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Response Selection modulates Visual Search Within And Across Dimensions.

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Abstract

In feature search tasks, uncertainty about the dimension on which targets differ from the nontargets hampers search performance relative to a situation in which this dimension is known in advance. Typically these cross-dimensional costs are associated with less efficient guidance of attention to the target. In the present study participants either had to perform a feature search task or had to perform a non-search task, i.e., respond to a target presented without nontargets. The target varied either in one dimension or across dimensions. The results showed similar effects both in search and non-search conditions: preknowledge of the target-dimension gave faster response times than when the dimension was unknown. Similar results were found using a trial-by-trial cueing. It is concluded that effects that typically have been attributed to early top-down modulation of attentional guidance may represent effects that occur later in processing.

Response Selection Modulates Search Within And Across Dimensions.

How do we select information from the environment? This has been a topic of research for the last twenty years. Typically, the paradigm of visual search is one of the most widely used methods to study the way we select information from the environment. In this paradigm, participants have to detect one defined target that is presented among a variable number of nontarget elements. In most versions of this paradigm, the target either differs from nontargets in one dimension (i.e., a feature search task), or it differs in two (or more) dimensions (i.e., a conjunction search task). Typically, observers detect the presence or absence of the target. Time to detect the target is plotted as a function of the number of items in the display (set size). For the simple feature searches, detection of the target is independent of the number of nontargets, as shown by a flat function relating set size to reaction times (RTs). This result is taken as evidence for a parallel, efficient search process in order to detect the target. Feature search is sometimes referred to as singleton search or pop-out target detection. In a conjunction search, however, the corresponding function is linearly increasing. This pattern has been taken as evidence for a serial, inefficient search process (Treisman & Gelade, 1980).

Typically, in feature search both the target dimension (e.g., color) and the target feature value in this dimension (e.g., red) are constant and known to the observer. For example, observers consistently search for red amongst green items. Recently, there has been a renewed interest in feature search (e.g., Cohen & Magen, 1999; Müller, Heller, & Ziegler, 1995; Treisman, 1988; Wolfe, Butcher, Lee, & Hyle, 2003). Instead of keeping the target identity the same across trials, the identity of the target varies across trials. For example, the target may be a red horizontal line or a green horizontal line amongst a variable number of gray horizontal lines (within-dimensional search) or the target may be a red horizontal line or a gray vertical line among gray horizontal lines (cross-dimensional search). The consequence of varying the target identity randomly across trials is that observers do not know what target is going to be presented on the next trial. Usually, feature value uncertainty is compared with dimensional uncertainty.

Treisman (1988) was the first to investigate these two types of uncertainty. In a within-dimensional search condition, the target dimension was constant (e.g., orientation), but the target feature value was unpredictable (left-oriented, right-oriented or horizontal). In a cross-dimensional search, the target dimension was unpredictable (color, orientation, or size), but the feature value within a particular dimension was constant (e.g., in color dimension the target is always red). A cross-dimensional cost of about 100 ms was found relative to within-dimensional search. Müller, Heller, and Ziegler (1995) replicated the cross-dimensional cost and explained their findings by assuming that pop-out target detection must be based on the output of dimension-specific saliency maps. Furthermore, Found and Müller (1996) described a dimension-specific intertrial facilitation effect: if a target was preceded by a target defined along the same dimension, detection was faster relative to a preceding target defined along a different dimension. To explain these effects, Müller and colleagues (Krummenacher, Müller, & Heller, 2001, 2002; Müller et al., 1995; Müller, Reimann, & Krummenacher, 2003) proposed a dimension-weighting account of visual search, according to which master map units compute the weighted sum of dimension-specific saliency signals in parallel. If the dimension of the target is known in advance, that dimension is assigned a larger weight than the other dimensions, allowing a faster detection of the target. However, if the target-defining dimension is not known in advance, a particular dimension can not be given preferential treatment and thus the master map salience signal might stay longer below threshold required for response. Thus, fast target detection requires the target dimension be weighted sufficiently to amplify the saliency signal generated within this dimension above the detection threshold. Dimension change incurs a cost because attentional weight must be shifted from the old to the new dimension.

Müller and colleagues found besides a dimension-specific intertrial effect, also a feature-specific intertrial effect for color targets: detection of a color singleton (e.g. red) was facilitated when a color singleton defined by the same color (red) was detected in the previous search trial(s) relative to when another color singleton (e.g. blue) was detected (see also Hillstrom, 2000; Kumada, 2001). They explained this by dividing the color dimension in relatively independent sub-dimensions, each computing feature contrast within separate 'wavelength' channels. The dimensional weighting account can be applied in these sub-dimensions in the same way as in the broader dimensions, e.g. in the dimension shape (Found & Müller, 1996).

In line with these results, Maljkovic and Nakayama (1994) have demonstrated also feature-specific intertrial effects for color targets. They referred to this phenomenon as <u>priming of pop-out.</u> Maljkovic and Nakayama (1994) showed that even though participants knew the upcoming target feature, this did not influence the repetition effect. They argued that these repetition effects are passive and autonomous, and not influenced by top-down control. However, Hillstrom (2000) found also a feature-specific intertrial effect, but with responses faster to trials in an alternating sequence (in which the participants knew the color of the target on each trial) relative to a random sequence. This suggests that there can be a top-down modulation on the feature repetition effect. Indeed, in a recent study of Müller, Reimann and Krummenacher (2003), observers were precued either to the most likely target-defining dimension or to the most likely feature value. This trial-by-trial cueing procedure reduced, but did not abolish, the intertrial effects. Müller and colleagues argued that top-down dimensional control can modulate stimulus-driven processes in the detection of pop-out signals.

Closely related to the dimensional weighting theory is the <u>Guided Search account</u> of Wolfe (1994). Guided Search assumes that visual stimuli are analyzed into basic features in different dimension-specific modules (e.g., color, orientation). The activation for each stimulus is calculated, separately in each dimension module. This activation is based on differences between the items (bottom-up) and on task demands (top-down). These activations are summed onto an activation map. In visual search, focal attention is guided to the location with the most activation.

In a recent study, Wolfe, Butcher, Lee and Hyle (2003) investigated the contributions of top-down and bottom-up processes in feature search tasks, by means of varying the uncertainty about the target's feature value and dimension. They used a fully mixed condition in which both the target dimension and the target feature value were uncertain from trial to trial. Also, items that were targets on one trial can appear as distractors an another. For example, on one trial the target could be a red horizontal line with green horizontal lines as distractors, whereas on a next trial the target could be a green horizontal line with red horizontal lines as distractors. This method increased uncertainty about the feature and dimension of the target, in order to obtain less top-down information. Note that Wolfe et al. (2003) used the term top-down guidance even though this effect is typically referred to as stimulus identity (e.g., Posner, 1978). Wolfe et al. (2003) reasoned that implicit knowledge of what happened on a previous trial can help tuning the sensory systems for the next trial. Whereas Wolfe and colleagues called these intertrial effects the result of top-down guidance, Maljkovic and Nakayama (1994) considered these very same effects as the result of passive bottom-up priming and not influenced by top-down control.

Wolfe et al. (2003, Experiment 3) showed that intertrial effects are based more strongly on target than on distractor identity. Furthermore, the results revealed a cost for cross-dimensional relative to within-dimensional search. Wolfe and colleagues suggested that these RT differences might be based on the salience of the difference between the target and the non-targets. The activation of the target is considered as the signal; the activation of the non-targets as distracting noise. This signal to noise ratio (S/N ratio) is a hypothetical measure of the size of the signal guiding attention to the target among its non-targets. Top-down processes act to set weights to optimize the S/N ratio. In a cross-dimensional condition, all features are comparable and thus receive equal weight. In a within-dimensional condition, however, one dimension receives the strongest weight. Consequently, this gives an advantage for the within-dimensional condition.

Cohen and Magen (1999) suggested another explanation for the cross-dimensional cost. They argued that this effect reflects response stage processes and not perceptual processes as proposed by Müller and colleagues (Müller et al., 1995; Found & Müller, 1996) and Wolfe et al. (2003). They also compared within- and cross-dimensional search. However, they changed the stimulus-to-response mapping from a present/absent task (as in Müller et al., 1995) to a discrimination task (either between two features in one dimension, or between two dimensions). They reasoned that if perceptual processes caused the difference between the two conditions, a different stimulus-to-response mapping should not affect the cross-dimensional cost. Instead, if such a difference would be obtained, the results should be attributed to response selection processes. Cohen and Magen (1999) found that the typical cross-dimensional cost disappeared. In fact, in some conditions cross-dimensional search was even more efficient as within-dimensional search. To explain these results, they refer to the response selection model of Cohen and Shoup (1997). In this model, visual stimuli are analyzed into features in different dimension maps (see also Cave & Wolfe, 1990; Cohen, 1993; Treisman & Sato, 1990). More importantly, they assume that after visual selection, the response assignments to single features are determined separately within each dimension module. In other words, there is not a single response selection mechanism, but there is one for each dimension module (see also Mordkoff & Yantis, 1993). Recently, the model was elaborated by Cohen and Feintuch (2002), resulting in a visual system linking perception and action, referred to as the dimensional action system. However, these results can also be explained by the dimension-weighting theory. In the intra-dimensional task, the target's identity had to be determined, whereas in the cross-dimensional task, only the target's dimension was necessary for a correct response. This resulted in an advantage for the cross-dimensional condition. This was also pointed out by Cohen and Magen (1999, p.306).

The aim of this study was to distinguish between a search-based account and a response-based account. Guided Search (Wolfe et al., 2003) assumes that cross-dimensional costs and intertrial facilitation are due to speeding up or slowing down the actual search for the singleton target. In other words, this theory assumes that the within-dimensional search is faster because the actual search for the feature target becomes faster. Also, intertrial facilitation occurs because the search for the singleton target is speeded. Recent work by Theeuwes, Reimann & Mortier (in press) suggests that these effects may have nothing to do with actual search. In the present study we examined cross-dimensional costs and intertrial facilitation (dimension-specific or feature-specific) in conditions in which there was no search at all. If these effects occur in a non-search task, this would indicate that these effects cannot be attributed to search processes. If these effects are not present when the search component is removed, then it is fair to argue that cross-dimensional costs and intertrial facilitation are related to the actual search process.

In Experiment 1 and 2 participants either had to perform a visual search task, i.e., search for a within- or cross-dimensional target element or had to perform a non-search task, i.e., respond to a within- or cross-dimensional target element presented at the center of the visual field. Experiment 3 and 4 used a trial-by-trial cueing procedure in a non-search task.

