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Positional noise in Landolt-C stimuli reduces spatial resolution: A study with younger and older observers

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ABSTRACT

In the present study we examined the effect of positional noise on spatial resolution in younger and older observers. We used a yes/no discrimination task in which observers indicated whether the size of two gaps in a Landolt-C-like contour was the same or not. The proportion of trials observers perceived one gap larger was measured when gaps-position was fixed (low positional noise) and random (high positional noise). Specifically, we compared, across conditions and groups, the values of threshold, lower and upper asymptote of the psychometric function. In the younger group, noise does not prevent detection of gap-size difference although sensitivity is lower, as revealed by higher threshold and lower upper asymptote, i.e., the proportion of responses "I see a larger gap" at the largest gap-size difference (asymptotic performance). In the older group detection is prevented, as revealed by threshold, lower and upper asymptote data. This may be because, at stimulus onset, high positional noise has associated coarse filter analysers averaging across the two gaps, which cannot be switched off.

1. Introduction

Psychophysical studies have demonstrated that prior information about the position of a target increases spatial resolution in a variety of tasks such as acuity (Baldassi & Burr, 2000; Balz & Hock, 1997; Morgan, Ward, & Castet, 1998), texture segmentation (Carrasco, Loula, & Ho, 2006; Yeshurun & Carrasco, 1998, 2000; Yeshurun, Montagna, & Carrasco, 2008), resolution of gratings (Abrams, Barbot, & Carrasco, 2010; Davis & Graham, 1981; Gobell & Carrasco, 2005; Lee et al., 1999; Shulman & Wilson, 1987) and gaps (Carrasco, Williams, & Yeshurun, 2002; Gobell & Carrasco, 2005; Shalev & Tsal, 2002; Yeshurun & Carrasco, 1999). Most of these studies increased visual information at a given location by spatial pre-cueing the target position, whereas others reduced the attentional spread (Balz & Hock, 1997; Beck & Ambler, 1973). Most of these studies used a forced choice task but others (Balz & Hock, 1997; Beck & Ambler, 1973; Shalev & Tsal, 2002) used a yes/no task. The improvement in spatial resolution occurred regardless of the paradigm and the task used.

Many neurophysiological studies interpreted the effects of pre-cueing the target position as due to a shift and/or constriction of the receptive field of the cell at the attended location (Anton-Erxleben, Stephan, & Treue, 2009; Moran & Desimone, 1985; Reynolds & Desimone, 1999; Womelsdorf et al., 2006). Psychophysical studies have long debated whether the effect of pre-cueing is to increase the sensitivity of small spatial filters – thus allowing for a more fine grained analysis of the attended area with the result of increasing the perceived size of attended stimulus (Anton-Erxleben, Stephan, & Treue, 2009) – the sensitivity to the relative position of two bars (Balz & Hock, 1997), the apparent spatial frequency of gratings (Abrams, Barbot, & Carrasco, 2010), the resolution for Gaps in a line (Shalev & Tsal, 2002) and in Landolt-C stimulus (Gobell & Carrasco, 2005). The balance of evidence is that pre-cueing the target position affects sensitivity. Indeed, the presence of the attentional cue influences both the *point of subjective equality (PSE)* – namely the point at which two stimuli appear equal – and the *just noticeable difference (JND)* between two stimuli – namely the difference in one of their dimensions that is perceived in most of the trials (Abrams, Barbot, & Carrasco, 2010; Anton-Erxleben, Henrich, & Treue, 2007; Gobell & Carrasco, 2005). Most studies that used a pre-cue paradigm have manipulated involuntary (exogenous) attention by presenting the cue at a short (about 100 ms) stimulus onset asynchrony (SOA) from briefly presented target (50 ms). There is however evidence that directing voluntary (endogenous) attention (Abrams, Barbot, & Carrasco, 2010) also affects PSE. Moreover, varying the attentional spread (Balz & Hock, 1997) – which likely results in a modulation of *positional uncertainty* (or *positional noise*) – only affects JND. This result was obtained using detection of misalignment measured with a yes/no task, suggesting that the effect of manipulating the prior information about the target location does not depend on the task.

From the reviewed literature it appears that both exogenous and endogenous attention increase spatial resolution, possibly as a consequence of a reduction in positional noise. Note however

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that studies that used a pre-cue paradigm did not really reduce positional uncertainty insofar as there were generally two locations, both relevant for the judgement. Here we directly manipulated positional noise to address the issue of how positional noise affects spatial resolution. To do this we did not direct attention to a location by presenting a pre-cue (Abrams, Barbot, & Carrasco, 2010) nor we varied the spread of attention (Balz & Hock, 1997). We instead manipulated the position (fixed vs. random) of gaps along the contour of a circle and involved observers in a spatial resolution task, asking them to say whether they perceived the difference in size between two gaps. Differently from others that measured absolute threshold for one gap (Carrasco, Williams, & Yeshurun, 2002; Yeshurun & Carrasco, 1999), we measured difference threshold between two gaps. Gap position along the contour of a circle was either fixed, and positional noise low, or random, and positional noise high. We used the same long exposure duration (400 ms) in both fixed and random position condition. Balz and Hock (1997) observed that once attention “fully arrives” at the target, it could enhance processing (spatial resolution) as much as when there was a valid pre-cue. Watt (1987) argued that for the first 300–500 ms following the onset of a stimulus, the sensitivity of relatively small spatial filters (detecting units responsive to relatively fine details) increases relative to the sensitivity of large filters (detecting units responsive to coarser spatial information). Based on this reasoning, voluntary attention may be fully allocated at stimulus offset, in both the fixed and random position. However, even though 400 ms exposure are sufficient to allocate both covert and overt attention to the stimulus, attention may be focused on the gaps in the fixed condition and spread over the whole contour of the circle in the random one. In this case it is possible that fixed and random position conditions have associated a different scale of “stimulus analyser”, small- and coarse-scale respectively. The increase in size of stimulus analyser increases threshold and/or decreases the upper asymptote. Moreover, a too large stimulus analyser averages over the two gaps so preventing gap-size comparison (Morgan, Ward, & Castet, 1998).

