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Is contrast just another feature for visual selective attention?

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Abstract

The biased-competition theory of attention [Annual Review of Neuroscience 18 (1995) 193] suggests that attention and stimulus contrast trade off, and implies that high-contrast stimuli should be easy to attend to and hard to ignore. To test this, observers searched displays for a target digit. Observers were well able to exclude high-contrast distractors when attempting to search only among low-contrast stimuli (Experiment 1). In Experiments 2 and 3, location determined which stimuli were relevant. When contrast of relevant and irrelevant stimuli was uncertain (due to contrast varying between trials, Experiment 2), increasing the contrast of distractors impaired performance. However, when contrast was certain (due to blocking of trials, Experiment 3) and targets were of low contrast, high contrast distractors produced *less* interference than low contrast distractors. The ability of subjects to attend selectively to low vs. high contrast items in Experiments 1 and 3 suggests that selectivity for stimulus contrast might be similar to other types of feature selectivity (e.g., color and location). Such findings are inconsistent with the biased competition theory regarding the interplay of contrast and attention. However, results from Experiment 2 suggest that, when target contrast varies, the default tendency is to attend to high-contrast items.

1. Introduction

It is a basic finding of visual science that contrast has dramatic effects on both perceptual and neural responses to patterned stimuli (Wandell, 1995). Patterns with greater luminance contrast (and to a lesser extent, greater chromatic contrast) with respect to their background are more accurately and quickly discriminated than are lower-contrast patterns. They also produce more vigorous neural responses in numerous visual areas (e.g., Albrecht & Hamilton, 1982; Sclar & Freeman, 1982).

Despite the large amount of research devoted to exploring the visual and neural effects of contrast, there is little psychophysical evidence examining how contrast interacts with the functions of selective attention. An understanding of this should illuminate basic questions about the mechanisms of attention and their physiological underpinnings. The present article describes three experiments that examine this issue using a visual search task in which the observers select objects based either on contrast (Experiment 1) or location (Experiments 2 and 3).

1.1. Contrast and attention and cortical neural responses

While the psychophysical interactions of contrast and visual attention have been little studied, the effects of the two variables on firing rate of neurons have been examined in a number of studies involving primates. Firing rates of neurons in the visual system typically exhibit a monotonically increasing function of stimulus contrast, which asymptotes at a certain contrast level. Data from single-unit recordings have also shown that neural responses to to-be-attended stimuli are greater than responses to to-be-ignored stimuli in several areas of visual cortex, including V1 (Roelfsema, Lamme, & Spekreijse, 1998), V4 (e.g., Moran & Desimone, 1985) and MT (Seidemann & Newsome, 1999) (see Kastner, De Weerd, Desimone, & Ungerleider, 1998; Martinez et al., 2001; Saenz, Buracas, & Boynton, 2002 for similar evidence obtained from humans, using fMRI). Recent evidence from neurons in area V4 (Reynolds, Pasternak, & Desimone, 2000) and MT (Martinez-Trujillo & Treue, 2002) has shown that paying attention shifts the contrast-response function leftward, enhancing neural

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responses to low-contrast stimuli to a degree sufficient to make the response comparable to that elicited by an unattended higher-contrast stimuli.

1.2. Attention effects: biased competition vs. featural selectivity

One currently very influential interpretation of these and other results is offered by the "biased competition" model of attention (Desimone & Duncan, 1995; Duncan, 1996). According to this model, attentional selection involves a competitive process. The responses of neurons in different visual areas to distinct objects in the visual field are observer to competitive interactions based on mutual inhibition. Selective attention based on any particular attribute drives up the responses to objects sharing these attributes in all the visual areas concurrently. Stimulus contrast determines the initial potency of a stimulus in this competition, and thus a low-contrast stimulus requires more attention to win the competition. Conversely, a high-contrast but irrelevant stimulus will tend to retard the "victory" of a relevant stimulus in the competition (Duncan, 1996).

One reason this prediction is of great interest is because a more traditional perspective on selective featural attention would seem to make a starkly different prediction. Attention researchers have long noted that manipulations that decrease the similarity of to-be-attended and to-be-ignored stimuli invariably improve performance, with the notion that attention can allow for selective monitoring of one stimulus feature vs. another (Broadbent, 1982; Kahneman & Treisman, 1984; von Wright, 1968). If this generalization applies to stimulus contrast (e.g., higher vs. lower contrast) as well as other attributes, one would expect that when the relevant stimuli are of high contrast, performance should be better when the distractors are of low-contrast rather than high-contrast (agreeing with the prediction of biased competition); on the other hand, when the relevant stimuli are of low contrast, performance should be better when the distractors are of high contrast (conflicting with the predictions of biased competition). We refer to this latter hypothesis as the "contrast selectivity" model.

