

# **Cueing the dimension of a distractor: Verbal cues of target identity also benefit same-dimension distractor singletons**

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## **Abstract**

Cueing the identity of an upcoming target speeds its detection. These effects are generally assumed to operate on the level of the target dimension, not its feature identity. Here, we investigated whether that was the case in a design in which preparing for a cued dimension would incur costs as well as benefits. Participant searched for targets that could be defined on several dimensions, but were also presented with distractors that were defined on the same dimensions. Cueing the identity of an upcoming target increased the effect of distractors defined on the same dimension as the target. This suggests that cueing a target's identity has effects that operate at least partly at the level of the target dimension.

**Key Words:** attention, top-down set, visual search, singleton, guided search

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## Introduction

We spend a lot of time searching for things, such as a traffic sign at a busy crossroad, our car in the parking lot or one of our kids in a busy shopping mall. Common sense suggests that knowing what we are looking for helps this search process. For example, when searching for one of our lost kids in at the daycare center, we try to remember what the child was wearing that day so that the exact color of the sweater may guide our search process.

Almost all theories of visual search assume that pre-knowledge of specific properties of the target will generate top-down activation that can guide the search process (Müller, Heller, & Ziegler, 1995; Müller, Reimann, & Krummenacher, 2003; Treisman, 1991; Wolfe, 1994, 1998; Wolfe, Butcher, Lee, & Hyle, 2003). Top-down activation refers to the extent to which an item matches the current attentional set. Even though there is general agreement that pre-knowledge may guide search there is some controversy at what level top-down guidance operates. Some theories maintain that top-down attentional set can only operate on specific dimensions such as color, shape, and luminance (see Müller et al., 1995; Müller et al., 2003; Treisman, 1991). Others (e.g., Wolfe et al., 2003) suggest that top-down set can operate both on stimulus dimension as well as on specific levels within such a dimension (e.g., direct attention to the color red or a left tilted line segment). Finally, in some models of attention there is no reference to any stimulus dimensions but it is claimed that top-down activation may directly act upon pre-attentive features (e.g., Navalpakkam & Itti, in press).

When confronted with a display in which one element is unique in a basic visual dimension (such as a red element surrounded by green elements) one is able to immediately detect this element without any effort. Elements that pop-out from the display are referred to as feature singletons or simply singletons. It is generally assumed that when confronted with such a display, it is segmented in parallel, as a set of basic stimulus attributes in different dimension-specific 'modules' (such as color, orientation, etc.). When in a singleton search task the target may be defined on one of two or more dimensions, performance typically suffers relative to the case in which there is only one possible target dimension (Found & Müller, 1996; Müller et al., 1995; Treisman, 1988). In such experiments, participants have to detect the presence or absence of a singleton target among homogeneous filler elements. The target can be defined by for example a unique color, or a unique orientation.

While knowing the actual feature value of the target (e.g., whether it is blue or red) hardly speeded search, Treisman (1988) showed that knowing the dimension of the target (whether it would be a unique color or a unique shape) speeded search by about 100 ms. Treisman (1988) suggested that there is no top-down selectivity within dimensions; yet, across dimensions knowing in what dimension the target will be presented speeds up search significantly. In this study knowledge of target identity was manipulated by presenting different targets either in different blocks, or by randomly intermixing them. This confounds target knowledge with the automatic priming effects that have also been observed in visual search (Müller et al., 2003). A way to disentangle expectancy and priming effects is to randomly intermix different targets, but to inform participants of the dimension of the upcoming target with a symbolic cue. Such cueing also speeds target detection (Müller et al., 2003; Theeuwes, Reimann, & Mortier, in press): If a color target is preceded by a cue consisting of the word "color", it is found faster than if no cue is provided, or if the word "orientation" is incorrectly given as cue.

