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Attention and the detection of masked radial frequency patterns: Data and model

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ABSTRACT

A radial frequency (RF) stimulus is strongly masked by a second, surrounding RF stimulus that follows the first after a critical stimulus onset asynchrony (SOA) of around 100 ms. We sought to determine whether a mask-dependent attentional cuing effect, like that found when detecting pattern-masked sinusoidal gratings, would be obtained with RF stimuli. Observers detected RF modulations in cued or miscued stimuli that were masked with a simultaneous (SIM) RF mask or a delayed (SUC) RF mask that followed it after 100 ms. There were large cuing effects in the SUC condition and small cuing effects in the SIM condition, replicating previous findings. The data are well described by a model in which masks affect the informational persistence of stimuli and cues affect the rate at which stimulus information is transferred into visual short-term memory.

1. Introduction

In this article, we investigate the relationship between attention and a new form of visual masking, *radial frequency pattern masking*, reported by Habak, Wilkinson, Zakar, and Wilson (2004) and Habak, Wilkinson, and Wilson (2006). This form of masking is found with pairs of radial frequency (RF) pattern stimuli, like those depicted in Fig. 1. An RF stimulus is formed by sinusoidally modulating the radius of a suprathreshold-contrast circle that is band-limited in spatial frequency. The observer's task is to judge whether the stimulus that is presented is a true circle (zero RF modulation), or has been radially deformed. The measure of interest is the modulation threshold, that is, the minimum depth of modulation needed to distinguish between a deformed and an undeformed circle. Such stimuli are interesting theoretically because they appear to be processed holistically—at least at low modulation frequencies (Bell, Badcock, Wilson, & Wilkinson, 2007). This has been taken as evidence that they stimulate higher-order visual mechanisms, possibly in area V4, which may act as basis functions for human pattern perception (Habak et al., 2004).

Habak et al. (2006) showed that an RF stimulus is strongly masked by a second RF stimulus whose contours surround the first stimulus, but do not touch or overlap it, and which follows the first after a critical delay of 80–110 ms. The masking function that is obtained is a strongly U-shaped, or Type B, masking function, of the kind that has been found in metacontrast masking and masking-by-structure paradigms (Breitmeyer, 1984; Breitmeyer & Ogmen, 2000). There is relatively little masking when the mask precedes the target (forward masking) or when the target and mask are presented simultaneously. When the mask trails the target (backward masking), the magnitude of the masking effect increases sharply with increasing mask delay up to the critical target-mask stimulus onset asynchrony (SOA) and then decreases. An RF mask of the same frequency and phase angle as the target, presented at the critical SOA, can produce a 16-fold elevation of modulation thresholds. Fig. 2 shows a masking function of this kind. There is a relatively small amount of forward masking, but substantial backward masking.

In the masking literature, this type of masking function has been distinguished from a second, V-shaped, or Type A masking function (Breitmeyer, 1984). Unlike Type B functions, Type A masking functions are symmetrical; forward and backward masking effects are equal in magnitude and masking is maximal when target and mask are presented simultaneously. Type A masking functions are typically found in noise masking and masking by light paradigms. These two kinds of masking function have been taken as evidence that masks can disrupt visual processing in one of two ways, either by *interruption masking* or by *integration masking* (Kahneman, 1968). In interruption masking, the mask terminates processing of a preceding target before it is complete. In integration masking, the target and mask fuse to form a perceptual composite, whose signal-to-noise ratio is lower than that of the target in isolation. The visual processes assumed to underlie integration masking and interruption masking predict Type A and Type B masking functions, respectively.

For attention researchers, the distinction between different kinds of masking mechanisms is important because links between masking and attention have been found in a number of settings. In metacontrast and object-substitution masking paradigms, the

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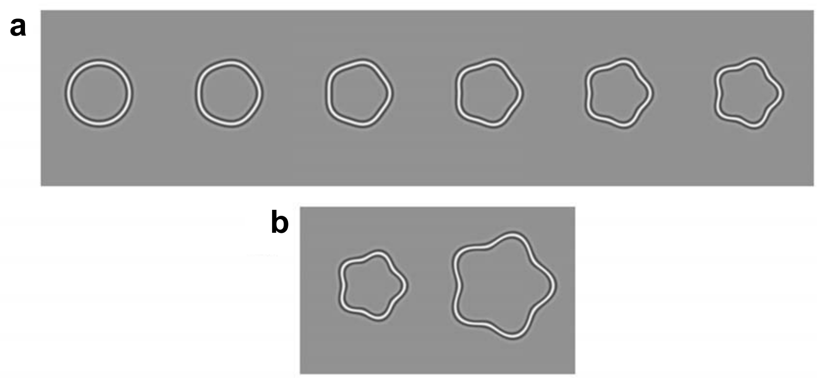

Fig. 1. (a) Example RF patterns. The stimuli are RF(5) patterns with modulation fractions of 0, 0.024, 0.048, 0.072, 0.096, 0.120. (b) RF(5) target stimulus and mask. The modulation of the mask is held fixed while the modulation of the target varies. The target and mask are both presented at the same phase angle, which varies randomly from trial to trial.

magnitude of the masking effect depends on whether or not the stimulus is attended (Enns & Di Lollo, 1997; Ramachandran & Cobb, 1995). Conversely, in spatial cuing and attentional blink paradigms, the magnitude of the attentional effect depends on whether stimuli are masked and on the way they are masked (Enns, 2004; Giesbrecht & Di Lollo, 1998; Lu & Dosher, 1998; Smith, 2000; Smith & Wolfgang, 2007). These findings suggest that studying the relationship between attention and masking may help us understand how attention affects visual processing in a more general way. In this article, we investigate this relationship in an RF masking paradigm.