Some preliminary support for this was provided by an experiment carried out by Manuel Sanches, one of the present authors (Pashler), and John Duncan; the experiment was presented (along with figures depicting the results) in Duncan (1996). Observers searched for a target letter A in displays composed of 2, 4, or 8 letters. Displays were either all high contrast, all low contrast, or mixed. When contrast was mixed, the target could be high or low contrast. Dim targets in displays of mixed contrast produced much slower responses (especially at the larger display set sizes) than were found with all low contrast displays. This condition also produced a marked elevation in the rate at which observers missed targets. As Duncan (1996) noted, these results are strongly consistent with the idea that low contrast puts a target at a relative disadvantage in a competitive process, yielding effects that cannot be attributed merely to a slowing of the perceptual analysis of low contrast items.

1.3. Present research

In the three studies described below, observers saw displays of grey digits on a (locally) black background and searched for a target digit (either an 8 or a 9, but not both, was present somewhere among a subset of the items that the observer was told to consider relevant—the definition of relevance varied between experiments). In Experiment 1, observers were instructed to attend to just the high- or low-contrast digits within a block of trials; sometimes this necessitated ignoring other elements of varying contrast. Here, the basic question was: are observers well able to filter out high-contrast stimuli, or is it only low-contrast stimuli that can be efficiently excluded? In Experiments 2 and 3, the criterion of relevance was location: observers searched for a target among just the items in four positions in a 3×3 grid, ignoring, as best they could, digits in the other 5 positions. The contrast of the relevant and irrelevant stimuli was manipulated between trials (Experiment 2) or between block (Experiment 3).

Another manipulation was used in order to partially remove a potential confound present in studies of stimulus contrast using shapes like alphanumeric characters. If one varies the contrast of, say, a gray digit against a black background, one alters not only the contrast of the edges that define the digit, but also the conspicuity of the digit as an object. To put it crudely, not only is it hard to identify the letter—it is also harder to see that there is anything there. To roughly equate conspicuity, we also included a condition in which each digit rested on a small black rectangle, which was slightly larger than the digit itself. This black rectangle was very conspicuous because the background for the rest of the display was made significantly (25×) brighter than the black rectangle. Here, regardless of the contrast level of the digit, all appeared highly conspicuous against the brighter background. Not surprisingly, by altering the adaptation state of the visual system, the brighter background reduced the effective contrast of all the digits appearing in these blocks, slowing responses and magnifying the effects of contrast upon latency. As will be seen, the results below are qualitatively the same with respect to the most important predictions, suggesting that relative conspicuity was not playing an important role.

2. General method

2.1. Observers

Observers were volunteers from the University of California, San Diego. All had normal or corrected-to-normal vision. There were 18 observers in each of the three experiments (54 in total).

2.2. Apparatus

Stimuli were presented on a high-resolution MAG DX-15T color monitor driven by a PC. Responses were recorded from two adjacent keys using a standard keyboard. The observers viewed the displays from a distance of about 60 cm.

2.3. Stimuli

The observers searched for an 8 or 9 from a set of digits (one or the other was always present). Each digit was green and measured 0.43° by 0.57°. Digits were presented on a black background (0.2 cd/m^2) and the luminance of each digit was either 24 or 1.5 cd/m^2. The higher luminance digits (24 cd/m^2) were considered "high contrast", producing a Michelson contrast with the background of 98%. The lower luminance digits (1.5 cd/m^2) were considered "low contrast", producing a Michelson contrast of 76%. [1] In some blocks, the entire background of the display was black (0.2 cd/m^2). In other blocks, each digit appeared on a small black rectangle (0.2 cd/m^2, $0.46° \times 0.60°$), while the rest of the background of the display was made significantly brighter (5 cd/m^2). [2] This created a situation in which the location of each digit/rectangle was highly conspicuous, thus equating conspicuity across the low- vs. high-contrast digits. We refer to this equated conspicuity condition as the "bright background" condition, while the condition without the equated conspicuity cue is referred to as the "dark background" condition.

