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A method for quantifying visual field inhomogeneities

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ABSTRACT

It is well known that performance is not homogeneous across the visual field, even at isoeccentric locations. Several inhomogeneities in particular have been identified – a Horizontal–Vertical Anisotropy (HVA – better performance in the horizontal than in the vertical direction); a Vertical Asymmetry (VA – better performance in the lower than the upper visual field); and a Vertical Meridian Asymmetry (VMA – better performance below than above the point of fixation *on the vertical meridian*). Performance has also been reported to be particularly poor at the location directly above the point of fixation, i.e., the "North" (N) location and sometimes at the location directly below the point of fixation, i.e., the "South" (S) location. These phenomena are typically characterized by statistics that compare performance across the visual field to a homogeneous (*circular*) model. Here we propose an alternative method for assessing visual field inhomogeneities, which involves comparing performance to an *elliptical* model of the visual field. We maintain that this method provides a more robust analysis of visual field inhomogeneities because it does not overestimate the North and South effects.

1. Introduction

It is well known that performance is not homogeneous across the visual field, even at isoeccentric locations. In addition to the well-known foveal/peripheral differences, visual fields are generally elongated in the horizontal direction. Performance is superior in the horizontal compared to the vertical direction (Cameron, Tai, & Carrasco, 2002; Carrasco, Giordano, & McElree, 2004; Carrasco, Talgar, & Cameron, 2001; Carrasco et al., 1995; Rijsdijk, Kroon, & van der Wilt, 1980; Rovamo & Virsu, 1979), which has been referred to as the *Horizontal–Vertical Anisotropy* (*HVA*; Carrasco, Talgar, & Cameron, 2001; Kröse & Julesz, 1989; Nazir, 1992). Performance is often better in the lower than upper visual field (Altpeter, Mackeben, & Trauzettel-Klosinski, 2000; Edgar & Smith, 1990; He, Cavanagh, & Intrilligator, 1996; Levine & McAnany, 2005; Previc, 1990), which has been referred to as the *Vertical Asymmetry* (*VA*). A *Vertical Meridian Asymmetry* (*VMA*) has been reported; performance is superior for stimuli that are placed below compared to above the horizontal meridian *on the vertical meridian* (Cameron, Tai, & Carrasco, 2002; Carrasco, Giordano, & McElree, 2004; Carrasco, Talgar, & Cameron, 2001; Talgar & Carrasco, 2002). In some studies, better performance in the lower visual field could be considered either a VA or VMA (He, Cavanagh, & Intrilligator, 1996; Rubin, Nakayama, & Shapley, 1996). Under some conditions, performance is particularly poor at the location directly above fixation (i.e., the "North" or "N" location), particularly in comparison to performance on the horizontal meridian. This phenomenon was first noted by Carrasco, Talgar, and Cameron (2001) and has been referred to as a *North effect* (Cameron & Rathje, 2006). Under some conditions, performance is particularly poor at the location directly below fixation (i.e., the "South" or "S" location). We call this a *South effect*.

Visual field inhomogeneities have been reported in detection, discrimination and localization tasks (e.g.: Carrasco, Talgar, & Cameron, 2001). Specific details of the inhomogeneities have been studied by Abrams, Nizam, and Carrasco (2012). Some studies have reported that sustained attention improves performance more in the lower visual field (e.g.: He, Cavanagh, & Intrilligator, 1996), while others have shown visual field inhomogeneities are maintained with directed attention (e.g.: Carrasco, Talgar, & Cameron, 2001; Talgar & Carrasco, 2002). Visual field inhomogeneities have also been examined within a crowding paradigm (Livne & Sagi, 2011; Toet & Levi, 1992) and may guide visual search (see Eckstein, 2011; for a review). Since these inhomogeneities have been studied in a variety of contexts, it is valuable to have a standardized way to quantify them.

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2. Definitions of performance field inhomogeneities

Performance fields are characterized by polar plots with the locations indicated as compass directions (N at the top); in most cases, percent correct is plotted at eight equally-spaced isoeccentric locations and distance from the center reflects performance level (e.g., Fig. 1). Viewing is typically binocular. The radial direction represents a measure of performance (such as discriminability, detectability or sensitivity). Five commonly reported inhomogeneities are described in Table 1 (second row).

