Available online at www.sciencedirect.com
ScienceDirect
Vision Research 47 (2007) 2305–2313
Vision Research
www.elsevier.com/locate/visres

Masks reveal processing time for alignment across space

Sarah J. Waugh *

Anglia Vision Research, Anglia Ruskin University, Cambridge CB1 1PT, UK

Received 12 February 2007; received in revised form 20 May 2007

Abstract

Does spatial separation incur a processing time requirement before precise alignment judgements can occur? Alignment thresholds for separated lines are measured for exposure durations from 27 to 500 ms, with and without post-masks. The effect of masks on visibility is controlled. Unlike without a post-mask, with an effective post-mask, alignment thresholds improve substantially with time, i.e. in square-root fashion. Alignment across space may be important for further shape analysis. Threshold improvement is probably not explained by a spatial scale shift of visual analysis over time. A higher-order collection stage appears to refine relative position information for up to 200 ms.

Keywords: Visual alignment; Spatial separation; Time; Temporal integration; Spatial masking

1. Introduction

Spatial location and orientation, inherent features in spatial alignment, are two of the most elementary units of information used in shape representation and therefore constitute spatial 'primitives' (Marr, 1976). Judgements of relative spatial position and orientation are also among the most precise that the human visual system is capable of. Is the ability to judge spatial misalignment then, immediate? It is thought that the visual system processes spatial alignment information in different ways, depending on the spatial proximity of the targets involved and the availability of useful differential contrast cues (e.g. Burbeck & Yap, 1990; Waugh & Levi, 1993a). That is, for touching or closely separated targets where local contrast changes are a useful cue to a change in position or alignment, relative position thresholds such as vernier thresholds, can be accounted for by combining the differential outputs of the early contrast detection filters in vision (Klein & Levi, 1985; Wilson, 1986). For vernier acuity then, providing the target energies are kept approximately equal to the visual system, the ability to judge misalignment is approximately equal, precise and essentially immediate. Thresholds are equally precise for detecting misalignment when such targets are presented for a few milliseconds or for 1000 ms (Hadani, Meiri, & Guri, 1984; Waugh & Levi, 1993b; Westheimer & Pettet, 1990) although they are also dependent on having same contrast polarity (e.g. Levi & Waugh, 1996; Levi & Westheimer, 1987; O'Shea & Mitchell, 1990) and being simultaneously visible within the temporal integration time of the underlying spatial filter (Beard, Levi, & Klein, 1997; Wehrhahn & Westheimer, 1993). Furthermore, the results of a study using a simultaneous masking paradigm suggest that the precision of vernier thresholds is predominantly dependent on the signal-to-noise properties of a small range of contrast sensitive filters (Waugh & Levi, 2000), rather than on a shift from the large towards the finest spatial scales in vision (an alternative suggested by Watt (1987) for the processing of spatial geometrical information).

What happens when local contrast cues cannot provide sensitive information about spatial misalignment to the visual system, such as when the targets are distinctly

* Present address: Anglia Vision Research, Department of Optometry and Ophthalmic Dispensing, Anglia Ruskin University, Cambridge CB1 1PT, UK. Fax: +44 1223 417 712.
E-mail address: s.j.waugh@anglia.ac.uk

0042-6989/$ - see front matter
doi:10.1016/j.visres.2007.05.009

separated in space? The contrast dependencies of these thresholds are far weaker (Waugh & Levi, 1993a) and not dependent on the contrast polarity (e.g. Levi & Waugh, 1996; Levi & Westheimer, 1987; O'Shea & Mitchell, 1990) or the temporal synchrony of the component lines (Beard et al., 1997). Indeed, computational models which rely on contrast sensitivity responses of early spatial filters to fully account for these thresholds, fail, once target separations exceed about 10 arcmin for foveal viewing conditions (Klein & Levi, 1985; Wilson, 1986). Theories proposed to account for these thresholds, therefore, invoke second-order, or later stages above contrast detection, that either suggest a comparison process across absolute position tags or local signs (Hering, 1899), or a transmission of positional information between targets by collector type mechanisms (Levi & Waugh, 1996; Morgan, Ward, & Hole, 1990). To give further insight into the nature of the process used to extract relative positional alignment from separated targets, clearly a task related to some further shape analysis tasks (e.g. Levi & Klein, 2000; Saarinen & Levi, 2001), experiments in the current paper investigate processing time aspects of simple two-line spatial alignment. As has been done previously for vernier acuity (Waugh & Levi, 1993b; Waugh & Levi, 2000), spatial noise masks are used to directly follow an equally visible alignment stimulus, ostensibly to limit the processing time to the stimulus exposure duration. This is a paradigm similar to that used by several other authors for other spatial tasks in an attempt to end any useful visual persistence or visual processing once the stimulus is turned off (e.g. Foster & Westland, 1998; Hess, Beaudot, & Mullen, 2001; Watt, 1987; Waugh & Levi, 1993b). An alternative view is that rather than simply limiting the processing time of the spatial stimulus, the post-mask may affect thresholds through a backward masking mechanism (e.g. Breitmeyer, 1980; Breitmeyer & Ganz, 1976). Whatever the exact mechanism, the effect of similar post-masks to the ones used in this study on vernier acuity, appears to be explained by its effect on target detectability. What becomes interesting to study in this paper is whether or not, once the effect of any post-mask on target visibility is taken into account, the processing of alignment information across space displays a different time-consuming process.