Experiment 1

We examined whether a cross-dimensional cost was specific for search processes. One way to determine this is to eliminate search. Consequently, there is no need to guide attention to the target. We compared a classic feature search task, in which participants have to discern the presence or absence of the target, with a non-search task. In this non-search task only one stimulus is presented and observers had to indicate whether the stimulus is a target or not. Both tasks had two conditions: a within-dimensional condition, in which the dimension of the target is known in advance and a cross-dimensional condition, in which the dimension of the target is uncertain.

Method

Participants. Eight undergraduates, ranging in age from 19 to 23 years participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus and Stimuli. Participants were seated in front of a computer monitor with their heads fixed on a chinrest. Viewing distance was approximately 75 cm. All participants were instructed not to move their eyes during the trials. The display background was black (0.6 cd/m^2). In the search task, the display contained stimuli on an imaginary circle drawn around the center of the display with a radius of 3.6 degrees of visual angle. The display size existed of 3, 6 or 9 items. The position of each element was randomly chosen, the only restriction being that distances between neighboring display elements were equal.

In the non-search task, the display contained only one stimulus, which appeared randomly on the imaginary circle to keep the displays similar. Both tasks had two conditions, a within-dimensional condition and a cross-dimensional condition. In the within-dimensional condition the target was a colored circle, either yellow, green or red. In the cross-dimensional condition, the target could be a gray triangle (shape), or a big gray circle (size) or a red circle (color). The non-targets in the search task were gray circles. A target-absent trial in the non-search task was one gray circle. All stimuli (yellow, green, red and gray) were equiluminant (approximately 9.0 cd/m^2).

Procedure. Participants began each trial by fixating a central fixation cross. After 700 ms, the stimulus display was presented during 200 ms on a black background (see Figure 1). Observers had 2 seconds to respond. The intertrial interval was 800 ms. The three possible targets were mapped onto one response button and the target-absent trials were mapped onto the other response button. Participants were told to respond as quickly as possible with either left response ("z"-button) or right response ("/"-button). When the observers made an error, a tone (300 Hz) was presented for 100 ms.

Insert Figure 1 about here

Design. All observers participated in the search- and the non-search task. These two tasks were blocked and presented in counterbalanced order. Each task consisted of two conditions, a within-dimensional condition and cross-dimensional condition. For each task, the conditions were also blocked and presented in counterbalanced order. Each task consisted of 1080 experimental trials, with each condition 540 trials. Each condition comprised 6 experimental blocks, with each block consisting of 90 trials. For each condition, there were 270 target-present trials and 270 target-absent trials. On the target-present trials, each of the three targets was presented equally often. Only in the search task, the display size was varied, with the three display sizes equally often presented. Within each condition, all types of trials were randomly varied. Participants received 18 practice trials before each condition. At the end of each block there was a short break in which the participants received feedback on their accuracy and reaction times (RTs). The response mapping was counterbalanced across participants.

Results

RTs of incorrect responses in response to the red target (4.76 %) and RTs longer than 1100 ms (0.04 %) were excluded from the analysis.

Reaction Times. The main interest is the comparison of mean RTs for the identical target present in within-dimensional condition and cross-dimensional : the response to the red circle. Only the data in response to this target were analyzed.

First, we determined whether in the search-task search for the red target was performed in parallel. An ANOVA was performed on the mean reaction times in the search task with display size and condition as factors. There was no display size effect, [F(2,14) = .32], with the average slope 0.7 ms per item, indicating that the search-task was indeed a pop-out search task. There was a main effect of condition, F(1,7) = 33.28, p < .01. There was a significant interaction between display size and condition, F(2, 14) = 5.74, p < .05. Note however, that this interaction is only due to the deviating pattern at display size 3, in which RTs for the cross-dimensional condition were slower then for the other display sizes, whereas in the within-dimensional condition, the RTs were faster with display size 3 relative to the other display sizes. If display size 3 was excluded from the analysis, then there was no significant interaction, F < 1 (see Figure 2).

Insert Figure 2 about here

Second, a repeated measures ANOVA was performed on the individual mean reaction times of the target present trials with task (search or non-search) and condition (within dimension or across dimensions) as factors. Since only the red circle was present in both conditions, we only analyzed these results. The main effect of task was not significant, F (1,7) = 1.06. Importantly, there was a main effect of condition: F(1,7) = 71.73, p < .0001. The interaction task x condition was not significant, F (1,7) = .34 (see Figure 3).

Insert Figure 3 about here

A separate analysis was performed on the target-absent trials, with task and condition as within-subjects factors. There was no main effect of task, F < 1 (search task: 407 ms, non-search task: 406 ms). There was a main effect of condition, F(1,7) = 89.17, p < .001, with slower RTs in the cross-dimensional condition (439 ms) relative to the within-dimensional condition (374 ms). The interaction between task and condition was not significant, F(1,7) = 1.74, p > .05.

Intertrial effects. An ANOVA was performed on the trials containing the red circle as target with task (search or non-search), condition (within dimension or across dimensions) and intertrial transition (same target or different target on the previous trial) as factors. Trials were excluded of which the previous trial was a target-absent trial.

There was a main effect of condition, F(1, 7) = 46.76, p < .001 (within: 374 ms, cross: 412 ms). There was no effect of task, F(1, 7) = 1.11 (search: 389 ms, non-search: 397 ms). Importantly, there was a main effect of intertrial transition, F(1, 7) = 17.47, p < .01, with target-repeating trials (382 ms) being faster than target-alternating trials (404 ms). There were reliable interactions between intertrial transition and condition, [F(1, 7) = 11.26, p < .05] and between intertrial transition and task, F(1, 7) = 5.52, p = .051. There was a significant three-way interaction between condition, task and intertrial transition, F(1, 7) = 19.32, p < .01. Planned comparisons showed that there was no significant difference between target-repeating trials (379 ms) and target-alternating trials (381 ms) in the within-dimensional condition of the non-search task, F(1, 7) < 1. Whereas there was a significant difference between the target-repeating trials (387 ms) and the target alternating trials (439) in the cross-dimensional condition of the non-search task, F(1,7) = 26.7 p <.01. In the search task, there was a significant difference between target-repeating trials and target-alternating trials, as well in the within-dimensional condition, F(1,7) = 7.13, p < .05 (target-repeating trials: 361 ms, target-alternating trials: 374 ms), as in the cross-dimensional condition F(1,7) = 7.8, p< .05 (target-repeating trials: 402 ms, target-alternating trials: 422 ms).

Error analysis. The total number of errors in response to the red circle and to target-absent trials was 4.8 % (target misses 4.76 %, false alarms 4.85 %). The errors were calculated for each condition of each task for each participant. An ANOVA was performed on these totals with type of error (target miss or false alarm), task and condition as within-subject variables. There were no main effects: type of error, F <1; task, F(1,7) = 2.04; condition, F < 1. Only the interaction between type of error and condition was significant, F(1,7) =16.24, p <.01, with more target misses (5.3 %) and fewer false alarms (4.2 %) in the within-dimensional condition than in the cross-dimensional condition (target misses 4.2 %, false alarms 5.5%). Therefore speed accuracy trade-off effects were not apparent in the data.

Discussion

Relative to responding to a target of which the dimension is known but the feature value is not known, a cost was found in the feature search task for responding to a target of which the dimension is uncertain. In other words, if participants had to search for a target, they were faster to detect the target if they knew the dimension in advance. These results basically replicate previous obtained results (e.g., Müller et al., 1995; Treisman, 1988). More importantly, however, exactly the same results were obtained in the condition where there was nothing to search. In the non-search condition, there was only one element in the display and exactly the same cross-dimensional costs were found. Indeed, the interaction between type of task (search vs. nonsearch) and condition (cross vs. within) was not reliable (F<1) and 48 ms cost in the search task was comparable with the 42 ms cost in the non-search task. It might be that the main effect of task was obscured, since half of the participants performed first the search-task and then the non-search task, and half in reversed order. In the non-search task, the task was to identify the color of the target in order to discriminate it from the non-target. In the search task, however, only detection of the target was needed. It could be that the participants who first performed the non-search task, carried over this identity analysis to the search task. If this would be the case, it would be difficult to find an effect of task. However, there was no reliable difference, not even a tendency, between this group and the group which performed first the non-search task, F < 1.

Rts were faster if the target was repeated relative to when the target was different from the previous trial. This effect is similar to previous results (Found & Müller, 1996; Hillstrom, 2000). However, this effect was absent in the within-dimensional condition of the non-search task. It remains unclear why this absence occurred (see the results of Experiment 2, which did show this effect.

These results suggest that the cross-dimensional effect as typically is found in visual search tasks, may have nothing to do with attentional guidance. However, one may argue that in Experiment 1 there was still some guiding of spatial attention in the non-search task. Indeed, the exact location of the single target element varied from trial to trial. Thus, even though there were no nontargets, one could claim that it was possible that attention was guided to the target. Experiment 2 was designed to investigate this issue.

Experiment 2

In Experiment 2, the uncertainty of the target location in the non-search task in Experiment 1 was removed. In this experiment the target was always placed at the same location (i.e. in the middle of the screen). In this way, observers knew the location of the target, and there is no need for localizing the target.

Method

Participants. Eight undergraduates, ranging in age from 19 to 26 years participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus, Stimuli and Procedure. The apparatus was the same as in Experiment 1. The stimuli were the same as in the non-search condition of Experiment 1. The procedure was identical to the one in Experiment 1 with two changes. First, there was only a non-search task. Second, the target was always placed in the center of the screen.

Design. All observers participated in the within-dimensional condition and the cross-dimensional condition. These two conditions were blocked and presented in counterbalanced order. Participants received 18 practice trials before each condition. Each condition comprised 4 experimental blocks, with each block consisting of 45 trials. This resulted in a total of 360 experimental trials. For each condition, there were 90 target-present trials and 90 target-absent trials. On the target-present trials, each of the three targets were presented equally often. Within each condition, all types of trials were randomly varied. At the end of each block there was a short break in which the participants received feedback on their accuracy and reaction times.

Results

The analysis performed on the results was the same as in Experiment 1. Only the results of the response to the red circle were analyzed. Reaction times from incorrect response trials in response to the red circle (4.4 %) and reaction times more than 1100 ms (0.4 %), were excluded from the analysis.