In agreement with Treisman (1988), Müller et al. (2003) suggest that effects of the cue operate at the level of the target dimension, not at the level of its feature value. In their Experiment 3, they cued target features instead of dimensions. For example, green targets were cued with the word "green" instead of with the word "color". When a cue for a particular feature was followed by a target that was defined by another feature on the same dimension (e.g., a "red" cue followed by a green target), performance was still better than when no feature was cued. Moreover, for the orientation dimension the difference between a correct feature cue, and a cue that cued the correct dimension but the wrong feature, was not reliable (e.g., a right oblique target was detected equally fast after a "left oblique" cue as after a "right oblique" cue). If one sees the benefit of cueing as the result of preparation, it seems that participants prepare for a target dimension, and not a target feature.

Although these experiments suggest that cueing normally operates at the level of dimensions, it is unclear to what extent preparation for target dimensions (and not target features) is obligatory. In other words, is it impossible to prepare for just the target feature? Or is it simply more beneficial to prepare for a whole dimension? Indeed, if there are no obvious costs associated with preparing for all features of a particular dimension, as opposed to preparing only for one feature of that dimension, then one simply may not see feature-specific preparation in the data. Observers simply prepare for all features of a dimension because preparation for a whole dimension is just as easy as preparing for just one feature.

A design in which preparing for all features in a given dimension would incur costs as well as benefits would enable an assessment of whether preparing for a dimension instead of for a feature is obligatory. A manipulation to ensure costs as well as benefits is to include distractor singletons, which can be defined on either the cued or the uncued dimension. If distractor singletons slow responses more when their dimension is cued than when it is not cued, one can conclude that preparing for a dimension, as opposed to preparing for a feature, is obligatory.

## Methods

To investigate the effects of dimensional cues on distractor singletons, participants had to find a target that could be defined on one of two dimensions, while disregarding possible distractor singletons that were defined on the same dimensions. Targets could either be green or oblique gray stripes, both of which popped out against a background of vertical gray elements (see Figure 1). Distractor singletons were either red or horizontal.

On some trials, the search display was preceded by a verbal cue that predicted the identity of the target with 100% validity (e.g., after a “color” cue participants knew that a target would be either green or absent). We investigated the effects of these cues on distractor singletons. If cueing the identity of a target elicits preparation for the target dimension, distractor singletons should have a larger effect on RT when they are defined on the dimension corresponding to the cue, than when they are defined on the uncued dimension (e.g., red distractor singletons should slow responses more after a “color” cue than after an “orientation” cue). If cueing elicit preparation for the target feature alone, cueing should not change the effect of distractor singletons.

It is possible, though not very likely, that observers prepare for a dimension after a dimension cue, and for a feature after a feature cue. We therefore conducted two experiments, Experiment 1A and 1B. In Experiment 1A, observers received cues that indicated the target’s dimension, while in Experiment 1B they received cues that indicated the target’s feature.

Cueing the distractor singleton is confounded with cueing the target. For example, a ‘color’ cue may lead to better processing of red distractor singletons, but it also enhances processing of green targets. To disentangle the effects of cues on distractor singletons from the effects of cues on targets, we only investigated the effect of cues on distractor singletons in trials in which the target would equally benefit from ‘color’ and ‘orientation’ cues. There are two categories of trials for which this is the case: target absent trials, and trials on which the target is an oblique green stripe (i.e., a target that pops out on both dimensions). Following Krummenacher et al. (2001), we call the oblique green targets *redundant targets*. On trials with such redundant targets, both dimension cues cued the target, but cues could match or not match the distractor singleton dimension. This allows a clean measure of the effect of cueing on distractor singletons. If cues affect distractor singletons there should be an interaction between the dimension that is cued, and the dimension of the distractor singleton. In particular, red distractor singletons should increase RT more after a ‘color’ cue than after an ‘oblique’ cue, while the opposite should be true for horizontal distractor singletons. On target-absent trials cueing cannot affect processing of a target either. We therefore tested the same hypothesis for target-absent trials.

Although our hypotheses are tested only on trials with redundant targets and on target-absent trials, we also included trials with green targets and oblique targets to give participants an incentive to heed the cues. If all targets had been green *and* oblique, a cue would not have been informative about target identity.

In summary, we set out to test three hypotheses. First, cueing should lower RTs. Second, for redundant target trials, there should be an interaction between cue identity and distractor identity, in that RTs should be slowed more when cue and distractor identity match. Third, the same interaction should be present for target-absent trials.