In Experiment 1, 10 or 20 digits were placed in randomly chosen locations within a $16.2° \times 16.2°$ region (with the constraint that the distance between the centers of any two items was at least 1.15°, both horizontally and vertically). In Experiments 2 and 3, nine digits were shown in the center of the screen as a 3×3 matrix. The distance between centers of neighboring elements was 1.53°, both horizontally and vertically.

2.4. Procedure

Each trial began with a small green fixation cross presented in the center of the screen. Observers were instructed to fixate the cross, which remained present for 400 ms. The cross was followed by a short blank interval (400 ms), which was then followed by the critical display containing the target and distractor digits. This display remained present until response.

In all the experiments, after the display was presented, the observers pressed the "j" key on the computer keyboard if the target was "8" and "k" if the target was "9", using the index and middle fingers of the right hand. They were told to respond as quickly and accurately as possible. A positive or negatively associated sound was played, providing feedback on the accuracy of the response. Each observer performed 14 blocks of 70 trials, with the first two blocks considered as practice. In each study, the 12 blocks cycled between the different block types, with the starting condition counterbalanced across observers.

3. Method and results of Experiments 1–3

3.1. Experiment 1

In Experiment 1, observers were asked to search a subset of the display based on contrast values.

3.1.1. Method

In Experiment 1, the target contrast (high or low) was specified to the observer before each block. There were three types of trials randomly mixed within each block: 10 digits all of the specified target contrast (condition *10-relevant*); 20 digits all of the specified target contrast (condition *20-relevant*); or 10 relevant digits of the specified target contrast and 10 irrelevant digits of the opposite contrast level to the target (condition $10+10$). The three types of trials were equally likely and randomly mixed within a block. There were $2 \times 2 = 4$ types of blocks: high vs. low target contrast × dark vs. bright background. There was never an 8 or 9 among the irrelevant digits (i.e., the digits with contrast differing from that of the target).

3.1.2. Results and discussion

The mean response times for correct trials are shown in Fig. 1, separately for the dark background (left panel) and bright background (right panel) conditions. For both backgrounds, the RT increase between the 10-relevant condition and the $10+10$ condition (10 relevant

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[1] Our manipulation, by necessity, confounds contrast with luminance. Although we believe that contrast is the critical variable here, future research will be needed to verify this.

[2] Although not important to the purpose of this condition, the color of the brighter background was blue. This color was chosen because in earlier versions of this experiment, we had a color manipulation employing red vs. green digits and we wanted the color of the background to be different than either digit type.

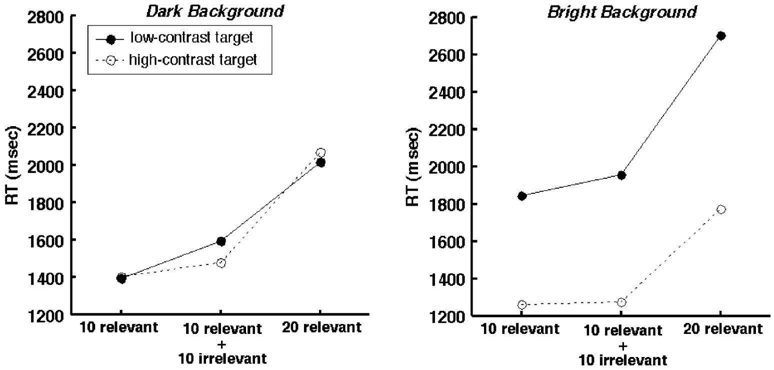

Fig. 1. Mean response times in Experiment 1 for correct trials to detect either low-contrast (solid lines) or high-contrast (dashed lines) target digits, as a function of number of digits of the relevant contrast level (and number of irrelevant digits, i.e., those of differing contrast level). Left panel presents data obtained on a dark background. Right panel presents data obtained on a bright background, employed to equate conspicuity across items in the display (see text).

and 10 irrelevant contrast) was much smaller than the increase between the 10-relevant condition and the 20-relevant condition, and this pattern held regardless of target contrast (low or high). To verify this, we used mean RT for the 10-relevant condition as a baseline, and divided mean RTs in the critical display-composition conditions (10 + 10 condition and 20-relevant condition) by this baseline. The overall average was 1.45 for the 20-relevant condition. That is, as expected, adding 10 more relevant-contrast digits to the display increased RTs by an average of 45%. The corresponding average was 1.07 for the 10 + 10 condition. That is, adding 10 more irrelevant-contrast distractors to the display increased RTs by only 7%, indicating that observers could nearly perfectly exclude digits of the irrelevant contrast dimension.