Reaction Times and Error Analysis. We compared the mean reaction times of the responses to the red target in the within-dimension (color) condition with those in the cross-dimensional condition by means of a paired t-test. The average difference of 59 ms was significant, $t(7) = 3.8$, $p < .01$ (valid: 340 ms versus invalid: 399 ms). As in Experiment 1, a strategy effect needs to be excluded. There was a main effect of type of trial (target present vs. target absent), $F(1,7)=18.58$, $p <.01$. However, the RTs for target absent (391 ms) were slower relative to target present trials (370 ms).

The total number of errors in response to the red circle and to target-absent trials was 5.2 % (target misses 4.4 %, false alarms 5.9 %). The errors were calculated for each condition for each participant. An ANOVA was performed on these totals with type of error (target miss or false alarm) and condition as within-subject variables. There were no main effects: condition, $F < 1$; type of error, $F(1,7) = 2.59$, ns. The interaction was not significant, $F < 1$. This indicates that the results of the reaction times cannot be attributed to a speed-accuracy trade-off.

Table 1 gives the RTs and error percentages of Experiment 2.

Insert Table 1 about here

Intertrial effects. A two-way ANOVA was performed on the trials containing a red circle as target with condition (within dimension or across dimensions) and intertrial transition (same target or different target on the previous trial) as factors. Trials were excluded of which the previous trial was a target-absent trial. There was a main effect of condition, $F(1, 7) = 18.9$, $p < .01$, as was also shown in the reaction time analysis. There was also a main effect of intertrial transition, $F(1, 7) = 9.89$, $p < .05$, with target-repeating trials (342.5 ms) faster responded to than target-alternating trials (391.5 ms). The interaction was not significant, $F(1, 7) = 1.59$.

Discussion

Experiment 2 replicated the results of the non-search task of Experiment 1. A significant cost of 59 ms was found in responding to a target defined in an uncertain dimension relative to a known target-dimension. The intertrial effect was significant for both the within-dimensional condition and the cross-dimensional condition. This is in contrast with Experiment 1, in which the intertrial effect was absent in the within-dimensional condition of the non-search task. It is unclear why this difference occurred.

Since the target was consistently located in the center of the screen there was clearly no need to search. Taking together, the results of Experiment 1 and 2 show cross-dimensional costs and intertrial effects as have been reported in previous studies (e.g., Found and Müller, 1996; Müller et al., 1995), yet these effects occur in a task in which there is no need to guide attention to the target.

The presence of cross-dimensional costs and intertrial effects under conditions in which there is no search, indicates that search processes are not necessary to induce these effects.

A general framework which can explain these findings both under search and non-search conditions is the dimensional action model of Cohen and Shoup (1997; Cohen and Magen, 1999). These findings indicate that when the dimension one has to respond to does not vary from trial to trial (i.e., the within-dimensional condition), the response selection mechanism of a particular dimension (in our case, color) may get primed by the previous trial. In the cross-dimensional condition, there is no priming of just one dimension specific response selection mechanism, since both the color-specific and the shape-specific response selection mechanisms were necessary to perform the task.

Even though these findings suggest that the previously reported cross-dimensional costs may have nothing to do with search processes, one may argue that active trial-by-trial dimensional cueing may allow participants to set-up a top-down setting that enables to facilitate attentional guidance to the featural singleton. In a recent study, Müller et al. (2003) employed a trial-by-trial dimensional cueing procedure. Before each trial, a verbal cue (the word "color" and "shape") indicated the likely target-defining dimension. It is assumed that the cue allows participants to actively set themselves for the likely upcoming stimulus dimension. In terms of the dimensional weighting account (Müller et al., 2003) or guided search (e.g., Wolfe et al., 2003) it is assumed that participants use the advance cue to allocate attentional weight to the likely target dimension. In experiments 3 and 4, we used the same trial-by-trial procedure as Müller et al. (2003). However, instead of using a search task we used a non-search task in which only one element was presented in the display.

Experiment 3

In Experiment 3, identical to Müller et al (2003), a symbolic (verbal) cue indicated with 80 % probability the dimension of a single stimulus, presented in the middle of the screen: ‘color’ or ‘shape’. This resulted in two different types of trials: a valid dimension trial, in which the cue indicates validly the dimension of the target (e.g., the cue is ‘color’ and the target is a red circle); and an invalid dimension trial, in which the cue indicates a different dimension as the target dimension (e.g., the cue is ‘color’ and the target is a gray triangle). The main interests were the validity effects and the intertrial effects.

Participants. Twelve undergraduates, ranging in age from 18 to 27 years participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus and Stimuli. The apparatus was the same as in Experiment 1. The target could be a red or a green circle, a gray triangle or a gray square. The non-target was a gray circle.

Procedure. Initially, a verbal cue (“color” or “shape”) was presented at the center of the screen for 700 ms (see Figure 4). The cue was replaced by a fixation cross. After 850 ms, the stimulus was presented in the center of the screen for 200 ms. Participants had 2 seconds to make a response. When the observers made a error, a tone (300 Hz) was presented for 100 ms. The intertrial interval was 800 ms. The task was to respond as quickly as possible to the target with either left response (“z” -button) or right response (“/”). The four possible targets were mapped onto one response button and the target-absent trials were mapped onto the other response button. The response mapping was counterbalanced across participants.

Insert Figure 4 about here

Design. Participants received 100 practice trials, followed by 20 experimental blocks, each consisting of 50 trials. There was a total of 1000 experimental trials. Forty percent of the trials were target-absent trials and sixty percent target-present. On target-present trials, half the targets were defined in the color and half in the form dimension. The color targets were half red and half green; and the form targets were half triangle and half square. On target-absent trials, a gray circle was presented. In target-present trials, the cue indicated with 80 % probability the dimension of the target. All types of trials were randomly varied. At the end of each block there was a short break in which the participants received feedback on their accuracy and RTs. The independent variables were target (present, absent), and for target-present trials, cue validity (valid, invalid dimension), target dimension and, depending on the target dimension, target feature value (red, green, square, triangle).

Results

Reaction times from incorrect response to target-present trials (2.95%) and reaction times more than 1100 ms (0.2%), were excluded from the analysis.

Reaction Times. The averaged mean RT for target-absent trials was 393 ms. A repeated-measures analysis of variance (ANOVA) was performed on the individual mean reaction times of the target present trials with the cue validity (valid, invalid) and target dimension (color, shape) as factors. Both main effects were significant: cue validity, $F(1, 11) = 5.10$, $p < .05$ and target dimension, $F(1, 11) = 16.22$, $p < .01$. Color targets were detected faster than shape targets (380 vs. 399 ms); and RTs were faster on valid relative to invalid trials (375 vs. 404 ms). There was no significant interaction between cue validity and target dimension, $F(1, 11) = 1.48$, $p > .05$ (see Figure 5).

Insert Figure 5 about here

Intertrial effects. An ANOVA was performed on the valid target-present trials with target dimension (color, shape) and intertrial transition (same dimension, different dimension) as factors. Note that only the valid trials were analyzed. For invalid trials there were not enough trial transitions to perform a reliable analysis. Both target dimension (F(1, 11) = 14.03, p < .01) and intertrial transition (F(1, 11) = 11.64, p < .01) were significant. The interaction between target dimension and intertrial transition approached significance: F(1, 11) = 4.47, p = .058. RTs to targets (on trial N) with the preceding trial (N-1) containing a target defined in a different dimension (387 ms) were 21 ms slower than RTs to targets defined in the same dimension as in the preceding trial (366 ms). Planned comparisons were performed to further examine these effects separately for color targets and shape targets.

For the color targets (mean: 367 ms), irrespective of whether the target on trial N-1 was defined by the same feature value (348 ms), F(1,11) = 14.71, p <.01, or by a different feature value (358 ms), F(1,11) = 9.45, p <.05, a dimension change cost occurred, compared to RTs to color targets preceded by shape targets (380 ms). For the shape targets (mean: 386 ms), this dimension change cost was only caused by the trials in which the target was defined in a different feature value on the preceding trial (381 ms), F(1,11) = 8.21, p <.05. If the target on trial N-1 was defined in the same feature value as the target on trial N (377 ms), there was no reliable difference with dimension-change trials (393 ms), F(1,11) = 2.71. For both color targets and shape targets, feature repetition trials were not significant faster than feature alternation trials (color: F(1,11) = 4.51, p = .057; shape: F(1,11) = .17). In other words, there was no feature-specific intertrial facilitation effect, although for the color targets it was marginally significant.

Error Analysis. A repeated-measures analysis of variance (ANOVA) was performed on the target miss rates (2.95 %) with cue validity (valid, invalid) and target dimension (color, shape) as factors. Only the factor target dimension was significant, F(1,11) = 10.83, p < .01, with more errors in response to shape targets (3.6 %) relative to color targets (2.3 %). This mimics the reaction time data. There was no effect of cue validity, F < 1. The interaction target dimension and cue validity was not significant: F < 1. There was a 5 % false alarm rate.

Discussion

The results of Experiment 3 show that top-down modulation and bottom-up effects can be found in a non-search task. Typically, color targets are faster detected than shape targets. This finding corresponds to previous observations (Found & Müller, 1996; Hillstrom, 2000; Müller et al., 1995; Olivers and Humphreys, 2003). Symbolic cueing of the likely target dimension produced significant RT benefits for valid relative to invalid-cue trials (29 ms benefit). With valid dimension cues, there was a dimension-specific intertrial effect of 21 ms.

The current findings are basically the same as those reported by Müller et al. (2003). A valid cue gave faster RTs than invalid cues. They found a comparable cue-validity effect of 21 ms. Also, they found a dimension-specific intertrial effect of 10 ms for valid cue trials. Even though the cueing effects and intertrial effects were basically the same as in Müller et al, in the current task there was no search whatsoever. The target element was always presented in the center of the screen. Again, in line with our Experiment 1 and 2 the cueing effect that Wolfe et al (2003) would interpret as evidence for intentional top-down guidance of the visual search process may have nothing to do with visual search because in our task there was no search to perform.

Note that there was no feature-specific intertrial effect. However, for the color targets, the difference between feature-repetition trials and feature-alternation trials was almost reliable (see also Maljkovic & Nakayama, 1994; Found & Müller, 1996). This lack of a feature-specific intertrial effect (except for color) was also found in the study of Müller et al. (2003).

