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ORIGINAL ARTICLE

Independent and additive repetition priming of motion direction and color in visual search

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Abstract Priming of visual search for Gabor patch stimuli, varying in color and local drift direction, was investigated. The task relevance of each feature varied between the different experimental conditions compared. When the target defining dimension was color, a large effect of color repetition was seen as well as a smaller effect of the repetition of motion direction. The opposite priming pattern was seen when motion direction defined the target—the effect of motion direction repetition was this time larger than for color repetition. Finally, when neither was task relevant, and the target defining dimension was the spatial frequency of the Gabor patch, priming was seen for repetition of both color and motion direction, but the effects were smaller than in the previous two conditions. These results show that features do not necessarily have to be task relevant for priming to occur. There is little interaction between priming following repetition of color and motion, these two features show independent and additive priming effects, most likely reflecting that the two features are processed at separate processing sites in the nervous system, consistent with previous findings from neuropsychology & neurophysiology. The implications of the findings for theoretical accounts of priming in visual search are discussed.

Introduction

Recent years have seen an increased interest in how what we have just seen, perhaps only moments before, influences what we subsequently see. Such history effects are particularly evident when we search a visual scene for a particular target (e.g. Maljkovic & Nakayama, 1994). Earlier research indicated that salient features, based either on contrasts such as of background against foreground (He & Nakayama, 1992; see also Kristjánsson, 2006a), on luminance or color contrast (Theeuwes & Kooi, 1994; Treisman, & Gelade, 1980; Wolfe, 1994; Wang, Kristjánsson & Nakayama, 2005), on shape differences (Treisman & Gormican, 1988; Wolfe, Yee & Friedman-Hill, 1992; Kristjánsson & Tse, 2001) to name a few, controlled how we initially parse a visual scene and find a particular target among distractors, in conjunction with the operation of top-down, goal directed guidance to task-relevant features. The operation of such mechanisms is assumed to result in attentional selection of items for further analysis at a relatively late, capacity limited, stage in perceptual processing (e.g. Deutsch & Deutsch, 1963; Duncan, 1980; Treisman & Gelade, 1980; Wolfe et al., 1989).

Recent research has then indicated that priming in visual search, through repetition of target or distractor features, has a potent effect on how we orient our attention (see e.g. Kristjánsson, 2006b, for review). This research has shown that how we parse a given scene and what guides where we orient our attention can be strongly influenced by what we have viewed, if only a few moments before. This research approach has in many ways proved itself to be an effective way of investigating how we allocate attention across the visual field, showing that search for a particular target in visual search is faster if the same target appears as on a previous trial (see e.g. Goolsby & Suzuki, 2001; 2002; Maljkovic & Nakayama, 1994; Olivers & Meeter, 2006 for some examples of priming in feature search, and Kristjánsson, Wang & Nakayama, Treisman, 1992; Wang et al.,

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2005 for examples of priming in conjunction search), if the current target shares overlapping features with a preceding target (Kristjánsson, 2006c) and if it appears in the same position as on the last trial (Maljkovic & Nakayama, 1996; Kristjánsson, Vuilleumier, Malhotra, Husain & Driver, 2005; Geng, Ruff, Eger, Kristjánsson, Rothstein & Driver, 2006; Geyer, Müller & Krummenacher, 2007). Even the repetition of the context (or distractor set identity) of the target in visual search has been shown to speed the search considerably, independently of any effects of target repetition (Geyer, Müller & Krummenacher, 2006; Kristjánsson & Driver, 2008; Sævarsson, Jóelsdóttir, Hjaltason & Kristjánsson, 2008). Such priming patterns cannot be explained by response repetition or changes in decision criteria (Maljkovic & Nakayama, 1994; Sigurdardottir, Kristjánsson & Driver, 2008). For some other examples of priming in visual search in a number of different contexts, see e.g. Lamy, Carmel, Egeth & Leber (2006), Maljkovic & Martini (2005), Meeter & Olivers (2006), Pinto, Olivers & Theeuwes, (2005), Theeuwes, Riemann & Mortier (2006), Wolfe, Butcher, Lee & Hyle, (2003).

