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SEQUENCE EFFECTS IN SIMPLE COGNITIVE TASKS:

THE MULTIPLE-WEIGHTING-SYSTEMS HYPOTHESIS

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ABSTRACT

What we did recently influences our current behavior substantially. For example, responses are speeded if observers are to discriminate an item based on its color twice (e.g., color – color discrimination in trials *n-1* and *n*, respectively) compared to when the task-relevant dimension changes across trials (e.g., orientation – color discrimination). The dimension repetition effect (or DRE) was explained in two mutually exclusive ways: (i) selection-based approach assumes that DREs are a consequence of visual selection processes, while (ii) response-based approach claims these effects to originate from the later processes of response selection. Importantly, neither of the accounts can fully explain available findings on DREs: (i) selection-based approach cannot explain strong DREs observed when visual selection is very easy and fast, while (ii) response-based account cannot explain strong DREs in paradigms where the sequence of perceptual dimensions is response-irrelevant.

In my work, I focused on developing a theoretical framework which should account for all the available data by assuming existence of different dimension-sensitive mechanisms that affect different processing stages (visual selection, perceptual analysis). Additionally, a novel paradigm was developed in which two tasks, for which DREs were previously reported, alternated randomly across trials. Across two consecutive trials, the task could either repeat or change. Independently of the task sequence, the task-relevant dimension could either change or repeat. Different experiments used different tasks, that could, on the Multiple-Weighting-Systems (or MSW) hypothesis, engage either the same (e.g., both tasks engaged the visual selection mechanism) or different DRE mechanisms. Behavioral and electrophysiological data showed: (i) significant DREs across task changes when the two tasks engaged the same hypothesized mechanism, (ii) no DREs across task changes when the tasks engaged different systems. Overall, the data support the MWS hypothesis, in contrast to the single-mechanism accounts.

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1 THE MULTIPLE-WEIGHTING-SYSTEMS HYPOTHESIS: GENERAL INTRODUCTION AND DISCUSSION

1.1 Problem

Adaptive behavior is considered to be the main requirement for complex organisms (such as humans) to survive in a vast variety of different environments. Controlling what are the most appropriate responses in a particular environment is the function of the cognitive system. Conceptually, control of behavior necessitates several processing stages prior to overt actions: (i) selection of the task relevant item, (ii) perceptual analysis of the selected item, and (iii) selection of the appropriate response to the analyzed item. To illustrate, the task might be to turn on the light by using a switch (i.e., target) from a switch board. An initial processing step would be to select a potential target switch from several other switches. Following target selection, perceptual analysis processes should determine whether the selected item matches the target template or not. Finally, the outcome of the perceptual analysis stages is mapped to possible responses resulting in either turning on the light (if the right switch was identified) or selecting another switch. In summary, behavioral control could be thought of as a series of decisions taking place at different processing stages (selection, perceptual analysis, responding); each decision being controlled by the task rules (stimulus-response mapping) and properties of the current stimulation.

While one might assume that task rules and current stimulation fully determine the decision chain from stimulus to behavior, experimental evidence suggests that other factors also play an important role. Recent experience, for example, has been demonstrated to profoundly affect processes of visual selection, perceptual analysis and response selection. Found and Müller (1996) presented stimulus displays containing many items (i.e., multi-item displays, see Figure 1.1). On some trials, all items were identical (i.e., target-absent displays), while in a portion of trials there was one item (i.e., singleton target) different from the others in some respect (e.g., color or orientation). The task was to detect presence/absence of the singleton target and respond by pressing corresponding response buttons. Across two consecutive trials (n-1 and n) in both of which the target was present, the dimension of distinction between the target and distractors could either repeat (e.g., color – color) or change (e.g., orientation – color). Found and Müller reported faster reaction times (RTs) for dimension repetitions compared to reaction times for dimension changes. The dimension repetition effect (or DRE) was *dimension*- rather than *feature-specific*: comparable DREs were observed for both repetitions of the exact target feature (e.g., red – red) and feature changes (e.g., blue – red target) compared to dimensional changes (e.g., horizontal – red). The DREs demonstrate behavioral differences in processing the same stimulus (red) under same task rules (singleton detection) thus making a good case for the role of recent experience in behavioral control.

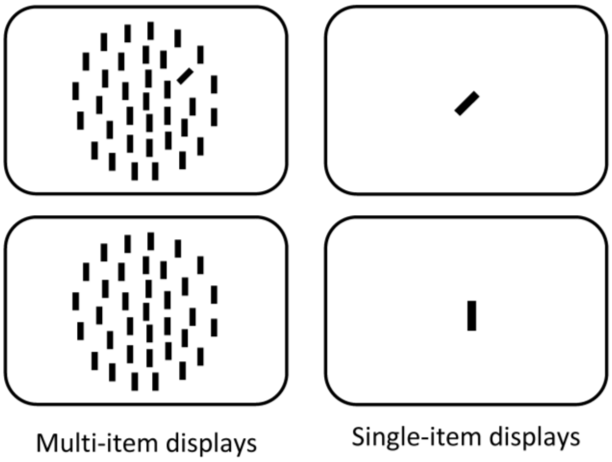

Figure 1.1. Illustration of different possible stimulus displays. Multi-item displays (left) contain many items, with one of them (upper panel) being different from the rest in some respect (e.g., orientation singleton). Alternatively, all items could be identical, i.e., the singleton could be absent (lower panel). In the detection task, observers are to discern the presence or absence of the singleton target. The single-item displays (right) depict target-present and target-absent conditions, but only with a single item presented. Notice that the same task, target detection, can be done in both display types.

Dominant theoretical accounts of DREs come in two versions, depending on what processing stage they postulate to be the origin of the intertrial effects. Müller and colleagues (e.g., Müller & Krummenacher, 2006) developed a selection-based account according to which perceptual dimensions influence processes of target selection. According to the Dimension Weighting Account (or DWA) of Müller and colleagues, the early processing stages prior to target selection are organized into independent dimension-specific channels for, e.g., color, orientation, or motion. Importantly, the signals coming from these channels are weighted in a way that weight for the currently relevant dimension (e.g., color when color singleton is presented) increases, while the weights for irrelevant dimensions decrease. Due to increased weights the selection processes are speeded across consecutive trials of same dimension compared to trials when dimension changes – giving rise to DRBs.

Alternative accounts assume that the processing stages other than target selection give rise to DREs. The Dimensional Action account (DA) of Cohen and colleagues (e.g., Cohen & Magen, 1999) assumes that response selection processes are affected by the dimensional sequence. According to DA, responses are generated from a dimension-specific response selection channel for, e.g., color, orientation, or motion targets. When the task-relevant dimension repeats across trials, the relevant response channel also repeats, speeding up response selection processes compared to trials in which dimension (and response channel) changes – giving rise to DREs.

Empirical findings provided mixed evidence in favor of one or the other account. Comparable DREs were observed in paradigms using multi-item displays (see Figure 1.1), with diverse stimulus-response (S-R) mappings: (i) singleton detection – target present/absent (Found & Müller, 1996), (ii) singleton feature discrimination – target blue/green of vertical/horizontal (Cohen & Magen, 1999), and (iii) singleton localization – target left/right (Rangelov, Müller, & Zehetleitner, 2010b). The commonality between these tasks is that the target has to be selected from a set of non-targets prior to responses – arguing that selection processes are the origin of DREs. Furthermore, independence of particular S-R mapping argues against response selection processes as the origin of DREs – supporting the selection-based accounts. However, studies using single-item displays (Mortier, Theeuwes, & Starreveld, 2005), also demonstrated DREs. Intertrial effects in the single-item displays (see Figure 1.1) cannot be easily explained by selection-based mechanisms, as in these displays there is no need to search for the target prior to responding – providing a support for response-based accounts.

To conclude, neither of the dominant accounts of DREs, selection- or response-based, can fully explain the available empirical findings. Consequently, I my doctoral work I focused on: (i) developing a new theoretical framework that could explain the available data in a comprehensive way; and (ii) constructing a novel paradigm to test predictions derived from the novel theoretical framework in both behavioral (RTs) and electrophysiological domain (EEG).

1.2 The Multiple-Weighting-Systems hypothesis

A shared property of selection- and response-based accounts is that they both assume a *single* mechanism, situated at either pre- or post-selective processing stages, giving rise to DREs. An alternative approach to the single mechanism accounts of DREs would be to assume *multiple mechanisms*, situated at different, pre- and post-selective, processing stages. These mechanisms would all, by virtue of being sensitive to task-relevant perceptual dimensions, produce DREs. According to the Multiple-Weighting-Systems (or MWS) hypothesis, one mechanism would influence dynamics of visual selection processes while another mechanism would modulate processes of perceptual analysis of the selected items.

What weighting system operates in a particular experimental setting is determined by the properties of the used tasks. If the paradigm uses multi-item displays containing dimension-specific target items (i.e., color or orientation singletons) the (visual) selection weighting system would be active. On the other hand, if the S-R mapping rules require retrieving featural identity of the target item prior to responding, the perceptual (analysis) weighting system would be active. Finally, a particular task can use both multi-item (search) displays and require feature identification, thus hypothetically engaging multiple weighting systems. An overview of the weighing systems active in tasks using different displays (multi- vs.

single-item displays) with different S-R mappings (detection, discrimination, and localization) is provided in Table 1.1.

Table 1.1. An overview of the hypothetical selection (S_ω) and perception (P_ω) weighting systems engaged in paradigms using different display types: a) multi-, and b) single-item displays; and different S-R mappings: a) detection – target present/absent, b) discrimination – target is blue/green, horizontal/vertical, and c) localization – target left/right. Single-item localization is not discussed as this task produces extremely fast RTs and, presumably, very small DREs.

	S-R mapping		
Display type	Detection	Discrimination	Localization
Multi-item	S_ω	$S_\omega + P_\omega$	S_ω
Single-item	P_ω	P_ω	

The crucial prediction of the MWS hypothesis is that DREs should arise across trials in which the same weighting system was active: trials n-1 and n must both engage either S_ω or P_ω systems. For paradigms using a single task this prediction is somewhat trivial, as the same task should always engage the same weighting systems. The critical test for the MWS hypothesis, however, is what happens when two different tasks are mixed across trials (e.g., multi-item detection and multi-item localization). In such a task-switching paradigm, the task can either repeat or change, and, independently of the task sequence, the task-relevant dimension can repeat or change. Thus, it is possible to asses DREs across both task repetitions and task changes. The MWS hypothesis predicts that DREs across task changes should persist only if the tasks in question share a common weighting system. If the two tasks involve different systems, no DREs are expected across task changes.

1.3 Overview of behavioral findings

In three behavioral studies using RTs as a dependent measure, two different tasks were mixed across trials. Different task combinations across studies helped differentiate between specific predictions derived from the single-mechanism accounts (of pre- or post-selective variety) and the MWS hypothesis. Specifics of every study are discussed in Discussion sections of respective studies (Chapters 2, 3, and 4).

As can be seen from Table 1.2, there were significant DREs for all tasks when the task repeated across trials. This argues that at least one dimension-sensitive mechanism was involved in all tasks. In contrast to task repetitions, DREs across trials of different tasks were significant across some task combinations, and non-significant across others. The pattern of DREs across trials of different task corresponded closely to the pattern of DREs expected on the MWS account: if the tasks in question shared a hypothesized weighting system (i.e., both S_ω or both P_ω), there were significant DREs across task changes, while if the tasks engaged different hypothesized weighting systems, no DREs were observed.

Table 1.2. Behavioral findings from three studies by Rangelov et al. (Chapter 2, 3, and 4). In all studies two tasks (marked as Task 1 and 2) alternated across trials. The main findings were that across trials of the same task, there were always strong DREs. The DREs across different tasks depended on whether the two tasks shared the weighting mechanism or not.

		Weighting system in		DREs across task	
Task 1	Task 2	Task 1	Task 2	repetitions	changes
		Rangelov et al. (2010a)			
Experiments 1 and 2					
Multi-item Detection	Single-item Discrimination	S_ω	P_ω	Yes	No
Experiment 3					
Multi-item Discrimination	Single-item Discrimination	$S_\omega + P_\omega$	P_ω	Yes	Yes
		Rangelov et al. (2010b)			
Experiment 1					
Multi-item Detection	Multi-item Localization	S_ω	S_ω	Yes	Yes
Experiment 2					
Multi-item Detection	Single-item Detection	S_ω	P_ω	Yes	No
Experiment 3					
Single-item Detection	Single-item Discrimination	P_ω	P_ω	Yes	Yes
		Rangelov et al. (2010c)			
Experiment 1					
Multi-item Detection	Multi-item Discrimination	S_ω	$S_\omega + P_\omega$	Yes	Yes
Experiment 2					
Single-item Detection	Multi-item Discrimination	P_ω	$S_\omega + P_\omega$	Yes	Yes

1.4 Electrophysiological correlates of S_ω and P_ω systems

The behavioral findings pointed at dissociation between at least two mechanisms capable of producing DREs: visual selection (S_ω) and perceptual analysis (P_ω) related weighting systems. This evidence would be strongly supported if a similar dissociation were demonstrated in another domain: there should be distinct markers of weighting of selection and weighting of perceptual analysis processes in the electroencephalogram (EEG) data.

An ongoing study used a task-switching paradigm identical to Experiment 1 of the Rangelov et al. (2010c) study (Chapter 4). The multi-item detection (target present/absent) and multi-item discrimination (target blue/green or left-/right-tilted) alternated randomly across trials. On the conceptual task analysis both detection and discrimination task, by virtue of using multi-item displays, engaged the selection weighting system (S_ω). By contrast, only the discrimination task, by virtue of having to identify the target's feature prior to responding, engaged the perception weighting system (P_ω).

EEG was recorded during the experiment, and segmented offline into 800 ms segments locked to the stimulus onset; the segments were sorted according to the task (detection vs. discrimination), task sequence (repetition vs. change) and dimension sequence (repetition vs. change) resulting in 2x2x2 design. Analyses focused on two event-related EEG components: a) posterior contra-lateral negativity (PCN) and b) sustained posterior contralateral negativity (SPCN). Figure 1.2 illustrates the method of extracting these components. PCN is usually associated with processes of visual selection (e.g., Eimer, 1996), while SPCN is interpreted as a correlate of post-selective processing prior to response selection (e.g., Jolicoeur, Brisson, & Robitaille, 2008).

Given that both detection and discrimination task involve selection weighting system (S_ω) presumably associated with the PCN component, comparable dimension sequence effects (DREs) on the PCN parameters were expected for both tasks, independently of the task sequence. On the other hand, a dissociation between tasks was expected for parameters computed in the SPCN time window, presumably associated with post-selective perceptual analysis, due to the fact that only discrimination task involved the perception weighting system (P_ω).

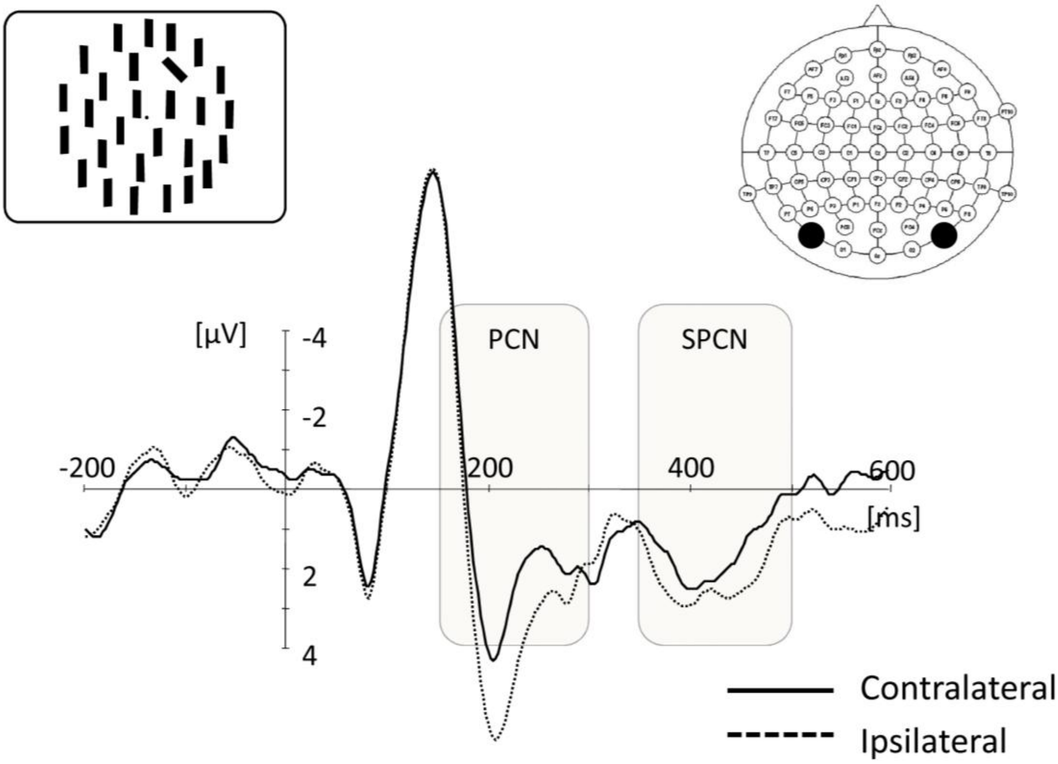

Figure 1.2. Illustration of the EEG recording and data analysis. A display containing a singleton was presented while recording EEG from 64 electrodes mounted to the observer's head by means of a tight elastic cap. The EEG was segmented offline into 800 ms segments (200 ms pre- and 600 ms post-stimulus onset). Analysis focused on electrode pairs located at left (PO7) and right (PO8) side of posterior head region (indicated by dark markers on the electrode layout). Depending on the location of the singleton (left or right side of the screen) the electrodes were renamed as ipsilateral (e.g., PO8 for right side singletons) and contralateral (PO7) to the target position, denoted as dashed and full lines, respectively. Notably, the ipsi- and contralateral signals differ in the time range 170-300 ms (PCN time window) and 350 – 500 ms (SPCN time window).

For the PCN component, a point in time when the ipsi- and contralateral signals differed most (= peak PCN latency) – indicating when was attention allocated to the singleton item – was computed for different experimental conditions. For the SPCN component, mean amplitude difference between ipsi- and contralateral signals was computed (= SPCN area amplitude), indicating the magnitude of post-selective perceptual processing. Figure 1.3

depicts mean PCN latencies, while Figure 1.4 shows mean SPCN amplitude, separately for different tasks, task sequences and dimension sequences.

Figure 1.3 shows that dimensional repetitions (dark bars) were associated with shorter PCN peak latencies relative to dimensional changes (bright bars). Most importantly, the same pattern was observed for both detection and discrimination task, independently of the task sequence.

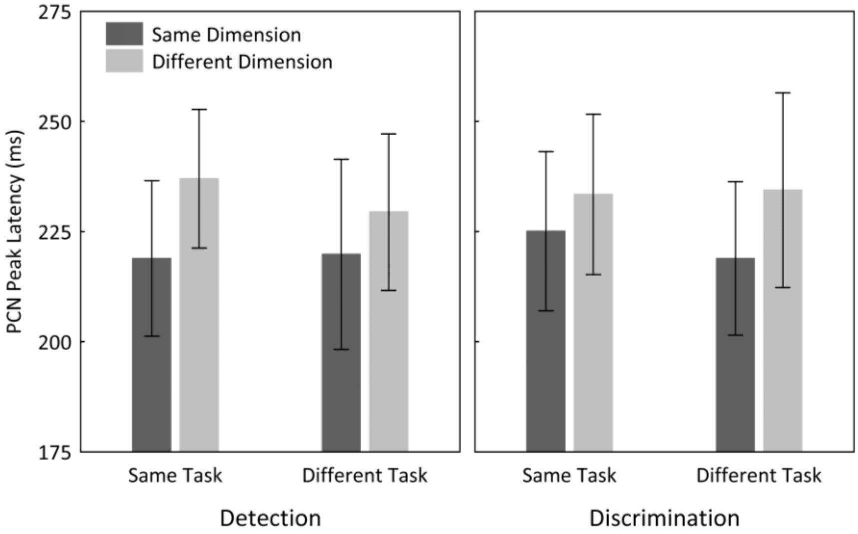

Figure 1.3. Peak PCN latencies (ms) as a function of task (detection, discrimination), task sequence (same task, different task), and dimension sequence (same dimension, different dimension). Vertical bars denote 95% confidence intervals (CI).

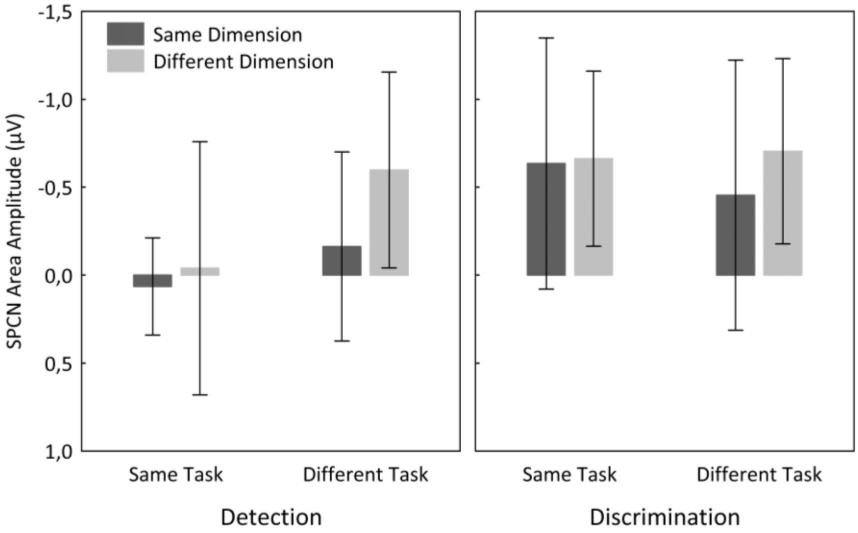

Figure 1.4. Mean SPCN area amplitude (µV) as a function of task (detection, discrimination), task sequence (same task, different task), and dimension sequence (same dimension, different dimension). Vertical bars denote 95% confidence intervals (CI).

Analysis of the SPCN area amplitude (Figure 1.4) showed differences between detection and discrimination task. For the detection task, there was a significant SPCN component only when both task and dimension changed across trials, in contrast to other conditions where a non-significant SPCN component was observed (as can be inferred from the fact that CI entailed zero). By contrast, a substantial SPCN was observed for the discrimination task across all conditions. SPCN was, however, significant only for dimensional changes (light bars) irrespectively of task sequence.

Taken together, the findings were in accordance with the MWS hypothesis: comparable effects were observed for both tasks in the time window related to visual selection processes (peak PCN latency), while a dissociation between tasks was observed in the time window related to post-selective perceptual analysis (SPCN area amplitude). Finally, it was demonstrated that dimensional intertrial sequence can influence multiple electrophysiological markers – in accordance with postulating multiple sources of DREs.

1.5 Conclusions

In the focus of my work was developing the Multiple-Weighting-Systems hypothesis, a new theoretical framework that can parsimoniously account for the sequence effects (DREs) in a variety of simple cognitive tasks. A novel paradigm, using the task-switching approach, was developed to test predictions derived from the MWS; both behavioral (Chapters 2, 3, and 4) and electrophysiological measures (an ongoing EEG study) were investigated. The main finding was that, provided that different tasks both engaged the same hypothesized weighting system (S_ω or P_ω), significant DREs were observed across task switches, thus providing an empirical support for the crucial prediction of the MWS hypothesis. In summary, the data strongly suggest the existence of multiple sequence-sensitive mechanisms which, together with properties of the current stimulation, determine dynamics of cognitive information processing and the ensuing behavior.

1.6 References

Cohen, A., & Magen, H. (1999). Intra- and cross-dimensional visual search for single-feature targets. *Perception & Psychophysics*, *61*(2), 291-307.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*(3), 225-34.

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: investigating a "dimension-weighting" account. *Perception & Psychophysics*, *58*(1), 88-101.

