 2002a, 2002b; Müller & Krummenacher, 2006a; Theeuwes et al., 2006; Töllner et al., 2008; see also Olivers & Meeter, 2006, who reported data showing a trend in this direction). Consequently, when DRBs are considered averaged across response (repetition/change) sequences, as was done by Kumada (2001) and Mortier et al. (2005), the main effect of dimension (repetition/change) sequence may not be significant.

Arguably, the Dimension Sequence × Response Sequence interaction must be taken into account for achieving a full understanding of how DRBs are generated in visual search (and non-search) tasks. An insight into the mechanisms underlying this interaction has recently been provided by Töllner et al. (2008), who used a compound-search task in which observers had to respond, with the left or the right hand, to the orientation of a grating, vertical or horizontal, within a color- or shape-defined pop-out target. Analysis of event-related potentials revealed dimension-specific intertrial effects in both amplitude and latencies of N2pc component (commonly interpreted as indexing processes of attentional selection); in particular, the N2pc latency (reflecting the transition between preselective and postselective processing) occurred significantly earlier when the target dimension repeated, rather than when it changed, and this DRB was evident whether the response was repeated or changed. However, analysis of stimulus-locked LRP (lateralized readiness potential) latencies (providing an index of all perceptual coding and stimulus–response mapping processes prior to response execution) did show a Dimension Sequence × Response Sequence interaction closely matching the corresponding interaction in the RT data. Because the stimulus-locked LRP includes the time required for attentional selection, and this time (estimated by the N2pc latency) was influenced only by dimension sequence, not by response sequence, Töllner et al. concluded that the interaction must arise at a postselective processing stage, such as stimulus-to-response mapping (or encoding of the response-relevant target feature).

Thus, the pattern of results reported by Töllner et al. (2008) provides evidence for existence of several sequence-sensitive mechanisms: one of which (indicated by effects in the N2pc parameters) influences attentional selection and is insensitive to response sequence, whereas the other (indicated by effects in the stimulus-locked LRP) influences postselective processes of stimulus–response mapping (e.g., weighting of certain stimulus–response linkages along the lines envisaged by Kingstone, 1992). Given this, the implication for dimension-specific intertrial effects in the RT domain is that these reflect the combined effects of several mechanisms, thereby lending further support to the multiple-weighting-systems hypothesis.

The finding of the present Experiment 3 that DRBs persist even across response changes appears, however, still at variance with the results of Kumada (2001) and of Mortier et al. (2005). One explanation might be that in the non-search compound tasks of Kumada and of Mortier et al., the dimensional identity of the target was irrelevant to the task. By contrast, in both the non-search detection task of Mortier et al. and the feature discrimination task in the present study, the identity of the target was task relevant. Arguably, the task relevance may have led to an increase in the magnitude of DRBs, yielding significant DRBs even across trials with different responses (see, e.g., Müller et al., 2004). Further studies are necessary to examine the role of task relevancy for the magnitude of DRBs in more detail.

Alternative Explanations

By consistently revealing significant DRBs across trials of the same task, but not trials of different tasks, the present results provide strong evidence for the task specificity of dimension-specific intertrial effects. The fact that the DRBs were significant even across nonconsecutive trials of the same task, with several task switches in between, is inconsistent with the (alternative) assumption that (underlying) DRBs across trials of different tasks are simply masked by processing costs associated with task switching. Analogously, the absence of effects of response se-

quence (response changes vs. repetitions) across trials with different tasks is inconsistent with the idea that (underlying) DRBs are masked by processing costs associated with response changes. Furthermore, the DRBs as such do not appear to be response specific: In the detection task, DRBs were observed across target-present trials, that is, across trials with the same response; and in the discrimination tasks, the DRBs persisted across response changes. Finally, examination of the role of display changes (in Experiment 3) showed that these, too, cannot account for the absence of DRBs across trials of different tasks.

One might argue, though, that the driving source of DRBs in the detection and discrimination tasks was not a dimensional repetition, but repetitions of stimulus–response (S-R) associations. For example, across two trials of the detection task, a repetition of dimension (e.g., color) was always associated with a complete trial repetition (e.g., red singleton: left button press on both trials $n - 1$ and n). Consequently, it is conceivable that the complete repetitions of S-R mapping across trials, rather than dimension repetitions, were the source of the DRBs observed in the detection task. Similarly, dimensional repetitions in the discrimination task were associated with complete S-R repetitions in half of such trials (e.g., blue bar: left button on both trials $n - 1$ and n). By contrast, across two trials of different tasks, no complete S-R repetitions ever occurred. Thus, one could envisage one mechanism generating intertrial effects in both detection and discrimination tasks, which would originate from S-R repetitions. In the present study, such repetitions were possible only within a task, resulting in DRBs exclusively across trials of the same task.

Although the S-R mapping account might explain the task specificity of DRBs, the present findings argue against the assumptions of this hypothesis: Experiment 3 demonstrated that DRBs ($\approx$20 ms) persisted across S-R mapping changes in the discrimination task (e.g., blue, left button; green, right button). This finding argues against S-R mapping repetitions being the sole generator of DRBs in the discrimination task. A similar analysis was not possible for the singleton detection task of the present study, because of the fact that there was only one feature per dimension. Consequently, S-R mapping repetitions cannot be excluded as a potential account of the DRBs for this task.