## Participants and apparatus

Eight observers participated in Experiment 1A for a small monetary compensation (4 men, 4 women, mean age 21). Sixteen observers participated in Experiment 1B (10 women and 6 men, with mean age 24). All had normal or corrected-to-normal eyesight, and normal color vision. They were seated in a dimly-lit room, at a distance of approximately 70 cm from a 21-inch monitor.

## Stimuli

Search displays consisted of 13 \* 9 line elements, covering an area of 8.2° by 7.4° of the visual field (see Figure 1). Targets and distractor singletons were present on half of the trials, and target and distractor presence were varied independently of one another (e.g., on 50% \* 50%=25% of trials a target and distractor singleton were both present). Filler line elements were vertical and gray, with a height of approximately 1° and a width of .16°. Targets were the same size as the filler elements, and could be a green color singleton, a right oblique orientation singleton (30° rotation), or, for redundant targets, a green oblique line element that was both a color and orientation singleton. Distractor singletons were either a red singleton (color distractor) or a horizontal singleton (orientation singleton) of the same size as filler elements. If present, targets and distractor singletons replaced one filler element on one of six positions on an imaginary circle of 5.5° diameter around the fixation point. Location of targets and distractor singletons was randomized, with the proviso that both could not be at the same location. In the display shown in Figure 1, an orientation target in the upper left quadrant is accompanied by a color distractor singleton to the right of fixation.

## Procedure

We used a factorial design with five factors: target presence, target identity, distractor presence, distractor identity, and cueing. A sixth factor, cue identity, covaried with target identity. Trials were organized in six blocks of 72 trials, preceded by 40 practice trials. In four blocks trials were preceded by a symbolic cue. In Experiment 1A, these were dimension cues: either the word “color” or the word “oblique”.<sup>1</sup> In Experiment 1B, they were feature cues denoting the target feature: either “green” or “right” (for right oblique). Both sets of cues were equally predictive, as only one target could appear after either a dimension or a feature cue.

In the two remaining blocks, no cue was given. Instead, a star preceded the search display. Order of presentation of the blocks was randomized. Cues were 100% valid, always predicting the dimension of the target if there was one. Target presence, target identity, distractor presence, and distractor identity were all randomly intermixed.

Trials began with a 400 ms presentation of a small fixation circle. Then, the cue (or a star in no-cue trials) was presented for 750 ms, followed by another 750 ms presentation of the fixation circle. Then the search display was presented until the participant responded. They were required to respond in target-absent trials with the “Z” key, in target-present trials with the “M” key. Errors were followed by a short beep, and every 24 trials participants were informed of their mean reaction time and error rate.

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<sup>1</sup> This was done because that word is short and common in Dutch, while the word “orientation” is long, low frequency, and therefore difficult to process. The word “Oblique” does not cover all features of the orientation dimension (i.e., not straight lines). However, the results show that the “oblique” cue works as dimension cue and not a feature cue.

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Figure 1 about here

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## Results

Trials with RTs longer than 1200 ms., less than 1% of total in both experiments, were excluded from the analysis. On average, participants made errors on 5.1% of trials in Experiment 1a and 5.4% of trials in Experiment 1b, which were also excluded from RT analyses.

We first performed an ANOVA on mean RT with target type, distractor presence, and cueing as factors (see Table 1). Degrees of freedom were corrected by Greenhouse-Geisser where the assumption of sphericity was violated. In Experiment 1A there were main effects of target type,  $F(3, 21)=19.88$ ,  $p<.001$ , and of distractor presence,  $F(2, 14)=13.69$ ,  $p=.001$ , with distractor singletons slowing RT's by about 30 ms. There was also a trend towards faster responding on cued trials than on uncued trials,  $F(1,7)=3.68$ ,  $p=.096$  (tested with a one-sided t-test, this effect was significant,  $p<.048$ ). The same main effects were present in Experiment 1B: of target type,  $F(1.45, 21.78)=18.71$ ,  $p<.001$ , of distractor presence,  $F(2,30)=10.31$ ,  $p<.001$ , with distractor singletons slowing RTs by around 30 ms, and of cueing  $F(1,15)=5.31$ ,  $p=.036$ : cued trials were faster than uncued trials. In Experiment 1A none of the interactions were significant, while in Experiment 1B there was an interaction between target type and distractor presence,  $F(6, 90)=5.16$ ,  $p<.001$ , with larger distractor effects in target-absent trials than in target-present trials.