Theoretical proposals

Some researchers have argued that repetition priming in visual search reflects the retention of an episodic memory trace of a preceding trial, that then facilitates response selection. This would entail that priming would be based on whole objects (Huang, Holcombe & Pashler, 2004; Hillstrom, 2000) while others have argued that priming reflects the facilitation of specific features (Goolsby & Suzuki, 2001; Maljkovic & Nakayama, 1994; Nakayama, Maljkovic & Kristjánsson, 2004); while even others have argued for a hybrid view where both types of priming may occur depending on the nature of the stimuli in each case (Campana et al. 2008; Kristjánsson, 2008; Kristjánsson, Ingvarsdóttir & Teitsdóttir, 2008).

Maljkovic & Nakayama (1994) found that when the target in a pop-out visual search task was of the same color from one trial to the next, performance on the task was speeded. A similar facilitation effect was found when the target appeared in the same position as previously (Maljkovic & Nakayama, 1996). Maljkovic & Nakayama thought of the priming pattern as reflecting the facilitation of relatively low-level memory traces. They said: “priming of pop-out increases the speed of attention deployments to subsequent targets having the same *feature* characteristic [and this] reflects a functionally beneficial memory system specialized for the rapid and automatic selection of items for focal attention and saccadic eye movements” (Maljkovic & Nakayama, 2000, p. 571, my italics; see also Goolsby & Suzuki, 2001; Kristjánsson & Nakayama, 2003; Nakayama et al., 2004, for similar views).

Huang et al. (2004) argued, on the other hand, that priming reflects an episodic memory representation of the previous trial facilitating response. This view entails that priming reflects facilitation at a late stage of the perceptual process, where objects are integrated (see e.g. Kahneman, Treisman & Gibbs, 1992). In the experiments reported by Huang et al., observers searched for an odd-sized target among distractors and had to report its’ orientation. When the same sized target was repeated as on the last trial, search was faster if the target color (which was independent of the task) was the same, but when the *size* of the target was different than on the last trial repeating the color actually harmed performance. Priming from repetition of target size could thus not proceed, uninfluenced by the target’s color. This result was seemingly inconsistent with what Maljkovic and Nakayama claimed, that the attended *feature* was selectively facilitated since the result indicated that priming for a particular object invokes effects upon response times for “all features or none”. The “episodic retrieval” account of priming entails that one should be less likely to see independent priming from separate features of a single object—and some features should not show a preferential priming pattern above others. Huang et al. acknowledged that their data did not actually rule out feature-based accounts but argued, from “razor of Occam” logic that an episodic memory account could most parsimoniously account for the data on priming in visual search.

Hillstrom (2000) argued that top-down visual search (where no single feature contrast defines the target) is also subject to repetition priming effects (see also Kristjánsson et al. 2002). Hillstrom observed that in conjunction search, there was a large effect of repeating the defining features of the target and no effect of repeating the reported feature (see, also, Treisman, 1992; Wang, Kristjánsson & Nakayama, 2005, for repetition effects in conjunction search). Furthermore there was a considerable set-size effect that was not affected by whether the target defining feature was repeated or not (consistent with Kristjánsson et al., 2002). Hillstrom argued that this reflects that repetition affected the speed of prioritizing elements rather than the priorities actually assigned. In other words, repetition does not “tune” a particular target template towards the targets features. This rests of course on the assumption that the search is actually based on such a template. Kristjánsson et al. (2002), also found that priming did not affect set size effects although, overall, search was speeded. Hillstrom argued for an episodic memory view of priming (in many ways similar to Huang et al.), stating that: “… a memory for a trial includes a representation of the features in the display and of which features were prioritized higher than others” (Hillstrom, 2000, p. 813).

Finally, Kristjánsson (2006c) argued that separate features can prime independently but that the nature of the features themselves, as well as their task relevance, determines whether they show independent priming or not. Kristjánsson tested priming in single-feature search for three-featured Gabor patches, varying in orientation, spatial frequency and color, testing whether simultaneous priming would occur, in particular in light of whether the features were task-relevant or not. Which of the 3 features defined the target in each case was varied between experiments. The results showed that there was little or no simultaneous priming for orientation and spatial frequency, whereas orientation and color, and spatial frequency and color showed simultaneous priming. This is a clear pattern of feature based priming since the priming was not dependent on whether the whole object was repeated or not, and in some cases repetition of two features on the target led to priming, while in some cases only one. In addition orientation and spatial frequency seemed, under some conditions, to mutually inhibit priming of the other feature, perhaps reflecting that the two share neural mechanisms to a greater degree than the other features tested. It should be noted here that Fecteau (2007) has found some conditions (in a different experimental paradigm) where priming of irrelevant features does not occur (see further discussion of this issue in the general discussion).

