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Perpendicularity misjudgments caused by contextual stimulus elements

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ABSTRACT

It has been demonstrated in previous studies that the illusions of extent of the Brentano type can be explained by the perceptual positional shifts of the stimulus terminators in direction of the centers-of-masses (centroids) of adjacent contextual flanks [Bulatov, A. et al. (2011). Contextual flanks' tilting and magnitude of illusion of extent. *Vision Research, 51*(1), 58–64]. In the present study, the applicability of the centroid approach to explain the right-angle misjudgments was tested psychophysically using stimuli composed of three small disks (dots) forming an imaginary rectangular triangle. Stimuli comprised the Müller-Lyer wings or line segments (bars) as the contextual distracters rotated around the vertices of the triangle, and changes in the magnitude of the illusion of perpendicularity were measured in a set of experiments. A good resemblance between the experimental data and theoretical predictions obtained strongly supports the suggestion regarding the common "centroid" origin of the illusions of extent of the Brentano type and misperception of the perpendicularity investigated.

1. Introduction

Assessment of the relative location of various objects is one of the routine tasks that the visual system effortlessly solves in the course of everyday activities. The ability to effectively operate within a dynamically changing environment indicates that the visual system possesses mechanisms that provide fast and reliable perception of the position of objects, regardless of their size, shape, and illumination. Although there are various cues in the objects luminance profiles (e.g., the peaks, or points of inflexion, or zero crossings) to judge their spatial separation, a considerable amount of experimental data indicates that the distances between the weighted means (centers-of-masses or centroids) of luminance envelopes are typically used by the visual system (Akutsu, McGraw, & Levi, 1999; Badcock, Hess, & Dobbins, 1996; Bocheva & Mitrani, 1993; Hirsch & Mjolsness, 1992; McGraw et al., 2003; Morgan & Glennerster, 1991; Morgan, Ward, & Cleary, 1994; Seizova-Cajic & Gillam, 2006; Ward, Casco, & Watt, 1985; Watt & Morgan, 1983; Westheimer & McKee, 1977; Whitaker et al., 1996; Whitaker & Walker, 1988; Wright, Morris, & Krekelberg, 2011). According to the hypothesis on the indirect positional coding *via* centroids (Morgan, Hole, & Glennerster, 1990), this phenomenon can be explained by the spatial integration of neural excitations evoked by the neighboring image parts. The integration causes the weighted pooling of positional signals which are utilized by higher-level brain mechanisms to compute perceptual decisions; as a result, the visual objects are perceived to be located at their centroids. Such pooling coarsens the positional acuity and can also be responsible for the emergence of some geometric illusions of extent (Morgan & Glennerster, 1991; Morgan, Hole, & Glennerster, 1990): for instance, in the Müller-Lyer figure (or its Brentano modification) the visual system fails to extract the position of stimulus terminators (wings vertices) independently of the adjacent contextual flanks (wings themselves), therefore, observers overestimate or underestimate the length of the spatial intervals flanked by outward-going or inward-going wings.

The ability to evaluate the mutual perpendicularity of image components is another notable feature of visual perception. There is a considerable body of evidence that right angles can be both perceived and reproduced quite precisely and that there is no need for any preliminary training (Bulatov, Bertulis, & Bulatova, 2005; Chen & Levi, 1996; Gray & Regan, 1996; Heeley & Buchanan-Smith, 1996; Nundy et al., 2000). On the contrary, the assessment of an acute or obtuse angle is a more complicated task, the solution of which may be facilitated provided the subject is given a verbal designation of the stimulus or its demonstration, prior to each trial during the experiment (Gray & Regan, 1996). However, even in this case observers still overestimated acute angles and underestimated the obtuse ones, whereas even slight deviations from the perpendicularity could be easily detected (Bulatov, Bertulis, & Bulatova, 2005; Chen & Levi, 1996; Gray & Regan, 1996; Nundy et al., 2000). These circumstances indicate that right-angle stimuli may be used as a convenient and robust tool in psychophysical studies, and suggest the existence of some visual mechanisms that are responsible for the intuitive notion of perpendicularity. Despite the fact that at present there is no generally accepted view concerning the nature of these mechanisms, it seems reasonable to

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presume that at least in the case of stimuli consisting of separate elements (e.g., three dots that form an imaginary rectangular triangle), the visual assessment of perpendicularity is based on neural processing of information about the relative location of these elements (Bulatov, Bertulis, & Bulatova, 2005). Thus, one can expect that equivalently to the case of the geometric illusions of extent (i.e., in the length-matching task), the presence of contextual distracters can significantly influence the perception of the relevant spatial attributes of the right-angle stimulus (i.e., evoke the illusion of perpendicularity in the angle-matching task), and the results obtained from our previous studies support such a suggestion. It has been demonstrated (Bulatov, Bertulis, Bielevicius, et al., 2009) that the effect of distracters can be explained by assuming the existence of spatial integration within some areas (areas of centroid extraction with a circular Gaussian weighting profile) in proximal surroundings of the target stimulus elements, and that the size of these areas grows linearly with eccentricity in the visual field.