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Table 1 about here

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## Errors

To determine whether the proportion of errors was influenced by any of the independent variables, we transformed error proportions to a form suitable for analyses of variance<sup>2</sup> (Winer, Brown, & Michels, 1991), and performed the same omnibus analysis as for reaction times.

In Experiment 1A, more errors were made when there was a distractor singleton than when there was none,  $F(2, 14)=15.94$ ,  $p<.001$ , and more errors on target-absent trials than on target-present trials,  $F(3, 21)=25.67$ ,  $p<.001$ . Moreover, fewer errors were made when the target dimension was cued,  $F(1, 7)=9.39$ ,  $p=.018$ . There were significant interactions between target type and distractor presence,  $F(6, 42)=2.48$ ,  $p=.038$ , with distractor presence leading to more errors on all types of trial, but less so on target-absent trials. Moreover, there was an interaction between cueing and target type,  $F(3,21)=7.38$ ,  $p=.001$ , with most errors being made with uncued orientation targets.

In Experiment 1B there was a main effect of target type,  $F(2, 45)=36.223$ ,  $p<.001$ , but not of distractor identity,  $F<1$ , or of cueing,  $F(1, 15)=2.70$ ,  $p>.1$ . There were interactions between target type and distractor presence,  $F(6, 90)=3.19$ ,  $p=.007$ , and between target type and cueing,  $F(3, 45)=12.69$ ,  $p<.001$ . Errors were made more often on target-present trials than on target-absent trials. They were more frequent with cueing in target-absent trials, but less frequent with cueing in target-present trials.

In both experiments, errors thus generally varied in the same direction as reaction times. Speed-accuracy tradeoffs are thus unlikely to have played a role in our reaction time analyses.

## Interaction between cueing and distractor dimension

The above analyses did not include cue identity as a factor. To investigate the effect of cue identity on distractor singletons, we investigated target-absent trials, and trials with redundant targets.

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<sup>2</sup>  $x=2 \arcsine \sqrt{(p+1/2n)}$ , where  $x$  is the transformed variable,  $p$  is the proportion, and  $n$  is the number of observations underlying the proportion.

Figure 2 shows the distractor effect (distractor singleton present – distractor singleton absent) for both kinds of trial in Experiment 1A, separately for color and orientation distractor singletons, and the two cues. For redundant target trials the interaction between cueing and distractor identity was significant,  $F(1,7)=10.45$ ,  $p=0.014$ . For target-absent trials, there was a trend towards an interaction in the right direction,  $F(1,7)=4.13$ ,  $p=0.08$ . As Figure 2 shows, in both conditions distractor effects were larger when the distractor singleton was defined on the cued dimension, than when it was defined on the uncued dimension. Thus right oblique distractor singletons slowed responses more after an ‘Oblique’ cue than after a ‘Color’ cue, while the opposite was true for red distractor singletons. In both conditions there were no main effects of either cue or distractor identity.

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Figure 2 about here

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Figure 3 shows distractor effects (distractor singleton present – distractor singleton absent) in Experiment 1B, separately for color and orientation distractor singletons, and the two cues. For redundant target trials, the interaction between cueing and distractor identity was again significant,  $F(1,15)=5.36$ ,  $p=0.035$ . The results were in the right direction for target-absent trials, although the interaction there was not significant,  $F(1,15)=2.48$ ,  $p=.13$ . As Figure 3 shows, in both conditions distractor effects were larger when the distractor singleton was defined on the cued dimension, than when it was defined on the uncued dimension. Thus, horizontal distractor singletons slowed responses more after a ‘Right Oblique’ cue than after a ‘Green’ cue, while red distractor singletons slowed responses more after a ‘Green’ cue than after a ‘Right Oblique’ cue.