Jolicoeur, P., Brisson, B., & Robitaille, N. (2008). Dissociation of the N2pc and sustained posterior contralateral negativity in a choice response task. *Brain Research*, *1215*, 160-172. doi:10.1016/j.brainres.2008.03.059

Mortier, K., Theeuwes, J., & Starreveld, P. (2005). Response selection modulates visual search within and across dimensions. *Journal of Experimental Psychology. Human Perception and Performance*, *31*(3), 542-57. doi:10.1037/0096-1523.31.3.542

Müller, H. J., & Krummenacher, J. (2006). Locus of dimension weighting: Preattentive or postselective? *Visual cognition*, *14*(4-8), 490-513.

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010a). Independent dimension-weighting mechanisms for visual selection and identification . *Journal of Experimental Psychology, Human Perception and Performance* (in press).

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010b). Independent dimension-weighting mechanisms for visual selection and identification (under review).

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010c). The Multiple-Weighting-Systems hypothesis: Theory and empirical support (under review).

2 DIMENSION-SPECIFIC INTERTRIAL PRIMING EFFECTS ARE TASK-SPECIFIC: EVIDENCE FOR MULTIPLE WEIGHTING SYSTEMS

2.1 Abstract

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 arise. 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 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, and task-switching.

2.2 Introduction

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). While 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 pre- or a post-selective 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.

2.2.1 Dynamics of visual selection processes

Mechanisms of visual selection are often investigated using the feature singleton detection paradigm, where 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, orientation, etc.) and then summed up into a (supra-dimensional) 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 *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 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.

2.2.2 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 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.

2.2.3 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, *post-selective* 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, while the DRB effects arise at the post-selective 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, Theeuwes, and Starreveld (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: (i) *within-dimension search,* where the singleton, when present, always differed from distractors in color; and (ii) *cross-dimension search*, where the singleton differed in color, shape, or size.

The *non-search* task was designed as 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: (i) a *within-dimension* condition, where the critical difference was always in color; and (ii) a *cross-dimension* condition, where 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 either relatively difficult (search task) or the search component was minimized (non-search task).

Participants responded faster to the target stimulus in the within-dimension 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 consecutive trials compared to 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 post-selective, response selection account of dimensional intertrial effects.

2.2.4 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 where no search was necessary. This striking similarity of behavioral data from both 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 post-selective processing stages. However, apart from this similarity, arguably, no direct empirical

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[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.

support for this hypothesis has been put forward thus far. Instead of assuming *a single* post-selective 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 pre-selective saliency signal computations, as elaborated in the DWA, and generate the DRBs in the search task. The other weighting mechanism would modulate post-selective 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 pre-selective, perceptual processing stages, and the other modulating post-perceptual, 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; Treisman, 1988; Müller et al., 1995), that is, faster mean RTs in trial blocks in which the relevant dimension is fixed, compared to 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 post-selective 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 post-selective processes (see, e.g., Müller & Krumenacher, 2006a, who acknowledged this possibility, and Töllner et al., 2008, for an elaboration of a post-selective mechanism sensitive to both dimension and response sequences). The two weighting systems would have a similar dimension-specific dynamics, producing similar data patterns of dimension repetition benefits in both search and non-search tasks. In contrast, post-selective 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 common source, namely, the response selection stage (e.g., Mortier et al., 2005).

2.2.5 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 by either a *single* weighting system operating at a post-selective processing stage, or by *multiple* weighting systems influencing different processes at pre- and, respectively, post-selective 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 hypothesis 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 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 display changed, the task changed as well). Given this, Experiment 3 assessed effects of display type change on DRBs, independently of task change effects.

2.3 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” CRT monitor, with a screen resolution of 1280 x 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): (i) search and (ii) non-search displays. The search display consisted of 28 bars organized in three concentric circles (around a central fixation mark) with four, eight, and sixteen 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° x 14° of visual angle. A search display could either 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° counter-clockwise 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 centre 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 2.1.

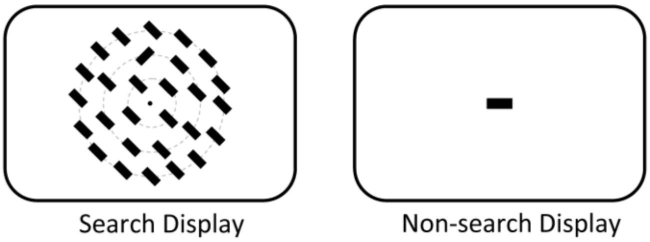

Figure 2.1. Illustration of the stimulus displays used in the present experiments. Original stimuli were plotted on a black background, and were of different colors. See text for more details.

Design. There were two tasks: (i) singleton detection (search task) and (ii) 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/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, left button for blue target bars). Different stimulus-response mappings for either task were balanced across participants.

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: (i) task (detection vs. discrimination), (ii) dimension (color vs. orientation), (iii) task sequence across pairs of trials (same vs. different), (iv) dimension sequence (same vs. different), and (v) 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 experiments 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 minutes to complete), was dedicated to practice. The second, experimental session consisted of 1800 trials (which took about one hour 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 minutes) for participants to get some rest and for the experimenter to check whether the stimulus-response mappings had been learnt.

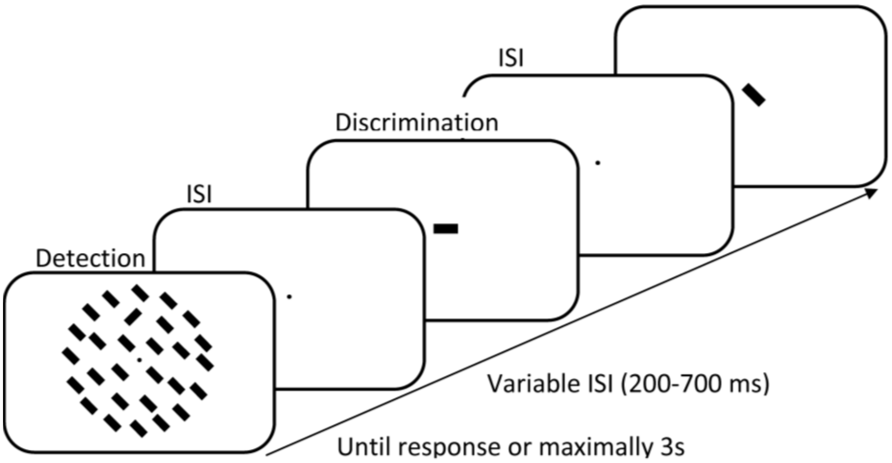

Figure 2.2. Illustration of trial sequence used in the present experiments. Participants performed the singleton detection task when presented with a search display, and the feature discrimination task when presented with a non-search display. See text for more details.

An example of the trial sequence with timing details is provided in Figure 2.2. Participants were to respond on every trial. Stimuli were presented either until a response was made or for three seconds if meanwhile no response was given. Trials were separated by a variable inter-stimulus interval. Following 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).

2.4 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 post-selective accounts of dimensional weighting. Conversely, the absence of intertrial effects across different tasks would be consistent with the hypothesis of multiple weighting systems.

2.4.1 Method

Participants. Eleven university students (3 female, mean age 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.

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.

2.4.2 Results

The recorded response data were first filtered for errors and extreme reaction times (outside ±3SD of the RT distribution). About 1% of trials per participant were excluded due to 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. Due to 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) x dimension (color vs. orientation) x task sequence (same vs. different task across consecutive trials) x dimension sequence (same vs. different dimension across trials). On average, for each experimental condition there were around 52 trials (range 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 reaction times (RTs) was carried out with main terms for (i) task, (ii) dimension, (iii) task sequence, and (iv) 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 x dimension sequence interaction ($F(1,9) = 62.69$, $p < .01$, $\eta_p^2 = .87$) and the task x task sequence x dimension sequence interaction ($F(1,9) = 10.14$, $p < .01$, $\eta^2_p = .53$) were significant. Neither the main effect of dimension (color vs. orientation) nor its interactions with any other factor reached significance (all $F < 4.94$, $p > .05$). 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 2.3.

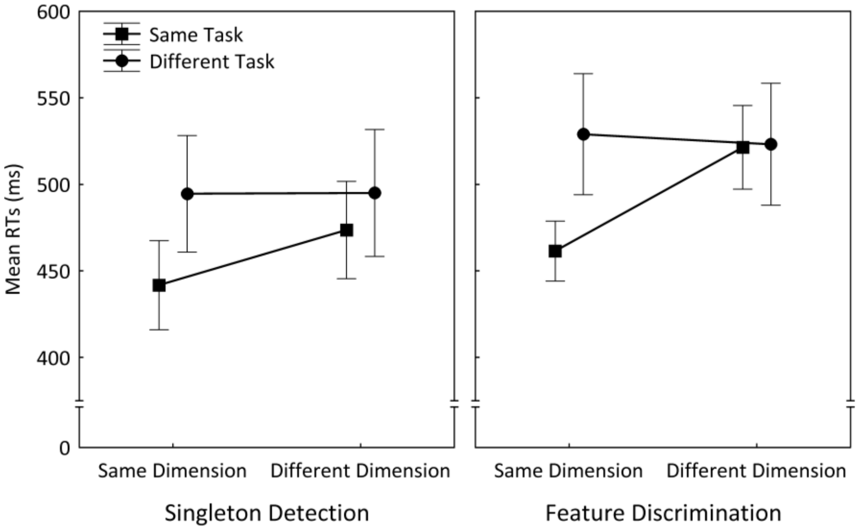

Figure 2.3. Mean RTs (in ms) across different tasks (detection and discrimination), task sequences (same task in both trial *n* and trial *n-1* – squares; different task – circles), and dimension sequences (same vs. different) in Experiment 1. Vertical bars denote standard errors of the means.

Figure 2.3 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), a post-hoc analysis (two-sided Tukey HSD, critical alpha level .05) was performed for the task x task sequence x 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 dimensions was the same as on the previous trial compared to 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 .05) were carried out for pairs of *non-consecutive* 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 non-consecutive trials *n* and *n-3* (due to the …AABBAA… sequence of tasks, it was not possible to asses 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 2.1.

Table 2.1. Mean RTs (in ms), standard errors of the means (M_{RT} [SE_M]), as well as magnitudes of the DRBs and corresponding Student's t-values for different dimension sequences (same vs. different) across non-consecutive pairs of trials in Experiments 1 and 2. These findings are presented separately for different tasks (detection and discrimination) and different task sequences (same vs. different).

	Dimension sequence			
Task sequence	Same	Different	DRB [a]	T
Experiment 1, df = 9				
Detection on trial *n*				
Same task on trial *n-3*	489 [25]	491 [23]	2	.49 ^{ns}
Different task	473 [22]	469 [25]	-4	.80 ^{ns}
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 ^{ns}
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 ^{ns}
Discrimination on trial *n*				
Same on trial *n-2*	524 [32]	542 [32]	18	4.78 **
Different task	541 [33]	539 [35]	-2	.54 ^{ns}

[a] DRB = $M_{RT\ different\ dimension} - M_{RT\ same\ dimension}$

** p < .01; * p < .05; ^{ns} not significant.

As can be seen in Table 2.1, the analysis of DRBs across non-consecutive 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 non-consecutive 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 (i) task, (ii) dimension, (iii) dimension sequence, and (iv) 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 did it interact 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.

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[2] Analysis of DRBs across non-consecutive 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*.

2.4.3 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 a 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 non-consecutive pairs of trials. This finding shows that the task-specific dimensional weight set can survive across several task switches – which seriously challenge the ‘weight-resetting’ hypothesis.

However, the significant DRBs for non-consecutive 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 non-consecutive trials of the discrimination task may be due to some specific strategy 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 the discrimination task. Accordingly, the dissociation between the two tasks may reflect differential strategies 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). As the *n-3* effects were smaller than 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* compared to trial *n-1*). As a consequence, in the detection task, this benefit might have decreased to a statistically non-reliable 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 non-consecutive 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 non-consecutive 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 non-consecutive 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.

2.5 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, adopting 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 non-consecutive 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 non-consecutive 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 the stronger between trials *n* and *n-2* than between trials *n* and *n-3*. And 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*. Due to 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 non-consecutive trials could be tested.

2.5.1 Method

Participants. Twelve university students (4 female, 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.

2.5.2 Results

Trials with extreme RTs (out of ±3SD range) and trials with response errors were first filtered out. About 2% of trials per participant were excluded due to 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. Due to 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 (i) task, (ii) dimension, (iii) task sequence, and (iv) 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 x dimension sequence (F(1,10) = 32.50, $p < .01$, $\eta_p^2 = .76$), task sequence x dimension sequence (F(1,10) = 57.55, $p < .01$, $\eta_p^2 = .85$), and task x task sequence x 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 F < 3.22, all p > .10). The mean RTs for the different tasks, task sequences, and dimension sequences are shown in Figure 2.4.

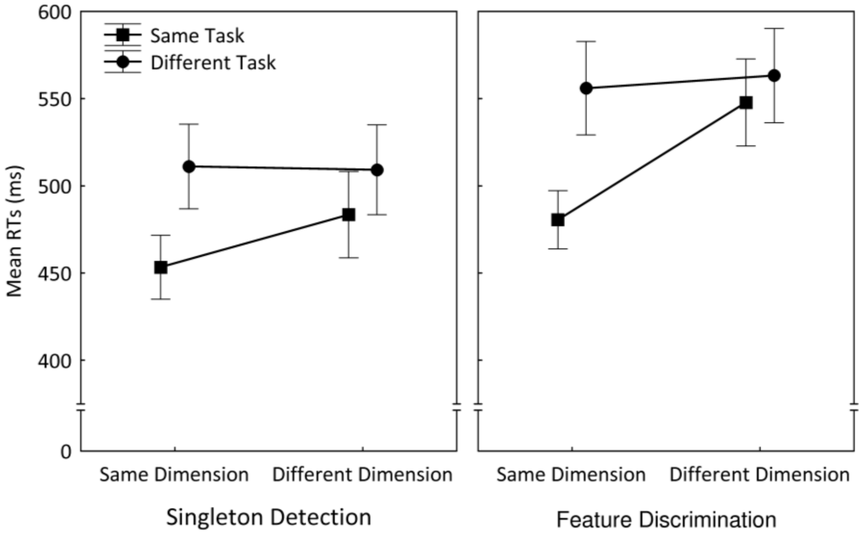

Figure 2.4. Mean RTs (in ms) across different tasks (detection and discrimination), task sequences (same task in both trial *n* and trial *n-1* – squares; different task – circles), and dimension sequences (same vs. different) in Experiment 2. Vertical bars denote standard errors of the means.

As depicted in Figure 2.4, 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*, compared to the 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 x task sequence x 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.

To test whether dimension repetitions across non-consecutive 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 2.1. Planned comparisons revealed significant DRBs for both detection and discrimination tasks between non-consecutive 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 (i) task, (ii) dimension, (iii) dimension sequence, and (iv) 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 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.

2.5.3 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 non-consecutive 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 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 post-selective 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, 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, post-selective weighting mechanisms would play little role for performance in the singleton detection task, because this task can, in principle, be performed based on the master saliency map representation (see, e.g., Krummenacher, Müller, & Heller, 2002). 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 non-consecutive 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

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

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.

2.6 Experiment 3

In order to assess the role of stimulus changes separately from task changes, only the feature discrimination task, however 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). Irrespectively of the display (multiple vs. single item), the target was always presented in the centre 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, while, 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 post-selective 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 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.

2.6.1 Method

Participants. Eleven university students (4 female, 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: (i) search display and (ii) 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 centre 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.

Since 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 emphasise 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, this terminology was preserved, 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 centre 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.

2.6.2 Results

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

The RT data were examined by a repeated-measures ANOVA with main terms for (i) display (search vs. non-search), (ii) relevant dimension (color vs. orientation), (iii) display sequence (same vs. different display relative to the *n-1* trial), (iv) dimension sequence (same vs. different dimension relative to previous trial), and (v) response sequence (same or different response relative 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 x 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), while 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 x dimension sequence ($F(1,10) = 20.98$, $p < .0<$, $\eta_p^2 = .68$), display sequence x response sequence ($F(1,10) = 10.13$, $p < .01$, $\eta_p^2 = .50$), dimension sequence x response sequence ($F(1,10) = 35.43$, $p <$

.01, $\eta_p^2 = .78$), and display sequence x dimension sequence x response sequence ($F(1,10) = 20.16$, $p < .01$, $\eta_p^2 = .67$). No other main effects or interactions proved significant (all $F < 3.39$, $p > .10$). 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 2.5.

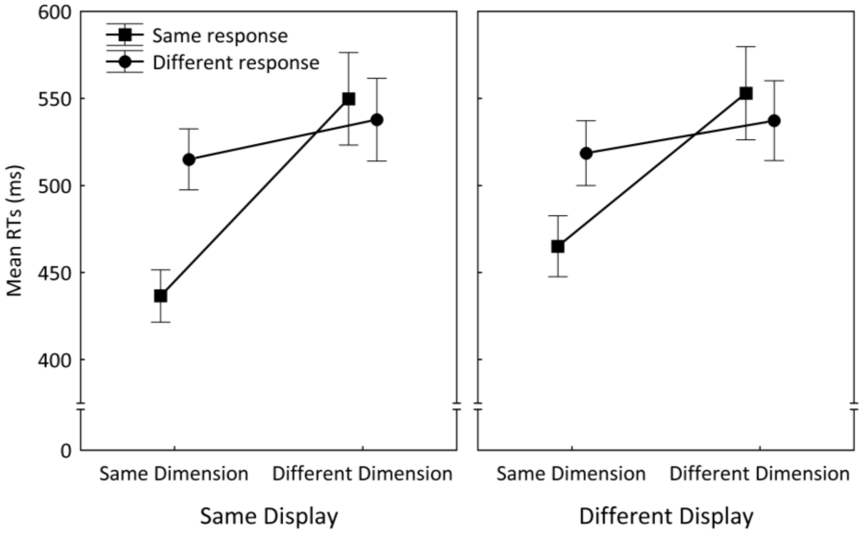

Figure 2.5. Mean RTs (in ms) across different display sequences (same vs. different display type across trials *n* and *n-1*), dimension sequences (same vs. different) and response sequences (same – squares; different – circles) in Experiment 3. Vertical bars denote standard errors of the means.

As can be seen from Figure 2.5, 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 x dimension sequence x 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.

2.6.3 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. On 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 as compared to ≈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: (i) the dimension of discrimination, (ii) the feature to be discriminated, and (iii) 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, as compared to 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.

2.7 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), dimensional 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. As 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, post-selective approaches used tasks that demanded additional, post-selective 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 non-consecutive 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.

2.7.1 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. Based on 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 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 a similar dynamics, but operate at different, pre- and post-selective, processing stages. This assumption is similar to Meeter and Olivers' (2006; Olivers & Meeter, 2006) 'ambiguity resolution' account of crosstrial ‘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 at early (pre-selective) or late (post-selective) 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 pre-selective 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 pre-selective weighting system which tracks (weights) the search-critical dimension on a given trial and biases the system towards 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 post-selective 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, 2010).

The second weighting system underlies the intertrial effects in the discrimination task. As this task makes minimal demands on target selection, the second weighting system is likely to influence later, post-selective processes. Experiment 3 revealed the DRB effect to persist

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[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)

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: 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 post-selective *perceptua*l 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).

2.7.2 Relation to previous studies

There are a number of parallels between the paradigms used in the present experiments and 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 the 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 towards a) dimension repetition *cost* (Krummenacher , Müller, & Heller, 2002; Müller & Krummenacher, 2006a; Theeuwes et al., 2006; Töllner et al., 2008; see also Olivers & Meeter, 2006, who report 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 x 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 pre-selective and post-selective 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 x response sequence interaction closely matching the corresponding interaction in the RT data. Since 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 post-selective 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, while the other (indicated by effects in the stimulus-locked LRP) influences post-selective 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 still at variance with the results of Kumada and Mortier et al. (despite the significant DRBs in compound tasks for response repetition trials). One explanation might be that in the non-search compound tasks of Kumada and 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.

2.7.3 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 non-consecutive 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 sequence (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 associations. To illustrate, 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 task, 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 SR-mapping account might explain the task-specificity of DRBs, the present findings argue against the assumptions of this hypothesis: Experiment 3 demonstrated that DRBs (≈ 20 ms) persisted across SR-mapping changes in the discrimination task (e.g., blue – left button, green – right button). This finding argues against SR-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, due to the fact that there was only one feature per dimension. Consequently, SR-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; Weidner et al., 2002; Krummenacher, Grubert, & Müller, 2010) 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 SR-repetitions being the critical source of DRBs in the detection task.

In summary, the lack of SR-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 SR-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 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, while 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 re-set 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 non-consecutive 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, while 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, based on 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 is 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 Zehetleitner (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 behavioural 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; Pollmann et al., 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 and/or response selection). That weighting processes operate also at post-selective processing stages, and independently of pre-selective weighting, has also 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 the single-weighting-system hypothesis.

2.7.4 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.

2.8 References

Bravo, M. J., & Nakayama, K. (1992). The role of attention in different visual-search tasks. *Perception & Psychophysics*, *51*(5), 465-72.

Broadbent, D. E. (1982). Task combination and selective intake of information. *Acta Psychologica*, *50*(3), 253-90.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*(4), 523-547.

Cohen, A., & Magen, H. (1999). Intra- and cross-dimensional visual search for single-feature targets. *Perception & Psychophysics*, *61*(2), 291-307.

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology*, *32*(2), 128-81. doi: 10.1006/cogp.1997.0648.

Cohen, A., & Shoup, R. (2000). Response selection processes for conjunctive targets. *Journal of Experimental Psychology. Human Perception and Performance*, *26*(1), 391-411.

Duncan, J. (1985). Visual search and visual attention. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and Performance XI* (pp. 85-106). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology. General*, *113*(4), 501-517.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*(3), 225-34.

Feintuch, U., & Cohen, A. (2002). Visual attention and coactivation of response decisions for features from different dimensions. *Psychological Science: A Journal of the American Psychological Society / APS*, *13*(4), 361-9.

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: investigating a "dimension-weighting" account. *Perception & Psychophysics*, *58*(1), 88-101.

Goolsby, B. A., & Suzuki, S. (2001). Understanding priming of color-singleton search: roles of attention at encoding and "retrieval". *Perception & Psychophysics*, *63*(6), 929-944.

Huang, L., Holcombe, A. O., & Pashler, H. (2004). Repetition priming in visual search: episodic retrieval, not feature priming. *Memory & Cognition*, *32*(1), 12-20.

Huang, L., & Pashler, H. (2005). Expectation and repetition effects in searching for featural singletons in very brief displays. *Perception & Psychophysics*, *67*(1), 150-157.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10-12), 1489-506.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews. Neuroscience*, *2*(3), 194-203.

Kingstone, A. (1992). Combining expectancies. The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology. 44A(1), 69-104.

Koch, C., & Ullman, S. (1985). Shifts in selective visual attention: towards the underlying neural circuitry. *Human Neurobiology*, *4*(4), 219-227.

Krummenacher, J., Grubert, A., & Müller, H. J. (2010). Inter-trial and redundant-signals effects in visual search and discrimination tasks: Separable pre-attentive and post-selective effects. *Vision Research* (revision, under review).

Krummenacher , J., Müller, H J, & Heller D. (2002). Visual search for dimensionally redundant pop-out targets: Redundancy gains in compound tasks. *Visual Cognition*, *9*, 801-837.

Krummenacher, J., Müller, H. J., & Heller, D. (2002). Visual search for dimensionally redundant pop-out targets: parallel-coactive processing of dimensions is location specific. *Journal of Experimental Psychology. Human Perception and Performance*, *28*(6), 1303-22.

Kumada, T. (2001). Feature-based control of attention: evidence for two forms of dimension weighting. *Perception & Psychophysics*, *63*(4), 698-708.

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, *22*(6), 657-72.

Maljkovic, V., & Nakayama, K. (1996). Priming of pop-out: II. The role of position. *Perception & Psychophysics*, *58*(7), 977-91.

Maljkovic, V., & Nakayama, K. (2000). Priming of popout: III. A short-term implicit memory system beneficial for rapid target selection. *Visual cognition*, *7*(5), 571-595.

Meeter, M., & Olivers, C. N. L. (2006). Intertrial priming stemming from ambiguity: A new account of priming in visual search. *Visual Cognition*, *13*(2), 202-222. doi: 10.1080/13506280500277488.

Mortier, K., Theeuwes, J., & Starreveld, P. (2005). Response selection modulates visual search within and across dimensions. *Journal of Experimental Psychology. Human Perception and Performance*, *31*(3), 542-57. doi: 10.1037/0096-1523.31.3.542.