Current experiment

The aim of the current study was to investigate whether priming from repetition of color and motion on the target in a visual search task would lead to independent and simultaneous priming or not. The studies were inspired by the experiments in Kristjánsson (2006c) where independent and additive effects of feature repetition were found (with some notable exceptions, as in Fectaeu, 2007, for example) in feature search tasks involving targets defined by color, orientation and spatial frequency. This time the aim was to study any potential interactions of color and motion.

The experiment had three conditions, run interleaved with one another in counterbalanced order (see methods). In condition A, the observers searched for an oddly colored (red or green) target Gabor patch among distractors (8 items were presented on the screen on each trial), while 4 Gabors drifted (locally) to the right, and 4 to the left (the sinusoidal pattern drifted within a stationary Gaussian envelope; see below). In condition B the task was to indicate whether a target item drifting in the odd direction relative to the others was present on the screen (this time 4 items were red and 4 were green). Finally, in condition C, priming was tested when both color and motion were irrelevant to the search and observers had to search for the Gabor patch of the odd spatial frequency (this time 4 items were red and 4 green, and 4 drifted to the right and 4 to the left).

Methods

Observers

Two experienced psychophysical observers participated, one of whom was the author. Each observer participated in 1500 trials under each experimental condition (conditions A, B and C), 4500 trials in all, run in 45 blocks of 100 trials in counterbalanced order.

Stimuli

Four examples of the Gabor patch stimuli are shown in Fig. 1a, varying in color and spatial frequency, but the Gabor patches also varied in terms of whether local motion within the Gaussian envelope was to the right or left (see further explanation below). Figure 1b shows a representative search display from condition A. The stimuli were

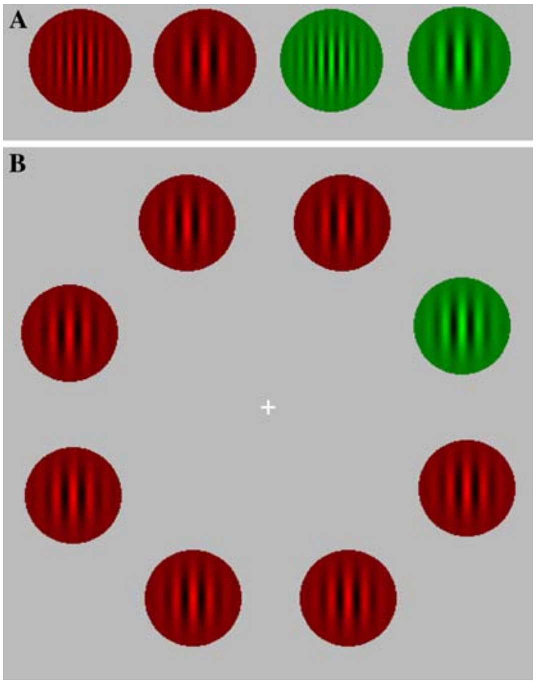

Fig. 1 Examples of the Gabor stimuli used in the experiments along with a representative search display. Panel a shows four Gabors varying in color and spatial frequency. Panel b shows a representative search display from condition A where the target was distinguished by it's unique color. The observers indicated whether the target was at the right or the left of the vertical midline running through the center of the screen (not actually shown on the screen, but the meaning of the midline was explained to the observers beforehand, see methods for further details). Note that the Gabors also varied in local drift direction on each trial (see text for details)

Gabor patches (a sinusoid multiplied by a two dimensional Gaussian envelope) that were either red so that their color varied sinusoidally from dark red (6.3 cdm^{-2}) to light red (24.7 cdm^{-2}), in the case of a “red-scale” Gabor and from dark green (5.9 cdm^{-2}) to light green (25.3 cdm^{-2}) in the case of a ‘‘greenscale’’ Gabor. The Gabors also contained luminance defined (see e.g. Kristjánsson, 2001) motion signals; they “drifted” locally to the left or the right in that the Gaussian envelopes actually stayed in place so the whole Gabor patch itself stayed in place but the sinusoidal grating was phase shifted to the right or left at a rate of 5°/s. In condition C where the target was defined by spatial frequency, the Gabor patches varied in spatial frequency, in addition to color and motion. The sinusoid constituting the Gabors of ‘‘low’’ spatial frequency (the rate at which the pattern varies between dark and light spatially) was 1.8 cycles per degree (cpd) of visual angle while the ‘‘high’’ spatial frequency Gabors were 3.1 cpd. In conditions A and B all the Gabors had a spatial frequency of 2.5 cpd (the midpoint of the other two spatial frequency values). The size of the Gabor patches was 2.4. arc deg. They were always oriented vertically (as shown in Fig. 1). At the edges, the brightness values for the Gabors were at the midpoint value of the greenscale or redscale, depending on the particular color of the Gabor patch.