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Figure 3 about here

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We repeated the same analysis with transformed error proportions. We found no interaction between cue and distractor identity, neither on target-absent trials,  $F(1,7)=1.15$ ,  $p=.33$ , nor on redundant targets ( $F<1$ ) in Experiment 1A (see Figure 2). The same is true for redundant targets ( $F<1$ ) in Experiment 1B, although there was a strong trend in the right direction for target-absent trials  $F(1,15)=4.23$ ,  $p=.06$  (see Figure 3). In all other conditions as well, the pattern for mean error proportions was the same as that for reaction times in both experiments, excluding speed-accuracy tradeoffs.

Inspection of the redundant target results in Figure 3 suggests that cueing in Experiment 1B may have had less of an effect on color than on orientation distractor singletons. We tested this formally by computing an ‘absolute cueing effect’ (as the absolute value of [RT after color cue – RT after oblique cue]) for both red and horizontal distractors, and testing whether they differed. This was not the case,  $t<1$ .

## Discussion

Our results show that cueing the identity of the target made detection of the target faster, and led to fewer errors. Cueing also had an influence on the processing of distractor singletons: when distractor singletons were defined on the dimension corresponding to the cue, they slowed responses more than when they were defined on a different dimension. This suggests that cueing leads to a preparation that makes observers more sensitive to all stimuli defined on the dimension corresponding to the cue. For example, cueing a color target may lead to preparation benefiting all color singletons, not only those in the color that defines targets (e.g., green). This was the case independently of whether the cue predicted the target dimension (Experiment 1A) or the target feature (Experiment 1B). Since preparing for the target dimension instead of the target feature carried costs in the current experiments, we conclude that participants may not be able to restrict their preparation to a specific target feature. Preparation for a target may instead by necessity occur at least partly at the level of the dimension.

Our results could be taken to suggest verbal cues only work at the level of dimension. Such a strong conclusion would be difficult to reconcile with findings in conjunctive search. Several findings suggest that participants can effectively ignore sets of nontargets on the basis of a feature, and search only among elements of a certain color (Kaptein, Theeuwes, & van der Heijden, 1995) or letters with a certain identity (Egeth, Virzi, & Garbart, 1984). It is possible that in these studies efficient use of features is not the result of top-down knowledge, but of bottom-up priming (e.g., Maljkovic & Nakayama, 1994, 2000), as the feature that guides selection usually remains constant over a number of trials. Another interpretation fitting both findings is that attentional selection can be based on a feature, but that during preparation attention 'leaks' to other features defined on the same dimension.

Several theories suggest that verbal cues as used here elicit top-down guidance that works at the level of dimensions (Müller et al., 1995; Müller et al., 2003; Treisman, 1991). None of these explains why top-down guidance should operate at the level of dimensions instead of at the level of specific feature maps. Evidence from cognitive neuroscience has suggested one answer. Different dimensions of visual stimuli are processed in different areas of the brain. When attention is directed towards visual dimensions, activation in commensurate brain areas has been found in advance of stimuli, reflecting top-down preparation (Liu, Slotnick, Serences, & Yantis, 2003; Shulman, d'Avossa, Tansy, & Corbetta, 2002). Within brain areas that analyze visual dimensions, neurons sensitive to different features are generally intermixed (Eysel, Mueche, & Worgotter, 1988; Roe & Ts'o, 1995). It is possible that while top-down mechanisms can activate dimension-specific processing areas, they are spatially too coarse to support preparation for specific features.

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Table 1

Mean reaction times (RT) and proportions of errors for all conditions defined by cue, target type and distractor singleton identity