Experiment 4

According to the dimension weighting account (Müller et al., 2003), cues should speed processing of a particular dimension rather than a specific feature value. Experiment 4 examined whether a valid feature cue (e.g., cue is ‘red’ and the target is a red circle) would speed the response relative to invalid same dimension cue (e.g., cue is ‘green’ and the target is a red circle). Whereas in Experiment 3, the cue indicated the likely dimension of the upcoming target, in Experiment 4, the cue indicated with 80 % probability the likely feature value of the upcoming target. This resulted in three types of trials: either a valid trial, in which the cue indicated the feature value of the target, or an invalid same dimension trial, in which the cue indicated the correct dimension of the target, but cued another feature value as that of the target, and invalid different dimension trial, the cue indicated another dimension than the target dimension.

Participants. Ten undergraduates, ranging in age from 19 to 30 years participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus and Stimuli. The apparatus and the stimuli were the same as in Experiment 3.

Procedure. The procedure was the same as in Experiment 3, with the only change that the verbal cue reflected now the feature value of the target: “red”; “green”; “square”; or “triangle”.

Design. Participants received 2 practice blocks, followed by 20 experimental blocks. Each block comprised 50 trials. There was a total of 1000 experimental trials. Forty percent of the trials were target-absent trials and sixty percent target-present. On target-present trials, half the targets were defined in the color and half in the form dimension. The color targets were half red and half green; and the form targets were half triangle and half square. On target-absent trials, a gray circle was presented. The cue indicated with 80 % probability the feature value of the target, in the target-present trials. All types of trials were randomly varied. At the end of each block there was a short break in which the participants received feedback on their accuracy and RTs. The independent variables were target (present, absent), and for target-present trials, cue validity (valid, invalid same dimension, invalid different dimension), target dimension and, depending on the target dimension, target feature (red, green, square, triangle).

Results

Reaction times from incorrect response to target-present trials (4.47 %) and reaction times more than 1100 ms (0.03 %), were excluded from the analysis.

Reaction Times. The averaged mean RT for target-absent trials was 391 ms. A repeated-measures analysis of variance (ANOVA) was performed on the individual mean reaction times of the target present trials with cue validity (valid, invalid same dimension, invalid different dimension) and target dimension (color, shape) as factors. The main effect of cue validity was significant: F(2, 18) = 14.19, p < .001, with valid trials being faster detected (343 ms) than invalid different dimension trials (412 ms) and invalid same dimension trials (391 ms) intermediate. There was also a main effect of target dimension, F(1, 9) = 23.86, p < .001: color targets (371 ms) were faster detected than shape targets (393 ms). There was no interaction, F(1,9) = .66 (See Figure 6).

Planned comparisons were performed to further examine these effects. Relative to valid trials, there was a significant cost for invalid same dimension trials, F(1, 9) = 10.77, p < .01 and for invalid different dimension trials, F(1,9) = 15.91, p < .01. In other words, there was a feature-specific cueing effect. Also, there was a dimension-specific cueing effect, with invalid same dimension trials significantly faster than invalid different dimension trials, F(1,9) = 27.19, p < .001. When the cue indicated the correct target-dimension, targets were detected faster than when the cue indicated the incorrect target-dimension, F(1,9) = 19.4, p < .01.

The same pattern was found for color trials and shape trials separately. Invalid same dimension trials were slower than valid trials (color: F(1,9) = 9.16, p < .05; shape: F(1,9) = 11.62, p < .01), but faster than invalid different dimension trials (color : F(1,9) = 29.78, p < .001; shape : F(1,9) = 7.85, p < .05). Invalid different dimension trials were slower than valid trials, color: F(1,9)

= 16.08, p <.01; shape: F(1,9) = 14.69, p < .01. When the cue indicated the correct target-dimension, targets were faster detected than when the cue indicated the incorrect target-dimension, color : F(1,9) = 21.49, p < .01; shape: F(1,9) = 14.58, p < .01.

Insert Figure 6 about here

Intertrial effects. An ANOVA was performed on the valid target-present trials with target dimension and intertrial transition (same feature, same dimension, different dimension) as factors. Both main effects were significant: target dimension: F(1,9) = 14.53, p < .01, with color targets (330 ms) being faster detected than shape targets (354 ms) and intertrial transition: F(1, 9) = 9.37, p <.01, with feature repetition trials (338 ms) being faster detected than trials with the target defined in a different feature value than the previous trial (336 ms), and both trials faster than trials with a target defined in a different dimension than the previous trials (351 ms). The interaction between target dimension and intertrial transition was not significant: F(2,10) = .99.

Planned comparisons were performed to analyze dimension and feature change effects. There was no significant difference between feature repetition and feature alternation trials, F(1,9) = .18. In other words, there was no feature-specific priming effect. In contrast, there was a dimension-specific priming effect: relative to trials with a dimension change, dimension-repetition trials with feature repetition (F(1,9) = 8.46, p < .05) and with feature alternation (F(1,9) = 17.6, p < .01) were faster detected.

Error Analysis. A repeated-measures analysis of variance (ANOVA) was performed on the target miss rates (4.47 %) with cue validity (valid, invalid same dimension, invalid different dimension) and target dimension (color, shape) as factors. Only the factor cue validity was significant, F(2,18) = 9.69, p < .01, with more errors in response to invalid different dimension trials (7.4 %), intermediate in invalid same dimension trials (4 %) relative to valid dimension trials (2 %). This mimics the reaction time data. There was no effect of target dimension, F(1,9) = 1.7, ns. The interaction target dimension and cue validity was not significant: F (2, 18) = 1.1, ns. There was a 4.3 % false alarm rate.

Discussion

As in Experiment 3, there was a cue validity effect. Valid cueing resulted in faster detection of the target relative to invalid cueing. There was a dimension-specific cueing effect showed by faster detection of the trials with the same dimension as the cue, but another feature value, relative to trials with another dimension as the cue indicated. There was also a feature-specific cueing effect, with valid feature cued trials being faster than trials which are cued with a valid dimension but an invalid feature value. Although, the intertrial effects did not show a feature-specific intertrial effect (see for a feature-specific intertrial effect, Found & Müller, 1996; Maljkovic & Nakayama, 1994), there was a dimension-specific intertrial effect. Again, we found that color targets were faster detected than shape targets.

It is clear that cross-dimensional costs and intertrial effects can be found in tasks without a need for guiding spatial attention. It is not clear, however, what the nature is of these effects. Are they more perceptual in nature as Müller and Wolfe and their colleagues suggested or are they based on response-selection processes as Cohen and colleagues suggested? The next experiment was designed to make an attempt to disentangle these two hypotheses.

Experiment 5

Experiment 5 tested whether the cross-dimensional cost and the intertrial effects are related to perceptual or response selection factors. The non-search task of Experiment 2 was used with the addition of a compound non-search task. It is called a 'compound' task, since the to-be-reported attribute of the stimulus is not the same as the defining attribute of the stimulus (cfr. Duncan, 1985).

In this compound non-search task, participants had to respond to a line presented inside the stimulus. This line could either be vertical (e.g., press left) or horizontal (e.g., press right). It was assumed that if the cross-dimensional cost and the intertrial effects are perceptual in nature, the effects would also be present in the compound non-search task, since only the response requirements were changed. In contrast, if these effects would disappear in the compound non-search task, then it would be fair to attribute these effects to non-perceptual processes, such as response selection processes.

Participants. Twenty-four undergraduates, ranging in age from 16 to 29 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Apparatus and Stimuli. The apparatus and stimuli were the same as in Experiment 2, except for a few changes. There were two different tasks. One task was a replication of the non-search task of Experiment 2, a detection non-search task, with the only difference that the stimuli contained vertical and horizontal lines, which participants had to ignore. In the compound non-search task, the participants had to determine whether the line, presented inside the stimuli was either vertical or horizontal.

Procedure. The procedure was the same as in Experiment 2, with the only change that the stimulus display was presented until response. Participants had two seconds to respond.

Design. Half of the observers participated in the detection non-search task and the other half participated in the compound non-search task. Both tasks had two conditions, a within-dimensional condition and a cross-dimensional condition (see Experiment 1 and 2), which was presented in counterbalanced order. Participants received 50 practice trials before each condition. Each condition comprised 9 experimental blocks, with each block consisting of 40 trials. This resulted in a total of 720 experimental trials. In the detection task, for each condition, there were 180 target-present trials and 180 target-absent trials. On the target-present trials, each of the three targets was presented equally often. Within each condition, all types of trials were randomly varied. In the compound task, in each condition, there were 180 trials with a vertical line and 180 trials with a horizontal line. At the end of each block, there was a short break in which the participants received feedback on their accuracy and reaction times. The response mapping was counterbalanced across participants.

Results

The analysis performed on the results was the same as in Experiment 1 and 2. Only the results of the response to the red circle (either to the line presented inside or to the circle itself) were analysed. Reaction times from incorrect response trials in response to the red circle (3.3 %) and reaction times more than 1100 ms (0.64 %), were excluded from the analysis.

Reaction Times. A repeated measures ANOVA was performed on the individual mean reaction times of the target present trials with task (compound task or detection) as between-subjects factor and condition (within dimension or across dimensions) as within-subjects factor. There was no main effect of task, $F < 1$. There was an effect of condition, $F(1, 22) = 32.4$, $p < .001$. The interaction between task and condition was also significant, $F(1, 22) = 20.83$, $p < .001$. Planned comparisons showed that the effect of condition was present only in the detection task, $F(1, 22) = 52.59$, $p < .001$, but absent in the compound task, $F < 1$ (See Figure 7).

Insert Figure 7 about here

Intertrial effects. An ANOVA was performed on the trials with a red circle as target with task (compound task or detection), condition (within dimensions or across dimensions), and intertrial transition (same target or different target) as factors. The trials on which the previous trial was a target-absent trial were excluded from the analysis. There was no main effect of task, $F(1, 22)$

= 1.26, p = .274. The effect of condition was significant, F(1, 22) = 17.38, p < .001 (within: 439 ms, cross: 483 ms). There was a main effect of intertrial transition, F(1, 22) = 49.01, p < .001 (same target: 448 ms, different target: 474 ms). All the interactions were reliable, the interaction between task and condition, [F(1, 22) = 11.03, p < .01], between task and intertrial transition, [F(1, 22) = 43.61, p < .001], and between condition and intertrial transition,[F(1, 22) = 7.34, p < .05]. The three-way interaction between task, condition and intertrial transition was also significant, F(1, 22) = 9.28, p < .01. Planned comparisons showed that the intertrial effect was absent in the compound task, F < 1, but present in the detection task, F(1,22) = 92.54, p < .011. In the detection task, the intertrial effect was present for both conditions (within: F(1,22) = 25.16, p < .001; cross: F(1,22) = 63.17, p < .001). See Figure 8.