In condition A, if the target was greenscale on a given trial all the other items were redscale, and vice versa. The color scale of the target Gabor (red or green) was determined completely randomly for each trial. The drift direction of each Gabor patch was also determined randomly on each trial, but with the constraint that there were always four each drifting to the left and four to the right. In condition B, if the target was the item drifting to the left, the 7 distractors drifted to the right and vice versa, and there were four redscale Gabors and four greenscale Gabors. In condition C, the target was defined by the odd spatial frequency, so if the target was of “low” spatial frequency, the distractors were of “high” spatial frequency and vice versa if the target was of high spatial frequency. Again the spatial frequency of the target was determined randomly from trial to trial. The display contained four redscale and four greenscale Gabors and four each of Gabors drifting to the left and to the right in condition C.

The stimuli were presented on an imaginary circle with a radius of 7.7 arc deg away from the screen centre where a black fixation cross (0.5 cdm^{-2}) was at dead centre (see Fig. 1b). Viewing distance was 60 cm. The stimuli were presented on a light grey (22.4 cd m^{-2}) background. An 85 Hz CRT display with a screen resolution of 768 by 1024 pixels was used for stimulus presentation, driven by a standard video card on an Apple Macintosh G4 microcomputer. Custom software prepared in the C programming language (utilizing the VisionShell function library) controlled the stimulus presentation. Observers had their heads stabilized with a chin rest.

Procedure

The task of the observers was to indicate whether the odd item on the screen (of odd color in condition A, odd drift direction in condition B and of odd spatial frequency in condition C) was positioned to the left or right of the vertical midline (see Fig. 1b). Each trial started with the presentation of the fixation cross on the empty light grey background. Twelve hundred to 1700 ms afterwards (determined randomly for each trial) the eight stimuli were presented until the subject responded after which a new trial began with an interstimulus interval of 1200 to 1700 ms. If the odd Gabor was on the left of the vertical midline the observers were instructed to press “4” on the numeric keypad of an Apple Macintosh standard keyboard, while if the Gabor was on the right they were told to press ‘‘6’’. Visual feedback was given after each trial, depending on whether the response was correct (in which case ‘‘!!OK!!’’ was presented in black on the screen, following the response) or incorrect (in which case ‘‘!!XX!!’’ was presented in black on the screen). A large number of trials was required to get a reliable set of results, since the effects of two different repetition types was tested and because the effects of 0, 1, 2 and 3 or more repetitions of the same stimulus types were investigated. Each observer participated in 4500 trials, 1500 for each condition, run in 45 blocks of 100 trials with data collection spanning several days. Each condition (A, B or C) was run intermingled with one another with blocks run in different counterbalanced order for each observer. Only trials on which the observers responded correctly were used in the analyses of response times.

Results

Condition A—target defining feature: color

The mean response times and error rates as a function of repetition for the two observers are shown in Fig. 2. Shown are response time decreases as color (black disks) or motion (white disks) is new, repeated once, twice or repeated three or more times. A robust priming pattern was seen for both color and motion in condition A. Response times decreased as both color and motion of the target were repeated. As seen before in many studies (e.g. Maljkovic & Nakayama, 1994; Kristjánsson, 2006c; Kristjánsson et al. 2002), the effect increased with each repetition.

A 4 (repetition of color on target) by 4 (repetition of motion direction on the target) ANOVA was carried out