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. *Perception & Psychophysics*, *57*(1), 1-17.

Müller, H. J., & Krummenacher, J. (2006a). Locus of dimension weighting: Preattentive or postselective? *Visual cognition*, *14*(4-8), 490-513.

Müller, H. J., & Krummenacher, J. (2006b). Visual search and selective attention. *Visual Cognition*, *14*(4), 389-410.

Müller, H. J., Krummenacher, J., & Heller, D. (2004). Dimension-specific intertrial facilitation in visual search for pop-out targets: Evidence for a top-down modulable visual short-term memory effect. *Visual Cognition*, *11*(5), 577-602.

Müller, H. J., & O'Grady, R. B. (2000). Dimension-based visual attention modulates dual-judgment accuracy in Duncan's (1984) one- versus two-object report paradigm. *Journal of Experimental Psychology. Human Perception and Performance*, *26*(4), 1332-51.

Olivers, C. N. L., & Meeter, M. (2006). On the dissociation between compound and present/absent tasks in visual search: Intertrial priming is ambiguity driven. *Visual Cognition*, *13*(1), 1–28.

Pashler, H. (1984). Processing stages in overlapping tasks: evidence for a central bottleneck. *Journal of Experimental Psychology. Human Perception and Performance*, *10*(3), 358-377.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychological Bulletin*, *116*(2), 220-244.

Pollmann, S., Weidner, R., Müller, H. J., & von Cramon, D. Y. (2000). A fronto-posterior network involved in visual dimension changes. *Journal of Cognitive Neuroscience*, *12*(3), 480-94.

Pollmann, S., Weidner, R., Müller, H. J., Maertens, M., & von Cramon, D. Y. (2006). Selective and interactive neural correlates of visual dimension changes and response changes. *NeuroImage, 30*(1), 254-65. doi: 10.1016/j.neuroimage.2005.09.013.

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2009). Independent dimension-weighting mechanisms for visual selection and identification (under review).

Santee, J. L., & Egeth, H. E. (1982). Do reaction time and accuracy measure the same aspects of letter recognition? *Journal of Experimental Psychology. Human Perception and Performance*, *8*(4), 489-501.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception & Psychophysics*, *50*(2), 184-93.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*(6), 599-606.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review*, *11*(1), 65-70.

Theeuwes, J., Reimann, B., & Mortier, K. (2006). Visual search for featural singletons: No top-down modulation, only bottom-up priming. *Visual Cognition*, *14*(4-8), 466–489.

Töllner, T., Gramann, K., Muller, H. J., Kiss, M., & Eimer, M. (2008). Electrophysiological Markers of Visual Dimension Changes and Response Changes. *Journal of Experimental Psychology, 34*(3), 531-542. doi: 10.1037/0096-1523.34.3.531.

Töllner, T., Zehetleitner, M., Gramann, K., & Müller, H. J. (2010). Top-down weighting of visual dimensions: behavioral and electrophysiological evidence. Vision Research (in press). doi: *10.1016/j.visres.2009.11.009*

Treisman, A. (1988). Features and objects: the fourteenth Bartlett memorial lecture. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *40*(2), 201-37.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology. Human Perception and Performance*, *8*(2), 194-214.

Weidner, R., & Müller, H. J. (2009). Dimensional weighting of primary and secondary target-defining dimensions in visual search for singleton conjunction targets. *Psychological Research*, *73*(2), 198-211. doi: 10.1007/s00426-008-0208-9.

Weidner, R., Pollmann, S., Müller, H. J., & von Cramon, D. Y. (2002). Top-down controlled visual dimension weighting: an event-related fMRI study. *Cerebral Cortex (New York, N.Y.: 1991)*, *12*(3), 318-328.

Wolfe, J. M. (1994). Guided search 2. 0. A revised model of visual search. *Psychonomic Bulletin & Review*, *1*(2), 202-238.

Wolfe, J. M., Butcher, S. J., Lee, C., & Hyle, M. (2003). Changing your mind: on the contributions of top-down and bottom-up guidance in visual search for feature singletons. *Journal of Experimental Psychology. Human Perception and Performance*, *29*(2), 483-502.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *15*(3), 419-33.

Zehetleitner, M., & Müller, H. J. (2009). Saliency from the decision perspective (under review).

Zehetleitner, M., Krummenacher, J., Geyer, T., & Müller, H. J. (2009). Intention and trial history modulate dimensional weights in localization of feature singletons (under review).

3 INDEPENDENT DIMENSION-WEIGHTING MECHANISMS FOR VISUAL SELECTION AND STIMULUS IDENTIFICATION

3.1 Abstract

Observers respond faster when the task-relevant perceptual dimension (e.g., color) repeats across consecutive trials relative to when it changes. Such dimension repetition benefits (DRBs) occur in different tasks, from singleton feature search to feature discrimination of a stimulus presented on its own. Here, we argue that the DRBs observed in different tasks originate from distinct mechanisms: pre-selective weighting of dimension-specific feature contrast signals and, respectively, post-selective stimulus processing. The multiple-weighting-systems hypothesis predicts significant DRBs across trials of different tasks that share the same weighting mechanism, but not across tasks involving different mechanisms. Experiment 1, 2 and 3 examined DRBs across localization and detection tasks (both involving feature contrast computations); across detection and identification tasks (which presumably involved different weighting systems), and across identification and discrimination tasks (both involving stimulus identification). As expected, significant DRBs were observed across different tasks in Experiments 1 and 3, but not in Experiment 2. These findings support the multiple-weighting-systems hypothesis.

Keywords: multiple-weighting-systems, task-switching, dimensional-weighting, intertrial effects, singleton search, stimulus identification

3.2 Introduction

The basic mechanisms underlying visual selection have long been a topic of scientific investigation. Variants of the visual-search paradigm have provided a fruitful approach for revealing the functional architecture of visual selection (e.g., Wolfe, 1994; Wolfe & Horowitz, 2004). In particular, feature singleton search has been a key paradigm for examining a number of controversial issues relating to mechanisms of visual selection. Essentially, in this paradigm, participants are presented with an array of items with one of them (the singleton), on some trials, being different than the rest in some respect (e.g., in color or orientation). In the simplest variant of the task, participants have to indicate presence/absence of a singleton item by pressing a corresponding response button. Typically, they are able to discern the singleton’s presence very fast and with high accuracy, independently of the number of presented items, or set size (e.g., Treisman, 1982). Additionally, participants are faster to detect the singleton if the dimension in which it differs from the distractor items (e.g., color) repeats across trials (e.g., Found & Müller, 1996; Müller, Krummenacher, & Heller, 2004; Treisman, 1988). Müller and colleagues took this Dimension Repetition Benefit (DRB) to reflect facilitation of search processes prior to the focal-attentional selection of the singleton item (e.g., Müller & Krummenacher, 2006a). However, other authors observed similar DRBs even in a paradigm with a single item presented at a fixed location on the screen, that is, under conditions in which no search for the target was necessary (Mortier, Theeuwes, & Starreveld, 2005). They concluded that the DRBs in this non-search task must reflect facilitation of post-selective processes involved in response selection or stimulus-to-response mapping. Furthermore, given the qualitative similarity between the DRBs observed in the search and non-search tasks, Mortier et al. (2005) assumed that the intertrial effects in both types of task have one common origin, namely, the stage of response selection. Implicit to this reasoning is the assumption that there is only one sequence mechanism generating the DRBs in the different tasks.

In the present study, we are arguing for an alternative explanation of the DRB effects observed in the search and non-search tasks: Not one, but multiple mechanisms are responsible for these effects, which affect different processing stages: visual selection and target identification, respectively. The main focus of the present study was to examine whether DRBs in the two tasks have the same, single source or multiple sources.

Rangelov, Müller, and Zehetleitner (2010) already demonstrated that DRBs do not generalize across trials of different tasks, providing evidence in favor of the multiple-weighting-systems hypothesis. However, the tasks in question differed in both search demands (search vs. non-search) and stimulus-response mappings, making it impossible to separate effects due to changes in search demands across tasks from effects attributable to changes of response requirements. On this background, the present study was designed to assess the potential roles of search and response requirements independently.

3.2.1 Search-based account of dimension repetition benefits

Studies investigating sequence effects in singleton feature search tasks have repeatedly demonstrated that performance is sensitive to the recent trial history (Found & Müller, 1996; Krummenacher, Müller, & Heller, 2002, 2001; Lamy, Bar-Anan, Egeth, & Carmel, 2006; Maljkovic & Nakayama, 1994, 1996; Müller, Heller, & Ziegler, 1995; Olivers & Humphreys, 2003). Observers respond to a singleton target faster when either its distinguishing feature (e.g., red target amongst green distractors) or the dimension in which it differs from the distractors (e.g., color, orientation, etc.) repeats across consecutive trials. Found and Müller (1996) demonstrated that the repetition benefit is (almost) as large when the target dimension repeats, but the specific target feature changes (e.g., red singleton followed by blue singleton on consecutive trials) as when the target feature repeats (red singleton on both trial n-1 and trial n). To explain this *dimension-specificity* of the intertrial effects, Müller and colleagues proposed a ‘Dimension-Weighting Account’, or DWA (Müller & Krummenacher, 2006a, 2006b).

The DWA assumes (similar to the existing models of visual selection, e.g., Itti & Koch, 2000, 2001; Koch & Ullman, 1985) that a visual scene is analyzed in terms of feature contrasts 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, orientation, etc.) and then summed up into a (supra-dimensional) master map of saliencies. Locations are then selected by focal attention in an order determined by the strength of the salience signals on the master map. Importantly, according to the DWA, the signal summation from dimension-specific maps to the master map of saliencies is weighted. On every trial, the weight for the dimension from which the informative signal came (e.g., color for a trial with a color singleton) increases, while the weights for other dimensions decrease. This weight set is persistent over time, so that an increased weight for, say, color dimension would facilitate color processing on the following trial. Thus, if the relevant dimension also happens to be color on the next trial, then singleton selection is speeded giving rise to the DRB (dimension repetition benefit).

3.2.2 Response-based account of dimension repetition benefits

Instead of attributing the origin of the DRBs to the weighting of dimension-specific feature-contrast signals (as in the DWA), alternative accounts assume that the DRBs originate from the response selection stages (Cohen & Magen, 1999; Cohen & Shoup, 1997, 2000; Feintuch & Cohen, 2002; Magen & Cohen, 2002, 2007; Mortier et al., 2005). One line of evidence favoring response-selection accounts of the DRB comes from paradigms in which the visual-search component of the task is minimized. For example, Cohen and Shoup (1997) demonstrated dimension-specific effects in a variant of the flanker task (e.g., Eriksen, 1995). In their paradigm, participants were to indicate either the color (red vs. green) or orientation (left- vs. right-tilted) of the centrally presented bar, with dimension of discrimination varying randomly across trials. Different features from the same dimension (e.g., red/green) were mapped to different responses (e.g., left/right), with features of different dimensions being mapped to the same response (e.g., red and left-tilted to right response button).The task-irrelevant feature was always response-neutral, that is, the stimulus was blue in case of orientation discrimination and, respectively, vertical in case of color discrimination. The target was flanked by either *same-dimension* flankers (e.g., red-vertical target between red- or green-vertical flankers) or by *different-dimension* flankers (e.g., red-vertical between left-tilted blue flankers). Independently of the dimensional congruency, the flankers could be either response-congruent (i.e., both target and flankers were associated with the same response) or response-incongruent. Cohen and Shoup reported significant response congruency effects only for the same-dimension condition, but not the different-dimension condition.

To account for these findings, they proposed a Dimensional-Action (DA) model (Cohen & Magen, 1999; Cohen & Shoup, 1997, 2000; Feintuch & Cohen, 2002). According to the DA, different perceptual dimensions (e.g., color and orientation) have their own response modules which are independent of each other (i.e., there is one module for color and another for orientation). Within this framework, the dimension-specific congruency effects observed by Cohen and Shoup (1997) are thus explained by the virtue of within-dimension response competition (e.g., competition, and mutual inhibition, between response units for ‘red’ and ‘green’) producing response congruency effects for the same-dimension flankers, whereas no such competition takes place between different dimensional response modules.

An analogous line of reasoning was pursued by Mortier et al. (2005), who sought to address the question of the origin of the DRBs in the singleton search task more directly. Here, participants performed two tasks, fixed per block of trials. In the first, standard search task, one response was required for singleton-present displays (regardless of the singleton’s featural or dimensional identity), another response for singleton-absent displays. In the other, so-called ‘non-search task’, only one item was shown at a fixed location (Experiment 2 of

Mortier et al., 2005). This item could be identical to the distractor items presented in the singleton search task, and it required one – target-absent – response. Alternatively, the presented item could be one of the items used as targets in the singleton search task; such items required a different – target-present – response. Independently of the task, there were two conditions with respect to the dimensional uncertainty of the target items. In the within-dimension condition, the target, when presented, always differed in color from distractors. In the cross-dimension condition, the target could differ in color, shape, or size from distractors, varying randomly across trials. Among other comparisons, the authors also examined for DRBs in the cross-dimension condition of both tasks – these were revealed to be significant in both search and the non-search task.

Given that the non-search tasks (with a single item presented at a fixed location) do not involve a search component (cf. Goolsby & Suzuki, 2001), Mortier et al. (2005) argued against facilitation of the search process as the source for the DRBs in this task; instead, they attributed these DRBs to facilitation of later, stimulus analysis and response selection processes, along the lines suggested by Cohen and colleagues (e.g., Feintuch & Cohen, 2002). Applied to the non-search task of Mortier et al. (2005), the DA account would interpret DRBs as reflecting the time costs to switch between response modules in cases when the critical dimension changes across trials relative to when it repeats. As the pattern of DRBs was strikingly similar between the search and non-search tasks, Mortier et al. proposed, by analogy, that in search tasks, too, the DRBs arise (exclusively) from the post-selective stages where a focally attended stimulus is translated into the associated response.

To examine whether the DRBs in the non-search task originated in response-related processes, Mortier et al. (2005; Experiment 5) looked for DRBs in a non-search compound task. Standard compound-search tasks, similar to the singleton search, always use displays composed of multiple items, with one item being the (to-be-detected) singleton target. However, unlike the singleton search task, observers are to respond to a (to-be-discriminated) attribute of this target, which is different from that relevant for discerning its presence. To illustrate, observers might be required to detect a color-defined singleton (color = target-defining attribute), but then discriminate and respond to the orientation of a small line (e.g., vertical vs. horizontal) within the target's outline shape (orientation = response-defining attribute). In the non-search compound task of Mortier et al. (2005), in which displays contained only one item presented at a fixed location, observers had also to respond to the orientation of an internal line within this 'target' object. Variably across trials, the target was either color-, shape-, or size-defined, permitting Mortier et al. to examine whether there would be DRBs under these changed response conditions. However, in contrast to the significant DRBs obtained in the non-search detection task (Experiments 1 and 2), there were no DRBs in the non-search compound task (Experiment 5). Consequently, Mortier et al. (2005) attributed these differential results between the two types of non-search task to the differences in response requirements. Note though that, because a 'target' item in the non-search compound task (unlike the non-search detection task) was presented on every trial, there was no need to distinguish this item from a non-target standard. In fact, it was essentially an irrelevant stimulus that did not need to be processed at all. Given this, the failure to find DRBs under these task conditions is not surprising.

In summary, the results of Mortier et al. (2005) convincingly demonstrate that search processes are not necessary for significant DRBs to arise. Furthermore, according to Mortier et al., the failure to find DRBs in the non-search compound task suggests that response relevance is necessary for DRBs to be observed. Finally, based on the parallels between standard search and non-search tasks, Mortier et al. argued for a common origin of DRBs in both types of tasks: response selection processes.

3.2.3 Multiple dimension-weighting systems hypothesis

However, exclusively assigning the origin of DRBs to response selection processes seems at variance with other findings in the literature. For example, examining event-related potentials in a compound-search task, have recently demonstrated dimension-specific intertrial effects on the latency and amplitude of the N2pc component (Töllner, Gramann, Muller, Kiss, & Eimer, 2008; Töllner, Zehetleitner, Gramann, & Müller, 2010) – which is commonly interpreted as a marker of focal-attentional selection processes (e.g., Eimer, 1996) Consequently, the finding of significantly shorter N2pc latencies for repetitions versus changes of the target-defining dimension across trials makes a strong case for search-based accounts of DRBs, at least with respect to tasks that do involve a search component. Consistent with this, cueing of the position of an upcoming singleton has been shown to abolish feature repetition effects in the 'priming of pop-out' paradigm (Goolsby & Suzuki, 2001), again suggesting that the dynamics of attentional selection plays an important role in generating intertrial effects in search tasks.

Thus, there is a puzzle: while there is evidence from search tasks that the dynamics of spatial attentional selection (i.e., search processes) is influenced by the dimensional intertrial sequence, evidence from non-search tasks indicate that search processes are not necessary for DRBs to arise. This data pattern cannot be fully accommodated by either an exclusive search-based or an exclusive response-based account. To solve this puzzle, Rangelov, Zehetleitner, and Müller (2010) hypothesized the existence of two separate (dimension sequence-sensitive) mechanisms that generate DRBs in different tasks: one mechanism generating DRBs in search tasks, the other in non-search tasks[5].

To examine whether a single or multiple mechanisms generate DRBs in search and, respectively, non-search tasks, Rangelov et al. (2010) presented both types of task either regularly or randomly alternating across trials. The search task required detection of a singleton target, which was either color-defined (*red* [left-tilted] bar) or orientation-defined (*right-tilted* [yellow] bar), amongst a set of homogeneous distractor items (yellow, left-tilted);

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[5] Other theorists have similarly proposed that intertrial effects might arise at multiple processing stages (see, e.g., the 'ambiguity resolution account of Olivers & Meeter (2006), and Meeter & Olivers (2006)).

observers had to make a simple target-present versus target-absent decision. By contrast, the non-search task (with a single display item presented at a fixed, central location) required feature discrimination; that is, the display item was either color-defined, a *blue* or *green* (left-tilted) bar, or orientation-defined, a *vertical* or *horizontal* (yellow) bar, and observers had to respond to either the color (blue vs. green) or the orientation feature (horizontal vs. vertical) of the presented item. Thus, for the detection task, the 'relevant dimension' refers to the dimension in which the target differs from the distractors; and for the discrimination task, it refers to the dimension whose features are to be discriminated.

Across consecutive trials, the relevant dimension could either repeat or change; and, independently of the dimension sequence, the task could repeat or change. Rangelov et al. examined for DRBs across different task sequences (repetition vs. change) – the critical assumption being that, if the same mechanism were responsible for DRBs in both search and non-search tasks, the intertrial effects should persist even across task switches.

However, while Rangelov et al. observed significant DRBs across same-task trials for both types of task, no DRBs were evident across trials of different tasks. Analyses of intertrial effects across non-consecutive trials of the same task (e.g., discrimination task on trials n-2 and n) with a task switch in between (in the example, detection task on trial n-1) also revealed significant DRBs. This finding argues against the idea that RT costs associated with task switches masked potential DRBs across different tasks. If that were true, no DRBs across non-consecutive same-task trials with a different task in between should arise by virtue of having two task switches between the analyzed trials. In a final experiment, observers performed only the feature discrimination task, but with two possible display types: single-item displays (identical to the displays used previously for the feature discrimination task), and multiple-item displays in which the target item (also always centrally presented) was surrounded by homogeneous distractor items (similar to the displays used for the detection task in the previous experiments). Across consecutive trials, the dimension of discrimination and the display type could repeat or change independently. The results revealed significant DRBs for both types of display, and these effects were significant even across trials with a different display. The latter finding indicates that display type changes, which were associated with task changes (from search to non-search or vice versa) in the preceding experiments, cannot account for the absence of DRBs across trials with different tasks.

In summary, the main finding of Rangelov et al. (2010) was that DRBs do not generalize across trials with different (search and, respectively, non-search) tasks. Furthermore, the lack of DRBs across trials with different tasks could not be attributed to either task change or display change costs. However, the multiple weighting-systems hypothesis can readily account for the absence of DRBs across different tasks by assuming the existence of separate and independent dimension-weighting mechanisms engaged in search and non-search tasks.

3.2.4 Role of search demands and response requirements in generating DRBs

Although Rangelov et al. (2010) demonstrated that DRBs do not generalize across trials of different (search and non-search) tasks, this does not provide direct evidence against the central assumption of Mortier at al. (2005) that the mechanisms engaged in *detection* tasks (search and non-search variety) are identical. In the study of Rangelov et al. (2010), the two tasks differed in terms of both search demands and response requirements. To illustrate, in the detection (search) task, one response was assigned to target-present, another to target-absent displays. In the discrimination (non-search) task, one response was assigned to one feature of the dimension of discrimination (e.g., blue), another response to the other feature of the same dimension (e.g., green). Thus, it could be that the differences in response requirements, rather than differences in weighting mechanisms, were the reason why no DRBs were observed when the tasks on consecutive trials were different.

Given this, the present study was designed to independently assess the potential roles of (i) search demands and (ii) response requirements in generating DRBs across trials with different tasks. To this end, in Experiment 1, two search tasks with different response requirements were presented intermixed across trials. In Experiment 2, one search and one non-search task with identical response requirements alternated randomly across trials. And in Experiment 3, two non-search tasks with different response requirements varied across trials.

In Experiments 1 and 3, both tasks were of either the search or the non-search type. In the two search tasks of Experiment 1, observers, irrespectively of the response mappings, had to select the singleton from an array of homogenous distractors. Conversely, in Experiment 3, the two tasks were of the non-search type, minimizing the search and selection processes in both tasks. Henceforth, whether or not it is necessary to search for the target in order to perform a task will be referred to as the 'search requirements' of this task. The particular stimulus-response mapping rules will be are referred to as the 'response requirements' of the task.

According to the multiple-weighting-systems hypothesis, if the two tasks within an experiment share search requirements (e.g., the two search tasks in Experiment 1, and, respectively, the two non-search tasks in Experiment 3), significant DRBs across these tasks should arise. By contrast, if the two tasks differ in search demands (as in Experiment 2), there should be no DRBs across trials of different tasks, even if the response requirements are identical across the different tasks.

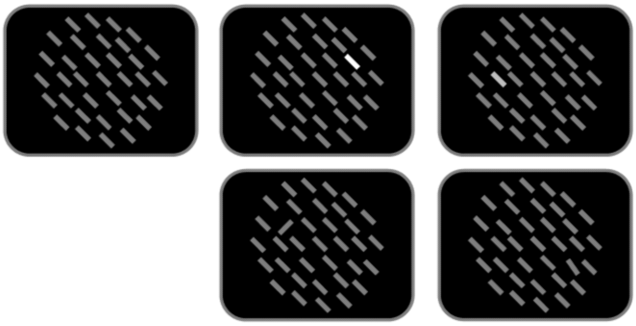
Alternatively, if the response requirements are the crucial factor in generating DRBs, the data pattern should be the opposite: DRBs should persist across tasks with the same response demands (Experiment 2), irrespectively of the search demands; and there should be no DRBs across tasks with different response requirements (Experiments 1 and 3), even if they share the search demands.

3.3 General Method

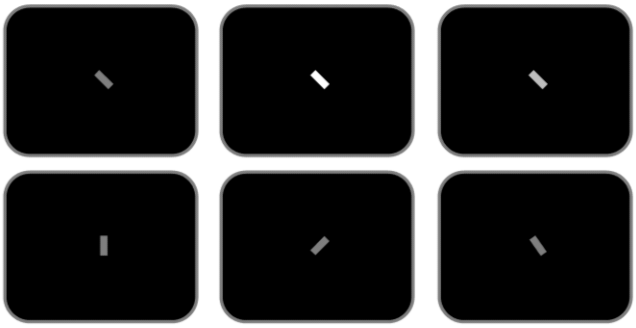
Participants. There were 12 participants (7 female, mean age 27 years) in Experiment 1, 13 participants (7 female, mean age 25 years) in Experiment 2, and 13 participants (6 female, mean age 26 years) in Experiment 3. All participants had either normal or corrected-to-normal vision; all of them had previous experience with psychophysical experiments, and were naive as to the purpose of the respective experiment. They received monetary compensation (8 €/h) in return for their participation in the experiments.