Insert Figure 8 about here

Error analysis. A repeated-measures analysis of variance (ANOVA) was performed on the target miss rates (3.4 %) in response to the red circle with task (compound task or detection) and condition (within dimensions or across dimensions). There were no significant effects: all F- values were smaller than 1. The false alarm rate in the detection task was 3.13 %, with no effect of condition, F < 1.

Discussion.

This experiment was conducted to investigate whether the cross-dimensional effect and the intertrial effects are the result of perceptual or response selection factors. The detection and the compound task had the same visual stimulation, only the response demands were different. If the results of the two tasks are identical, this means that the response requirements had no influence whatsoever. However, if there are differences in the results, this can only be due to the difference in response demands. The results showed a clear difference between the two tasks: the cross-dimensional cost and the intertrial effects were present in the detection non-search task, but were absent in the compound non-search task (see also Theeuwes, Reimann & Mortier, in press). These data are crucial for the localization of these effects. These findings show that these effects do not occur at the perceptual level, but rather at the response selection stage.

One might argue that there was no need to actually process the surrounding stimulus in the compound non-search task. Participants had to respond to a line segment presented inside a single object, presented in the center of the visual display. As there was always a line segment present, there was indeed no need to process the surrounding stimulus. Participants could have narrowed their focus of attention only to the line segment, and the stimulus would not be processed. Therefore, one may argue that it is not surprising that there were no dimensional based effects. Even though this is a viable explanation it should be realized that some processing of the surrounding stimulus occurred. In the cross-dimensional condition of the compound non-search task, there was an effect of type of target stimulus, $F(2,22) = 6.9$, $p < .005$. Participants were faster to respond to a line segment presented inside a red circle (479 ms), relative to a line segment presented in a gray big circle (488 ms) or in a gray triangle (491 ms). In other words, participants did process the surrounding stimulus. In addition, the actual RT to the line segment inside the red circle (479 ms) observed in the current task is similar to the RT observed in a comparable condition (Theeuwes, 1992; Exp.1) in which it was certain that observers had to search and process the red circle and respond to the line segment inside. Therefore, it is likely that observers did process the surrounding stimuli.

Note that the results of the detection task were a replication of the results of Experiment 1 (non-search task) and Experiment 2. As in Experiment 2, there was an intertrial effect in the within-dimensional condition. However, this effect was absent in the within-dimensional condition of Experiment 1. It is unclear why this difference occurred.

General Discussion

The present study has important implications for several leading visual search theories. Almost all visual search accounts (Müller et al., 2003; Wolfe et al., 2003) assume that top-down knowledge guides attention towards the target singleton. For example, the Guided Search (Wolfe et al., 2003) account assumes that top-down knowledge improves visual search for a singleton target. It is assumed that target selection is modulated by intentional, knowledge-based processes. Because processing is tuned to a specific dimension (i.e., the cued dimension), it is assumed that visual search for the relevant feature dimension is speeded. This mechanism explains benefits for within-dimensional over cross-dimensional search, dimension-specific intertrial effects and explains advance dimension cueing effects. The current study replicates these findings but demonstrates that these effects have nothing to do with actual guidance of search. The present results were obtained in a task in which there was no guidance of search because there was nothing to search for. Furthermore, these effects disappeared when the response requirements were changed. Indeed, in Experiment 5 in both tasks (non-search detection and non-search compound) exactly same visual stimuli were presented, but the response requirements were different. Just by changing the response requirement the reliable cross-dimensional and intertrial effect that occurred in the detection task completely disappeared in the compound task. This experiment demonstrates that effects that typically have been attributed to early top-down visual modulation (e.g., Müller et al, 1995; Found & Müller, 1996; Wolfe et al. 2003) may represent effects that occur much later in processing, possibly related to response selection.

Experiment 1 and 2 investigated whether the cross-dimensional cost and intertrial effects, typically attributed to search processes (e.g., Wolfe et al., 2003), would persist in a non-search task.

The results showed a significant increase in RTs of 42 ms in Experiment 1 and 59 ms in Experiment 2 when the dimension defining the target was not known in advance relative to if the target-defining dimension was known. Both experiments showed a significant facilitation of target-repetition as is found in previous studies (e.g., Hillstrom, 2000).

Experiment 3 and 4 were designed to test whether cueing effects regarding the identity of the target (the dimension or the feature value) found in a feature search task (e.g. Müller, Reimann, & Krummenacher, 2003), could also be found in a non-search task. Experiment 3 showed that cueing the dimension of a target resulted in faster detection of the target relative to invalid cueing. Experiment 4 revealed also a dimensional validity effect, with a feature-specific cueing effect. The intertrial effects in Experiment 3 showed besides a dimensional intertrial effect also a feature-specific intertrial effect, but only for color targets. The intertrial effects in Experiment 4 revealed only a dimension-specific intertrial effect. Thus, there was a feature-specific intertrial effect present when the target was cued by a verbal feature value, but absent when the target was cued by a verbal dimensional value. It could be that a feature-cue sums up with the feature-specific intertrial effects, resulting in significant intertrial effects. Whereas a dimensional cue can only influence dimensional intertrial effects and no feature-specific values.

Experiment 5 was designed to determine whether the effects occur on a perceptual level or more on a response selection stage. The results showed a clear distinction between the detection task and the compound non-search task. In the detection task, the cross-dimensional cost and the intertrial effects were present, whereas in the compound task these effects were absent. These findings suggest an interpretation in terms of a response-based account. Our findings are in line with data presented by Wolfe et al.(2003, Experiment 6). Similar to our set-up, Wolfe et al. used a detection or compound non-search task. They reported clear cross-dimensional costs in the detection non-search task (of about 114 ms), but hardly any costs in the compound non-search task (of about 12 ms). These findings are the same as we report here. Note that if the cross-dimensional cost is attributed to the deployment of attention, this cost should be around zero in the detection non-search task, since there is nothing to search for.

Even though Wolfe et al. (2003) and the present study found no cross-dimensional costs and intertrial effects in a compound non-search task, the literature is less clear cut regarding cross-dimensional costs and intertrial effects in a compound search task. On the one hand, Kumada (2001, Experiment 1a and 1b) showed cross-dimensional costs and intertrial facilitation effects in a detection search task but not in a compound search task. In line with these results, Theeuwes, Reimann and Mortier (in press) found dimensional cueing effects in a detection search task, but not in a compound search task. In contrast to Kumada (2001), Krummenacher et al. (2002) found a cross-dimensional cost and dimension-specific intertrial effects in a compound search task in which subjects had to discriminate between left or right pointing stimuli. Also Wolfe et al. (2003, Experiment 5) found a cross-dimensional cost and a dimensional intertrial effect in a compound search task. At this point it is not clear why some find cross-dimensional cost and dimension-specific intertrial effects in a compound search task while other do not. The bottom-line however is that in a non-search task as we employed here (Experiment 5) the compound task did not result in cross-dimensional costs and intertrial effects, a finding that is similar to that reported by Wolfe et al (2003, experiment 6).

The present obtained results are in line with the dimensional action account suggested by Cohen and colleagues (Cohen & Magen, 1999; Cohen & Shoup, 1997; Cohen & Feintuch, 2002). In a within-dimensional condition the observers know the dimension in which the target will appear. According to their model, this knowledge primes the relevant dimension-specific response selection mechanism. In contrast, in the cross-dimensional condition, there are more response selection mechanisms necessary to perform the task. As a result, the priming in the within-dimensional condition gives an advantage relative to cross-dimensional condition. With this model the cross-dimensional cost in Experiment 1 and 2 could be explained. This view could also be applied to the cueing effects found in Experiment 3 and 4. A valid cue in Experiment 3 indicates the dimension of the upcoming target. In that case, the dimension-specific response selection mechanism will be primed, or will receive larger weight relative to an invalid cue, which primes a different (the wrong) selection mechanism. In Experiment 4, the valid cue indicates the target feature value. According to the response-based account, a feature cue primes the dimension-specific response selection mechanism. Indeed, dimensional cueing effects were obtained.

Note however, that in the present feature cueing experiment, there were also feature-specific cueing effects. This can also be explained by Cohen’s dimensional action account. The feature-specific cueing effects could be attributed to decision processes after the target has been selected (see also Theeuwes, 1992, 1994). It seems that these feature cues assign a larger weight to a specific feature-to-response mapping. As noted in the paper of Cohen and Shoup (1997, p.174), ‘the response selection system can have direct access to the feature maps within each dimension”.

Furthermore, the intertrial effects in the present study are also in line with a dimensional action account. The dimension-specific intertrial effects of Experiment 3 and 4 can be explained in a similar vein as the cueing effects. A certain trial is responded to faster if the same response-mapping for target dimension is repeated relative to when it is not repeated. This mechanism can also be applied to the feature-specific intertrial effects in Experiments 1, 2, 3 and 5. It could also be that intertrial effects are a result of perceptual priming (see also Olivers & Humphreys, 2003). However, if this was indeed the case, we should find also feature-specific intertrial effects as well for the shape targets in Experiment 3, as for Experiment 4 for both target dimensions, and also in the compound task of Experiment 5.

It is plausible to assume that cross-dimensional costs and intertrial effects have a locus in more decisional or response selection processes. The results of Experiment 5 are totally in agreement with the dimensional action model of Cohen and colleagues (Cohen & Shoup, 1997; Cohen & Magen, 1999; Cohen & Feintuch, 2002). The stimulus-to-response-mapping in the compound task is between the horizontal line (inside the target) and a key press or between the vertical line and another key press. In other words, there is only one response-selection mechanism necessary to perform the task. This is the case as well for the within-dimensional condition as for the cross-dimensional condition. This explains why there are no differences between these two conditions. As already noted though, there are contradictory findings concerning the presence or absence of these effects in compound tasks.

In line with the dimensional action model proposed by Cohen and colleagues, we adhere the position that perceptual analysis may proceed in parallel across the visual field. However in order to select a response focal attention must be shifted to the location of the target. The crucial question addressed here is whether cross-dimensional and intertrial effects operate on processes that occur before attention is shifted to the location in space (i.e., involved in guidance of attention to the location of the target; cfr, Wolfe et al., 2003) or occur after attention is focused on the location of the target. Obviously, since the present paper shows that without search, similar effects can be obtained, we believe that cross-dimensional and intertrial effects operate on processes that occur after attention has been shifted to the location of the target.