An analysis of variance was performed on these ratios with three independent variables: display composition (10 + 10 vs. 20-relevant), target contrast (low vs. high), and background (dark vs. bright). Display composition was significant ($F(1,17) = 328.4$, $p < 0.001$), confirming that the 20-relevant condition produced a much larger increase in RTs than the 10 + 10 condition. Background did not have a significant effect ($F(1,17) = 2.4$, ns) nor did target contrast ($F(1,17) = 3.8$, ns), although there was a nonsignificant trend toward slightly less efficient exclusion of 10 high-contrast irrelevant distractors as against 10 low-contrast irrelevant distractors.

In sum, observers clearly succeeded well in ignoring distractors of the irrelevant contrast—even when distractors were of high contrast and targets were of low contrast, suggesting that observers can selectively attend to different contrast levels (in line with the "contrast selectivity" hypothesis). When the background was bright (right panel), which equated conspicuity across the different items in the display, there was a dramatic overall slowing of responses to the low-contrast target as compared to the high-contrast target (this is seen in the wide separation between the two lines). This presumably reflects the reduced visual sensitivity caused by adaptation to a brighter background. Even with this amplification of the effective contrast reduction due to low-contrast, however, high-contrast distractors were still very efficiently excluded when subjects searched only among the low-contrast targets.

3.2. Experiment 2

In Experiment 2, observers searched among digits presented in four locations of a 3×3 grid, while ignoring distractors in five other locations. The contrast of distractors and targets was varied within mixed-list blocks, so that there was uncertainty regarding the contrast level of either distractors or targets.

3.2.1. Method

The target was in one of four locations of a 3×3 matrix that were designated as relevant (these were center left, center right, top middle, and bottom middle). The other five locations (the four outer corners of the matrix and the central position) were designated irrelevant positions and their contrast was to be ignored. The four relevant locations could be occupied by four high-contrast stimuli, or by four low-contrast stimuli, with this difference varying between trials within the same block. The five irrelevant locations could be occupied by no distractors at all, by high contrast distractors, or by low-contrast distractors (also varied between trials). Thus, there were six types of trials within each block, all equally likely. Background (dark vs. bright) was varied between block. There could be 8s or 9s in the irrelevant locations, but when there were, these did not count as targets and were to be ignored.

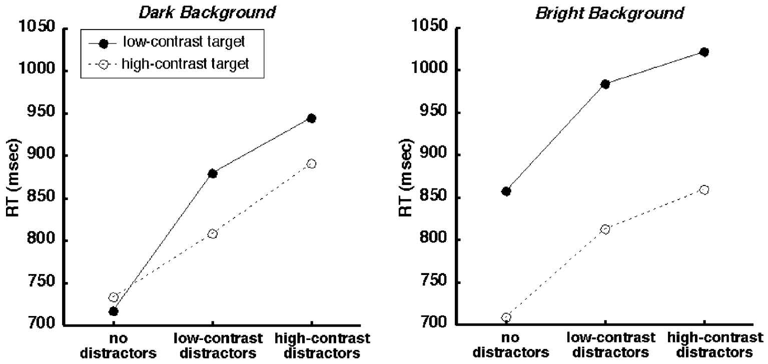

Fig. 2. Mean response times in Experiment 2 for correct trials to detect either low-contrast (solid lines) or high-contrast (dashed lines) target digits among a location-defined subset, as a function of the presence of irrelevant-location digits and their level of contrast. Left panel refers to dark background and right panel refers to bright background. Contrast of target and distractor was varied in mixed trials in this experiment.

3.2.2. Results and discussion

Data for Experiment 2 are presented in Fig. 2, separately for the dark background (left panel) and bright background (right panel) conditions. For both backgrounds, the presence of distractors slowed responses, and responses were further slowed whenever high contrast distractors were present. This pattern held true regardless of whether target contrast was high or low. An ANOVA confirmed that the high-contrast distractor produced slower responses than the low-contrast distractor (dark background: $F(1,17) = 12.8$, $p < 0.005$, bright background: $F(1,17) = 11.5$, $p < 0.005$). Also confirming that this effect was true regardless of target contrast, there was no interaction between distractor contrast and target contrast (dark background: $F(1,17) = 0.28$, ns, bright background: $F(1,17) = 0.17$, ns). These results look generally like what one might predict based on the biased competition model (and conform well to the findings of Sanches, Pashler, and Duncan that were described by Duncan, 1996).