Apparatus. The experiments were run on a Dell PC running under the Windows XP operating system. The stimuli were presented on a ViewSonic G90f-4 19” CRT monitor, with the screen resolution of 1024 x 768 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 53 cm, controlled by means of a chin rest. Participants were to respond by pressing the upper or lower button of a custom made response box, with their left or right index finger, respectively.

Stimuli. Two different stimulus display types were used: (i) search displays – containing 35 bars arranged in concentric circles of 1, 6, 12, and 16 elements, respectively; and (ii) non-search displays – containing only one bar presented in the center of the monitor. Individual bars subtended approximately 2° x 0.5° of visual angle, while the whole search display (i.e., all 35 elements together) subtended approximately 19° x 19° of visual angle. The search displays could either contain a feature singleton (= target) or not. Target-absent search displays consisted only of distractor items which were identical gray bars (7.5cd/m^2), tilted 45° counter-clockwise from the vertical (i.e., left-tilted). When present, the target differed from distractors either in luminance or orientation, the other feature (e.g., orientation for luminance targets) being the same as the respective distractor feature. Depending on the magnitude of the feature contrast between the target and distractors, there were two possible targets per dimension of distinction: (i) high contrast targets – bright bar (62.5 cd/m^2) for luminance, and right-tilted bar (45° clockwise from vertical) for orientation targets; (ii) low contrast targets – dim (22.5 cd/m^2) or slightly tilted (35° counter-clockwise) bar for luminance and orientation, respectively. Low- and high-feature-contrast targets were introduced because low-contrast targets, which are still found efficiently (in terms of the slope of the function relating search RT to the number of items in the search display), lead to longer decision times and the size of intertrial effects increases with increasing decision times (see Zehetleitner & Müller, 2010, for an elaboration of this argument). Thus, introducing targets of different contrast levels maximized chances of observing significant DRBs in the present study. In the non-search displays, the presented bar could be the same as a distractor bar in the search displays, the same as a target bar in the search displays, or a vertical bar of the same luminance as the distractor bar. An illustration of the stimuli is given in Figure 3.1.



Search displays



Non-search displays

Figure 3.1. Illustrations of the display types used in the present study. Search displays represent from left to right: target absent, bright singleton, dim singleton, right-tilted, and slightly tilted singleton. Non-search displays depict, from left to right: target absent (distractor), bright target, dim target, vertical, right-tilted, and slightly tilted target.

Tasks. There were four possible tasks: (i) singleton detection, (ii) singleton localization, (iii) stimulus identification, and (iv) feature discrimination. Search displays were used for detection and localization tasks; non-search displays for identification and discrimination tasks. A pilot experiment demonstrated that detection speed for all singletons used in the search displays was independent of the set size (i.e., efficient search). In detection task, participants were to indicate presence/absence of a target (presented in 60% of detection task trials) by pressing the corresponding response buttons. In the localization task, displays always contained target, presented on either the left or the right side. The task was to indicate the hemifield in which the target was presented (left vs. right) by pressing corresponding response buttons. The identification task required participants to indicate whether the presented bar was the distractor (on 40% of identification task trials) or a target (bright, dim, right-tilted or slightly tilted bar). The distractor bar required one response, any other bar (i.e., targets) another response. Thus, the response set in the identification task was virtually identical to that in the detection task, with the difference of the display types used in the two tasks (i.e., search displays for detection, non-search displays for identification). Finally, in the discrimination task, participants were to indicate the luminance (bright vs. dim) or orientation (vertical vs. tilted) feature of the presented bar. Vertical, rather than slightly tilted, bar was used for orientation discrimination, because the feature discrimination task would have been too difficult otherwise. Different features within a dimension of discrimination (e.g., bright vs. dim bar for luminance discrimination) were mapped to different responses (e.g., upper vs. lower button). Additionally, by virtue of only two possible responses (upper vs. lower), features of different dimensions (e.g., bright and vertical bar) were mapped to the same response (e.g., both required an upper button press). Different possible stimulus-response mappings across different tasks are summarized in Table 3.1. Different mappings per task and between tasks were balanced across subjects.

Procedure. Each of the experiments had 2100 trials in total, arranged in 30 blocks of 70 trials each. The first three blocks (= 210 trials) were considered as practice/learning blocks and excluded from the subsequent analyses. A short break (5-10min) was introduced after participants completed the first half of the experiment. On average, it took participants about 2h to complete all trials.

Table 3.1. Different S-R mapping versions for different tasks. The S-R mappings per task were balanced across subjects, e.g., in Experiment 1 half of the subjects did detection A, the other half detection B version. Different mappings per task were crossed with different mappings across tasks. For example, in Experiment 1 there were 4 possible combinations (2x2) of detection and localization S-R mappings (detection A/localization A, detection A/localization B, etc.), that were balanced across subjects.

Task	S-R version	Response 1	Response 2
Detection	A	Left-tilted, medium gray (distractors)	Left-tilted, bright gray Left-tilted, dim gray Right-tilted, medium gray Slightly tilted, medium gray
	B	Left-tilted, bright gray Left-tilted, dim gray Right-tilted, medium gray Slightly tilted, medium gray	Left-tilted, medium gray (distractors)
Localization	A	Left side of display irrespectively of the target type	Right side of display irrespectively of the target type
	B	Right side of display irrespectively of the target type	Left side of display irrespectively of the target type
Identification	A	Left-tilted, medium gray (distractor)	Left-tilted, bright gray Left-tilted, dim gray Right-tilted, medium gray Slightly tilted, medium gray
	B	Left-tilted, bright gray Left-tilted, dim gray Right-tilted, medium gray Slightly tilted, medium gray	Left-tilted, medium gray (distractor)
Discrimination	A	Left-tilted, bright Right-tilted, medium gray	Left-tilted, dim Vertical, medium gray
	B	Left-tilted, bright Vertical, medium gray	Left-tilted, dim Right-tilted, medium gray
	C	Left-tilted, dim Right-tilted, medium gray	Left-tilted, bright Vertical, medium gray
	D	Left-tilted, dim Vertical, medium gray	Left-tilted, bright Right-tilted, medium gray

Participants were to respond on every trial. Both response speed and accuracy were stressed. Trials began with a word (presented for 1s) denoting the task on the upcoming trial (e.g. “detection” for detection task trials). The task cue was followed by the stimulus display, presented on the screen until response or maximally for 3s. Correct responses were followed by a variable ISI (900-1100ms), during which only a fixation point was presented in the center of the screen. Erroneous responses were followed by an error feedback (the word “error”). An illustration of the trial sequence with the accompanying presentation times is given in Figure 3.2.

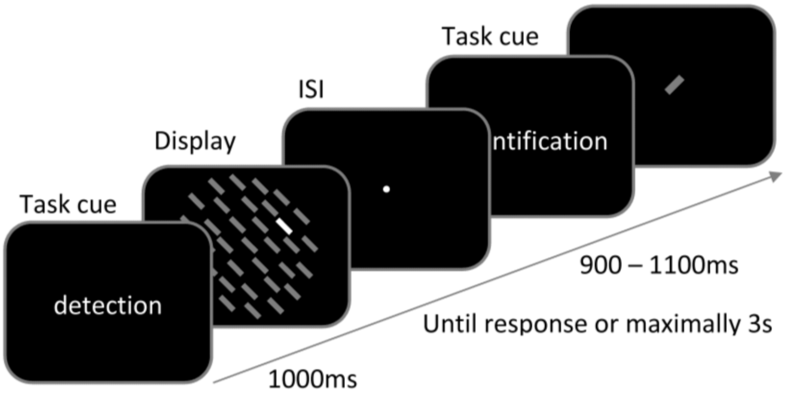


Figure 3.2. Illustration of the trial sequence used in the present study. Each trial started with a task cue – a word denoting the task to be performed in the trials. After 1000 ms, the task cue was repalces with a stimulus display, which was presented until response, or maximally for 3 seconds. An empty screen followed the stimulus display for a variable interval (900 ms – 1100 ms), after which a new trial was initiated.

Design. In Experiment 1, detection and localization (i.e., both search) task were mixed within blocks of trials; Experiment 2 mixed trials of detection (search) and identification (non-search) tasks, and Experiment 3 trials of identification and discrimination (both non-search) task. The design was same for all three experiments. Every trial was characterized by (i) the task to be performed, (ii) the relevant perceptual dimension (luminance or orientation), and (iii) the contrast level of the target (low vs. high). The task, dimension, and the target’s contrast levels were randomized across trials. From trial to trial, the task and the dimension could either repeat or change. This produced the following 2x2x2x2 design: (i) task on the current trial – e.g., detection vs. localization in Experiment 1, (ii) task sequence from the preceding to the current trial – repetition vs. change, (iii) dimension on the current trial – luminance vs. orientation, and (iv) dimension sequence – repetition vs. change. Depending on the experiment, the results were analyzed either separately for targets of different feature contrast levels (in Experiment 1) or averaged across contrast levels (Experiments 2 and 3). This difference in the analyses is owing to the fact that the contrast level was defined with regard to the distractor items; and identification and discrimination tasks used in Experiments 2 and 3 used single-item displays, effectively making the low/high-contrast distinction obsolete.

3.4 Results

3.4.1 Experiment 1

The collected data were first filtered for error responses and trials following errors (7% of trials across conditions). Inspection of error pattern across conditions revealed no indications of speed-accuracy trade-offs. Two participants made error in more than 10% of trials and were therefore excluded from subsequent analyses. Remaining trials were then filtered for RTs faster than 150 and slower than 1000 ms (approximately 5% of trials across conditions).

The remaining trials were then separated in two groups, based on the target type: (i) high contrast targets (e.g., bright or right-tilted bars), and (ii) low contrast targets. For each target type, the trials were sorted according to the following experimental conditions: (i) task (detection/localization), (ii) task sequence across consecutive trials (repetition/change), (iii) dimension (luminance/orientation), and (iv) dimension sequence (repetition/change). Mean RTs across trial repetitions per condition were computed individually per participant. Four-way repeated-measures ANOVAs, with main terms for task, task sequence, dimension, and dimension sequence, were performed over mean RTs, separately for low- and high-contrast targets.

Figure 3.3 depicts the mean RTs for the different tasks, task sequences, and dimension sequences for low contrast targets. As can be seen, observers were faster to localize (mean RT across different task and dimension sequences = 529 ms) than to detect the singleton (594 ms). Furthermore, observers responded faster when the task repeated (543 ms) than when it changed across trials (580 ms), irrespective of the task and the dimension sequence. Most importantly, observers were faster when the dimension repeated (550 ms) than when it changed (573 ms), irrespective of the task and the task sequence.

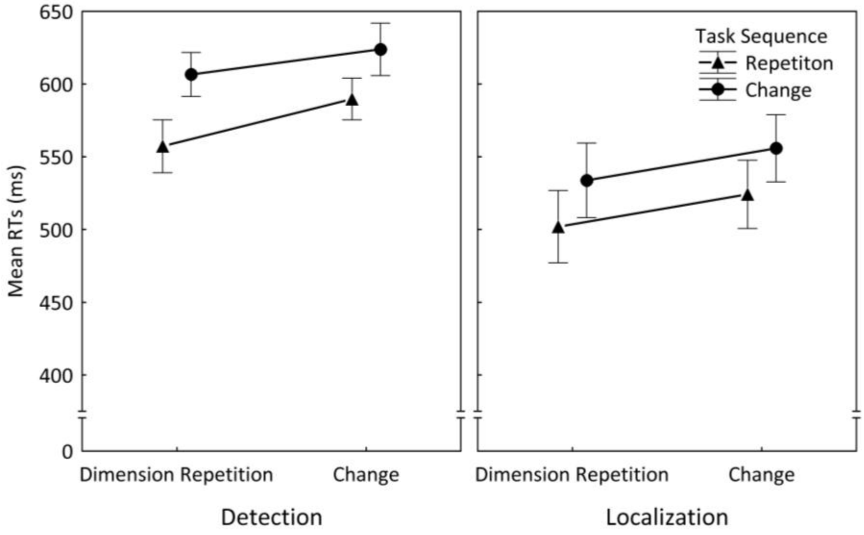


Figure 3.3. Mean RTs (in ms) for detection and localization task used in Experiment 1. Dimension and tasks sequences (repetition vs. change) across consecutive trials are shown separately. Triangles denote task repetitions, while circles stand for task changes across trials. The vertical lines denote ±1 SEM.

This description was confirmed by a four-way ANOVA for the low-contrast targets, which revealed significant main effects of task ($F(1,9) = 35.84$, $p < .01$, $\eta_p^2 = .80$), task sequence ($F(1,9) = 46.47$, $p = .00$, $\eta_p^2 = .84$), dimension ($F(1,9) = 7.36$, $p < .05$, $\eta_p^2 = .45$), and dimension sequence ($F(1,9) = 76.61$, $p < .01$, $\eta_p^2 = .89$). The dimension effect (not illustrated in Figure 3.3) was due to RTs being faster for luminance than for orientation targets (550 vs. 573 ms). None of the interactions reached significance (all $F < 1.23$, $p > .22$).

The ANOVA for high-contrast targets revealed significant main effects of task ($F(1,9) = 11.46$, $p < .01$, $\eta_p^2 = .56$), task sequence ($F(1,9) = 25.70$, $p < .00$, $\eta_p^2 = .74$), and dimension ($F(1,9) = 12.86$, $p < .01$, $\eta_p^2 = .59$). Participants were faster to localize than to detect the target (469 vs. 509 ms). Mean RTs were faster when the task repeated than when it changed (465 vs. 513 ms). Finally, luminance targets were processed faster than orientation targets (482 vs. 496ms). There was also a significant task x task sequence interaction ($F(1,9) = 11.55$, $p < .01$,

η_p^2 = .56). Post-hoc analysis (Tukey HSD) revealed that the task change costs (i.e., task change – task repetition) were more pronounced for target detection than for target localization (66 vs. 28 ms). No other main effects or interactions reached significance (all $F < 3.52$, $p > .05$).

Analysis of DRBs. The main goal of Experiment 1 was to test for DRBs (i.e., dimension sequence effects) across different tasks and task sequences (repetition/change). The ANOVA for high-contrast targets revealed neither the main effect of dimension sequence nor its interaction with task and task sequence to be significant. Although not significant, there was still a numerical difference (7 ms) between dimensional changes and repetitions. This result was not unexpected, given the generally expedited RTs to high-contrast singletons (whether in detection or localization tasks), which consequently limit the magnitude of potentially observable DRBs (see Zehetleitner & Müller, 2010, for a detailed argument). However, a larger and highly reliable dimension sequence effect was revealed for the low-contrast targets. To further examine whether DRBs across different experimental conditions were significant with low-contrast targets, one-tailed planned comparisons t-tests were performed between different dimension sequences for different tasks and task sequences.

For the detection task, the planned comparisons revealed significant DRBs (i.e. dimension change - dimension repetition) both when the task repeated (DRB ≈ 33 ms, $t(9) = 2.65$, $p_{\text{one-tailed}} < .01$) and when the task changed (17 ms, $t(9) = 2.73$, $p_{\text{one-tailed}} < .01$). The results were similar for the localization task: DRBs were significant for task repetitions (24 ms, $t(9) = 2.79$, $p_{\text{one-tailed}} < .01$), as well as task changes (22 ms, $t(9) = 2.14$, $p_{\text{one-tailed}} < .05$).

In summary, the results of Experiment 1 showed significant DRBs for trials of both detection and localization tasks. Moreover, the DRBs were significant whatever the task sequence (repetition/change), albeit reduced for task change sequences. As hypothesized from the multiple-weighting-systems perspective, the DRBs did persist across tasks that shared search demands. Differences in response requirements across tasks, although important, do not seem to play the crucial role in generating DRBs across tasks.

3.4.2 Experiment 2

In Experiment 2, detection (search) and identification (non-search) tasks varied in an unpredictable manner across trials. Detection task trials used search displays, identification trials non-search displays. The response set for different tasks was identical: one response was required for the target-absent display, the other for target-present displays. To illustrate, observes produced one response (e.g., pressed upper button) when target was present regardless of the task (detection or identification), and another response (e.g. lower button) for target absent trials, again regardless of the task.

The data from Experiment 2 were first filtered for erroneous responses and trials following errors (around 7% of trials). Inspection of the error pattern across experimental conditions produced no evidence of speed-accuracy trade-offs. One participant made an error in more than 10% of trials and was therefore excluded from the subsequent analyses. The remaining trials were then filtered for RTs out of 150 - 1000 ms range (about 2% of trials).

After filtering, the remaining trials were sorted according to the following experimental conditions: (i) task (detection/identification), (ii) task sequence (repetition/change), (iii) dimension (luminance/orientation), and (iv) dimension sequence (repetition/change). Mean RTs across trials per experimental condition were computed separately per participant. A repeated-measures ANOVA was performed on the mean RTs with task, task sequence, dimension, and dimension sequence as main terms. Unlike Experiment 1, no differentiation between target types (high/low contrast) was made given that the DRBs were expected for both types of target.

Figure 3.4 depicts the mean RTs for the different tasks, task sequences, and dimension sequences in Experiment 2. Observers were faster to detect (447 ms) than to identify the target (511 ms), irrespective of the task and dimension sequences. Similar to Experiment 1, observers responded faster overall when the task repeated (468 ms) than when it changed (511 ms), irrespective of the task and the dimension sequences. However, unlike Experiment 1, the dimension sequence effects (i.e., DRBs) appeared substantial only across task repetitions, for both the detection and the identification task, but not across task changes.

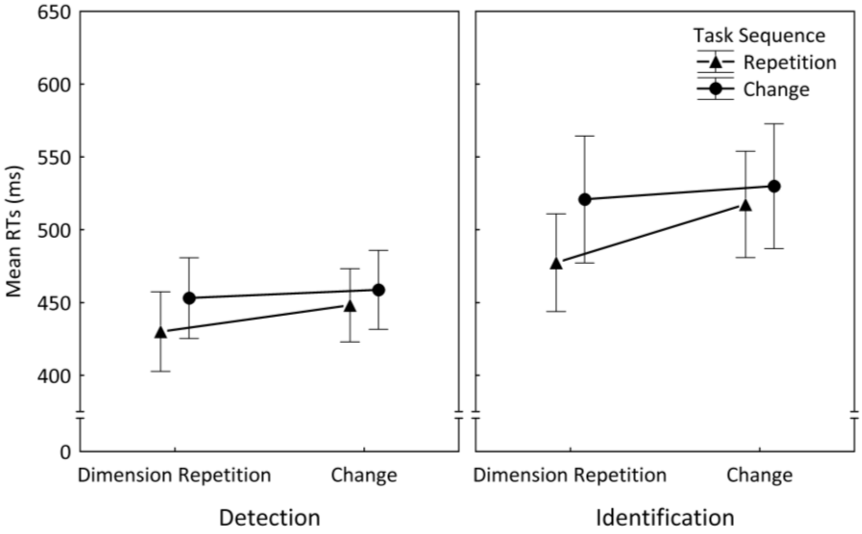


Figure 3.4. Mean RTs (in ms) for detection and identification task used in Experiment 2. Dimension and tasks sequences (repetition vs. change) across consecutive trials are shown separately. Triangles denote task repetitions, while circles stand for task changes across trials. The vertical lines denote ±1 SEM.

These observations were confirmed by a four-way ANOVA that revealed the main effects of task (F(1,11) = 28.19, p < .01, η_p^2 = .72), task sequence (F(1,11) = 41.06, p < .01, η_p^2 = .79), dimension (F(1,11) = 19.72, p < .01, η_p^2 = .64), and dimension sequence (F(1,11) = 26.48, p < .01, η_p^2 = .71) to be significant. Additionally, the task x dimension interaction (F(1,11) = 14.76, p < .01, η_p^2 = .57) and the task sequence x dimension sequence interaction (F(1,11) = 16.86, p < .01, η_p^2 = .60) were significant. No other interactions reached significance (all F < 4.57, p > .05).

Post-hoc analysis (Tukey HSD) of the task x dimension interaction revealed a significant difference (p < .05) between RTs to targets defined in different dimensions in the identification task (480 ms for luminance vs. 543 ms for orientation targets), but not in the detection task (441 vs. 454 ms). Post-hoc analysis of the task sequence x dimension sequence interaction revealed RTs to be faster for trials on which the dimension repeated rather than changed (454 vs. 483 ms), given that the task repeated; by contrast, when the task changed, there was no such difference between dimension repetitions and changes (487 vs. 494 ms).

Analysis of DRBs. Planned comparisons showed significant DRBs for both the detection (DRB ≈ 18 ms, $t(11) = 3.07$, $p_{\text{one-tailed}} < .01$) and the identification task (40 ms, $t(11) = 5.23$, $p_{\text{one-tailed}} < .01$) when the task repeated across consecutive trials. When the task changed, the DRBs were significant neither for the detection task (DRB ≈ 6 ms, $t(11) = 1.14$, $p_{\text{one-tailed}} > .05$) nor for identification task (9 ms, $t(11) = 1.50$, $p_{\text{one-tailed}} > .05$).

To summarize, in Experiment 2, significant DRBs were observed exclusively across trials of the same task. This finding is especially striking because the response sets were virtually identical for the detection and identification tasks. Like in Experiment 1, the results of Experiment 2 are in accordance with the prediction derived from the multiple-weighting-systems hypothesis.

3.4.3 Experiment 3

Identification and feature discrimination (both non-search) tasks varied randomly across trials of Experiment 3. Here, only non-search displays were used. Response sets differed across tasks. In the identification task, participants pressed one button for the distractor bar (i.e., target-absent display), another button for target bars (i.e., target-present display). In the discrimination task, participants were to determine either the luminance (bright vs. dim) or the orientation (vertical vs. right-tilted) feature of the presented bar, with different features being mapped to different responses (e.g., bright or vertical – upper button, dim or right-tilted – lower button).

The collected data were first filtered for errors and trials following errors (approximately 8% of trials). Inspection of error pattern across experimental conditions revealed no signs of speed-accuracy trade-offs. Two participants made errors in more than 10% of trials and were excluded from the subsequent analyses. Outlier RTs were produced in approximately 5% of the correct-response trials.

The remaining trials were sorted according to: (i) task (identification/discrimination), (ii) task sequence (repetition/change), (iii) dimension (luminance/orientation), and (iv) dimension sequence (repetition/change). A repeated-measures ANOVA was performed over the mean RTs with task, task sequence, dimension and dimension sequence as main terms.

Figure 3.5 depicts the mean RTs for the different tasks, task sequences, and dimension sequences in Experiment 3. As can be seen, RTs were comparable in the identification and discrimination tasks. RTs were faster when the task repeated than when it changed (509 vs. 532 ms). Most importantly, DRBs were substantial, irrespective of the task and the task sequence (dimension repetition vs. change: 502 vs. 539 ms).

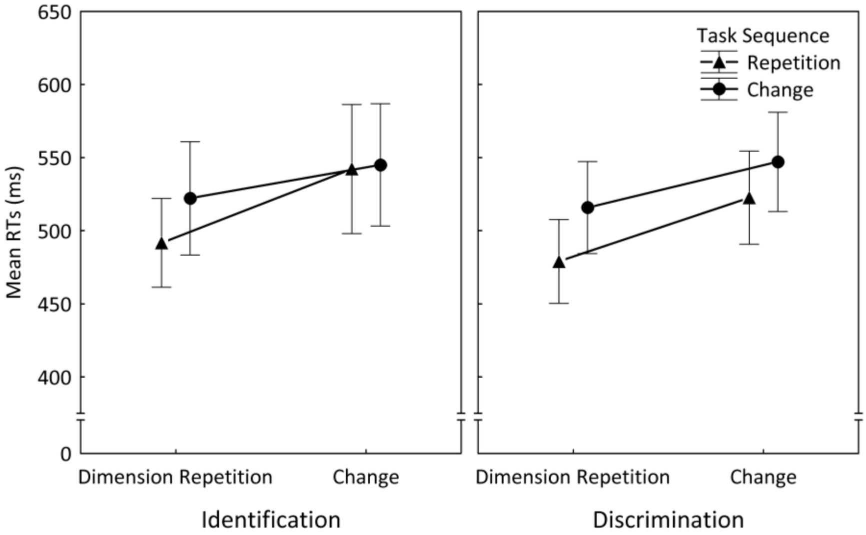


Figure 3.5. Mean RTs (in ms) for identification and discrimination task used in Experiment 3. Dimension and tasks sequences (repetition vs. change) across consecutive trials are shown separately. Triangles denote task repetitions, while circles stand for task changes across trials. The vertical lines denote ±1 SEM.