<b>target</b> distractor		<b>absent</b>			<b>redundant</b>			<b>color</b>			<b>oblique</b>		
		<i>none</i>	<i>color</i>	<i>oblique</i>	<i>none</i>	<i>color</i>	<i>oblique</i>	<i>none</i>	<i>color</i>	<i>oblique</i>	<i>none</i>	<i>color</i>	<i>oblique</i>
<i>Experiment 1</i>													
RT	no cue	512	573	572	464	487	473	516	539	569	500	502	496
	'color'	485	548	523	447	475	436	491	524	513			
	'oblique'	511	538	556	469	448	479				473	524	496
errors	no cue	0.017	0.044	0.058	0.010	0.030	0.036	0.085	0.104	0.016	0.129	0.151	0.085
	'color'	0.020	0.049	0.029	0.040	0.000	0.041	0.093	0.140	0.063			
	'oblique'	0.024	0.029	0.047	0.014	0.036	0.101				0.099	0.071	0.024
<i>Experiment 2</i>													
RT	no cue	586	614	637	526	543	534	594	596	612	577	610	599
	'green'	554	586	596	515	526	514	551	562	564			
	'right oblique'	563	588	622	512	526	539				540	575	552
errors	no cue	0.017	0.030	0.036	0.026	0.026	0.031	0.109	0.078	0.078	0.120	0.094	0.073
	'green'	0.019	0.054	0.056	0.073	0.036	0.021	0.133	0.089	0.086			
	'right oblique'	0.030	0.033	0.063	0.047	0.036	0.031				0.073	0.107	0.055

Figure 1 Example of a search display. Here, an oblique target (upper left) is accompanied by a color distractor singleton (middle right).

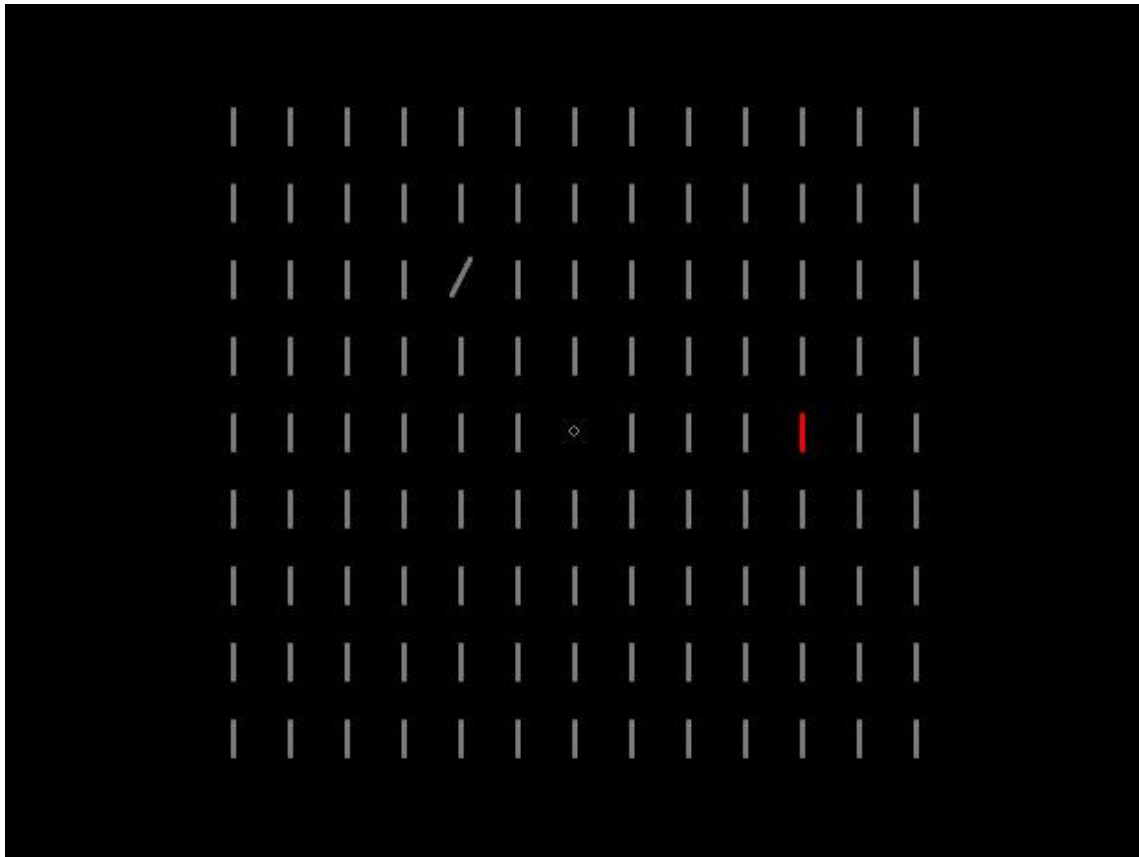


Figure 2 Slowing with respect to no-distractor baseline and error percentage in Experiment 1 for target-absent trials and trials with redundant targets, split out for distractor identity (color distractor singleton, orientation distractor singleton) and cue identity ('Color' cue, or 'Oblique' cue).