It is clear that the present findings can be explained by a response-based account. However, previous research has also shown a cross-dimensional cost in a non-search task and explained this finding by the dimensional weighting theory (Müller and O´Grady, 2000). Even though Müller and O´Grady (2000) also used a single stimulus in the center of the display, the paradigm was very different. In Experiment 2 of their study, participants had to judge two attributes of a single object, either belonging to the same dimension, e.g., the dimension form: line size and texture, or belonging to two different dimensions, e.g.: form (texture) and color (hue). The stimulus displays were presented briefly and then masked. Response accuracy was measured and there was no time pressure. Judgment accuracy was reduced for the condition in which participants had to judge two attributes, each in one dimension, relative to the condition in which these two attributes were in one dimension. Müller and O'Grady (2000) interpreted this cross-dimension cost as evidence for "a limit to the attentional weight that can be allocated at any one time to the various dimensions on which on object is defined" (Müller & O´ Grady, 2000, p.1349). This is in line with the dimensional weighting account, which states that the attentional weights allocated to the visual dimensional modules are limited. As suggested by Müller and O'Grady (2000) the effect most likely has it origin in perceptual processes rather than in response-related processes, since the stimulus displays were presented briefly and then masked. Since participants had ample time to respond, the argument is that the effect cannot be response related. It seems that this result is in contrast with a response-related account for dimension-based effects. However, there are two important differences between the cross-dimension cost found in the study of Müller and O´ Grady (2000) and the cross dimensional cost which occurred in the search-task and in the non-search tasks as presented in this study. First, the cross-dimension cost in the study of Müller and O´ Grady (2000) is different from the typical cross-dimensional cost as found in classic visual tasks (e.g., Müller et al., 1995; Treisman, 1988) and costs found in the current non-search task. In the study of Müller and O´ Grady (2000), an object needed to be selected followed by a judgment of the two object-attributes in two different dimensions. A switch from one dimension to the other for each trial is necessary to give the two correct responses. In contrast, the typical cross-dimensional cost comes from switches on a trial-by-trial basis. That is, in a cross-dimensional condition, participants have to respond to a target in one dimension in one trial, while on the next trial, they might have to respond to a target in another dimension. Second, related to the first, in the cross-dimensional condition of Müller and O´ Grady's study, participants know in advance the two dimensions they are required to judge. In contrast, in the cross-dimensional condition of the present study, participants do not know prior to target presentation the dimension in which the target will occur, so they do not know to which dimension they have to respond.

Still, it might be possible to explain the present results in terms of dimensional weighting. As was suggested in the study of Müller and O´Grady (2000), even in a non-search task, participants still have to segregate the stimulus from the empty background and a saliency signal needs to be computed, just as in a visual search task. In the framework of dimensional weighting, this computation is dimension-specific. For example, in a within-dimensional condition, the target-defining dimension is known in advance, so that dimension is assigned a larger weight than the other dimensions. On the other hand, in a cross-dimensional condition, the dimension of the target is not known in advance, and thus no specific dimension receives a larger weight. This interpretation is possible; yet it is hard to maintain such a position when the effect size for search with distractors is basically the same as non-search without distractors (see our Experiment 1). Indeed, one would expect that the role of a saliency signal is much larger when distractors are present than when they are absent.

It is important to note that some recent fMRI studies also provided evidence for the dimensional weighting account (Pollmann, Weidner, Müller & von Cramon, 2000; Weidner, Pollmann, Müller & von Cramon, 2002). A distinct network of brain structures was raised tonically during epochs starting from a switch to that dimension until a switch to the alternative dimension in cross-dimensional conjunction search. This supports the assumption that there exists visual dimension-specific modules in which stimuli are analyzed into basic features, which is commonly assumed. Furthermore, this was interpreted as a dimension-specific ´ memory´ that biases the system towards detecting signals in the respective dimension. However, with respect to the current debate (whether the effects are perceptual or response-based), it is not clear whether these activations represent processes associated with perceptual or response selection analysis. It is clear that dimension-pecific modules exist, however, it is unlikely that fMRI data can resolve the dispute whether these effects are perceptual or response related in nature. Even though the dimensional weighting account can explain most of the present results, it should be noted that it has difficulties to explain the findings of our Experiment 5. Müller and colleagues (Müller et al., 1995, 2003) would predict the same cross-dimensional cost and the intertrial effects in a compound task relative to a detection task, since these effects are assumed to be perceptual. If the visual stimulation remains the same, but the response demands are different, than no difference in perceptual processing is needed. However, the results showed a difference in response selection or response mapping mechanisms in the compound task relative to the detection task. To account for these results by a perceptual account, one has to assume that the perceptual stimulus analysis is different in both tasks, since both tasks require a different analysis of the stimulus in order to give the correct response. Müller et al. (2003) suggest that detection responses can be triggered directly on the detection of activity in the overall-saliency map without requiring focal attentional analysis. In this sense, a response-related role is ascribed to the activity of the saliency map units (see Müller et al, 2003, p. 1033). This means that also the response selection mechanisms are dimensionally weighted. This line of reasoning makes it difficult to differentiate between this account and the response-based account.

In sum, the present study showed that specific effects, typically attributed to top-down guidance of search processes, also occur in conditions in which there is no search. Moreover, these effects disappear when the response requirements are changed, but the visual stimulation remains the same. Therefore, we conclude that these effects are the result of later processes, presumably response selection.

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Figure Captions

Figure 1: An example of a trial sequence in the search task and non-search task of Experiment 1. The fixation cross was presented during 700 ms, followed by the stimulus display presented during 200 ms on a black background. Observers had 2 seconds to respond.

Figure 2: Experiment 1: Mean reaction time for target-present trials in the search task as a function of Condition (within dimension or across dimensions) and Display Size (3, 6 or 9).

Figure 3: Experiment 1: Mean reaction time for target present trials as a function of Condition (within dimensions or across dimensions) and Task (search or non-search).

Figure 4: An example of a trial sequence of Experiment 3. A verbal cue indicated with 80% validity the dimension ("color" or "shape") of the single stimulus. The cue was presented during 700 ms, followed by the fixation cross during 850 ms on a black background. The stimulus display was presented during 200 ms. Observers had 2 seconds to respond.

Figure 5: Experiment 3: Mean reaction time and error percentages for target present trials as a function of Cue Validity (valid or invalid dimension) and Target Dimension (color or shape).

Figure 6: Experiment 4: Mean reaction time and error percentages for target present trials as a function of Cue validity (valid, invalid same dimension, invalid different dimension) and Target Dimension (color or shape).

Figure 7: Experiment 5: Mean reaction time and error percentages as a function of Task (compound or detection) and Condition (within dimensions or across dimensions).

Figure 8: Experiment 5: Mean reaction time and error percentages as a function of Task (compound or detection), Condition (within dimensions or across dimensions) and Intertrial effects (same target or different target on the previous trial).

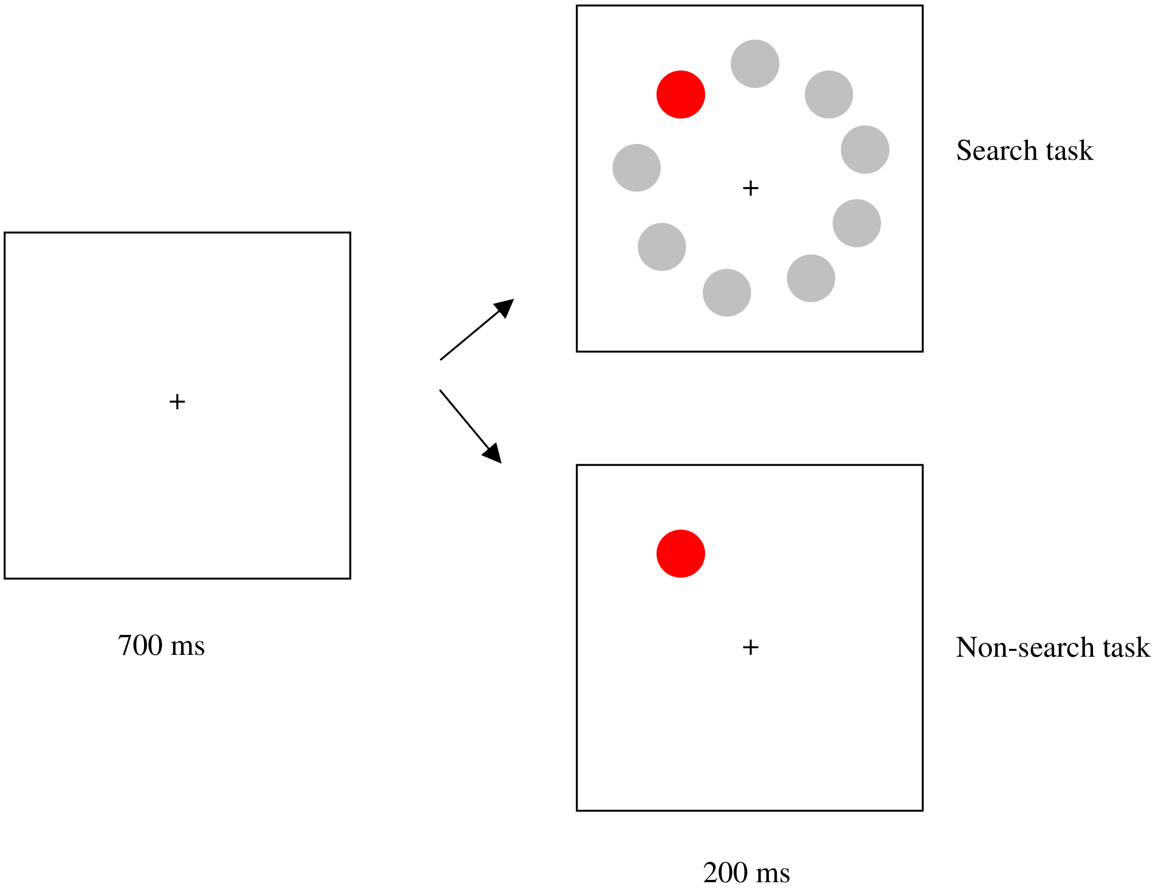
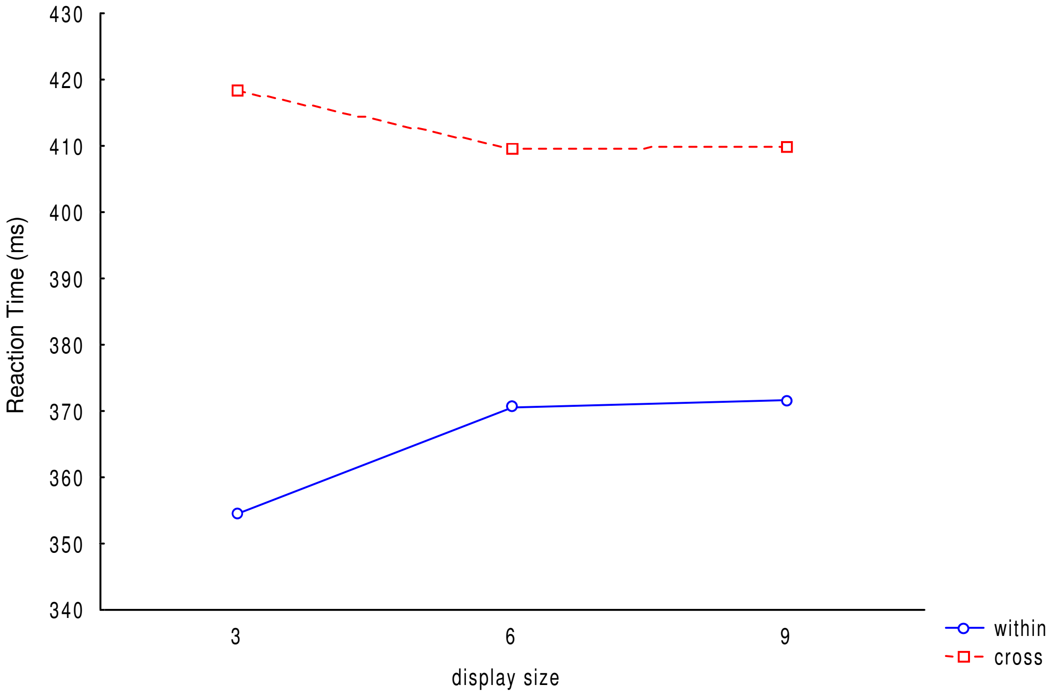