These observations were confirmed by a four-way ANOVA which revealed significant main effects of task sequence ($F(1,10) = 23.34$, $p < .01$, $\eta_p^2 = .70$), dimension ($F(1,10) = 10.84$, $p < .01$, $\eta_p^2 = .52$), and dimension sequence ($F(1,10) = 56.54$, $p < .00$, $\eta_p^2 = .85$). The task sequence x dimension sequence interaction also reached significance levels ($F(1,10) =$

5.94, $p < .05$, $\eta_p^2 = .37$). No other main effects or interactions proved significant (all $F < 4.72$, $p > .05$). Post-hoc (Tukey HSD) comparisons performed to examine the task sequence x dimension sequence interaction revealed that responses were significantly ($p < .01$) faster when the dimension repeated than when it changed (DRB ≈ 47 ms), provided the task repeated; when the task changed across trials, the DRB was smaller (27 ms), but still significant ($p < .01$).

Analysis of DRBs. To examine for DRBs across different tasks and task sequences, planned comparison t-tests were performed on the dimension sequence effects. These analyses showed significant DRBs for both tasks, whatever the task sequence. When the task repeated, there was a 50 ms DRB for the identification task ($t(10) = 4.65$, $p_{\text{one-tailed}} < .01$), and a 43 ms DRB for the discrimination task ($t(10) = 7.16$, $p_{\text{one-tailed}} < .01$). The respective DRBs for task changes were 23 ms for the identification task ($t(10) = 3.92$, $p_{\text{one-tailed}} < .01$) and 31 ms for the discrimination task ($t(10) = 4.09$, $p_{\text{one-tailed}} < .01$).

Overall, Experiment 3 demonstrated strong DRBs across trials of different tasks, despite disparate response sets in the two tasks. The pattern follows closely the predictions derived from the multiple-weighting-systems hypothesis, and is opposite to the prediction based on the idea that shared response requirements are the crucial factor in generating DRBs across different tasks.

3.5 General Discussion

The main goal of the present study was to evaluate the role of search and response requirements in generating DRBs, independently of each other. Experiments 1 and 3 examined for DRBs across tasks with similar search, but different response requirements; and Experiment 2 investigated DRBs across tasks with different search, but otherwise identical response demands – while all other conditions (number of trials, stimulus values, etc.) were kept as constant as possible across experiments. The three experiments yielded a coherent pattern of results: (i) there were DRBs for each task given the task (and, thus, both the search and response requirements) repeated across trials; (ii) there were DRBs across different tasks provided they shared search requirements, even when they did not share response requirements; and (iii) there were no DRBs across different tasks when they shared response requirements, but not search requirements.

Descriptive statistics demonstrated an insignificant trend for DRBs in Experiment 2. One might argue that, provided the tests had a sufficient power, these trends might have turned significant. To examine this, the DRBs across task switches for all three experiments were standardized by means of Cohen's d (e.g., J. Cohen, 1988; 1992). The respective effect sizes across task switches for $Task_1$-$Task_2$ and $Task_2$-$Task_1$ sequences were .87 and .68, .35 and .43, 1.22 and 1.19 for Experiments 1, 2 and 3, respectively. The mean effect size across task switches for all experiments was .79. A post-hoc power analysis for alpha > .05, effects size of .79 and 12 participants (as in Experiment 2) resulted in power index (1-ß) > .80. This implies that, provided the DRB effects across task changes in Experiment 2 were of the mean magnitude, the performed tests had a sufficient power to detect it. The insignificant trends for DRBs observed in Experiment 2 contrasted to significant (and stronger) DRBs in Experiments 1 and 3, observed under otherwise comparable conditions, support the idea that separate weighting mechanisms were engaged in the detection and identification task of Experiment 2.

In the following sections, this set of findings is discussed from the points of view of single-mechanism (search- and, respectively, response-based) accounts of DRBs and the multiple weighting-systems hypothesis.

3.5.1 Single mechanism explanations

Search-based origin of DRBs. Search-based accounts of DRBs, such the original Dimension Weighting Account (DWA; Müller et al., 1995), assumes that DRBs in search tasks originate from a modulation of feature contrast computation processes. These processes take place prior to (focal-attentional selection and) response selection, so that DRBs should persist across tasks with different response requirements as long as they share the search processes. Additionally, since no search component is involved in non-search tasks (with a single, centrally presented stimulus), there should be no DRBs in such tasks driven by feature contrast computations (as convincingly argued by Mortier et al., 2005). In line with this, Experiment 1 revealed significant DRBs across different tasks that both involved a search component but had different response requirements (detection and localization, respectively). Also, in Experiment 2, no DRBs were observed across trials of detection (search) and identification (non-search) tasks, even though they had similar response requirements – consistent with the idea that the postulated search-based weighting mechanism was not operating in the identification task.

One finding, however, which is difficult to accommodate within the DWA, is that there were significant DRBs in the non-search tasks (identification and discrimination, respectively). Given that single items presented in such tasks produce no unique dimension-specific activity at a pre-selective coding stage (they differ from the background in multiple dimensions simultaneously), dimensional weights would not have been preferentially allocated to one dimension. Consequently, there should not have been any (or at most weak) DRBs across trials of different non-search tasks. However, the results of Experiments 2 and 3 showed exactly the opposite: there were substantial DRBs for both transitions from identification to discrimination tasks and transitions from identification to discrimination tasks, as well as for identification and discrimination task repetitions.

While this finding is difficult to account in terms of pre-selective dimension weighting, it should be noted that the DWA, as originally proposed by Müller et al. (1995), was not designed to address potential DRBs in the non-search tasks (these effects were not known at the time). Rather, DWA was developed to account for dimension-specific intertrial effects in search tasks, while being open to the possibility that intertrial effects might also be generated at later, post-selective processing stages (as has been explicitly acknowledged by

Krummenacher, Müller, & Heller, 2002; and Müller & Krummenacher, 2006a). In this sense, the multiple-weighting-systems hypothesis complements the DWA by addressing the issue of post-selective weighting.

Response-based origin of DRBs. While search-based accounts such as the DWA leave the possibility that DRBs can also occur at processing stages following visual selection, the existing response-based accounts have been very ‘exclusive’ about the origin of dimension-specific intertrial effects: there is only one processing stage that is modulated by intertrial sequence, namely, response selection (e.g., Cohen & Shoup 1997, Cohen & Magen, 1999, Mortier et al., 2005). Significant DRBs within detection (search) (Mortier et al., 2005), identification (non-search) (Mortier et al., 2005), and discrimination tasks (Cohen & Magen, 1999, Experiment 4) had already been reported and (based on the evidence available at the time) plausibly attributed to different mechanisms of response selection. Thus, the significant DRBs observed within the detection, identification, or discrimination tasks of the present study are as expected on the response-based perspective.

However, the response-based explanation would have difficulties to account for the present finding of (i) significant DRBs across trials of repeated localization tasks and (ii) significant DRBs for across trials of localization and detection tasks (Experiment 1). As convincingly argued elsewhere (Chan & Hayward, 2009; Olivers & Meeter, 2006), localization can be thought of as a variant of compound search, as the stimulus attribute based on which the target is selected is different from that on which the response is based (Bravo & Nakayama, 1992; Duncan, 1985). Significant DRBs for target-defining (i.e., response-irrelevant) attributes are very difficult to accommodate within response-based accounts. This finding strongly implies that intertrial effects are generated at some perceptual processing stage that operates before response selection takes place.

Response-based accounts, such as the Dimensional Action model, do not specify any mechanism that could produce DRBs in compound tasks. In fact, proponents of such accounts do not see a need for such a mechanism, based on various failures to observe significant DRBs in such tasks (Chan & Hayward, 2009; Kumada, 2001; Mortier et al., 2005; Olivers & Meeter, 2006). On the other hand, there are a number of studies that did report substantial and significant intertrial effects in compound tasks (Becker, 2008; Fecteau, 2007; Müller & Krummenacher, 2006b; Olivers & Humphreys, 2003; Olivers & Meeter, 2006; Theeuwes, Reimann, & Mortier, 2006; Töllner et al., 2008). Interestingly, some of these reports are from the very same group that failed to find such effects in other studies.

A plausible explanation for intertrial effects in compound tasks may be offered by Meeter and Olivers' (2006; Olivers & Meeter, 2006) 'Ambiguity Resolution Account', on which intertrial mechanisms become functional only when there is a certain level of ambiguity in the particular task. The concept of ambiguity is broadly defined: it can relate to the uncertainty about the target's presence, its identity, or response mappings. The implication of this for compound tasks is that intertrial effects in such paradigms would be detectable only when ambiguity is high. This could account for the finding, in the present Experiment 1, of significant DRBs across trials involving localization tasks. Contrary to previous investigations of DRBs in localization tasks (Chan & Hayward, 2009; Olivers & Meeter, 2006), in the present Experiment 1, there were two feature contrast levels (high and low) per dimension; significant DRBs were evident only with low contrast levels – for which 'ambiguity' would have been increased. Thus, the finding of DRBs involving a localization task is consistent with the ambiguity resolution hypothesis, though one would have to assume that low feature contrast in Experiment 1 increased perceptual, rather than response-related, ambiguity. Given this, the results of Experiment 1 would be difficult to explain within a strict response selection perspective (as advocated by, e.g., Mortier et al., 2005).

Further at variance with such a strict response selection account are the results of the present Experiment 2, in which trials of detection (search) and identification (non-search) tasks varied randomly across trials, while involving the same stimulus-response mapping.

Recall that Mortier et al. (2005) attributed significant DRBs in the search and non-search tasks to a single, common cause: response selection processes. However, at variance with this common-cause assumption, no DRBs across detection and identification tasks were observed in Experiment 2. At the same time, there were significant DRBs across same-task trials for both detection and identification tasks, replicating the results of Mortier et al. (2005).

One could argue that potential DRBs across detection and identification tasks may have been masked by task change and/or display change costs. However, Experiment 1 also entailed task changes, and yet significant DRBs were observed. As to display change costs being suppressors of potential DRBs across the two tasks (detection and identification), this remains a viable alternative that will be discussed in more details below. However, even if display changes were the cause for the failure to observe DRBs across detection and identification tasks, this would demand (presumably major) modifications to pure response-based theories in order to take into account stimulus type (multiple- vs. single-item display) effects on response selection processes.

To conclude, while response-based accounts could coherently explain a good portion of the present results, they fail to account for at least two findings. The first, significant DRBs in a localization task, relates to a broader controversy about whether or not there are intertrial effects in compound tasks, and would require response-based accounts to specify a plausible mechanism that could generate such effects. The second finding that would need explaining is the absence of DRBs across tasks with same response requirements when the displays are different; this would require pure response-based accounts to incorporate effects of stimulus type on stimulus-response mapping.

3.5.2 The multiple-weighting-systems hypothesis

We propose that the pattern of significant DRBs across different search tasks (Experiment 1), significant DRBs across different non-search tasks (Experiment 3), and no DRBs across a search and non-search task (Experiment 2) is best explained by assuming existence of two dimension-sequence-sensitive mechanisms engaged in the search and non-search tasks, respectively.

The weighting system engaged in the search tasks would be as elaborated in the Dimension Weighting Account: weighting of dimension-specific feature contrast signals. In both detection and localization tasks (Experiment 1), the displays produced dimensionally specific feature contrast signals; thus, dynamic weighting of the respective target-defining dimensions would have allowed for significant DRBs both within and across the two types of task. This is not to rule out that there may be other mechanisms operating in detection or localization tasks that could produce dimension-specific intertrial effects. The multiple-weighting-systems hypothesis asserts only that the portion of DRBs persisting across these two tasks comes from the weighting of attentional selection processes, as these processes were common to both tasks.

The modulation of feature contrast signals is presumed to affect the speed of attentional selection. Given that no search was necessary to select the target in the identification task, there would be no carry-over of DRBs from the detection to the identification task (Experiment 2). On the other hand, single items (presented in the identification task) did not produce a dimension-specific feature contrast signal, so that there would be no carry-over effect from the identification to the detection task. Therefore, the multiple-weighting-systems hypothesis could account for results of both Experiment 2 as well as those of Experiment 1.

The second weighting mechanism was presumably engaged in the non-search tasks of the present experiments. The fact that single items at a fixed location were used in non-search tasks would argue against attentional-selection processes being the origin of the DRBs across trials of such tasks; instead, it is more plausible to invoke the response selection dynamics to explain the DRBs under these conditions (in line with Mortier et al., 2005). Findings of DRBs within both identification and feature discrimination tasks have already been reported by the proponents of the Dimensional Action model (Mortier et al., 2005, Experiment 2; Cohen &

Magen, 1999, Experiment 4). Thus, the finding of DRBs within non-search tasks (whether identification or discrimination) is relatively easily accommodated by the DA model: the (hypothesized) dimensional response weights would persist across trials, giving rise to DRBs. However, the response-based accounts have little to say, at present, about DRBs across different types of non-search task.

Despite the intuitive appeal of the response-based explanation, the existing literature provides arguments against it. For example, Müller and O'Grady (2000) reported significant dimension-specific effects in a paradigm using non-search displays of briefly presented (and masked) stimuli, in some conditions of a single stimulus only. Observers were to report two attributes of the presented item, either two from the same perceptual domain (e.g., hue and saturation for the color domain) or two from different domains (e.g., color and form). Response times were unconstrained (there was no emphasis on response speed; in fact, observers had to await the onset of a response display with various alternatives from which they had to select the appropriate one), and accuracy of judgments was measured. Performance was significantly higher for the same-domain judgments than for cross-domain judgments. Effects observed under conditions of brief stimulus exposure durations and unlimited response times are usually assumed to reflect processes prior to response selection and execution (e.g., Huang & Pashler, 2005; Santee & Egeth, 1982). This argues that the dimensional effects reported by Müller and O'Grady (2000) originated from stages prior to response selection. Furthermore, they used non-search displays (e.g., with a single item always presented at fixation), which argues against spatial-attentional allocation processes being the source of the observed effects. This leaves a *perceptual* processing stage after attentional selection as a likely source for the dimension-specific effects in the non-search paradigm of Müller and O'Grady (2000); for instance, focal-attentional analysis of a selected object on a given trial may simply start with the same dimension that was processed last on the preceding trial (see also Krummenacher, Gruber, & Müller, 2010).

In summary, the present Experiment 3 demonstrated significant DRBs across trials of different non-search tasks. Given the considerable differences in response requirements between the identification and discrimination tasks, the response selection stage is not a likely source of the DRBs across these tasks. By contrast, the multiple-weighting-systems hypothesis would assume that the DRBs observed across task changes in Experiment 3 originate from *post-selective perceptual* processing stages involved in item identity analysis (cf. Müller & O'Grady, 2000; Krummenacher et al., 2010).

3.5.3 The role of display changes

In the present experiments, search requirements were completely correlated with display types. Multi-item displays necessarily involved search for the task-relevant item, while single-item displays effectively eliminated this task requirement. Thus, instead of attributing the observed persistence of DRBs across different tasks to shared search demands (as in Experiments 1 and 3), one could equally assume that the cross-task DRBs were driven by display repetitions. This would explain why no DRBs were manifest in Experiment 2, where task changes also involved display changes.

The multiple-weighting-systems hypothesis accounts for the absence of DRBs across display changes by assuming that observers used different response strategies in performing the detection and the identification task. In Experiment 2, multi-item (detection task) displays alternated with the single-item (identification task) displays, while observers always had to discern the presence/absence of a target. In order to determine whether a single-item display contained a target or a distractor, observers had to process the presented item up to the featural level. By contrast, with multiple-item displays, observers had an alternative strategy at their disposal: as the target, if present, would always produce a strongest saliency signal, observers could respond 'target present' upon detecting any such signal (rather than having to identify the target's defining feature), akin to what Bacon and Egeth (1994) have referred to as 'singleton search mode'.

The singleton search mode operates overall faster than that involving target feature identification (see, e.g., Müller et al., 1995, Experiment 2), while permitting accurate performance under the conditions of Experiment 2. By contrast, with single-item displays, adopting a singleton search mode was not possible, because any single item, whether target or distractor, is kind of a singleton. Consistent with observers in Experiment 2 having adopted a singleton search mode with multi-item displays, but a target feature identification mode with single-item displays, RTs were 65 ms faster overall with multiple- compared to single-item displays (see also Krummenacher et al., 2010). If observers had used the same response strategy in both the detection and the identification task, no RT differences between tasks would have been expected (or, rather, one might have expected RTs to be slower in the detection task, given that this task involves an additional search stage). Thus, it is likely that the absence of DRBs across trials of different tasks was due to these differential response strategies (as well as differential selection demands), rather than to display differences per se.

3.5.4 Conclusions

The present study examined whether a single weighting mechanism, either search- or response-based, would suffice to explain the present pattern of dimension-specific carry-over effects across tasks, as well as the findings in the literature on dimension-specific intertrial effects. The main rationale was that, provided the same mechanism is engaged in two tasks, significant DRBs should arise across trials of different tasks. The main finding was that DRBs were manifest across trials of different search tasks, as well as across trials of different non-search tasks, but there were no DRBs across search and non-search tasks.

The persistence of DRBs across different tasks supports the idea that dimension-weighting systems are specific to particular task requirements (selection vs. identification), rather than being specific to a task as a whole. One type of DRB across different tasks is seen when the selection (search) requirements are shared by successive tasks, but not when they are different. This implies that the DRBs seen across different types of search task must originate in the (shared) selection component of the tasks, while there is a different dimension-sensitive mechanism generating DRBs in non-search tasks.

Attempts to explain the observed data pattern by invoking a single weighting mechanism (whether search- or response based) face serious challenges. Search-based accounts specify no mechanism that could account for DRBs in non-search tasks. By contrast, response-based mechanisms would need major modification to account for dimension-specific intertrial effects in compound tasks, as well as the role of display changes, to be able to accommodate the present finding.

Thus, arguably, the multiple-weighting-systems hypothesis offers a viable addition to search-based accounts, such as the DWA. A number of conflicting findings can be coherently explained by assuming existence of both a pre-selective, search-related mechanism and a post-selective mechanism that are sensitive to dimensional intertrial sequences.

3.6 References

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, *55*(5), 485-496.

Becker, S. I. (2008). Can intertrial effects of features and dimensions be explained by a single theory? *Journal of Experimental Psychology. Human Perception and Performance*, *34*(6), 1417-1440. doi: 10.1037/a0011386.

Bravo, M. J., & Nakayama, K. (1992). The role of attention in different visual-search tasks. *Perception & Psychophysics, 51*(5), 465-72.

Chan, L. K. H., & Hayward, W. G. (2009). Feature integration theory revisited: dissociating feature detection and attentional guidance in visual search. *Journal of Experimental Psychology. Human Perception and Performance, 35*(1), 119-132. doi: 10.1037/0096-1523.35.1.119.

Cohen, A., & Magen, H. (1999). Intra- and cross-dimensional visual search for single-feature targets. *Perception & Psychophysics*, *61*(2), 291-307.

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology*, *32*(2), 128-81. doi: 10.1006/cogp.1997.0648.

Cohen, A., & Shoup, R. (2000). Response selection processes for conjunctive targets. *Journal of Experimental Psychology. Human Perception and Performance*, *26*(1), 391-411.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. New York Academic Press.

Cohen, J (1992). Statistical power analysis. *Current Directions in Psychological Science. 1*(3), 98-101.

Duncan, J. (1985). Visual search and visual attention. *Attention and performance*, *11*, 85–105.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*(3), 225-34.

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition*, *2*(2), 101-118.

Fecteau, J. H. (2007). Priming of pop-out depends upon the current goals of observers. *Journal of Vision*, *7*(6), 1. doi: 10.1167/7.6.1.

Feintuch, U., & Cohen, A. (2002). Visual attention and coactivation of response decisions for features from different dimensions. *Psychological Science: A Journal of the American Psychological Society / APS*, *13*(4), 361-9.

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: investigating a "dimension-weighting" account. *Perception & Psychophysics*, *58*(1), 88-101.

Goolsby, B. A., & Suzuki, S. (2001). Understanding priming of color-singleton search: roles of attention at encoding and "retrieval". *Perception & Psychophysics, 63*(6), 929-944.

Huang, L., & Pashler, H. (2005). Expectation and repetition effects in searching for featural singletons in very brief displays. *Perception & Psychophysics*, *67*(1), 150-157.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10-12), 1489-506.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews. Neuroscience*, *2*(3), 194-203.

Koch, C., & Ullman, S. (1985). Shifts in selective visual attention: towards the underlying neural circuitry. *Human Neurobiology*, *4*(4), 219-227.

Kristjánsson, Á., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Perception & Psychophysics*, *72*(1), 5.

Krummenacher, J., Grubert, A., & Müller, H. J. (2010). Inter-trial and redundant-signals effects in visual search and discrimination tasks: Separable pre-attentive and post-selective effects. *Vision Research* (in press).

Krummenacher, J., Müller, H. J., & Heller, D. (2002). Visual search for dimensionally redundant pop-out targets: parallel-coactive processing of dimensions is location specific. *Journal of Experimental Psychology. Human Perception and Performance*, *28*(6), 1303-22.

Krummenacher, J., Müller, H. J., & Heller, D. (2001). Visual search for dimensionally redundant pop-out targets: evidence for parallel-coactive processing of dimensions. *Perception & Psychophysics*, *63*(5), 901-17.

Krummenacher, J., Müller, H. J., & Heller, D. (2002). Visual search for dimensionally redundant pop-out targets: Redundancy gains in compound tasks. *Visual Cognition*, *9*, 801-837.

Kumada, T. (2001). Feature-based control of attention: evidence for two forms of dimension weighting. *Perception & Psychophysics, 63*(4), 698-708.

Lamy, D., Bar-Anan, Y., Egeth, H. E., & Carmel, T. (2006). Effects of top-down guidance and singleton priming on visual search. *Psychonomic Bulletin & Review*, *13*(2), 287-293.

Magen, H., & Cohen, A. (2002). Action-based and vision-based selection of input: two sources of control. *Psychological Research, 66*(4), 247-59. doi: 10.1007/s00426-002-0099-0.

Magen, H., & Cohen, A. (2007). Modularity beyond perception: evidence from single task interference paradigms. *Cognitive Psychology*, *55*(1), 1-36. doi: 10.1016/j.cogpsych.2006.09.003.

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, *22*(6), 657-72.

Maljkovic, V., & Nakayama, K. (1996). Priming of pop-out: II. The role of position. *Perception & Psychophysics*, *58*(7), 977-91.

Meeter, M., & Olivers, C. N. L. (2006). Intertrial priming stemming from ambiguity: A new account of priming in visual search. *Visual Cognition*, *13*(2), 202-222. doi: 10.1080/13506280500277488.

Mortier, K., Theeuwes, J., & Starreveld, P. (2005). Response selection modulates visual search within and across dimensions. *Journal of Experimental Psychology. Human Perception and Performance, 31*(3), 542-57. doi: 10.1037/0096-1523.31.3.542.

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. *Perception & Psychophysics*, *57*(1), 1-17.

Müller, H. J., & Krummenacher, J. (2006a). Locus of dimension weighting: Preattentive or postselective? *Visual cognition*, *14*(4-8), 490-513.

Müller, H. J., & Krummenacher, J. (2006b). Visual search and selective attention. *Visual Cognition*, *14*(4), 389-410.

Müller, H. J., Krummenacher, J., & Heller, D. (2004). Dimension-specific intertrial facilitation in visual search for pop-out targets: Evidence for a top-down modulable visual short-term memory effect. *Visual Cognition, 11*(5), 577-602.

Müller, H. J., & O'Grady, R. B. (2000). Dimension-based visual attention modulates dual-judgment accuracy in Duncan's (1984) one- versus two-object report paradigm. *Journal of Experimental Psychology. Human Perception and Performance*, *26*(4), 1332-51.

Olivers, C. N. L., & Humphreys, G. W. (2003). Attentional guidance by salient feature singletons depends on intertrial contingencies. *Journal of Experimental Psychology. Human Perception and Performance*, *29*(3), 650-7.