For illustration, we have constructed four cases of hypothetical "data". The four hypothetical performance fields, reminiscent of results of previous research (e.g.: Cameron & Rathje, 2006; Cameron, Tai, & Carrasco, 2002; Carrasco, Talgar, & Cameron, 2001) are shown in Fig. 1A–D. All of our hypothetical data include an HVA. They can be described as follows:

Case A "Simply Elongated": Best performance is observed along the horizontal meridian and relatively poor performance is observed on the vertical meridian, which results in a performance field that is elongated horizontally. It is not obvious whether performance at the N or S locations is poorer than expected from the generally elongated field.
Case B "Notch at North": Best performance is observed along the horizontal meridian, but performance is clearly poor at the N location compared to other isoeccentric locations. It is not obvious whether performance at the S location is poorer than expected from the generally elongated field.
Case C "Notch at North and South": Best performance is observed along the horizontal meridian and performance at the N and S locations is poor compared to other isoeccentric locations.
Case D "Lower Field Advantage": Best performance is observed along the horizontal meridian, and performance is better in the lower visual field compared to the upper visual field. It is not obvious whether performance at the N or S locations is poorer than expected from the generally elongated field.

Hypothetical performance in Fig. 1 is plotted on a ratio scale (from zero to some maximum) because fitting an elliptical model requires a (0,0) center. However, data are often obtained by the two alternative forced choice method (2AFC), for which theoretical performance ranges from 50% to 100% correct. In that case, performance must be normalized to extend from 0 to 100; this can be accomplished by subtracting 50% from the raw percentage correct and doubling the result. (An analogous normalizing transform can be used for 3AFC or 4AFC.) The performance field so obtained is identical to a graph of the raw percentage correct (2AFC) plotted on a scale from 50 to 100 (see right axis in Fig. 1B). The normalized score is a valid representation of performance, but it could be replaced by a measure of detectability or sensitivity.

The issue addressed in this paper is how best to characterize these performance fields and how to quantify the visual field inhomogeneities, particularly those on the vertical meridian (i.e., VMA, North and South effects). We propose that characterizing performance fields and quantifying visual field inhomogeneities should be done within the context of the HVA and the VA. The argument is as follows: Given that visual performance fields are not homogeneous (the HVA is nearly ubiquitous, and the VA is often observed), inhomogeneities such as the VMA, the North effect and the South effect must be shown to be greater than what would be predicted in the context of the HVA and the VA.

3. Quantifying performance field inhomogeneities

3.1. Circular model

Visual field asymmetries have been characterized by using standard statistics to compare relative performance at locations across

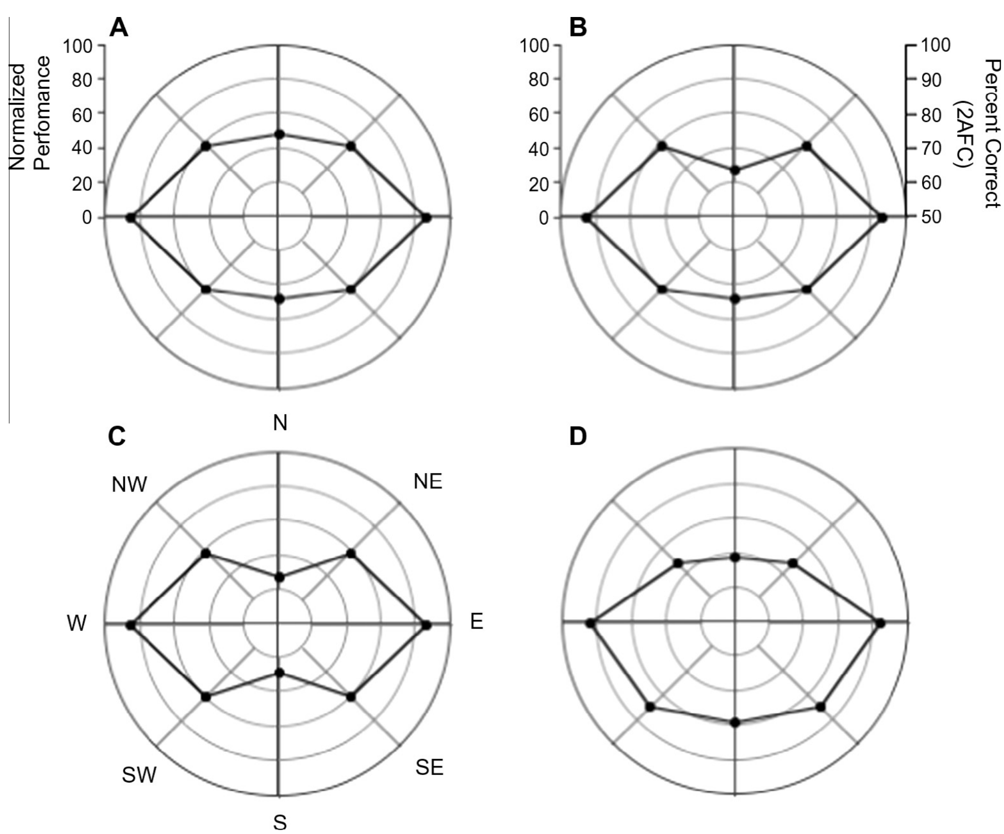

Fig. 1. Four cases of hypothetical data designed to be comparable to figures in previously published studies.