Note that when the background was bright, RTs were dramatically slowed for low-contrast targets. When the background was dark, this effect only held true when distractors were present. This presumably reflects the reduced visual sensitivity caused by adaptation to a brighter background.

3.3. Experiment 3

In Experiment 2, high-contrast distractors did prove to be more disruptive than low-contrast, despite the fact that subjects attempted to select based on a dimension orthogonal to contrast (namely, location). In that experiment, however, contrast (of both the target and distractors) varied from one trial to the next. In Experiment 3, the contrast manipulations were blocked thus providing certainty regarding target contrast. Although not instructed to do so, this manipulation allowed subjects to selectively monitor contrast level (in addition to location).

3.3.1. Method

Experiment 3 was identical to Experiment 1 except that the six types of trials (high vs. low contrast targets × high vs. low contrast distractors vs. no distractors) were presented in separate blocks, rather than mixed within the same block. Background (dark vs. bright) was again manipulated between blocks, so there were a total of 12 different types of blocks. The order in which observers performed the different block conditions was counterbalanced.

3.3.2. Results and discussion

Data for Experiment 3 are presented in Fig. 3, separately for the dark background (left panel) and bright background (right panel) conditions. For both backgrounds, increasing distractor contrast slowed responses, but only when the targets were of high contrast. That is, when the targets were of low contrast, increasing distractor contrast *reduced* mean reaction times. This effect is supported statistically by a significant interaction between target contrast × distractor contrast (dark background: $F(1,17) = 21.1$, $p < 0.001$, bright background: $F(1,17) = 32.0$, $p < 0.001$). In line with the results from Experiment 1, this interaction conforms well to the "contrast selectivity" hypothesis. As in Experiment 2, reducing target contrast had a much greater effect against a bright background than it did against a dark background. On a final note, overall RTs were found to be significantly shorter in Experiment 3 as compared to Experiment 2 (across subjects ANOVA: $F(1,34) = 5.07$, $p < 0.05$), which might result from differences in uncertainty between the two. We return to this possibility in Section 4.

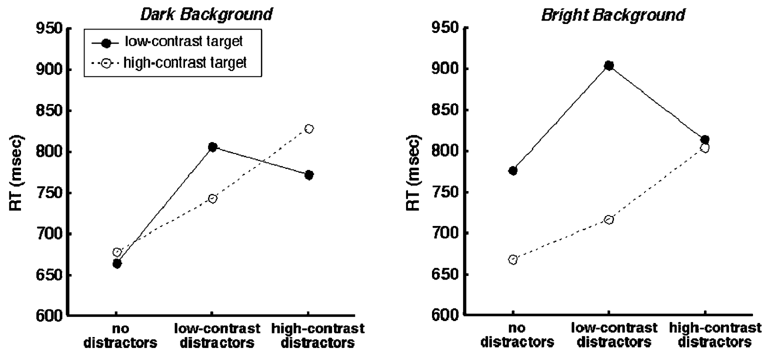

Fig. 3. Mean response times in Experiment 3 for correct trials to detect either low-contrast (solid lines) or high-contrast (dashed lines) target digits among a location-defined subset, as a function of the presence of irrelevant-location digits and their level of contrast. Left panel refers to dark background and right panel refers to bright background. Contrast of target and distractor was varied between blocks in this experiment.

4. General discussion

The three experiments described here yielded several findings regarding the effect of varying the contrast of relevant and irrelevant stimuli in visual selective attention tasks. First, when the task involves selection based on contrast level (Experiment 1), observers were able to efficiently exclude high contrast distractors and select low contrast targets, in line with the "contrast selectivity" hypothesis. While it would perhaps overstate the results to claim that observers were able to do this exactly as well as they were able to exclude low contrast targets and select high contrast targets, performance differences between these two tasks appeared very modest (aside from the gross slowing in processing of low-contrast items with the bright background). Second, when the relevant portion of the display was defined by location, and the contrast of the relevant and irrelevant items was certain (by blocking conditions, Experiment 3), observers benefited from a difference in contrast between target and distractor. Increasing the contrast of distractors proved helpful when the target was of low contrast. Thus, results from Experiments 1 and 3 run precisely opposite to the predictions of biased competition as presented by Duncan (1996). A third finding, however, was that when selection is by location and the contrast of targets and distractors was uncertain (by varying conditions from one trial to the next, Experiment 2), increasing distractor contrast made the task more difficult, regardless of target contrast. This result seems consistent with the biased competition interpretation (and with the data of Sanches, Pashler, and Duncan, as presented in Duncan, 1996 and described in Section 1).