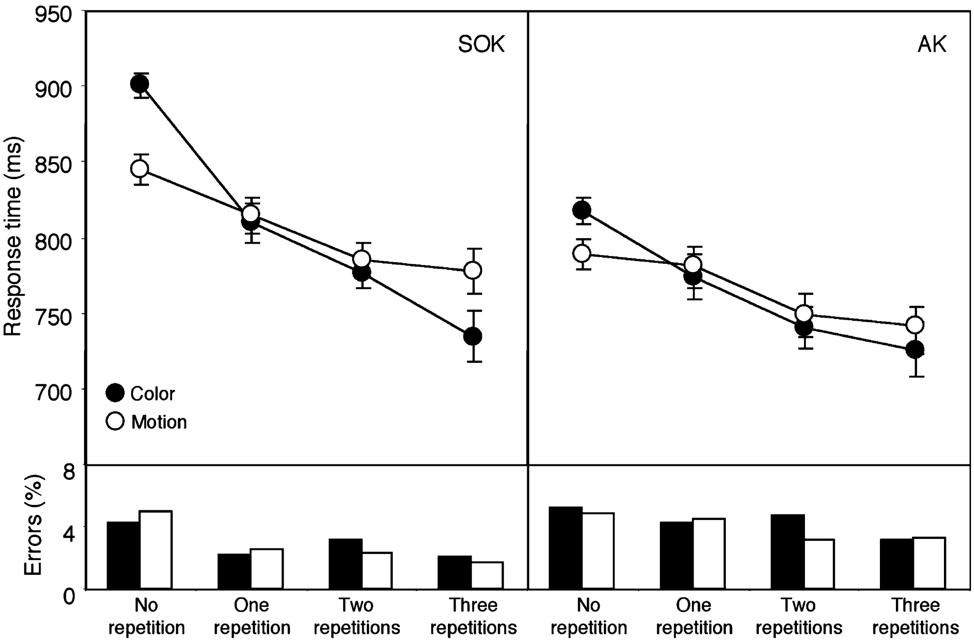

Fig. 2 The results from condition A for the two observers. The upper graph for each shows the results for response times as a function of feature repetition on the target while the bottom graph shows the error rates as a function of feature repetition (0, 1, 2 or 3 or more repetitions of each feature type). The error bars show the standard error of the mean

on the data for each observer, contrasting variation within performance for each observer with variation accounted for by repetition of target properties. The ANOVA revealed a main effect of repetition of target color for both observers (for SOK: $F_{(3,1438)} = 83.4$, $p < 0.001$; for AK: $F_{(3,1422)} = 61.7$, $p < 0.001$) and repetition of motion direction (for SOK: $F_{(3,1438)} = 43.9$, $p < 0.001$; for AK: $F_{(3,1422)} = 47.6$, $p < 0.001$). Furthermore there was no interaction between the two factors (for SOK: $F_{(9,1438)} = 1.11$, n.s; for AK: $F_{(9,1422)} = 0.79$, n.s) which indicates that the priming effects were independent from each other, and had an additive effect on response times, with performance being fastest when both features have remained constant for 3 or more trials in a row.

The priming was overall larger for color than motion (for SOK: $\text{eta}_{\text{color}} = 0.38$; $\text{eta}_{\text{motion}} = 0.29$; for AK: $\text{eta}_{\text{color}} = 0.34$; $\text{eta}_{\text{motion}} = 0.3$[1]). It is unclear at this point whether this difference in effect sizes can be accounted for by saliency differences between the two features or because color was task relevant whereas motion was not.

In sum, the results from condition A show that both the target defining feature (color in this case) and an irrelevant feature that varies between trials (in this case motion direction) show repetition priming in a visual search task. The results from this first condition indicate that motion and color do *not* interfere with each other in terms of repetition priming as was the case for orientation and spatial frequency in the experiments in Kristjánsson (2006; experiments 1 & 3), to take an example.

Condition B—task defining feature: motion direction

The results from condition B are shown in Fig. 3. The priming pattern was again strong for the two features that varied (motion and color) even though only motion direction was task relevant. The speeding effect with repetition increased the more often the features are repeated on the target, as was seen in condition A.

A 4 (repetition of motion direction on target) by 4 (repetition of color on the target) ANOVA was performed on the data for each observer (within-subject variation was the source of error). The results from the ANOVA showed a main effect of repetition of motion direction on the target for both observers (for SOK: $F_{(3,1446)} = 33.8$, $p < 0.001$; for AK: $F_{(3,1428)} = 48.7$, $p < 0.001$) and repetition of target color (for SOK: $F_{(3,1446)} = 27.6$, $p < 0.001$; for AK: $F_{(3,1428)} = 29.3$, $p < 0.001$). Again (as in condition A) there was no interaction between the two factors (for SOK: $F_{(9,1446)} = 0.76$, n.s; for AK: $F_{(9,1428)} = 1.18$, n.s) which again indicates that the priming effects were independent and have an additive effect on response times, as in condition A.