Previous research has reported a rather slight, though not always consistent effect of exposure duration on alignment thresholds (Waugh & Badcock, 1996, 1998; Waugh & Levi, 1993a), amounting to an improvement overall in threshold with increasing exposure duration according to a power function with slope of about −0.10. This was found using equally visible line and blob stimuli across exposure duration, however, no attempt was made to constrain available processing time by using for example, a mask, to immediately follow the target presentation. The effects of exposure duration on spatial interval discrimination thresholds for widely separated bars have been investigated and in some cases were found to be substantial (Burbeck, 1986; Burbeck & Yap, 1990), however, in these studies, target visibility was not well controlled and again experiments did not employ a post-mask. In addition, the results of one study (Beard et al., 1997) using equally visible though unmasked stimuli has shown that when the two lines of an alignment target were presented with asynchronies of up to about 200 ms, alignment thresholds were not adversely affected. This finding might suggest that the extraction of alignment information could not possibly be immediate. Indeed, in the current study, a substantial effect of exposure duration on alignment thresholds (i.e. slope of −0.5) using a high-energy post-mask as a tool is revealed perhaps for the first time.

2. Methods

All stimuli were generated using a Cambridge Research Systems VSG2/3 graphics card, which drove a Hitachi monitor (P4 phosphor) at 150 Hz. The alignment target stimuli were two horizontal thin dark lines, each 30 arcmin long and separated by 90 arcmin, presented on a mean luminance (40 cd/m^2) background. The mean luminance screen was surrounded by a large grey field of a slightly lower mean luminance. The stimulus lines were always 2 pixels wide (1.14 arcmin), unless in order to obtain higher visibility for the observer, they were made slightly wider, however, in all cases the alignment line stimuli had the same dimensions as the detection line stimuli used under all experimental conditions, to ensure that visibility of the alignment stimuli was kept constant across all conditions. A control experiment confirmed that maximum changes in line width did not influence alignment thresholds. All stimuli were viewed monocularly; from 3 m.

Alignment thresholds were measured for stimuli presented for 27, 50, 100, 200 and 500 ms with abrupt onset and offset. For the alignment task, the observers were instructed to fixate the leftmost target line, the reference line, while making alignment judgements about the non-fixated line, the test line (see Waugh & Levi, 1993a for diagram of stimuli and justification of this strategy). The alignment stimulus was immediately followed by a mean luminance screen (no mask condition) or after 7 ms (1 frame), by a spatial noise mask, which remained on for 500 ms. The 7 ms time was selected based on the results of pilot experiments, where the temporal asynchrony of the mask was varied and on average, optimal interference was found on the alignment task for this duration, decreasing for longer durations and slightly more than occurred for an immediate onset. This timing of mask effectiveness is not at all like the longer duration of effectiveness found for backward metacontrast masking (Breitmeyer & Ganz, 1976). The 7 ms asynchrony also matches that used in previously published work for vernier acuity (Waugh & Levi, 1993b). There were two types of mask. One-dimensional spatial noise masks were constructed by adding in random phase, integral sinusoidal wave components specified within the desired bandwidth (1.24–4.92 c/deg) and oriented at 20 deg. The mask contrast, the maximum peak to peak variation in the luminance profile, was either 40% or 100%. Random dot masks consisted of bright white dots/blocks, either 1.7 arcmin or 6.8 arcmin square, on the mean luminance background, so that they produced an overall brightness change as well as a spatial change. Both types of mask filled the entire stimulus field. The spatial characteristics of the masks were estimated from previous results (Waugh & Levi, 1995) to produce maximum interference on the specific alignment judgement for each observer. It was not the intention of this study to carefully carry out a full range of mask energy levels, although this may well be of interest in future studies.

To ensure that the effects of exposure duration and post-masks on target visibility during the alignment task were carefully accounted for, contrast thresholds for the non-fixated line were measured for each observer at all exposure durations and under all post-mask conditions. The stimulus arrangement for measurement of contrast thresholds was the same as that used for the alignment task, however, the leftmost fixated line was always clearly visible and judgements were made about the rightmost