One explanation for the difference in results between Experiments 2 and 3 is that stimulus certainty in Experiment 3 allowed subjects to selectively attend to a particular contrast level (as well as location). Although not instructed to do so, this strategy could improve subjects' performance in two ways. First, it could allow them to monitor a single (rather than multiple) contrast level at the target locations. Second, on blocks where the distractor locations contained digits of the opposite contrast level, it could help to filter out those distractors. In support of the possibility that certainty provided some general benefit of this sort, overall RTs were significantly shorter in Experiment 3. By this certainty account, we can also explain why, in Experiment 3, increasing distractor contrast improved performance when the target contrast was low.

Although this explanation seems viable, we also considered the possibility that differences observed between Experiments 2 and 3 were driven by differences in the degree of repetition of stimulus condition (possibly producing differences in the state of adaptation between the two experiments). To investigate whether this factor contributed, we re-analyzed the data from Experiment 2 (where contrast of target and distractor varied across trials) to examine repetition effects involving contrast.

As shown in the left panel of Fig. 4, for those trials where the features were not repeated (either target contrast or distractor contrast or both changed from the previous trial), the pattern generally followed the overall averages seen in Fig. 2. However, for the subset of trials where both target and distractor contrast values repeated those of the previous trial, an interaction began to emerge as seen in the middle panel (with high distractor contrast proving less disadvantageous when target contrast was low). This interaction became much more obvious when the features repeated the preceding trial and the trial before that (third panel). Here, the results look generally similar to Experiment 3 with blocked contrast values.

ANOVAs were performed to confirm these observations. The interaction between target contrast × distractor contrast was not significant when features were not repeated ($F(1,17) = 0.037$, ns), but it was significant when features were repeated ($F(1,17) = 5.999$, $p < 0.025$). The three-way interaction of target contrast × distractor contrast × feature repetition was significant

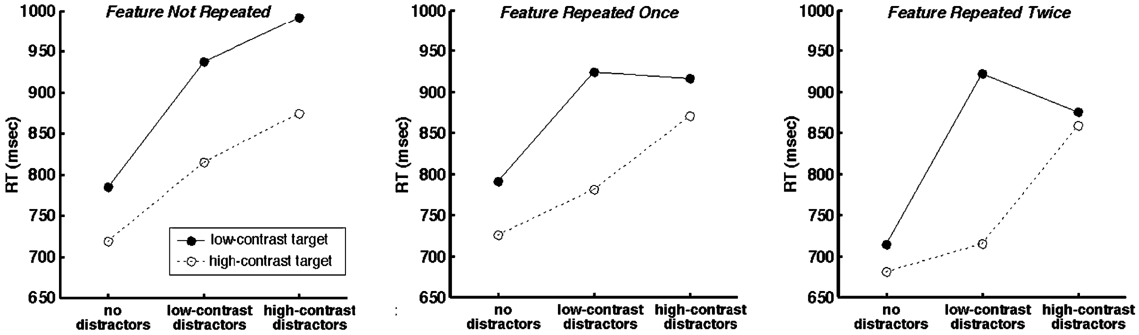

Fig. 4. Mean response times in Experiment 2 for correct trials to detect either low-contrast (solid lines) or high-contrast (dashed lines) target digits among a location-defined subset, as a function of the presence of irrelevant-location digits and their level of contrast. The three panels illustrate trials with no repetition of distractor and target contrast, trials with repetition of both of these features from the previous trial, and trials with repetition of both of these features from the previous trial and the trial preceding that.

($F(1,17) = 6.446, p < 0.025$). Analysis of more than one successive repetition was not possible because there were not enough data to support such an analysis.