Figure 1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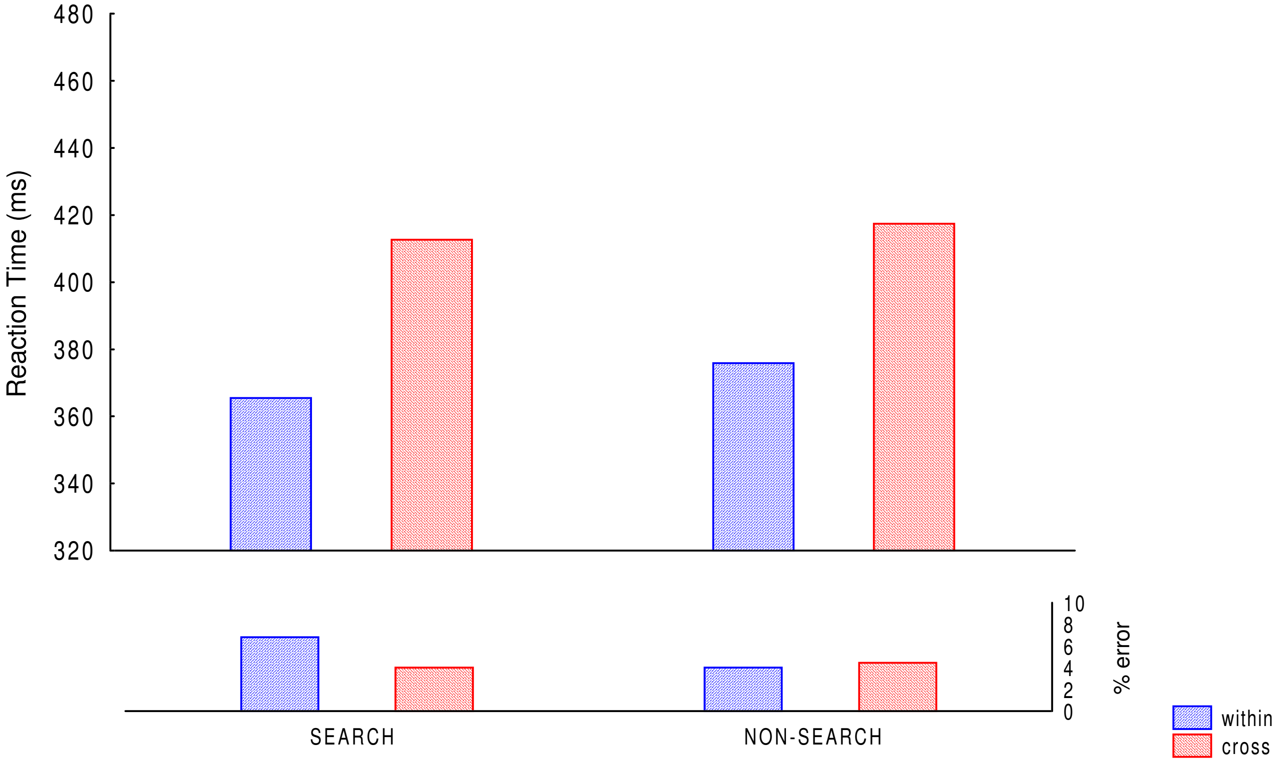
410
400
390
380
370
360
350
340
Reaction Time (ms)
3
6
9
display size
within
cross

Figure 2


Reaction Time (ms)
480
460
440
420
400
380
360
340
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10
8
6
4
2
0
% error
SEARCH
NON-SEARCH
within
cross

Figure 3

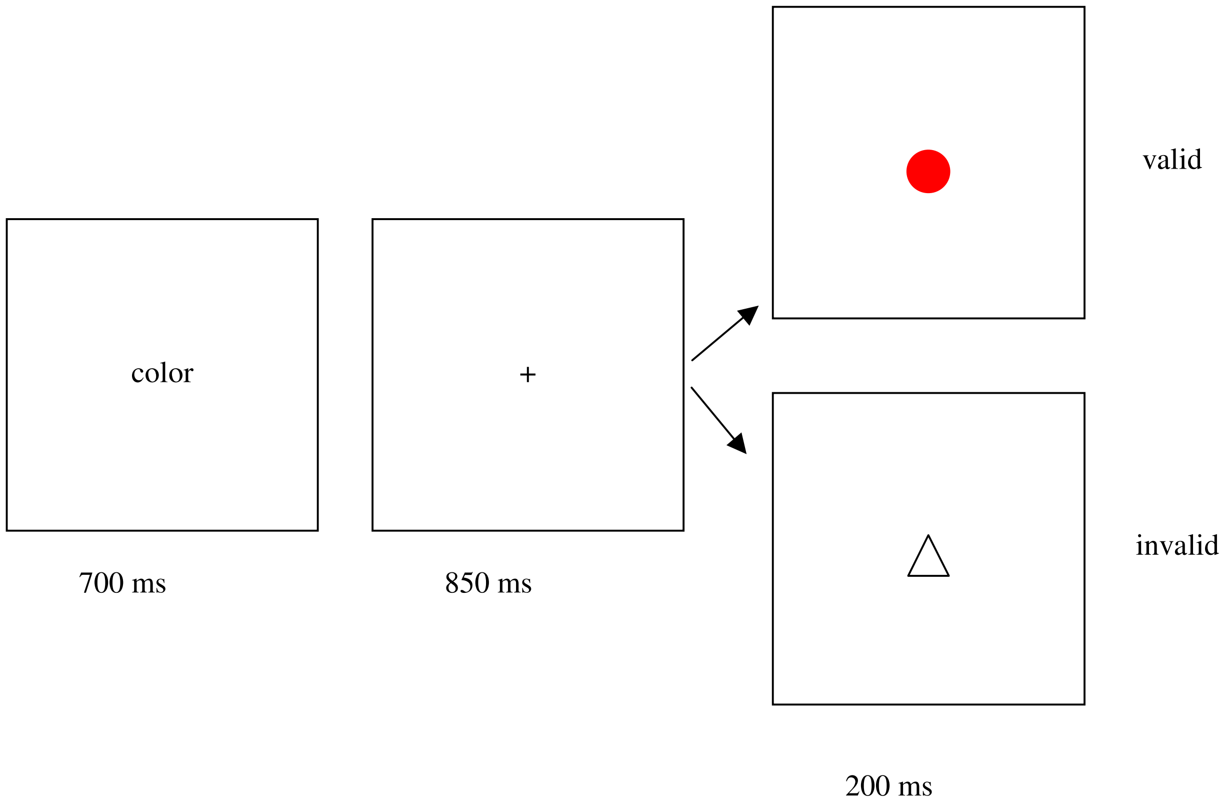
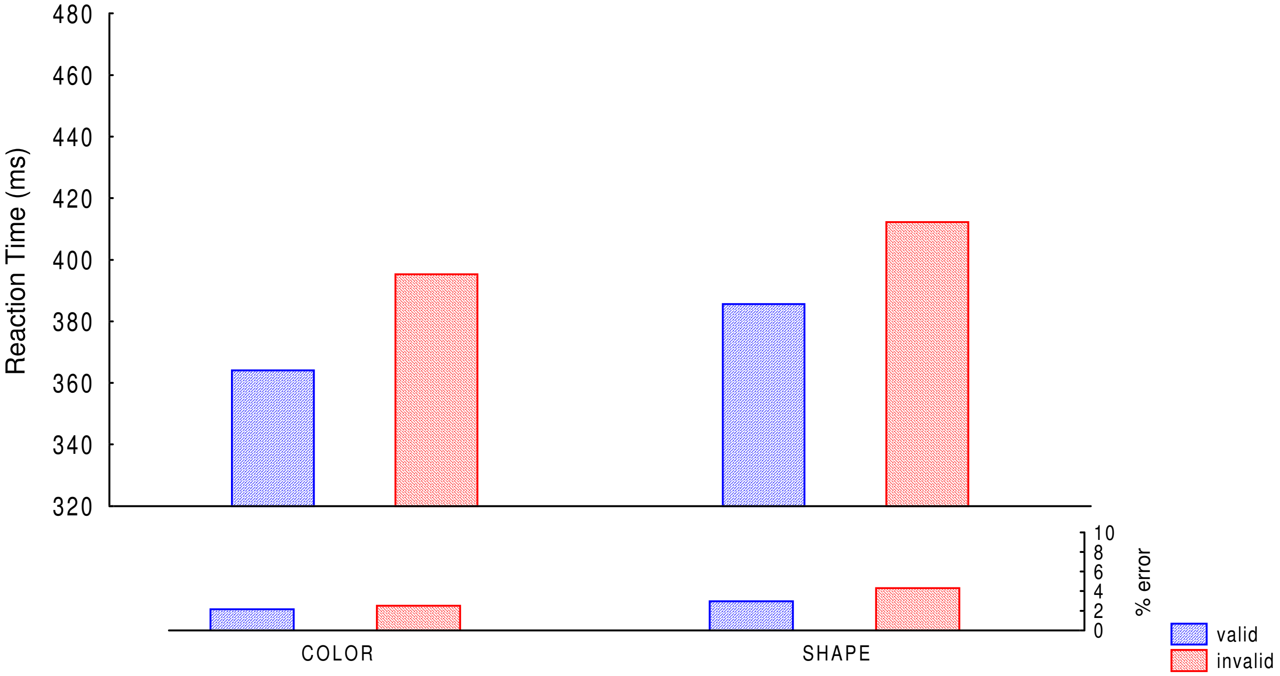