However, a number of studies in the literature (e.g., Found & Müller, 1996; Krummenacher, Grubert, & Müller, 2010; Weidner et al., 2002) have already shown that DRBs are (almost) as large when the dimension repeats but the target's feature changes (e.g., red followed by blue singleton) as when both the dimension and the feature repeat (e.g., red in both trials). The evidence that DRBs persist across feature changes argues against S-R repetitions being the critical source of DRBs in the detection task.

In summary, the lack of S-R repetitions across trials of different tasks is not a likely cause for the absence of DRBs across trials with a task change. This is because S-R repetitions across trials of the same task (whether detection or discrimination) have been demonstrated not to be a crucial requirement for observing DRBs within a repeated task.

A simple, coherent account of this pattern of findings can be achieved by assuming the existence of several sequence-sensitive mechanisms that influence separate processes. According to this multiple-weighting-systems hypothesis, which weighting system is engaged depends on the task demands. If two tasks share a particular process, DRBs are expected to persist across trials of different tasks. Conversely, if the tasks involve different sequence-sensitive mechanisms, no DRBs should be observed across trials of different tasks. On this logic, the results of the present study (i.e., the failure to find DRBs across trials of different tasks) would argue that different weighting systems were engaged in the search and the non-search tasks.

The core assumption of the multiple-weighting-systems hypothesis (as is formulated above) is that a particular weighting system influences performance whenever a task to be solved requires the respective process, that is, the weighting systems are task demand specific. The two processes identified in the present study were focal-attentional selection and target identification: The singleton detection task required selection but no explicit identification, whereas the feature discrimination required identification but no selection (because there was no location uncertainty). Thus, depending on the task demands (selection or identification), different weighting systems would have influenced performance in the different tasks.

An alternative account of the present findings might assume that there is only one weighting system, which is task specific in the sense that it may be bound into only one task (performance controlling) representation at a time, permitting a particular weight set to be dynamically established across trials of the same task; if the task changes, the weight set would be reset and the weighting system would be bound into the representation for the new task. This could also account for the finding of DRBs across consecutive trials of the same task, but not across trials of different tasks. However, it would fail to explain why the weight set for a particular task survives across nonconsecutive trials of the same task, that is, with performing a different task on the intervening trials. To accommodate this finding, the alternative account would have to assume that the weight set established across trials of a particular task is somehow stored, so that it can be retrieved when there is a change back to this task in the trial sequence. This would imply that multiple weight sets and their association with the respective tasks would have to be stored (and retrieved) independently, whereas each dynamic weighting process is driven by one-and-the-same weighting system no matter the task to be performed. Consequently, this account resembles the multiple-weighting-systems hypothesis advocated here. However, in principle, on this account, there would have to be as many stored weight sets as there are tasks that give rise to DRBs. By contrast, the present hypothesis assumes multiple independent weighting systems associated with particular processes involved in task performance, on the basis of the specific demands made by the task to be currently solved (such as selection or identification). This appears to be more appealing theoretically because the number of such demands and the respective processes are likely to be limited.

Ultimately, however, whether DRBs are task specific or task demand specific is an empirical question. Both alternatives make strong, mutually exclusive predictions. Task specificity would predict no DRBs across different tasks, no matter what tasks are involved. By contrast, task demand specificity would predict significant DRBs across tasks that share demands. Deciding between these alternatives requires experiments that are based on a thorough conceptual analysis of various tasks, in order to identify tasks that share demands and those making entirely different demands. Such a study was undertaken by Rangelov, Müller, and Zehetle-

itner (under review), who demonstrated DRBs across trials of different tasks that share demands.

Furthermore, assuming a single weighting system with task-specific (stored) weight sets, the effects of the weighting would become manifest at one particular time during task performance; by contrast, on the multiple-weighting-systems hypothesis, weighting effects would become manifest either early or late during task performance, depending on the task demands. Consistent with the latter prediction, there is good behavioral and electrophysiological evidence to suggest that weighting effects occur early in simple singleton detection tasks (e.g., Goolsby & Suzuki, 2001; Huang & Pashler, 2005; Pollmann et al., 2000, 2006; Töllner et al., 2008; Weidner et al., 2002). For example, using a compound-search task, Töllner et al. (2008) found a DRB in terms of the latency of the N2pc component, which is commonly associated with focal-attentional selection. By contrast, as convincingly argued by Mortier et al. (2005), weighting of selection processes cannot account for DRBs in the non-search task because, with the target location being fixed, this task does not involve selection. Consequently, in line with Mortier et al. (2005), the DRBs in this task would have to arise at a later stage of processing (attentional target analysis, response selection, or both). That weighting processes operate also at postselective processing stages, and independently of preselective weighting, has been shown by Töllner et al. (2008).

In summary, then, the multiple-weighting-systems hypothesis, which assumes that independent weighting systems are engaged in accordance to the specific task demands, appears theoretically more plausible and empirically better supported by the available data than is the single-weighting-system hypothesis.

Conclusions

The present study showed that dimension-specific intertrial effects were task (demand) specific, which is at variance with the idea that the explanation of DRBs observed in a particular task generalizes directly to DRBs in (all) different tasks. Consequently, theories of sequence effects in the simple cognitive tasks would have to take into account the specific tasks or paradigms for which the respective explanations are being developed.

The theoretical framework advocated here is that of the existence of multiple weighting systems that have similar (weighting) dynamics, but influence different cognitive processes. Accordingly, which weighting system is engaged in a particular paradigm is primarily determined by the task demands. A feasible (though arguably less plausible) alternative is that there is a single, but task-specific, weighting system. Further work is necessary to decide between these two possibilities.

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