Olivers, C. N. L., & Meeter, M. (2006). On the dissociation between compound and present/absent tasks in visual search: Intertrial priming is ambiguity driven. *Visual Cognition*, *13*(1), 1–28.

Rangelov, D., Müller, M., & Zehetleitner, M. (2010). Dimension-specific intertrial effects are task-specific: Evidence for multiple weighting systems. *Journal of Experimental Psychology: Human Perception and Performance,* in press.

Santee, J. L., & Egeth, H. E. (1982). Do reaction time and accuracy measure the same aspects of letter recognition? *Journal of Experimental Psychology. Human Perception and Performance*, *8*(4), 489-501.

Theeuwes, J., Reimann, B., & Mortier, K. (2006). Visual search for featural singletons: No top-down modulation, only bottom-up priming. *Visual Cognition*, *14*(4-8), 466–489.

Töllner, T., Gramann, K., Muller, H. J., Kiss, M., & Eimer, M. (2008). Electrophysiological Markers of Visual Dimension Changes and Response Changes. *Journal of Experimental Psychology*, *34*(3), 531-542. doi: 10.1037/0096-1523.34.3.531.

Töllner, T., Zehetleitner, M., Gramann, K., & Müller, H. J. (2010). Top-down Weighting of Visual Dimensions: Behavioral and Electrophysiological Evidence. *Vision research*. doi: 10.1016/j.visres.2009.11.009.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology. Human Perception and Performance*, *8*(2), 194-214.

Treisman, A. (1988). Features and objects: the fourteenth Bartlett memorial lecture. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *40*(2), 201-37.

Wolfe, J. M. (1994). Guided search 2. 0. A revised model of visual search. *Psychonomic Bulletin & Review*, *1*(2), 202-238.

Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nat Rev Neurosci*, *5*(6), 495-501. doi: 10.1038/nrn1411.

Zehetleitner, M., & Müller, H. J. (2010). Saliency from the decision perspective. Manuscript submitted for publication.

4 THE MULTIPLE-WEIGHTING-SYSTEMS HYPOTHESIS: THEORY AND EMPIRICAL SUPPORT

4.1 Abstract

Observers respond faster when the task-relevant perceptual dimension repeats across consecutive trials (e.g., color – color) relative to when it changes (orientation – color). This Dimension Repetition Effect (DRE) was observed in diverse paradigms, leading to two opposing explanations: visual selection-based versus response selection-based. Here, we argue for an integrative, multiple-sources account of DREs: behaviorally comparable DREs could originate from either pre-selective or post-selective processes dependent on the specific task used. If two tasks activate the same sequence-sensitive mechanism, significant DREs are expected across trials of different tasks. Experiment 1 randomly alternated between tasks that shared the pre-selective mechanism across trials, while Experiment 2 alternated between tasks sharing the post-selective mechanism. In line with the predictions of the Multiple-Weighting-Systems (MWS) hypothesis, significant DREs were observed across task switches in both experiments. Overall, the reviewed evidence, complemented by the present novel findings, argues in favor of the MWS hypothesis providing a comprehensive and, at the same time, parsimonious explanatory framework for dimension-specific intertrial effects.

Keywords: dimension repetition effect, task switching, multiple-weighting-systems, dimensional weighting

4.2 Introduction

What we did recently has a substantial effect on our current performance. For example, we are likely to set a table faster when we put all plates down first relative to setting down plates and cutlery in a mixed order. Conceptually, one can think of three broadly defined processes that are potentially facilitated by such action sequencing: (i) visual selection (e.g., detecting plates amongst cups and bowls), (ii) perceptual analysis (e.g., deciding if the selected plate belongs to the appropriate set), and (iii) action execution (e.g., how to transfer the plate to the table). When setting the table, all three processes (selection, analysis, action) are involved, thus making it difficult to isolate the specific cognitive processes affected by the recent experience. Evaluating the role of different cognitive processes as a source of history effects on human performance is in the main focus of the present study.

Investigation of how recent experience influences current performance usually employs simple tasks that engage, relatively selectively, processes of either visual selection or perceptual analysis. For example, presenting multiple-item displays introduces the necessity to search for the task-relevant item. By contrast, presenting a single item in a display effectively excludes search and visual-selection processes. Independently of the display type, associations between task-relevant stimuli and the required responses can vary. A particular combination of the stimulus material and required responses may result in a paradigm in which some processes (e.g., visual selection) are necessary, while other processes (e.g., perceptual analysis) are not crucial for performing the task.

Several memory effects on current performance have been described in the literature. For example, observers are faster to select an odd-one-out item (i.e., target) from a set of items if the target’s feature (in the target-defining dimension), as well as the distractor feature, repeats across consecutive trials (e.g., Maljkovic & Nakayama, 1994, 1996, 2000). Furthermore, observers are slower to select the target if it shares features with a previously irrelevant, to-be-ignored item (‘negative priming’; e.g., Tipper, 1985).

Of special interest for the present discussion is a particular type of intertrial effect, referred to as dimension repetition effect (DRE; Found & Müller, (1996)). Found and Müller presented multiple-item (i.e., search) displays containing, on different trials, either identically colored and oriented distractor items (i.e., target-absent trials), or containing one item (i.e., target) that differed from the distractors (target-present trials). Participants' task was to simply discern the presence of a singleton target (singleton detection task), that is, they indicated whether the target was present or absent by pressing the corresponding response button. Across consecutive target-present trials (trials n-1 and n), the dimension of distinction between the target and distractors could either repeat (e.g., color singletons on both trials) or change (e.g., color singleton following orientation singleton). Observers responded faster when the dimension repeated relative to when it changed. Importantly, this dimension repetition advantage was evident even if the exact feature of the target changed across consecutive trials (e.g., red singleton following blue singleton vs. red singleton following orientation-defined singleton). Thus, unlike other intertrial effects (e.g., priming of pop-out or negative priming), the DRE is observed even when the exact stimulus changes across trials (as long as it is defined in the same dimension), arguing that the DRE originates from mechanisms other that simple passive priming.

In the following sections, we (i) describe the dominant accounts proposed to explain dimension repetition effects (DREs) and (ii) review the available evidence favoring one or another approach. Importantly, neither of the reviewed accounts, in their present formulation, can explain the whole body of available data in a straightforward, coherent manner. Consequently, the reviewed findings yield a puzzle as to the origin of DREs. We then (iii) present an integrative approach, which assumes multiple sources of the memory effects, and (iv) discuss existing, as well as (v) novel evidence in favor of the multiple-weighting-systems (MWS) hypothesis.

4.2.1 Single-mechanism accounts of DREs

To account for the DREs observed in the singleton detection task, Müller and colleagues (e.g., Müller & Krummenacher, 2006; Müller, Krummenacher, & Heller, 2004; Muller, Reimann, & Krummenacher, 2003) proposed a Dimension-Weighting Account (DWA). Similar to dominant models of early visual processing (e.g., Itti & Koch, 2001, 2000; Wolfe, 1994; Wolfe, Cave, & Franzel, 1989), the DWA assumes that visual information is sampled along several independent perceptual dimensions in parallel. This early processing stage gives rise to a representation of visual input in terms of local feature-contrast signals forming dimension-specific saliency maps. These signals are then integrated across dimensions into an overall-saliency, or master map of the visual field. Focal attention then selects locations, in a winner-take-all process, based on the comparative strengths of the saliency signals registered on the master map. Importantly, integration of the (feature contrast) signals from the various dimensions occurs in a weighted manner, that is: signals from one (or more) dimension(s) are assigned a greater weight than signals from other dimensions. These dimensional weights are, in turn, sensitive to trial sequence: if the target-defining signal on a given trial stems from a certain dimension, then the weight is increased for this dimension, while the weights for the other dimensions are decreased. Thus, if the critical dimension repeats across consecutive trials, the increased weight for this dimension results in an above-threshold overall-saliency signal being generated faster at the master map level, giving rise to the dimension repetition (benefit) effect.

In contrast to taking DREs to reflect facilitation of visual selection processes (as in the DWA); alternative accounts assume these effects to be a consequence of (repeated) response selection processes. The Dimensional-Action (DA) model, proposed by Cohen and colleagues (Cohen & Magen, 1999; Cohen & Shoup, 1997, 2000; Feintuch & Cohen, 2002), assumes that responses in the singleton detection task are generated post-selectively by *dimension-specific response modules*. Upon having selected the target item, a target-present response is generated via the orientation response module if the target is orientation-defined targets or, respectively, via the color module if the target is color-defined. Importantly, the previously (on trial n-1) used response module remains in a state of heightened activation until the next trial (trial n). Consequently, if the target is, say, orientation-defined on both trials n-1 and n, the response on trial n is facilitated (because the same dimensional response module can be re-used) compared to when there is a need to switch response modules (e.g., if the target is orientation-defined on trial n-1 and color-defined on trial n). Restated, there is a DRE.

One of two important distinctions between the two accounts (DWA and DA) lies in the role they ascribe to feature-contrast signals and, associated with this, the role of visual selection processes in generating DREs. For the DWA, DREs originate from differential processing of feature-contrast signals prior to focal-attentional selection of the task-relevant item. By contrast, the DA ascribes no functional role to the dynamics of feature-contrast and overall-saliency signal computations: the DREs are generated after the target item was selected.

The second important difference between the accounts concerns the role of stimulus–response mapping in generating DREs. The DWA assumes that at least a portion of DREs originate from stages prior to response selection, that is, a portion of the DREs is relatively independent of the particular response mapping used in an experimental paradigm. By contrast, the DA model assumes that DREs can arise only in paradigms in which perceptual dimensions are response-relevant.

To test differential predictions derived from the DWA and DA account, Mortier, Theeuwes, and Starreveld (2005) examined the importance of visual selection processes for DREs in a paradigm that compared dimension-specific intertrial effects in two similar tasks. One task was the so-called search detection task, in which participants indicated the presence/absence of a singleton-feature (‘pop-out’) target in multiple-item displays. In the other, non-search detection task, only one item was presented at a fixed location on the screen. One item (identical to the distractor items in the search task) was defined a distractor and required a target-absent response. Any other item (sampled from the set of items used as targets in the search task) different from the distractor was considered a target, requiring a target-present response. Thus, the search- and non-search detection tasks differed only in the presence/absence of dimension-specific feature-contrast signals, while stimulus-response mapping was virtually identical across tasks. The authors reported significant DREs for both search and non-search detection tasks.

To test the importance of response-relevancy in observing DREs, Mortier et al. (2005, Experiment 5) used a non-search compound task in which only one item, with a small line inside the item’s outline shape, was presented (single-item, non-search display). The item could be either the distractor or a target item from the non-search detection task to be performed in previous experiments. As in the non-search detection task, the dimension of distinction between target and distractor could repeat/change across consecutive trials, thus potentially giving rise to DREs in the non-search compound task as well. However, unlike the non-search detection task, observers were to report the orientation of the inner line, thus making the dimension of distinction between target and distracters response-irrelevant. In contrast to the non-search detection tasks, testing for DREs in the non-search compound task revealed no significant intertrial effects.

In summary, Mortier et al. (2005) took the finding of DREs in the non-search detection task to indicate that search processes are not necessary for DREs to arise. Furthermore, the comparison between non-search detection and non-search compound tasks was taken to suggest that DRBs in non-search tasks are critically dependent on the response-relevancy of perceptual dimensions.

In contrast to the absence of DREs in the *non-search* compound task, a number of studies using compound-*search* tasks have shown that DREs can arise even when the target-defining perceptual dimensions are not response-relevant. In compound-search tasks (e.g., Bravo &

Nakayama, 1992; Duncan, 1985), participants select the task-relevant item based on one, target-defining feature, but make a response based on a different feature. For example, one may need to select a singleton based on its unique color (target-defining attribute), but then respond on the orientation (response-defining attribute) of the selected item. Results reported by independent groups (Becker, 2008; Fecteau, 2007; Olivers & Humphreys, 2003; Olivers & Meeter, 2006; Töllner, Gramann, Muller, Kiss, & Eimer, 2008) have repeatedly shown that performance in compound-search task is influenced by the sequence of target-defining (i.e., response-irrelevant) dimensions. On the other hand, there are a number of studies that failed to find such effects (Chan & Hayward, 2009; Kumada, 2001; Olivers & Meeter, 2006). However, there is a growing consensus that, under certain conditions[6], it is possible to observe reliable DREs in compound-search tasks.

The studies reviewed thus far yield a puzzle: DREs observed in search paradigms seem to be related, at least to some extent, to processes of visual selection, while the DREs observed in the non-search paradigms seem to rise at post-selective processing stages. Neither of the existing theoretical approaches, the (original) DWA or the DA model, can account fully for this data pattern. Despite the theoretical differences between the accounts, they also have an important assumption in common: they both propose a single mechanism that can give rise to DREs. However, the individual mechanisms envisaged by the DWA and DA model both fail to account for the complete set of findings on DREs. The weighting of feature contrast signals (as assumed in the DWA) cannot account for dimension sequence effects in non-search paradigms – given that no unique dimension-specific feature contrast signals are computable for single-item displays. Conversely, the weighting of response modules (as assumed in the DA account) cannot explain the existence of DREs in compound-search tasks, where DRBs are observed for response-irrelevant stimulus attributes.

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[6] Olivers and Meeter (Meeter & Olivers, 2006; Olivers & Meeter, 2006), in their Ambiguity Resolution account, dealt in detail with conflicting findings with regard to DREs in compound-search tasks.

4.3 An integrative approach: The Multiple-Weighting-Systems hypothesis

An alternative to *single-mechanism* accounts of DRBs may be that there are *multiple mechanisms* sensitive to sequences of perceptual dimensions. These mechanisms would be situated at different, pre- and post-selective, processing stages. The idea that different mechanisms, operating at different stages, can produce similar behavioral effects is not entirely novel. For example, this idea is acknowledged in (Kristjánsson & Campana, 2010) recent review of a variety of intertrial effects (e.g., 'priming of pop-out', DREs). A more elaborate rendering of this idea has been provided by (Meeter & Olivers, 2006; Olivers & Meeter, 2006) in their Ambiguity Resolution (AR) account. In essence, the AR account specifies the properties of a paradigm that are likely to lead to intertrial effects: these different properties are collectively referred to as the 'ambiguity' of the paradigm. Ambiguity can originate from uncertainty about what the task-relevant stimuli are (i.e., processes of visual selection), what the responses to be made to the selected stimuli are (i.e., processes of response selection), or other, non-specified processes. Given this, the AR account explicitly allows for the possibility of processes at different stages to give rise to DREs.

Despite the fact that the idea of multiple sources of DREs has a precedent in the literature, the approaches outlined above are not informative as to the question at issue in the present study, namely: is there a single mechanism that can account for DREs in all tasks? To illustrate, the AR would in principle be compatible with both a unitary mechanism that is activated by 'ambiguity signals' generated at different, either pre- or post-selective, processing stages, and with having multiple mechanisms at different processing stages that, by virtue of having a similar dynamics, can all give rise to DREs. This means that acknowledging the possibility that DREs can arise from *multiple processing stages* does not tell whether *a single* or *multiple mechanisms* produce DREs. To conclude, existing accounts are not ultimately informative with regard to the question whether DREs in different tasks are a consequence of a single or of multiple mechanisms.

The Multiple-Weighting-Systems (MWS) hypothesis is designed to address this issue explicitly. The MWS assumes the existence of several independent mechanisms situated at different processing stages, which can all give rise to DREs. What weighting mechanism is active depends on specific paradigm properties. A paradigm is specified by (i) the stimuli it uses and (ii) the responses that are required; furthermore, the stimuli and responses are related by (iii) paradigm-specific S–R mappings. These paradigm specification criteria are illustrated in Figure 4.1.

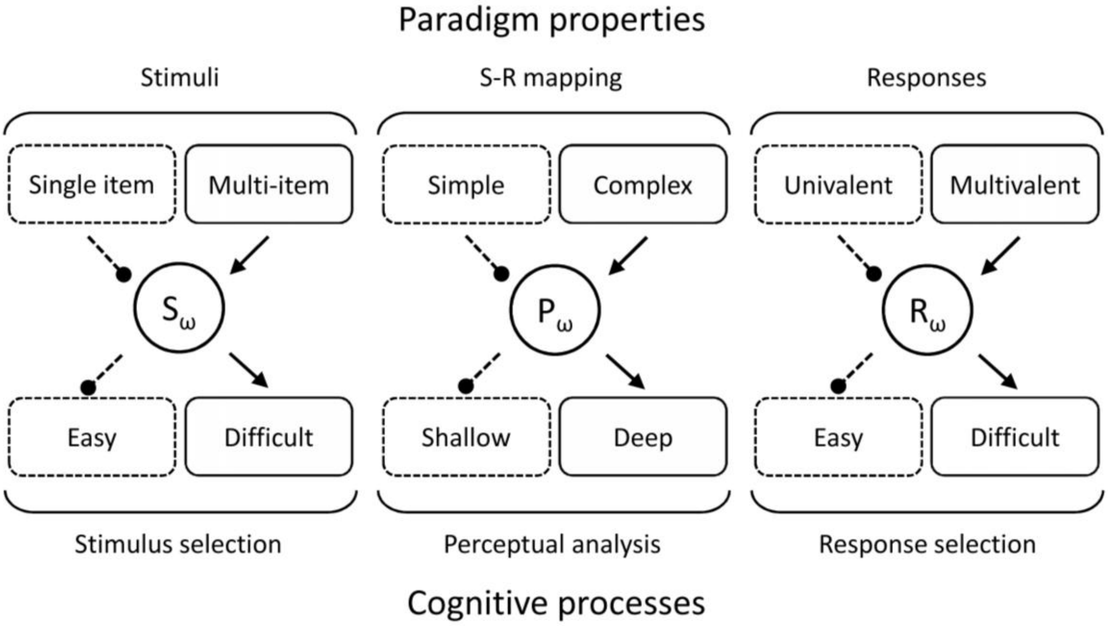

Figure 4.1. Mapping between paradigm properties and cognitive processes. A paradigm is defined by its stimuli, responses, and mapping between stimuli and responses (S–R mapping). There are three broad groups of cognitive processes: visual selection, perceptual analysis, and response selection. The stimulus material (single- vs. multiple-items displays) influences the visual selection processes (easy vs. difficult); S–R-mapping (simple vs. complex) influences perceptual analysis processes (shallow vs. deep); and required responses (univalent vs. multivalent) influence response selection processes (easy vs. difficult). Associated with the different processes (selection, analysis, responding) are different sequence-sensitive systems (S_ω, P_ω, and R_ω, respectively). Different paradigm properties can influence the state of these systems (full connectors), or not (dashed connectors), with these changes subsequently influencing related cognitive processes. See text for more details.

Different paradigms can be distinguished based on these three criteria. For example, search tasks use multiple-item displays, whereas non-search tasks employ single-item displays. Furthermore, singleton detection tasks involve a simple S–R mapping (i.e., target present/absent response) irrespective of the target's identity; by contrast, compound-search tasks would involve a complex S–R-mapping which is dependent on the identity of the response-relevant target attribute. Finally, the required responses can be either univalent, that is, one stimulus (attribute) is mapped to one response, or multivalent, that is, several stimuli (or attributes) are mapped onto the same response.

The paradigm properties directly influence which cognitive processes are necessary for performing a particular task. As mentioned earlier, these processes can be grouped into three broad categories, relating to (i) stimulus selection, (ii) perceptual analysis of the selected stimuli, and (iii) response selection processes. Based on the stimulus material, stimulus selection can be either easy, as in single-item displays, or relatively difficult, as in multi-items displays. The particular S–R mapping can either require shallow perceptual analysis, as in the singleton detection task, in which discerning the presence of a unique, odd-one-out stimulus suffices to produce a response; or it can require deep perceptual analysis, as when features of the selected stimulus have to be determined prior to responding. Finally, the response selection processes can be either easy, when the responses are univalent, or relatively difficult, when the responses are multivalent.

The core assumption of the MWS hypothesis is that different cognitive processes are associated with different weighting mechanisms, represented in Figure 4.1 as S_ω, P_ω, and R_ω for the mechanisms associated with stimulus selection, perceptual analysis, and response selection, respectively. The three mechanisms are all sensitive to intertrial sequences, thus potentially giving rise to intertrial effects. Importantly, as suggested by the evidence reviewed below, these three mechanisms are independent of each other, and state changes in one of them do not affect the state of other systems.

The (stimulus) selection weighting system (S_ω) modulates the efficiency with which feature-contrast signals in the various perceptual dimensions influence overall-saliency coding. With single-item displays, feature-contrast signals are generated in multiple dimensions (i.e., there are no signals generated uniquely in one dimension): a single yellow, vertical bar on a black background would differ from its surroundings in luminance, color, and orientation. Consequently, the S_ω is not affected by dimension sequence in single-item displays (dashed connectors to S_ω in Figure 4.1). By contrast, paradigms using the multiple-item displays can modulate the state of the S_ω (full-line to S_ω in Figure 4.1). The S_ω, in turn, influences performance in paradigms in which stimulus selection is difficult; the mechanism underlying this influence has been elaborated within the DWA (e.g., Müller & Krummenacher, 2006a, 2006b).

The second weighting system (P_ω) influences processes of perceptual analysis of the selected items. The P_ω system is engaged in tasks that involve complex S–R mapping rules and thus require deep perceptual analysis of the selected stimulus prior to deciding upon a response. By contrast, tasks with simple S–R mappings and shallow perceptual analysis would be little influenced by the P_ω system.

With regard to the exact mechanism via which P_ω modulates the dynamics of perceptual analysis, several alternatives are possible. One, argued for by Krummenacher, Grubert, and Müller (2010), would be that the processes of *feature identification* are speeded for the previously relevant dimension relative to the previously irrelevant stimulus dimension: identification of a repeated feature is expedited because analysis starts with the same, specific feature in the dimension that led to a successful response on the last trial. Alternatively, the P_ω system may be based on task-set representations, with DREs observed in paradigms with complex S–R mappings reflecting *task-set reconfiguration* processes (e.g., Rogers & Monsell, 1995). For example, the non-search detection task of Mortier et al. (2005) requires discrimination between a distractor and targets that can differ from the distractor in one of several possible ways (e.g., in color, shape, or size). Thus, detecting a color target could be thought of as a *color discrimination* task, whereas detecting a shape target would constitute a *shape discrimination* task. Consequently, changing the dimension of discrimination across trials would introduce a task change as well, so that task change/repetition sequences are perfectly correlated with dimension change/repetition sequences. An important difference between task-change cost and identification facilitation mechanisms is that according to the former, DREs would arise as a function of active *task-set reconfiguration* processes, whereas according to the latter, the DREs occur due to *biasing of the order of identifying* different stimulus attributes. In summary, the DREs in paradigms with complex S–R mappings could either reflect facilitated feature identification or task-set reconfiguration processes (or both). The MWS hypothesis, as such, is agnostic as to the exact mechanism; it essentially states that the processes underlying the P_{ω} system are separate from those underlying the S_{ω} processes.

The third hypothesized system is associated with the processes of response selection (R_{ω}). The reason for postulating such a system derives from the work carried out within the framework of response-based accounts, such as the DA model of Cohen and colleagues. Additionally, findings from the dual-task and task-switching literature show that dual-task or task-switch costs increase if the two tasks involve the same response sets (i.e., multivalent mapping), relative to tasks using non-overlapping response sets (i.e., univalent mapping; (e.g., Gade & I. Koch, 2007; I. Koch, Gade, Schuch, & Philipp, 2010; Mayr, 2001). Furthermore, investigation of ERP markers of effector-specific response-sequence effects has shown these to be independent of the ERP markers of dimension-sequence effects in a paradigm that used a compound-search task, that is, dimension- and response-sequences were uncorrelated (Töllner et al., 2008). Finally, behavioral studies have demonstrated that across task-switch trials, response repetition produces inhibitory effects additive to facilitatory effects of stimulus repetition (Druey & Hübner, 2008).

Taken together, the existing evidence warrants postulating a mechanism sensitive to response-selection processes, which is independent of the mechanisms modulating processes of perceptual analysis and stimulus selection.