The size of the priming effects in condition B was reversed compared to condition A since the repetition priming effect for motion was this time larger than the one for color (for SOK: $\text{eta}_{\text{motion}} = 0.26$, $\text{eta}_{\text{color}} = 0.23$; for AK: $\text{eta}_{\text{motion}} = 0.3$, $\text{eta}_{\text{color}} = 0.24$). This indicates that the differences in priming found for color and motion in

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[1] $\text{eta} = \sqrt{F(df_{effect})/(F(df_{effect}) + (df_{error}))}$.

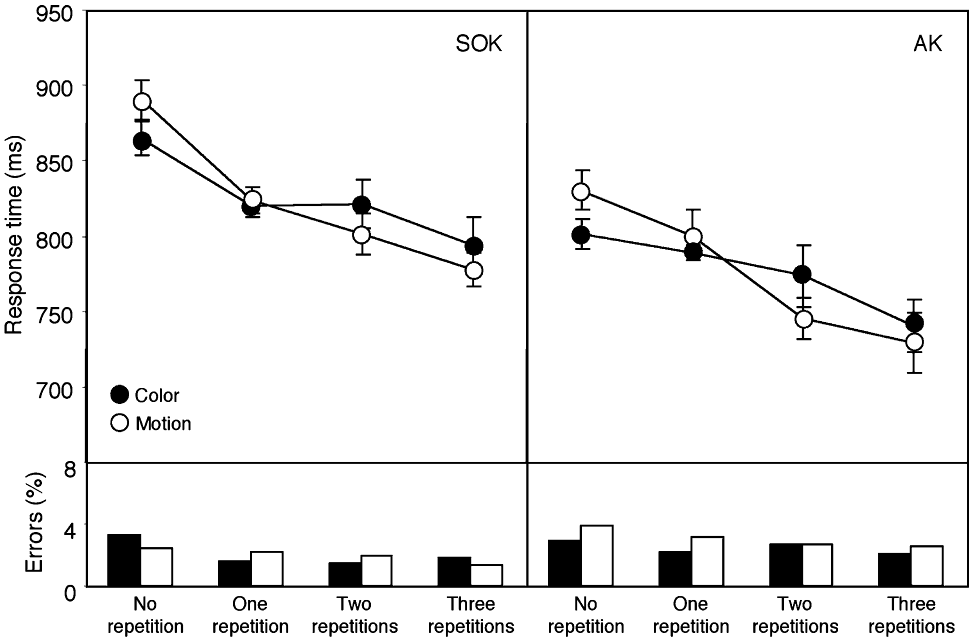


Fig. 3 The results from condition B for the two observers. The upper graph for each shows the results for response times as a function of feature repetition on the target, while the bottom graph shows the error rates as a function of feature repetition (0, 1, 2 or 3 or more repetitions). The error bars show the standard error of the mean

condition A (and indeed here in condition B) are unlikely to be due to saliency differences between these two features of the Gabor patches, but rather that the size of the priming effect is modulated by task relevance, being quite a bit larger for the feature that defines the target. Task relevance has been shown to strongly modulate priming effects in various contexts (Fecteau, 2007; Found & Muller, 1996; Hillstrom, 2000; Kristjánsson, 2006c) and the results here are consistent with this.

The results of condition B again indicate that priming of motion and color are independent and have an additive effect upon response times, and that there is no interaction between the two priming patterns.

Condition C—task defining feature: spatial frequency

In condition C the aim was to investigate priming effects of motion repetition and color and any interactions between such effects when color and motion were *both* irrelevant to the task. For that reason, the target was this time defined by differences in spatial frequency. The observer searched for the Gabor patch of the odd spatial frequency, and once again indicated whether the target was on the right or left of the vertical midline. The results from condition C are shown in Fig. 4. Priming following feature repetition was again considerable for both motion and color even though both were this time irrelevant to the task. Again the speeding effect with repetition increases the more often the features are repeated on the target.