Figure 4


480
460
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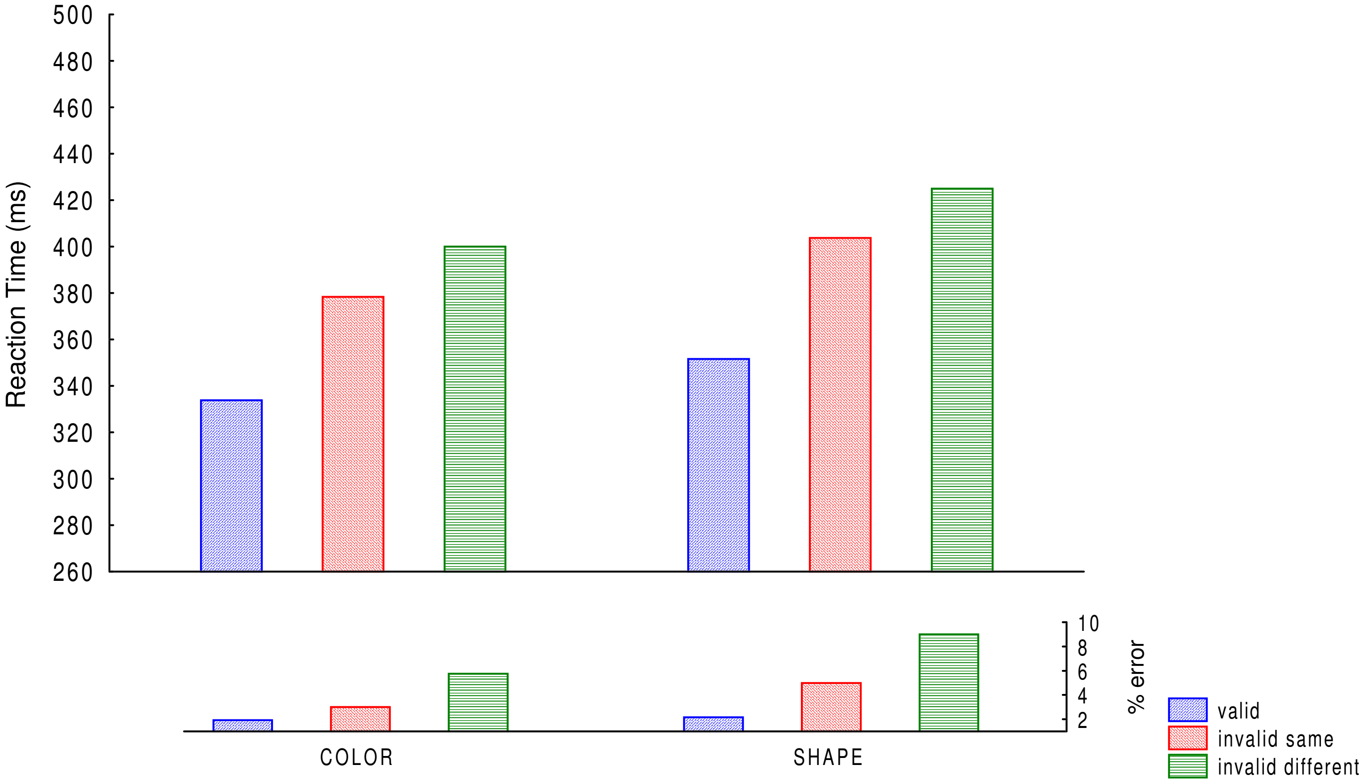
420
400
380
360
340
320
Reaction Time (ms)
10
8
6
4
2
0
% error
COLOR
SHAPE
valid
invalid

Figure 5


Reaction Time (ms)
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480
460
440
420
400
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360
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260
10
8
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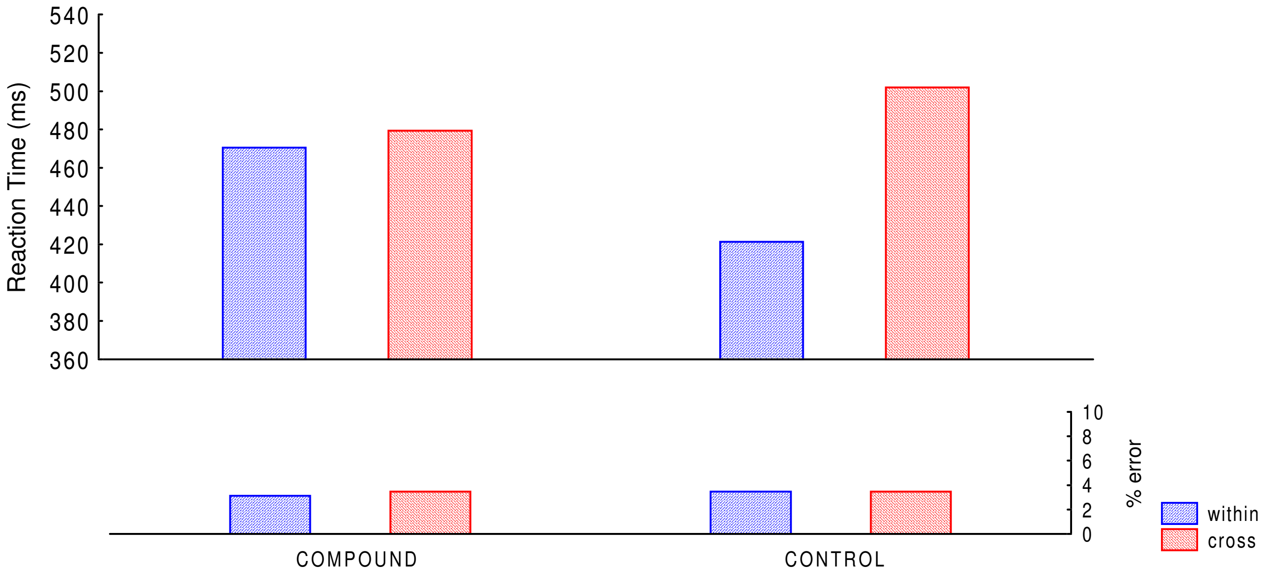
2
% error
COLOR
SHAPE
valid
invalid same
invalid different

Figure 6


Reaction Time (ms)
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520
500
480
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440
420
400
380
360
10
8
6
4
2
0
% error
within
cross
COMPOUND
CONTROL

Figure 7

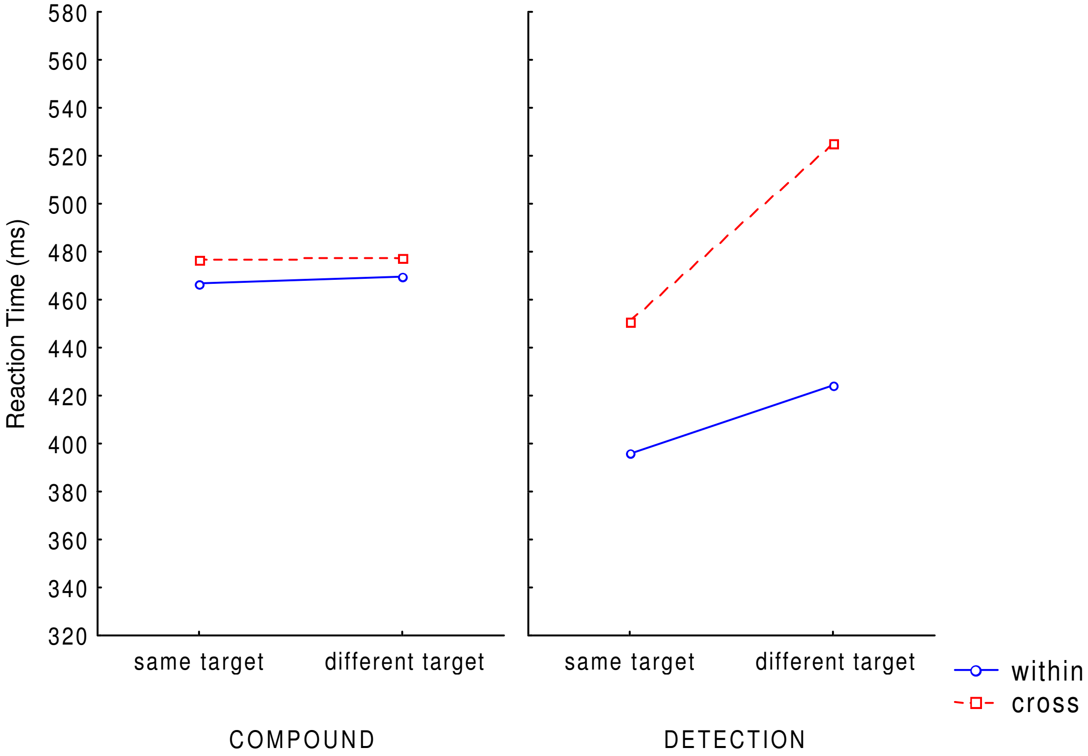
Reaction Time (ms)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
same target
different target
same target
different target
COMPOUND
DETECTION
within
cross

Figure 8

Tables

Table 1. Mean reaction times and error percentages (between brackets) in response to the red circle with mean reaction times for the target absent trials and percentages of total errors (between brackets) in italics in Experiment 2, for within-dimensional condition and cross-dimensional condition.

Table 1

	Condition	
Experiment 2	Within-dimension	Cross-dimension
Non-search	340 (3.75 %) *366 (5%)*	399 (5.8 %) *417 (6.9 %)*