These additional analyses show that repetition with the relevant contrast value can produce the same pattern of results observed in Experiment 3. Although this might be driven by some low-level adaptation effect, we tend to think this unlikely for the following reason. To explain increasing distractor contrast improving performance for low-contrast targets (Fig. 4, solid lines), one would need to suppose that adaptation selectively dampens the effectiveness of high-contrast stimuli, in fact, so much so that high contrast stimuli become overall *less* effective than low-contrast stimuli. However, if this were the case, we would expect to see the same pattern for high-contrast targets (Fig. 4, dashed lines), which we did not. Instead, we propose that the repetition effect observed in Fig. 4 may reflect some "automatic" tuning of the mechanisms that selectively monitor particular contrast levels. Although the stimulus contrast (targets and distractors) was always uncertain in Experiment 2, this tuning may result in selective monitoring of the contrast level observers had just experienced in the previous trial (a form of hysteresis). Further research, in which stimulus conditions are varied across trials but subjects are pre-cued to the stimulus type before the start of each trial, will be needed to elucidate this issue more fully (Table 1).

Table 1
Error rates (mean percent error) for Experiments 1–3

Background	Target contrast	Distractor contrast	Attending to contrast	Attending to location (mixed)	Attending to location (blocked)
Dark	Low	None	3.0	3.3	2.5
Dark	Low	Low	3.6	6.0	3.8
Dark	Low	High	2.7	5.1	4.0
Dark	High	None	3.0	5.0	1.8
Dark	High	Low	2.5	4.3	2.5
Dark	High	High	3.2	4.1	3.2
Bright	Low	None	3.8	4.2	2.5
Bright	Low	Low	3.9	4.8	3.3
Bright	Low	High	2.8	4.4	3.0
Bright	High	None	2.4	4.7	2.2
Bright	High	Low	2.4	3.8	3.4
Bright	High	High	3.0	3.2	3.6

4.1. Implications

We began the study with a question: does the "conventional" generalization that target-distractor discriminability always enhances selective attention hold for contrast (i.e., is there "contrast selectivity"), as has been repeatedly found for other features like color and location (and similarly, features in other sensory modalities such as audition)? Or alternatively, do increases and decreases in contrast have inherently asymmetric effects upon selective attention, as the biased competition theory of Duncan (1996) would predict? As described above, on that account, increases in distractor contrast should impair the ability to ignore an object, even—indeed *especially*—when the target is of low contrast.

The results make it clear that contrast need not have the effects proposed by Duncan (1996) account. When observers have the opportunity to consistently implement a selection regime that favors low contrast elements, as in Experiments 1 and 3, they are well able to do so, and there appears to be little or no residual cost to excluding high-contrast stimuli. These results suggest that selectivity for stimulus contrast might be similar to other types of feature selectivity (e.g., color and location). A potential neural substrate for this sort of feature selectivity has recently been reported by Xinmiao and Van Essen (submitted for publication), who found neurons tuned along the dimension of luminance in V1 and V2. In addition, a small proportion of neurons in area MT appear to be tuned for contrast (A. Thiele & B. Krekelberg, personal communication).

However, when observers cannot consistently implement such a regime, the asymmetry between high and low-contrast appears, conforming to the expectations of biased competition. One way of reconciling these data would be to suppose that a tendency to select in favor of high-contrast stimuli is a sort of system *default*, to which the visual system regresses in the absence of active influences to the contrary—a bias that is not, however, obligatory or fixed. It has recently been argued that another visual property—abrupt onsets—may interact with attention in just this way. While abrupt onsets have often been shown to attract attention (e.g., Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1990), when there is no top-down incentive to attend to abrupt onsets, they frequently fail to attract attention (Folk, Remington, & Johnston, 1993). For example, when observers search for the red items in a display, and green distractors continually flash, move, or even assume new forms several times per second, this actually *enhances*, rather than impairs, selection (Pashler, 2001; see also Gibson & Kelsey, 1998). However, when observers simply look at a one-shot display without any task set, flashing items receive strongly preferential attention (Pashler & Harris, 2001).

It may be that high contrast has a similar status to abrupt visual onset: absent any specific top-down influence to the contrary, visual attention "relaxes" into a mode that assigns a positive weight to these features. This may account for the findings of Sanches, Pashler, and Duncan referred to in the Introduction (Duncan, 1996). However, this weighting is readily overcome, as the studies described above indicate. Given these observations, attempts to draw a straightforward link between the mechanisms of visual attention and the neurophysiological evidence for ubiquitous contrast-dependent firing thresholds in the visual brain (Duncan, 1996) may be limited. The control of visual attention may reflect a more complex architecture than has so far been proposed—one readily capable of employing contrast rectification and/or applying negative weights to contrast when it is useful to do so.

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