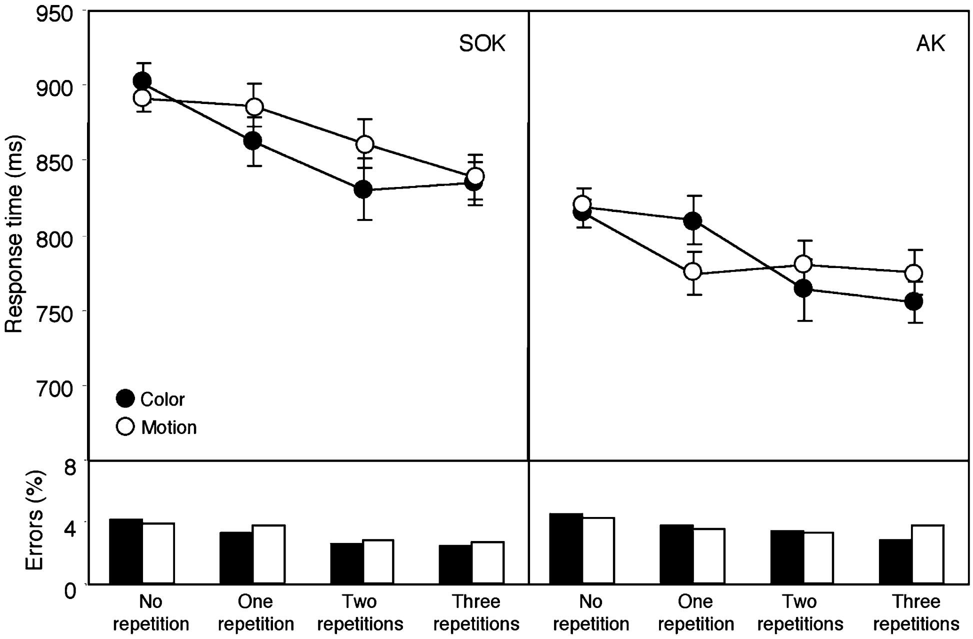
As in the previous condition a 4 (repetition of motion direction on target) by 4 (repetition of color on the target) ANOVA was performed on the data for each observer. The results from the ANOVA showed a main effect of repetition of motion direction on the target (for SOK: $F_{(3,1428)} = 27.6$, $p < 0.001$; for AK: $F_{(3,1402)} = 18.7$, $p < 0.001$) and repetition of target color (for SOK: $F_{(3,1428)} = 22.9$, $p < 0.001$; for AK: $F_{(3,1402)} = 11.8$, $p < 0.001$). Again (as in conditions A and B) there was no interaction between the two factors (for SOK: $F_{(9,1428)} = 1.81$, n.s; for AK: $F_{(9,1402)} = 1.29$, n.s) which indicates that the priming effects were independent and have an additive effect on how fast the observers responded.

The size of the priming effects in condition C was somewhat smaller than in condition A (for SOK: $\text{eta}_{\text{motion}} = 0.23$, $\text{eta}_{\text{color}} = 0.21$; for AK: $\text{eta}_{\text{motion}} = 0.2$, $\text{eta}_{\text{color}} = 0.16$), and this is consistent with the conjecture that was put forth in light of the priming pattern in the previous two conditions, that priming effects are larger for task relevant features. This is also what Kristjánsson (2006) observed.

General discussion

The main conclusion from the current experiments is that repetition of color and motion direction results in independent and additive priming effects. No interaction was found between the effects of repeating color and of repeating motion direction on the target in any of the three conditions tested here, with color (condition A), motion direction (condition B) and spatial frequency (condition C) as the target defining features. Strong priming effects of repetition of color were found in all conditions and these

Fig. 4 The results from condition C for the two observers. The upper graph for each shows the results for response times as a function of feature repetition while the bottom graph shows the error rates as a function of feature repetition (0, 1, 2 or 3 or more repetitions of the feature in each case). The error bars show the standard error of the mean



effects were largest when color was the target defining dimension (condition A). Repetition of motion direction also led to strong priming effects, and again those effects were strongest when motion direction defined the target (condition B). These results show convincingly that features do not have to be task relevant for repetition priming to occur, but the results also show that the priming effects are larger for task-relevant than task-irrelevant features, consistent with previous results (Hillstrom, 2000; Kristjánsson, 2006c; Fecteau, 2007; Found & Müller, 1996). Fecteau (2007) found that task-irrelevant features did not result in priming, in seeming contradiction to what has been found here (and in some other studies, see e.g. Huang et al., 2004; Kristjánsson, 2006c). There was, however, an important methodological difference between the Fectau study and the others in that the relevant dimension (color or shape) was precued before each trial so that the irrelevant feature was more likely to be actively suppressed in accordance with the cued instructions, under those conditions, than in the other studies where the irrelevant dimension was *never* relevant within a whole block of trials.