Hitherto, the study of dimension-specific intertrial effects has focused mainly on the issue of whether DREs are the result of pre- or post-selective processes. Different post-selective processes (perceptual analysis, response selection) were considered summarily and contrasted with stimulus selection processes (e.g., Cohen & Magen, 1999; Krummenacher et al., 2010; Mortier et al., 2005). Mortier et al. (2005) accounted for DRBs in their non-search detection task by invoking response selection processes, while Krummenacher et al. (2010) explained analogous effects by assuming facilitation of feature identification processes. The MWS hypothesis makes a conceptual distinction between two potential post-selective mechanisms. Future research will show whether the two are reducible to a single post-selective mechanism, or they are dissociable, as suggested by the literature reviewed above. At present, the most pertinent tests of the MWS hypothesis would involve demonstrating that there exist at least two independent, pre- and, respectively, post-selective, weighting systems.

4.3.1 Evidence for the MWS hypothesis

If a particular task engages any of the postulated weighting systems, significant DREs are expected. That is, the behavioral signature of the mechanism(s) giving rise to DREs is identical for tasks involving different sequence-sensitive mechanisms. Consequently, DREs observed in single task paradigms (of the search or the non-search type) could be accounted for by assuming either single or multiple weighting mechanisms. However, examining for DREs across trials of *different tasks* would provide evidence in favor of, or against, the MWS hypothesis. If the tasks in question engage *identical weighting systems*, significant DRBs are expected across trials of different tasks. By contrast, if the weighting systems *differ* between tasks, no DRBs are expected to arise.

Figure 4.2A illustrates the reasoning underlying the above predictions. DREs are observed across sequences of trials (n-1 and n). However, the path of influence from trial n-1 to trial n is mediated by weighting systems. If the task on trial n-1 entails difficult visual selection, the S_ω system will be affected (as illustrated with full line connectors between trial n-1 and S_ω). Biasing of weights assigned to different dimensions in S_ω might give rise to DREs when the dimension repeats, as compared to when it changes, across trials n-1 and n. Importantly, DREs can arise across consecutive trials only if the task on trial n also engages S_ω system (full line connectors between S_ω and trial n). In other words, one can think of processes occurring during trial n-1 as the “source” of DREs, by virtue of being the cause of changes in a weighting system, while the processes during trial n are a sort of “sink” because the changes in the weighting system manifest on that trial. Finally, for DREs to arise there has to be an unbroken connection between the source trial, a weighting system, and the sink trial.

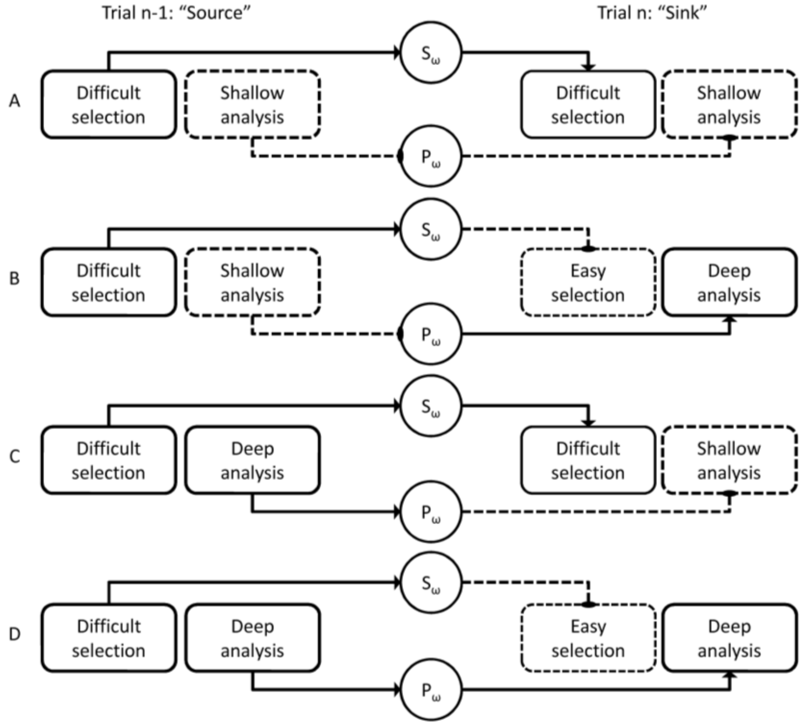

Figure 4.2. “Source-sink” metaphor of DREs. Intertrial effects across two trials are mediated via changes in the state of a weighting system. On trial n-1 (or “source” trial for DREs), the system is biased toward a particular dimension. Observers are faster to respond on trial n (or “sink” of DREs) when the dimension repeats, relative to when the dimension changes across trials, due to the fact that the system was biased towards that particular dimension on the previous, “source” trial. Panels: (A) tasks on both “source” and “sink” trials engage S_ω system; (B) tasks in different trials engage different systems; (C) and (D) one task engages more than one weighting system. See text for details.

Paradigms using the same task across all trials would always have a connection between the source and sink trials via at least one weighting mechanism. By contrast, when two tasks are mixed across trials, the pattern of DRBs across different task sequences (repetition/switches) would depend on whether or not the two tasks share the same weighting system(s). If different tasks influence a common weighting system, significant DREs are expected even across trials of the different tasks (Figure 4.2A, note the unbroken connection between the source and sink trials). On the other hand, if the tasks influence no common weighting systems, no DREs are expected across the different tasks. Figure 4.2B illustrates a case in which the two tasks engage different systems: the task in the source trial demands a difficult selection and shallow perceptual analysis, the task in the sink trial easy selection and deep analysis processes. The former task would influence the S_ω system (full line connector between the source trial and S_ω), but the latter, by requiring easy selection, would be insensitive to the weighting of selection (dashed connectors between S_ω and the sink trial). Consequently, no DREs originating from selection processes would be expected. On the other hand, while the task on the sink trial could be potentially affected by weighting of perceptual analysis (P_ω), the source task does not influence the P_ω system, consequently preventing any DREs arising from this system.

To test predictions derived from the MWS hypothesis, we recently performed two behavioral studies (Rangelov, Müller, & Zehetleitner, in press; under review). Both used a similar paradigm: mixing two tasks within trial blocks. Different tasks could engage either a common (assumed) weighting mechanism (e.g., both S_ω) or different mechanisms (e.g., S_ω vs. P_ω). An overview of these studies, the tasks used, the mechanisms hypothesized to be involved, and the DREs observed across task repetition/changes is provided in Table 4.1 and Figure 4.3.

Rangelov, Müller, and Zehetleitner (in press) mixed a search detection task, with multi-item displays requiring a target-present/absent response, with a non-search feature discrimination task, either in a predictive (Experiment 1) or random task sequence (Experiment 2). In the non-search feature discrimination task, only one item was presented at a fixed location (making selection easy), and observers were to report either the color (green/blue) or the orientation (vertical/horizontal) of this item by pressing the corresponding response button (left/right). On the conceptual task analysis, the search detection task (difficult selection, shallow analysis) engages the selection weighting system (S_ω), while the non-search feature discrimination (easy selection, deep analysis) engages primarily the perceptual-analysis system (P_ω). In Experiment 3, trials of non-search discrimination task (S_ω) alternated with a search discrimination task (both S_ω and P_ω). The difference between these two tasks was in the display types they used (single and multiple-items for the non-search and search tasks, respectively), while the S–R mapping remained the same.

Table 4.1. Overview of the experimental setup in the previous studies of Rangelov et al. (in press, under review). All studies used a task-switching paradigm in which two tasks (denoted as Task 1 and 2) alternated unpredictably across trials. Different experiments used different tasks that could, according to the conceptual task analysis, either share a weighting mechanism, or not. Predictions, derived from the MWS hypothesis, about DREs across task repetitions and switches are also shown.

		Weighting system in		DREs across task	
Task 1	Task 2	Task 1	Task 2	Repetitions	Changes
		Rangelov et al. (in press)			
Experiment 1					
Search Detection	Non-search Discrimination	S_ω	P_ω	Yes	No
Experiment 2					
Search Discrimination	Non-search Discrimination	S_ω and P_ω	P_ω	Yes	Yes
Experiment 3					
Search Discrimination	Non-search Discrimination	S_ω and P_ω	P_ω	Yes	Yes
		Rangelov et al. (under review)			
Experiment 1					
Search Detection	Search Localization	S_ω	S_ω	Yes	Yes
Experiment 2					
Search Detection	Non-search Detection	S_ω	P_ω	Yes	No
Experiment 3					
Non-search Detection	Non-search Discrimination	P_ω	P_ω	Yes	Yes

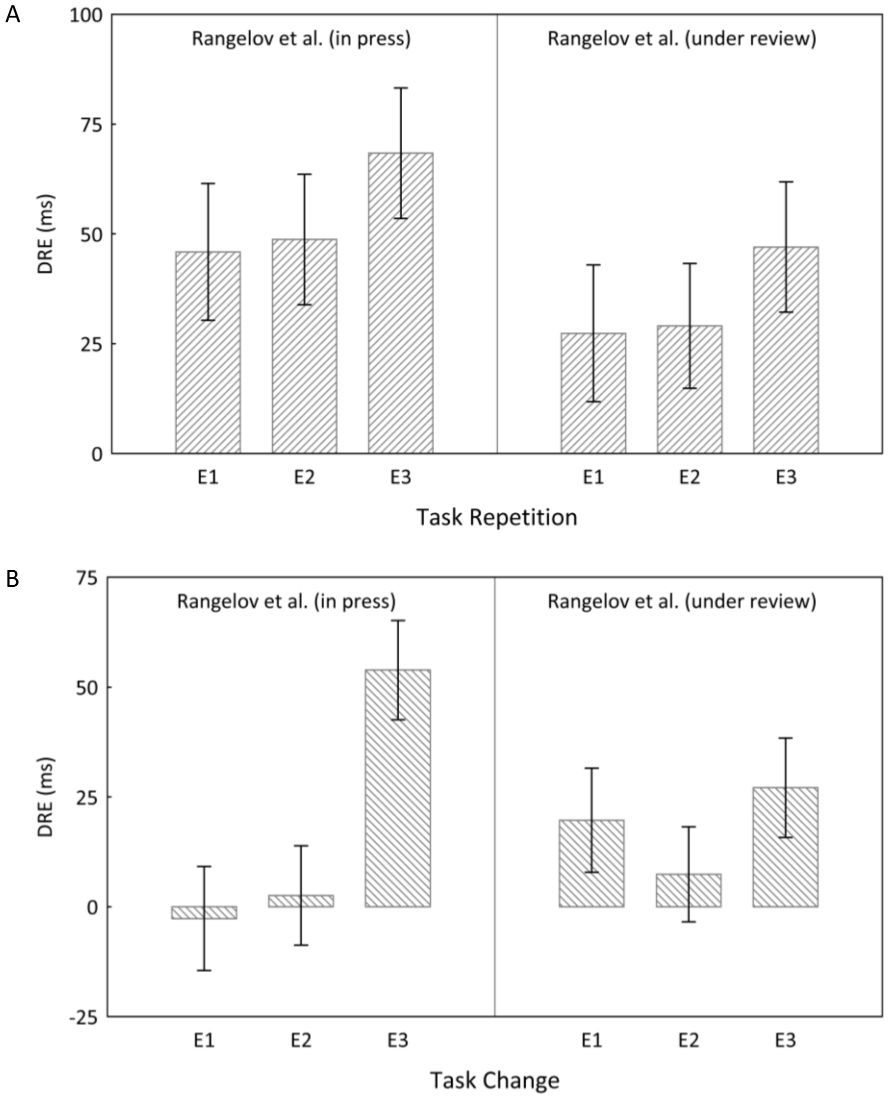

Figure 4.3. Mean DREs (ms) across: (A) task repetitions, and (B) task changes, in the studies of Rangelov et al. (in press, under review). Note the difference in scales between DREs for task changes/repetitions. Vertical lines denote 95% confidence intervals (CI); DREs for which zero lies outside the associated CI, are significant at p < .05.

Examining for DREs across task repetition revealed significant effects in all three experiments (Figure 4.3A). By contrast, no DREs were observed across task switches in Experiments 1 and 2 (see Figure 4.3B). Finally, there were significant DREs observed across trials of search and non-search discrimination tasks in Experiment 3.

The absence of DREs across the search detection and non-search discrimination tasks is well explained by assuming that independent weighting mechanisms give rise to DREs in the different tasks. However, alternative explanations are possible. For instance, one could hypothesize that weighting processes are specific for a given task. This means that whether or not tasks share a weighting system, DREs would never be expected across different tasks. This alternative explanation challenges the initial (underlying) rationale that it should be possible to observe DREs across two different tasks provided the intertrial effects in both tasks are generated by the same weighting system. To investigate this, Rangelov et al. (under review) mixed the following tasks within trial blocks: (i) search detection (target present/absent, multi-item displays) and singleton localization (target left/right, multi-item displays); (ii) search detection (target present/absent, multi-item displays) and non-search detection (target present/absent, single-item displays); and (iii) non-search detection and non-search discrimination task (reporting the exact target's feature, either color or orientation in single-item displays) in three experiments, respectively. The search detection and localization tasks (Experiment 1) both involved relatively difficult selection processes, that is, weighting of selection (S_ω) was assumed to operate in both tasks. By contrast, different weighting systems were presumed to operate in the search detection (difficult selection, shallow analysis – S_ω system) and the non-search detection task (easy selection, deep analysis – P_ω system) used in Experiment 2. Finally, weighting of perceptual analysis (P_ω) was assumed to operate in both non-search detection and discrimination tasks (Experiment 3). Data analysis revealed significant DREs across same-task trials for all tasks, demonstrating that a dimensional-weighting mechanism operated in all tasks (Figure 4.3A). Analysis of DREs across tasks showed significant DREs in Experiment 1, that is, across search detection and localization tasks (both involving the the S_ω mechanism), as well as in Experiment 3, that is, across non-search detection and non-search discrimination tasks (both involving the P_ω mechanism). However, there were no DREs in Experiment 2 across search detection (S_ω) and non-search detection (P_ω) tasks (Figure 4.3B). In summary, the results of Rangelov et al. (under review) demonstrate that it is possible to observe DREs across trials of different tasks, and that the pattern of effects follows closely the predictions (see Table 4.1) derived from the MWS hypothesis.

Taken together, the results of Rangelov et al. (in press, under review) seriously challenge single-mechanism explanations of DRBs, while favoring the MWS hypothesis and the reasoning behind it (as illustrated in Figures 4.1 and 4.2).

4.3.2 Problem of the present study

The findings outlined above (Rangelov et al., in press, under review) demonstrate a behavioral dissociation between two dimension-sensitive mechanisms. The evidence available to date indicates that spatial tasks (i.e., search detection and localization) involve one mechanism, whereas non-spatial tasks (non-search detection and non-search discrimination) involve a different mechanism. This raises the question about the relationship between the two systems, specifically: what would the pattern of DREs be for a task that involves both difficult stimulus selection and deep perceptual analysis, thus presumably engaging both the S_ω and P_ω weighting mechanisms?

From the MWS perspective, if a task influences several weighting mechanisms (i.e., both S_ω and P_ω), then the DREs observed in such a task would have multiple origins. Consequently, one would expect the DREs in such tasks to be stronger than DREs observed in tasks that primarily engage only one weighting system: ($DRE_{S\omega}$ + $DRE_{P\omega}$) > ($DRE_{S\omega}$ XOR $DRE_{P\omega}$). Furthermore, if such a task alternates across trials with a task engaging only one system, there should be significant DREs across task changes regardless of the specific weighting system (S_ω or P_ω) influenced by the latter task. This derives from the fact (illustrated in Figures 2C and 2D) that there would always be at least one continuous connection between source and sink trials, which, as set out earlier, is a precondition for DREs to arise.

To test these new hypotheses, a search feature discrimination task was used. This task involved multi-item displays containing a feature singleton on every trial (defined in either the color or the orientation dimension), with observers having to report the exact singleton feature (left- vs. right-tilted, or blue vs. green). Conceptual analysis of this search discrimination task reveals that it entails both difficult selection (involving S_ω) and deep perceptual analysis (involving P_ω). This search discrimination task was mixed with either a search detection task (difficult selection, shallow analysis – S_ω) or a non-search detection task (easy selection, deep analysis – P_ω) in Experiments 1 and 2, respectively. Data analysis focused on testing DREs across different tasks and different task sequences (repetition/change).

4.4 General Method

The two experiments used similar stimulus material and the same general procedure. For this reason, the methods for both experiments are presented together.

Participants. One group of 10 participants (5 female, mean age 25 years) and another group, also of 10 participants (4 female, mean age 26 years), took part in Experiments 1 and 2, respectively, for either monetary compensation (8 €/h) or course credit. All participants reported normal or corrected-to-normal vision as well as previous experience with psychophysical studies. They were all naïve with respect to the purpose of experiments.

Apparatus. The experiments were controlled by a Dell PC running under the Windows XP operating system. The stimuli were presented on a Fujitsu Siemens 21” CRT monitor, with a screen resolution of 1280 x 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 monitor. Head-to-monitor distance was 57 cm, controlled by means of a chin rest. Participants responded by pressing the left or the right button of a computer mouse, with their left or right index finger, respectively.

Stimuli. There were two different displays types (illustrated on Figure 4.4): (i) single-item displays, with only one bar presented in the screen center, and (ii) multiple-items displays, with 35 bars arranged in four (virtual) concentric circles made up of 1, 6, 12, and 16 bars, respectively. Stimuli were presented on a homogeneous, medium gray background (CIE xyY .283, .311, 31, respectively). Individual bars subtended approximately 0.6°x2.2° of visual angle, with multiple-items displays subtending approximately 21°x21° of visual angle. There were five possible bars: (i) yellow (CIE xyY .378, .518, 83), vertical – considered a distractor bar, (ii) yellow, tilted 45 clockwise from the vertical (right-tilted), (iii) yellow, tilted 45 counter-clockwise from the vertical (left-tilted), (iv) blue (.225, .283, 83), vertical, and (v) green (.279, .505, 83), vertical. Left- and right-tilted bars (differing from the distractor in orientation) were considered orientation targets, while blue and green bars (differing from the distractor in color) were considered color targets.

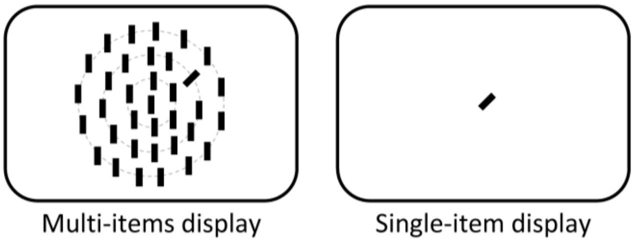

Figure 4.4. Illustration of stimulus displays used in the present study. See text for more details.

<u>Tasks.</u> There were three possible tasks: (i) search detection, (ii) non-search detection, and (iii) search discrimination. In both search- and non-search detection tasks, participants had to discern whether the presented stimulus display contained a target (in 60% of trials) or not (target present vs. absent) and press a corresponding response button (left/right). Thus, search- and non-search detection tasks were identical in terms of response mappings. The tasks, however, differed in the displays types: the non-search detection task used single-item displays, and the search detection task multiple-items displays. The search discrimination task also used multiple-items displays, however, with a target present on all trials. Instead of responding target-present/absent, participants had to report the exact feature of the target (left- vs. right-tilted, blue vs. green) by pressing the corresponding response button (left/right). Different features within a dimension of discrimination (e.g., blue vs. green for color) were mapped to different responses, while different features across dimensions (e.g., blue and left-tilted) were mapped to the same response. The task to be performed on a given trial was pre-

cued by a task-specific cue word: (i) “detection” for search detection, (ii) “identification” for non-search detection, and (iii) “discrimination” for search discrimination task.

In a previous study (Experiment 2, Rangelov et al., under review; see Table 4.1), the non-search and search detection tasks alternated across trials. In order to differentiate between the tasks, it was necessary to introduce different cue words (“detection” for search detection and “identification” for non-search detection). These cue words could have influenced participants to perform the tasks in different ways. Note, though, that Krummenacher et al. (2010) did not label the search detection and non-search detection tasks in any way (i.e., there was no need for cue words as the tasks were blocked) and yet they found systematic differences in how the two tasks were performed. In the present study, the same tasks (search and non-search detection) were mixed with a third task (the search discrimination) in separate experiments. To maintain comparability between Experiment 2 of Rangelov et al. (under review) and the present study, especially with regard to any specific strategies induced by the different cue words, the same task labels, “detection” and “identification”, were used in the present experiments as well.

Procedure. Every trial started with a task cue presented for 1000 ms. The cue was followed by a stimulus display which was presented until the participant responded. In case of an incorrect response, the word “error” was presented for 1000 ms. Between trials, a blank screen was shown for a variable ISI (950–1050 ms). The trial sequence, along with the respective timings, is illustrated in Figure 4.5. There were 35 blocks of 60 trials, resulting in 2100 trials in total. The first three blocks were considered a practice session and not included in the analyses. Participants took approximately two hours to complete all trials.

Participants were to respond on every trial. Different tasks involved different S–R mappings: (i) target present/absent for the detection tasks (whether of the search or the non-search variety), and (ii) color or orientation discrimination for the discrimination task. There were two possible S–R-mappings for detection tasks (present/absent: left/right or present/absent: right/left), and four mappings for the discrimination task: 2 mappings per dimension (e.g., blue/green: left/right or blue/green: right/left) x 2 dimensions (color and orientation). Two mappings in detection x four mappings in discrimination tasks resulted in eight possible combinations of S–R assignments, which were counter-balanced across participants.

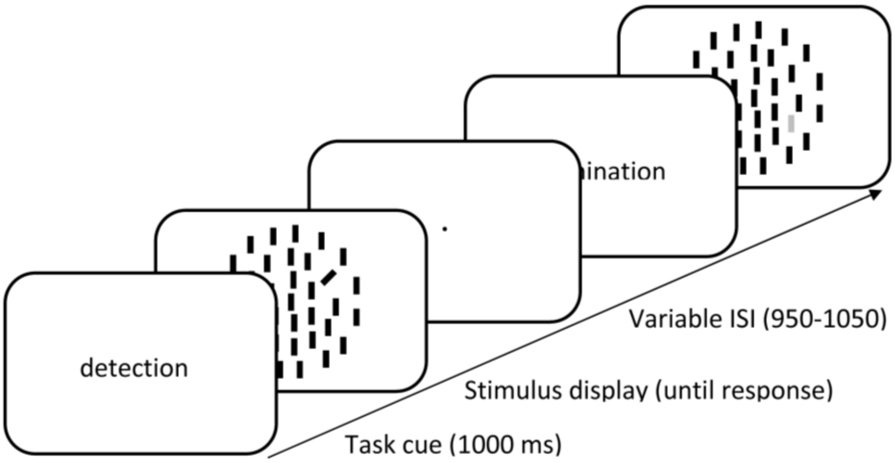

Figure 4.5. Stimulus sequence and associated presentation times during trials of the present experiments.

Design and data analyses. Every trial was characterized by the task to be performed and by the task-relevant dimension. Tasks and dimensions were randomized across trials. Thus, across consecutive trials, the task and dimension could either repeat or change. This resulted in a 2 (search detection vs. search discrimination task in Experiment; non-search detection vs. search discrimination in Experiment 2) x 2 (task repetition vs. change) x 2 (color vs. orientation dimension) x 2 (dimension repetition vs. change) design. The mean RTs were examined by a repeated-measures analysis of variance (ANOVA) with main terms for task, task sequence, dimension, and dimension sequence.

4.5 Results

4.5.1 Experiment 1

Trials of search detection and search discrimination tasks were mixed in Experiment 1. Both tasks used multiple-items displays, albeit with different response mappings. Participants made response errors in approximately 6% of total number of completed trials. Inspection of the error pattern did not reveal any indications of speed-accuracy trade-offs, and errors were not further analyzed. Trials with a correct response were filtered for extreme RTs (below 200 ms and above 1000 ms), resulting in the elimination of 2% of the correct-response trials. The remaining trials were sorted according to task, task sequence, dimension, and dimension sequence into 16 conditions, with, on average, 53 trials (inter-quartile range 36–72 trials) per condition per participant.