Recently, referring to the "centroid" hypothesis, we have developed a quantitative model which was successfully applied to describe the data, obtained in experiments with the Brentano type of illusory figures comprising different contextual flanks: either the Müller-Lyer wings, or vertical bars, or pairs of dots (Bulatov, Bertulis, Bulatova, et al., 2009; Bulatov et al., 2010). One of the crucial points of the model is that it implies the perceptual positional shifts of the stimulus terminators in the direction of centers-of-masses of the contextual flanks. Accordingly, the rotation of flanks of any shape around the corresponding terminators should evoke a cosinusoidal modulation of the magnitude of length-matching errors. This pattern of changes was fully confirmed by our experiments with modified Brentano figures comprising the Müller-Lyer wings or arcs of a circle (Bulatov et al., 2011).

The aim of the present study was to verify whether our current "centroid" approach can explain the influence of the rotation of contextual distracters on the magnitude of the illusion of perpendicularity (i.e., perceptual errors in the right-angle adjustment), and, if successful, to evaluate the parameters of centroid extraction in order to compare them with the results of our previous studies of the illusions of extent. For this purpose, we have performed psychophysical experiments with the right-angle stimuli supplemented by distracters of two different types: short line segments (bars) and Müller-Lyer wings (Fig. 1). We have concentrated on the idea that misjudgments of perpendicularity for this type of stimuli (i.e., those made up of separate elements) can be determined by the neural processes of centroid extraction, and the present study was designed to investigate this particular source of perceptual distortions. Therefore, examination of perpendicularity perception *per se*, and in more general conditions when the right angles are defined by lines or edges is left beyond the scope of the present communication.

2. Methods

2.1. Participants

Four observers (LE, KA, RD, and BE) participated, two of whom (RD and BE) were naïve to the purpose of the study. All observers were refracted professionally prior to the experiments. Viewing was monocular, and the right eye was always tested irrespective of whether it was the leading eye or not. All participants gave their informed consent before taking part in the experiments that were performed according to the Declaration of Helsinki and were approved by the ethics committee of the Lithuanian University of Health Sciences.

2.2. Apparatus

The experiments were carried out in a dark room (the surrounding illumination <0.2 cd/m^2). A *Sony SDM-HS95P* 19-in. LCD monitor (spatial resolution 1280 × 1024 pixels, frame refresh rate 60 Hz) was used for the stimuli presentations. A *Cambridge Research Systems OptiCAL* photometer was applied to the monitor luminance range calibration and gamma correction. A chin and forehead rest was used to maintain a constant viewing distance of 400 cm (at this distance each pixel subtended 0.25 min of arc), and an artificial pupil (an aperture with a 3 mm diameter of a diaphragm placed in front of the eye) was applied to reduce optical aberrations.

Stimuli were presented in the center of a round-shaped background of 4° in diameter and 0.4 cd/m^2 in luminance (the monitor screen was covered with a black mask with a circular aperture to prevent observers from being able to use the edges of the monitor as a vertical/horizontal reference). For all the stimuli drawings, the *Microsoft GDI+* anti-aliasing technique was applied to avoid jagged edges of lines and dots.

2.3. Stimuli

Stimuli used in experiments consisted of three terminators (three dots, or one dot and two vertices of the Müller-Lyer wings, or two dots and one vertex of the wings) placed at the apexes of an imaginary isosceles rectangular triangle; the distracters, either the Müller-Lyer wings themselves or short bars, were rotated around the corresponding terminators (Fig. 1). Two different modes of stimulus presentation were employed in two series of experiments. In the first series, two distracters were rotated around the lateral stimulus terminators (i.e., those at the crossings of the triangle legs and hypotenuse); the central terminator was represented by a single dot (Fig. 1, *upper row*). The tilt angle, ϕ of the bisector of the lower distracter (i.e., that is adjacent to the dot forming the horizontal leg of an imaginary triangle) was randomly changed from 0° to 360°, whereas the tilt angle of the upper distracter was varied as $90^\circ - \phi$ (i.e., mirror-symmetrically relative to $45^\circ-$inclined axis). In the second series of experiments, a single distracter was rotated around the central terminator (i.e., that at the apex of the right angle), and the lateral stimulus terminators were represented by dots (Fig. 1, *lower row*).

The diameter of the dots and the width of the bars (or lines forming the wings) were 1 min of arc; their luminance was 75 cd/m^2. The other stimuli parameters that remained constant throughout the experiments were as follows: the length of imaginary triangle legs (60 min of arc); the height of the bars (8 min of arc), and the bar-to-dot distance (5 min of arc); the length (6 min of arc) and internal angle (75°) of the Müller-Lyer wings. It is known that the visual field anisotropy can cause significant systematic biases in angle estimations for stimuli with obliquely oriented components (Bulatov, Bertulis, & Bulatova, 2005; Snippe & Koenderink, 1994). In order to reduce this effect we used horizontal/vertical orientation of the legs of an imaginary triangle in our experiments.

2.4. Procedure

The standard method-of-adjustment paradigm was used in our present experiments. The subjects were asked to manipulate the keyboard buttons "←"and "→" to move the lateral stimulus terminators (together with the adjacent distracters, if presented) symmetrically along the arc of a circle (centered at the apex of the "right" angle) into the position that made both triangle legs perceptually orthogonal to each other. A single button press varied the angle between the triangle legs by ±0.2°. The initial deviations of the angle from 90° were randomized and distributed evenly within the range of ±5°.