To evaluate the effect of positional noise on gap resolution we carried out a quantitative comparison of the parameters of the psychometric function obtained when the position of gaps was constrained (fixed position condition) and when it varied randomly from trial to trial (random position condition). In particular, we compared quantitatively the following parameters of the psychometric function[1]: (i) *upper asymptote* (ii) *lower asymptote* (iii) *threshold*, defined as the gap-size difference associated to 0.5 probability of detecting the presence of a larger gap. These parameters are estimated by fitting with a psychometric function the proportion of “yes” responses obtained as a function of log-gapsize ratio). Thresholds were defined as the log-gapsize ratio producing a proportion of ‘yes’ responses equal to 0.5.

1.1. The effect of aging

The second goal of our study was to establish whether aging affects the way in which positional noise reduces spatial resolution. Many factors may be responsible for age-related changes in vision. Some of the effects of age may be attributed to changes in the optical quality of the eye (Weale, 1992) and should not be affected by positional noise. These changes do not manifest themselves as increased equivalent input noise either (Bennett, Sekuler, & Ozin, 1999; Pardhan et al., 1996). Furthermore, neural mechanisms might also affect the response to the stimulus and introduce internal noise that could reduce spatial resolution. These effects would also occur regardless of positional noise and they should also be expected in the fixed condition. On the other hand, aging may reduce spatial resolution in the random condition only, suggesting not a deficit in spatial resolution per se but specifically related to high positional noise conditions more likely interpretable within the framework of selective attention. The differentiation between these possibilities is important because the effect of positional noise is not controlled when measuring visual acuity with Landolt-C (Bach, 2007).

2. Experiment 1

2.1. Methods

This research adhered to the tenets of the Declaration of Helsinki, and has been approved by the bioethics committee of the Psychology Faculty of the University of Padua. Informed consent was obtained from all participants.

2.1.1. Stimuli

Stimuli were composed of cosine-phase Gabor patches arranged in a circle. The standard deviation of the 2-D Gaussian envelope was 0.16 deg and the sinusoidal grating had a wavelength λ of 0.32 deg (spatial frequency = 3.13 cyc/deg). Stimuli were achromatic with a Michelson contrast of 0.87 and presented on a background with mean luminance of 38.9 cd/m^2. We used high contrast Gabors to ensure that the lower sensitivity that older observers have for carriers of this spatial frequency (Owsley, Sekuler, & Siemsen, 1983) could not cause group differences.

We created the target stimuli by first placing 12 equally spaced Gabors of random orientation (centre-to-centre distance = 0.84 deg or 2.6λ) along an imaginary circle (radius = 1.62 deg) centred on the screen.

We then created two gaps equal in size (60°) in this circular disconnected contour. To do this we removed two non-adjacent Gabors, with the constraint that one Gabor remained between the two gaps (Fig. 1). At this point in the stimulus creation procedure we shifted (either clockwise or anticlockwise) the Gabor between the two gaps. We used 11 levels of shift such that one gap resulted x% larger than the other, with x ranging from 0 to 70 (step of 7). Fig. 1 shows two examples of the stimuli where one gap (71.8°) is 49% larger than the other (48.2°).

In the “fixed-position” condition (Fig. 1a) the two gaps were always in the upper part of the circular contour, one in the *11 o’clock position* and the other in the *1 o’clock position*. The larger gap randomly assumed one of these two positions. In the “random-position” condition (Fig. 1b) the two gaps could assume any position along the contour, always with the constraint that one Gabor was between them.

The target stimulus was followed by a mask with 12 randomly oriented, equally spaced Gabors placed along an imaginary circle (same radius as the target stimulus).

2.1.2. Apparatus

The stimuli were programmed in Matlab (Mathworks; Natick, MA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) and were presented on a 17-in “P70f ViewSonic” CRT monitor (refresh rate: 100 Hz; resolution: 1024 × 768 pixels). A Pentium 4 computer was used for generating and presenting the stimuli. Experiment control and collection of behavioural responses were undertaken using E-Prime (version 1.2).

Contrast sensitivity was measured using CRS Psycho 2.36 software. The stimuli were generated by a Cambridge Research System VSG2/3 graphics card and displayed on a 17-in “Philips Brilliance 107P” CRT monitor (refresh rate: 70 Hz; resolution: 1024 × 768 pixels).

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[1] Note that these parameters are trends obtained by fitting psychometric functions.