Inspection of the mean RTs revealed that the detection task was performed overall faster than the discrimination task (473 vs. 538 ms); furthermore, RTs were faster for task repetitions compared to changes (488 vs. 523 ms), and faster for dimension repetitions compared to changes (DRE: 488 vs. 523 ms). These observations were confirmed by a four-way repeated-measures ANOVA, which yielded significant main effects of (i) task ($F(1,9) = 14.52$, $p < .01$, $\eta_p^2 = .61$), (ii) task sequence ($F(1,9) = 38.58$, $p < .01$, $\eta_p^2 = .81$), and (iii) dimension sequence ($F(1,9) = 23.43$, $p < .05$, $\eta_p^2 = .72$).

Analysis of DREs. Inspection of DREs revealed this intertrial effect to be more marked for the discrimination than for the detection task (see Figure 4.6), which was confirmed by a significant task x dimension sequence interaction ($F(1,9) = 8.38$, $p < .05$, $\eta_p^2 = .48$). Planned t-tests revealed the DREs to be significant both in the discrimination task ($t(9) = 4.38$, $p_{\text{one-tailed}} < .05$) and, albeit smaller, in the detection task ($t(9) = 3.43$, $p_{\text{one-tailed}} < .05$). The DREs were larger across task repetitions than across task changes (see Figure 4.7), as confirmed by a significant task sequence x dimension sequence interaction ($F(1,9) = 15.94$, $p < .01$, $\eta_p^2 = .64$), but significant in both cases (across task repetitions: $t(9) = 5.48$, $p_{\text{one-tailed}} < .05$; across task changes: $t(9) = 2.48$, $p_{\text{one-tailed}} < .05$).

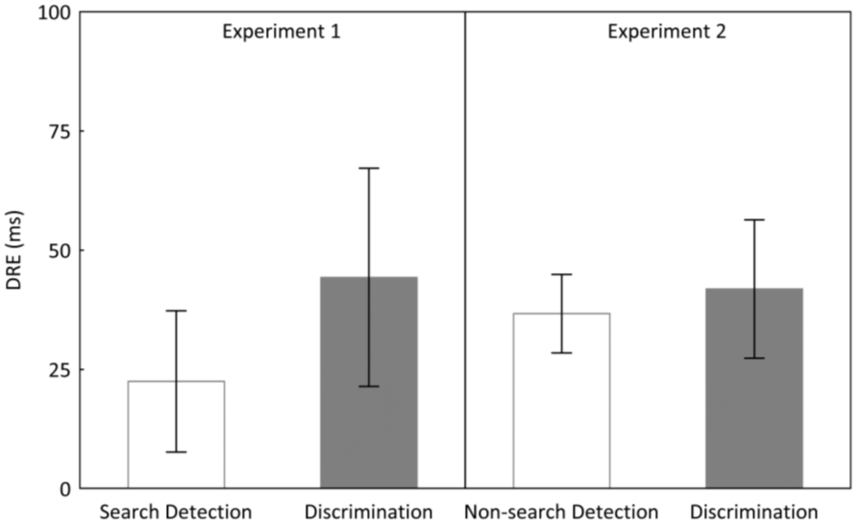

Figure 4.6. Mean DREs (ms) across different tasks in Experiment 1 (search detection and search discrimination) and Experiment 2 (non-search detection and search discrimination). Vertical lines denote 95% confidence intervals (CI).

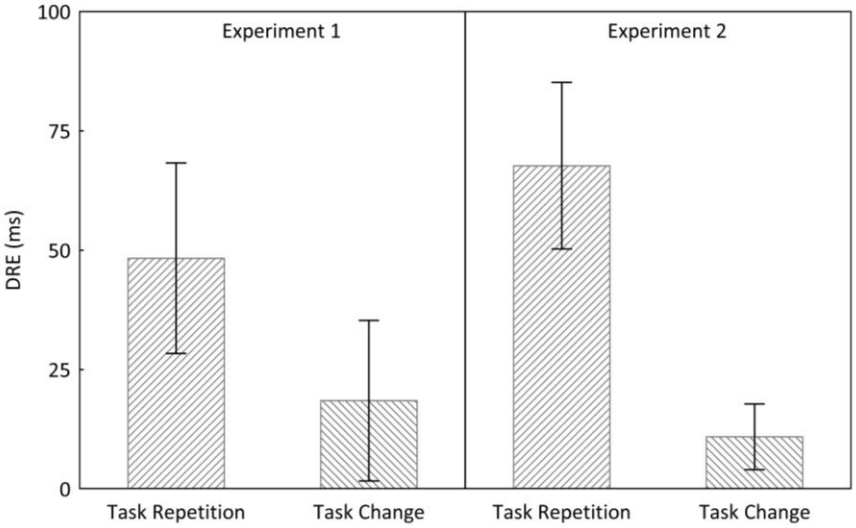

Figure 4.7. Mean DREs (ms) across different task sequences (repetition/change) in Experiments 1 and 2. Vertical lines denote 95% confidence intervals (CI).

Other effects. The ANOVA also revealed the task x dimension sequence interaction (F(1,9) = 8.38, $p < .05$, $\eta_p^2 = .48$) and the dimension x dimension sequence interaction (F(1,9) = 5.29, $p < .05$, $\eta_p^2 = .37$) to be significant. Furthermore, the task x dimension x dimension sequence interaction was marginally significant (F(1,9) = 3.68, p = .09, $\eta_p^2 = .29$). Post-hoc analyses revealed that these interactions were due to more marked DREs for color (62 ms) than for orientation (32 ms) in the discrimination task, which contrasts with comparable DREs for the two dimensions in the detection task (25 and 19 ms, respectively). Finally, the task x task sequence interaction was significant ($F(1,9) = 5.37$, $p < .05$, $\eta_p^2 = .37$): it was more difficult to switch from the discrimination to detection task (46 ms) than vice versa (24 ms). No other main effects or interactions proved significant (all $F < 2.32$, $p > .16$). Importantly, the task x task sequence x dimension sequence interaction was nowhere near significance levels ($F(1,9) = 0.03$, $p = .87$), indicating that task sequence x dimension sequence interaction was not task-specific.

4.5.2 Experiment 2

Trials of the non-search detection and the search discrimination task were mixed in Experiment 2. As in Experiment 1, the S–R mappings differed between tasks; and unlike Experiment 1, the stimulus displays also differed across tasks: (i) single-item displays were used for the non-search detection task, and (ii) multiple-items displays for the search discrimination task. Participants made an error response in approximately 5% of all trials. Extreme RTs were produced in approximately 2% of correct response trials. The remaining trials were sorted according to task, task sequence, dimension, and dimension sequence, yielding approximately 56 trials (interquartile range 37–72 trials) per condition per participant.

Inspection of mean RTs revealed that non-search detection was performed faster than search discrimination (496 vs. 568 ms); task repetitions were faster than task changes (510 vs. 554 ms); and that dimension repetitions were faster than dimension changes (DRE: 512 vs. 552 ms). These effects were confirmed by a four-way repeated-measures ANOVA, which revealed the main effects of task ($F(1,9) = 11.66$, $p < .01$, $\eta_p^2 = .56$), task sequence ($F(1,9) = 29.39$, $p < .01$, $\eta_p^2 = .76$), and dimension sequence ($F(1,9) = 87.50$, $p < .01$, $\eta_p^2 = .91$) to be significant.

Analysis of DREs. DREs were slightly (5 ms) larger for the discrimination task than for the non-search discrimination task (see Figure 4.6), but this difference was not reliable (non-significant task x dimension sequence interaction: $F < 1$, $p > .05$). Furthermore, as depicted in

Figure 4.7, DREs were stronger across task repetitions than across task changes (significant task sequence x dimension sequence interaction: $F(1,9) = 48.96$, $p < .01$, $\eta_p^2 = .84$), but significant in both cases (task repetitions: $t(9) = 8.77$, $p_{\text{one-tailed}} < .05$; task changes: $t(9) = 3.57$, $p_{\text{one-tailed}} < .05$). No other main effects or interactions proved significant (all $F < 3.25$, $p > .10$).

4.5.3 Between-experiments analyses

Within-experiments analyses had revealed the task x dimension sequence interaction to be significant in Experiment 1, but not in Experiment 2. According to the MWS hypothesis, the DREs should have been larger in the search discrimination task than in the other two tasks (search detection, non-search detection), because in the search discrimination task the DREs would originate from multiple weighting systems, whereas those in the other tasks would have one source only. Thus, a significant task x dimension sequence interaction was expected in both experiments.

Inspection of the DREs in the search discrimination task showed them to be of comparable magnitude in both experiments (44 and 42 ms in Experiments 1 and 2, respectively; see Figure 4.6); this was substantiated by an independent sample t-test comparison of the mean DREs between the two experiments ($t < 1$, $p > .05$). By contrast, for the search detection task (Experiment 1), the DREs were 15 ms smaller than those for the non-search detection task (Experiment 2, see Figure 4.6); this difference was significant ($t(14) = -1.91$, $p_{\text{one-tailed}} < .05$).

Taken together, the comparisons across experiments suggest that the non-significant task x dimension sequence interaction in Experiment 2 was due to strong DREs in the non-search detection task, rather than due to changes in DRE magnitude for the search discrimination task between experiments.

4.6 General Discussion

In the present study, the search discrimination task (difficult search, deep analysis – S_{ω} and P_{ω}) alternated randomly across trials, intermixed with either the search detection task (difficult search, shallow analysis – S_{ω}) or the non-search detection task (easy search, deep analysis – P_{ω}) in Experiments 1 and 2, respectively. According to the MWS hypothesis, the DREs in the search discrimination task should have been larger (by virtue of having two weighting systems as sources) than those in either the search or non-search detection task (one source). Furthermore, the MWS hypothesis predicted significant DREs across task changes in both experiments because the tasks used in either experiment always shared at least one weighting system.

In accordance with the MWS, the results of both Experiments 1 and 2 showed significant DREs across both task repetitions and task changes. Furthermore, the DREs for the search discrimination task were stronger than the DREs for the search detection task (Experiment 1). Finally, there were no significant differences in DRE magnitude between the search discrimination and the non-search detection task (Experiment 2). Between-experiments analyses showed that DREs for the discrimination task were comparable across experiments, while the DREs for the search detection were weaker than those for the non-search detection task.

4.6.1 Single-mechanism explanations

The present findings can be considered from either the Dimension-Weighting (e.g., Müller & Krummenacher, 2006a, 2006b) or the Dimensional-Action (e.g., Cohen & Magen, 1999; Cohen & Shoup, 1997) perspective.

The DA account would argue that the same mechanism caused DREs to arise in all tasks: weighting of response selection modules. Consequently, the DA account would predict significant DREs across task repetitions for all tasks used in this study. With regard to the

DREs observed across task switches in the present study, one could argue that if the same response-based mechanism was engaged in all tasks, significant DREs should have arisen across all (combinations of) tasks, which is in line with the present findings. However, if an identical weighting system had been operating in both the search and non-search detection tasks, then one would have expected DREs of comparable magnitude. However, this was not the case – thus challenging the DA model. To account for the significantly increased DREs in the non-search detection task relative to the search detection task (different display types, with identical SR-mappings between tasks), the DA account would have to assume either that the change in stimulus type (across the two tasks) changed the dynamics of the weighting process or that different sources of DREs are operating in different tasks. The former assumption would effectively turn the DA account into a hybrid model sensitive to both stimulus- and response-related process; the latter would effectively be a variant of the MWS hypothesis.

On the other hand, early work within the DWA framework specified only one mechanism giving rise to DREs: weighting of dimension-specific feature-contrast signals at pre-selective processing stages. This mechanism would give rise to DREs in tasks demanding visual selection of the task-relevant item from a set of distractors. Accordingly, the DREs observed across tasks involving difficult selection (i.e., search tasks) are in accordance with the DWA. However, this single (pre-selective) mechanism cannot provide a straightforward account for the strong DREs observed in non-search tasks, in which the stimulus displays do not give rise to dimension-specific feature contrast signals. Note, however, that the proponents of the DWA quite explicitly acknowledged the possibility that other, post-selective processing stages may also be influenced by the sequence of dimensions across trials (Müller & Krummenacher, 2006a). In this sense, the MWS hypothesis may be regarded as an extension of the DWA to account for the DREs observed in the non-search paradigm.

4.6.2 Multiple-Weighting-Systems explanation

In contrast to single-mechanism models, the MWS hypothesis can account for the present findings in a straightforward manner. There were significant DREs across task repetitions for all tasks because at least one dimension-sensitive mechanism was engaged in every task. There were significant DREs across task switches for both Experiments 1 and 2 because across any two tasks, there was always at least one shared weighting system. In fact, the present results closely follow the predictions derived from the MWS hypothesis, as illustrated in Figures 4.1 and 4.2.

One prediction of the MWS was, however, not confirmed by the data, namely: DREs in the search discrimination task were expected to be larger than in the non-search discrimination task. While there was a numerical tendency in the expected direction (5 ms), this difference was not significant. On the other hand, the DREs for the search discrimination task were comparable across experiments and, in line with MWS predictions, stronger than the DREs in the search detection task (Experiment 1). This pattern indicates that the large DREs in the non-search detection task (relative to the smaller DREs in the search detection task) were responsible for non-significant task x dimension sequence interaction in Experiment 2.

While large DREs in the non-search detection task were not explicitly predicted, they are not entirely surprising. Mortier et al. (2005, Experiment 1) also reported larger DREs in their non-search detection than in their search detection tasks (50 vs. 20 ms) – which is in accordance with the DRE magnitudes observed in the present study. Furthermore, the differential DRE magnitude between the search- and non-search detection tasks is compatible with the MWS hypothesis. If the DREs were indeed generated by different weighting systems (S_ω or P_ω) in the search- and non-search detection tasks, then differences between the tasks can be readily explained by assuming that S_ω and P_ω systems can give rise to DREs of different magnitude (in fact, there is no reason to assume that all systems give rise to effects of the same magnitude). By contrast, as discussed above, a single-mechanism account would encounter a difficulty in explaining the present finding without assuming a complex interaction between stimulus- and response-related processes.

4.6.3 Theoretical implications

Several properties of the MWS hypothesis argue in favor of it representing a viable alternative to the single-mechanism accounts of DREs. First, it provides an extension to older theoretical notions (in particular, the DWA), accounting for post-selective sources of DREs. Second, the conceptual analysis of how paradigm properties are mapped to diverse cognitive processes (see Figure 4.1), as well as which tasks are affected by which weighting mechanisms, generates a number of testable predictions. Third, and most importantly, the empirical evidence is consistently in line with these predictions (see Figure 4.3 and Table 4.1).

As for the further empirical and theoretical developments of the MWS hypothesis, there are two main directions. First, it would be important to demonstrate a dissociation between the different weighting systems in a data domain other than (behavioral) RTs. In particular, electrophysiological or fMRI (functional magnetic resonance imaging) studies should be carried out to examine whether it is possible to identify temporal or spatial ‘brain’ markers of neural activity selectively sensitive to one or the other weighting system. Previous work (Pollmann, Weidner, Müller, & von Cramon, 2000; Weidner, Pollmann, Müller, & von Cramon, 2002) suggests that singleton feature search tasks and singleton conjunction search tasks have distinct neural correlates of DREs, the former located in lateral pre-frontal cortex (lPFC), the latter in fronto-median brain areas (pregenual ACC). On a conceptual task analysis, the MWS hypothesis would assume that the two tasks activate different weighting systems: singleton feature search would involve S_ω and singleton conjunction search P_ω. Consequently, one might hypothesize that the S_ω system is related to lPFC brain areas and the

P_ω system to ACC areas. Further research should examine whether comparable brain areas are activated across task switches for which behavioral evidence demonstrates significant DREs.

Second, the nature of the post-selective weighting systems demands elaboration. One issue relates to the possibility of dissociating weighting of perceptual analysis from response weighting. As already discussed, the empirically established post-selective DREs have been interpreted as being either perceptual (Krummenacher et al., 2010) or response-based (Mortier et al., 2005) in origin. However, it could also be the case that post-selective DREs originate from both perceptual and response-based sources. To examine these issues, paradigms would need to be devised that permit these two factors to be pitted against each other, so that their (independent) contributions to generating DREs can be evaluated. This work would provide an extension to the MWS perspective, which thus far has focused on demonstrating a dissociation between selection-related and post-selective sources (discussed summarily) of DREs.

4.6.4 Conclusions

Review of findings on DREs in different psychophysical paradigms suggested that the single-mechanism accounts proposed in the literature cannot fully explain all the available data. To fill this explanatory gap, a multiple-weighting-systems (MWS) hypothesis was developed. On this hypothesis, there exist several independent mechanisms that can all produce DREs, by virtue of being sensitive to (sequences in) perceptual dimensions. Previous findings, based on a task-switch approach, demonstrated a behavioral dissociation between sources of DRBs in search and non-search paradigms. In the present study, using a similar approach, we demonstrated that a single task can engage multiple weighting mechanisms at the same time. Although separable, these weighting systems are all situated along the same processing path, leading from stimulus selection through perceptual analysis to response selection and response execution.

4.7 References

Becker, S. I. (2008). Can intertrial effects of features and dimensions be explained by a single theory? *Journal of Experimental Psychology. Human Perception and Performance*, *34*(6), 1417-1440. doi:10.1037/a0011386

Bravo, M. J., & Nakayama, K. (1992). The role of attention in different visual-search tasks. *Perception & Psychophysics*, *51*(5), 465-72.

Chan, L. K. H., & Hayward, W. G. (2009). Feature integration theory revisited: dissociating feature detection and attentional guidance in visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *35*(1), 119-132. doi:10.1037/0096-1523.35.1.119

Cohen, A., & Magen, H. (1999). Intra- and cross-dimensional visual search for single-feature targets. *Perception & Psychophysics*, *61*(2), 291-307.

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology*, *32*(2), 128-81. doi:10.1006/cogp.1997.0648

Cohen, A., & Shoup, R. (2000). Response selection processes for conjunctive targets. *Journal of Experimental Psychology. Human Perception and Performance*, *26*(1), 391-411.

Druey, M. D., & Hübner, R. (2008). Response inhibition under task switching: its strength depends on the amount of task-irrelevant response activation. *Psychological Research*, *72*(5), 515-527. doi:10.1007/s00426-007-0127-1

Duncan, J. (1985). Visual search and visual attention. *Attention and performance*, *11*, 85–105.

Fecteau, J. H. (2007). Priming of pop-out depends upon the current goals of observers. *Journal of Vision*, *7*(6), 1. doi:10.1167/7.6.1

Feintuch, U., & Cohen, A. (2002). Visual attention and coactivation of response decisions for features from different dimensions. *Psychological Science: A Journal of the American Psychological Society / APS*, *13*(4), 361-9.

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: investigating a "dimension-weighting" account. *Perception & Psychophysics*, *58*(1), 88-101.

Gade, M., & Koch, I. (2007). The influence of overlapping response sets on task inhibition. *Memory & Cognition*, *35*(4), 603-609. doi:VL - 35

Hillstrom, A. P. (2000). Repetition effects in visual search. *Perception & Psychophysics*, *62*(4), 800-17.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10-12), 1489-506.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews. Neuroscience*, *2*(3), 194-203.

Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010). The role of inhibition in task switching: A review. *Psychonomic Bulletin & Review*, *17*(1), 1-14. doi:10.3758/PBR.17.1.1

Kristjánsson, Á., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Perception & Psychophysics*, *72*(1), 5.

Krummenacher, J., Grubert, A., & Müller, H. J. (2010). Inter-trial and redundant-signals effects in visual search and discrimination tasks: Separable pre-attentive and post-selective effects. *Vision research*. doi:10.1016/j.visres.2010.04.006

Kumada, T. (2001). Feature-based control of attention: evidence for two forms of dimension weighting. *Perception & Psychophysics*, *63*(4), 698-708.

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, *22*(6), 657-72.

Maljkovic, V., & Nakayama, K. (1996). Priming of pop-out: II. The role of position. *Perception & Psychophysics*, *58*(7), 977-91.

Maljkovic, V., & Nakayama, K. (2000). Priming of popout: III. A short-term implicit memory system beneficial for rapid target selection. *Visual cognition*, *7*(5), 571-595.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging*, *16*(1), 96-109. doi:10.1037/0882-7974.16.1.96

Meeter, M., & Olivers, C. N. L. (2006). Intertrial priming stemming from ambiguity: A new account of priming in visual search. *Visual Cognition*, *13*(2), 202-222. doi:10.1080/13506280500277488

Mortier, K., Theeuwes, J., & Starreveld, P. (2005). Response selection modulates visual search within and across dimensions. *Journal of Experimental Psychology. Human Perception and Performance*, *31*(3), 542-57. doi:10.1037/0096-1523.31.3.542

Müller, H. J., & Krummenacher, J. (2006a). Locus of dimension weighting: Preattentive or postselective? *Visual cognition*, *14*(4-8), 490-513.

Müller, H. J., & Krummenacher, J. (2006b). Visual search and selective attention. *Visual Cognition*, *14*(4), 389-410.

Müller, H. J., Krummenacher, J., & Heller, D. (2004). Dimension-specific intertrial facilitation in visual search for pop-out targets: Evidence for a top-down modulable visual short-term memory effect. *Visual Cognition*, *11*(5), 577-602.

Muller, H. J., Reimann, B., & Krummenacher, J. (2003). Visual search for singleton feature targets across dimensions: Stimulus- and expectancy-driven effects in dimensional weighting. *Journal of Experimental Psychology. Human Perception and Performance*, *29*(5), 1021-35. doi:10.1037/0096-1523.29.5.1021

Olivers, C. N. L., & Humphreys, G. W. (2003). Attentional guidance by salient feature singletons depends on intertrial contingencies. *Journal of Experimental Psychology. Human Perception and Performance*, *29*(3), 650-7.

Olivers, C. N. L., & Meeter, M. (2006). On the dissociation between compound and present/absent tasks in visual search: Intertrial priming is ambiguity driven. *Visual Cognition*, *13*(1), 1–28.

Pollmann, S., Weidner, R., Müller, H. J., & von Cramon, D. Y. (2000). A fronto-posterior network involved in visual dimension changes. *Journal of Cognitive Neuroscience*, *12*(3), 480-94.

Rogers, R. D., & Monsell, S. (1995). Costs of a Predictable Switch Between Simple Cognitive Tasks. *Journal of Experimental Psychology: General*, *124*(2), 207–231.

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010a). Independent dimension-weighting mechanisms for visual selection and identification . *Journal of Experimental Psychology, Human Perception and Performance* (in press).

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010b). Independent dimension-weighting mechanisms for visual selection and identification (under review).

Tipper, S. P. (1985). The negative priming effect: inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *37*(4), 571-590.

Töllner, T., Gramann, K., Muller, H. J., Kiss, M., & Eimer, M. (2008). Electrophysiological Markers of Visual Dimension Changes and Response Changes. *Journal of Experimental Psychology*, *34*(3), 531-542. doi:10.1037/0096-1523.34.3.531

Weidner, R., Pollmann, S., Müller, H. J., & von Cramon, D. Y. (2002). Top-down controlled visual dimension weighting: an event-related fMRI study. *Cerebral Cortex (New York, N.Y.: 1991)*, *12*(3), 318-328.

Wolfe, J. M. (1994). Guided search 2. 0. A revised model of visual search. *Psychonomic Bulletin & Review*, *1*(2), 202-238.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *15*(3), 419-33.

Zehetleitner, M., & Müller, H. J. (2010). Saliency from the decision perspective. Manuscript submitted for publication.

5 PUBLISHED AND SUBMITTED MANUSCRIPTS

Müller, H. J., Töllner, T., Zehetleitner, M., Geyer, T., Rangelov, D., & Krummenacher, J. (2010). Dimension-based attention modulates feed-forward visual processing - A reply to Theeuwes (2010). *Acta Psychologica*. doi:10.1016/j.actpsy.2010.05.004

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010a). Independent dimension-weighting mechanisms for visual selection and identification . *Journal of Experimental Psychology, Human Perception and Performance* (in press). – Chapter 2 of the thesis

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010b). Independent dimension-weighting mechanisms for visual selection and identification. . *Journal of Experimental Psychology, Human Perception and Performance* (under review). – Chapter 3 of the thesis

Rangelov, D., Müller, H. J., & Zehetleitner, M., (2010c). The Multiple-Weighting-Systems hypothesis: Theory and empirical support. *Attention, Perception, & Psychophysics* (under review). – Chapter 4 of the thesis