1.1. The mask-dependent cuing effect in visual signal detection

Our investigation of the link between attention and RF masking grew out of a series of studies by Smith and colleagues on the role of attention in visual signal detection (Gould, Wolfgang, & Smith, 2007; Smith, 1998, 2000; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004; Smith, Wolfgang, & Sinclair, 2004; Smith & Wolfgang, 2007). These studies investigated one of the enduring questions in attention, namely, whether detecting a simple, well localized, luminance stimulus in an otherwise empty display benefits from, or requires, attention. The idea that it does not—that detection is, in Neisser's (1967) terminology, a preattentive process—has a long and controversial history that goes back to the first decade of modern attention research, to the pioneering auditory experiments of Cherry (1953) and to the filter theory of Broadbent (1958). Pashler (1998) and Smith (in press) have discussed the theoretical origins of this idea and Palmer, Verghese, and Pavel (2000) have provided a review and an analysis of the recent literature.

The first study to test the preattention hypothesis using near-threshold stimuli was reported by Bashinski and Bacharach (1980). They found, contrary to the hypothesis, that spatial cues increased detection sensitivity for luminance stimuli. A number of other studies addressed this question using a variety of methods during the following decades, with conflicting results. Studies by Carrasco, Penpeci-Talgar, and Eckstein (2000), Cameron, Tai, and Carrasco (2002), Downing (1988), Hawkins et al. (1990), Luck et al. (1994), Müller and Humphreys (1991), and Smith (1998), reported results consistent with those of Bashinski and Bacharach. These studies all found increased detection sensitivity for attended stimuli. However a second group of studies, by Bonnel, Stein, and Bertucci (1992), Bonnel and Hafter (1998), Brawn and Snowden (2000), Foley and Schwarz (1998), Davis, Kramer, and Graham (1983), Graham, Kramer, and Haber (1985), Lee, Koch, and Braun (1997), Müller and Findlay (1987), Palmer (1994), Palmer, Ames, and Lindsey (1993), and Shaw (1984), found little or no evidence that attention increases detection sensitivity. Several studies in this latter group compared detection and more complex perceptual judgments, such as discrimination or recognition of form (Bonnel & Hafter, 1998; Bonnel et al., 1992; Brawn & Snowden, 2000; Lee et al., 1997; Müller & Findlay, 1987; Palmer, 1994; Palmer et al., 1993; Shaw, 1984). These studies found results consistent with the traditional preattention–attention dichotomy: attention had little or no effect on detection but substantially improved performance for more complex judgments.

Smith (2000) argued that the critical factor distinguishing between the two groups of studies was whether or not backward masks were used to limit the information extracted from the display. He pointed out that, with a few exceptions, studies finding increased sensitivity for attended stimuli limited stimulus information with backward masks. Studies finding no increase in sensitivity limited stimulus information by limiting exposure duration or contrast alone. Discussions of this literature, including an analysis of the exceptional cases, can be found in Gould et al. (2007) and Smith, Wolfgang, et al. (2004). Smith (2000) compared the effects of attention on the detectability of masked and unmasked stimuli in a spatial cuing paradigm and obtained results consistent with this idea. Sensitivity was higher for attended stimuli when stimuli were backwardly masked; when they were unmasked, sensitivity for attended and unattended stimuli did not differ. We refer to this finding as the *mask-dependent cuing effect.*

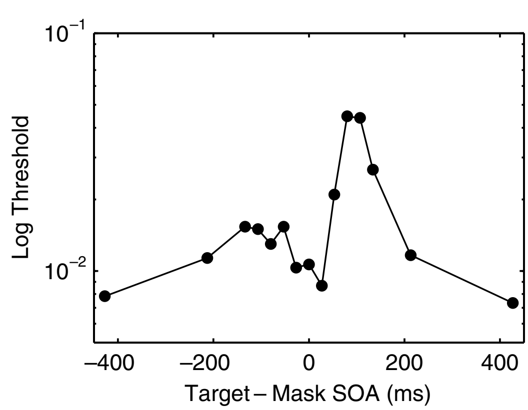

Fig. 2. Type B masking function for RF patterns. The function shows the logarithm of the modulation threshold. There is a relatively small amount of forward masking (negative target-mask SOAs) and a large amount of backward masking (positive cue-target SOAs) that peaks at a critical SOA of around 100 ms. Plot based on data from Habak et al. (2006).