Kristjánsson (2006c) found that color and orientation, on the one hand, and color and spatial frequency on the other, showed independent and additive priming effects but importantly, orientation and spatial frequency did not show such additive priming effects, except when both were task relevant, in other words it seems that some features interfere with one another in terms of priming while others do not, and that this interference is modulated by task relevance. Only when both spatial frequency and orientation were both task relevant did both lead to priming effects. When spatial frequency or orientation were task relevant and the other feature of the two task irrelevant, priming was not seen for the task irrelevant feature (Kristjánsson, 2006c, Experiments 1 and 3). On the other hand, priming was seen for orientation (Kristjánsson, 2006c, Experiment 4) and spatial frequency (Kristjánsson, 2006c, Experiment 5) when they were task irrelevant but *only* when the other feature was also task irrelevant but importantly remained constant and was the same for both target & distractors throughout the experiment.

Kristjánsson (2006c) suggested that overlap in neural mechanisms devoted to the analysis of orientation and spatial frequency resulted in interference in terms of priming effects. While certainly quite speculative in this context, evidence from neuroimaging and transcranial magnetic stimulation indicates that priming in visual search is partly correlated with activity modulations in early visual areas (Campana, Cowey & Walsh, 2002, 2006; Geng et al., 2006; Kristjánsson et al., 2007). The results here, where priming for color and motion show no interdependency nor interaction, may suggest that there is little such overlap in neural machinery for the two. This accords rather well, of course, with what is known about neural mechanisms involved in the analysis of these features, such as V4 (Bartels & Zeki, 2000) or V8 (Hadjikhani, Liu, Dale, Cavanagh & Tootell, 1998) for color and MT/V5 for motion (Newsome & Pare, 1988; Tootell et al., 1995).

Magnussen & Greenlee (1999; see also Magnussen, Greenlee, Asplund & Dyrnes, 1991) argued for the existence of a rather primitive (early) memory system that is perchance tied to residual activity in early visual areas. They suggested that residual activity in feature specific mechanisms could act as a visual short-term memory system. A similar idea was suggested by Tulving and Schacter (1990). Independent and additive priming effects for different features may indicate that the priming effects reflect residual activity in feature specific mechanisms early in the visual process, which show little within-interference, or in other words little overlap with each other in terms of processing. Again, this is consistent with recent neuroimaging results of priming (Geng et al., 2006; Kristjánsson et al., 2007).

Finally, the results from the current experiments (and Kristjánsson, 2006c) indicate that attention shifts towards target do not simply selectively facilitate the feature that defined the target in the first place, but also features that are "hangers-on", as motion is for the color defined target, and color for the motion defined one. But the strongest facilitation is on average seen for the target defining feature.

Object-based or feature-based priming?

An important question in the light of recent findings on these history effects is the degree to which these priming effects are feature specific. To put this in other words: Do these speeded attention shifts reflect facilitation based on features or do they reflect facilitation at more advanced processing stages, perhaps where objects are integrated as Huang et al. (2004) and Hillstrom, (2000) have suggested?

I wish to argue that extreme versions of either account are unlikely to reflect the true state of things. There are at least three reasons that I hold this view. Firstly, recent evidence from neurophysiology (Bichot & Schall, 2002), neuroimaging (Geng et al. 2006; Kristjánsson et al. 2007) neuropsychology (Kristjánsson et al., 2005) transcranial magnetic stimulation (Campana et al., 2002; 2006) and lesioning studies (Walsh et al., 2000) indicates that priming may reflect activity at various sites in the brain – both at sites where objects may (at least to a degree) be integrated *as well as* areas that may reflect processing at the level of features (such as color or motion in the case of the current experiments). Priming effects have even been found as early as in extrastriate cortex with fMRI. Secondly, recent results from Kristjánsson et al. (2008) suggest that whether the priming pattern reflects facilitated processing of integrated objects or features depends heavily on the *type* of stimulus that priming is being tested for. In a relatively difficult search task, where observers searched for diamonds that contained two colors, the degree to which particular features tended to be perceived as whole objects or separate features determined strongly whether the objects' repetition reflected what one might call object-based priming or feature-based priming. Thirdly, the results of Kristjánsson (2006c) where dissociable priming effects from repetition of different features was observed also indicate that priming of whole objects cannot be the whole story.

Priming is thus likely to involve facilitation at several levels of the perceptual process. A "hybrid" view in which priming is thought to involve the facilitated processing at various different processing levels is perhaps the most parsimonious account of the data. While the current results do not address directly this question, they are consistent with such a hybrid view.

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