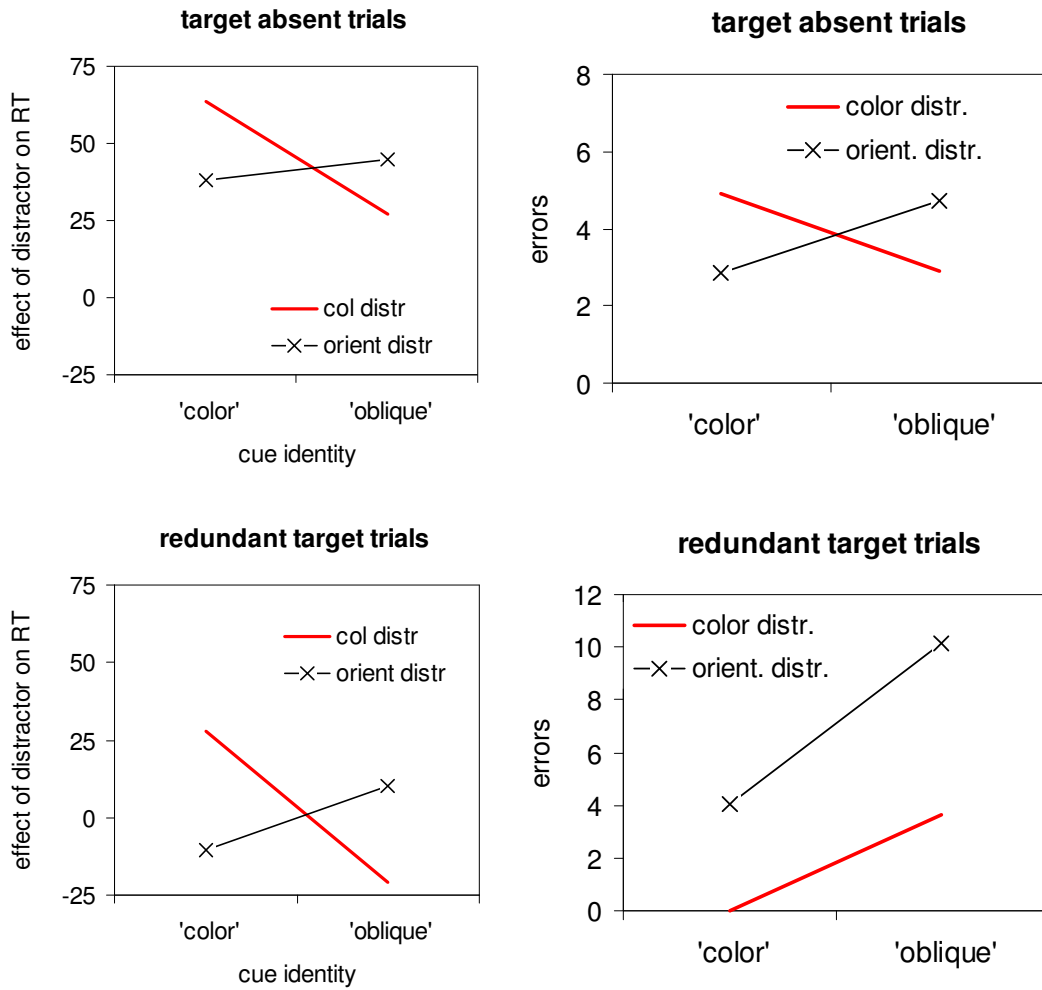


Figure 3 Slowing with respect to no-distractor baseline and error percentage in Experiment 2 for target-absent trials and trials with redundant targets, split out for distractor identity (color distractor singleton, orientation distractor singleton) and cue identity ('Green' cue, or 'Right Oblique' cue).

