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Geometrical features underlying the perception of collinearity

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ABSTRACT

The magnitude of the Poggendorff bias in perceived collinearity was measured with a 2AFC task and roving pedestal, and was found to be in the region of 6–8 deg, within the range of previous estimates. Further measurements dissected the bias into several components: (1) The small (∼1 deg) repulsion of the orientation of the pointer from the parallel, probably localized in the part of the line near the intersection (2) A small (<1 deg) location bias affecting the intersection of pointers and inducing lines; and (3) A larger (>1 deg) bias in the orientation of virtual lines crossing the gap between two parallels, towards the orientation of the parallels, or equivalently (4) An orthogonal bias in actively constructing a virtual line across the gap. We conclude that orientation repulsion by itself is an inadequate explanation of the Poggendorff effect, and that a full explanation must take account of the way in which observers construct virtual lines in visual space in order to carry out elementary geometrical tasks such as extrapolation.

1. Introduction

It is not understood how the visual system makes elementary geometrical constructions, such as measuring the collinearity of separated line segments (Morgan, 1999; Ninio, 2014). We should not be surprised, then, that we also fail to understand the causes of biases in perceived collinearity, such as the bias shown in the famous Poggendorff figure (Fig. 1). Most readers will see the two 45 deg pointers more aligned in the right-hand configuration than in the left, although the opposite is actually the case.

Conceptual confusion has resulted when variants of the basic Poggendorff figure are called the 'Poggendorff illusion' and are assumed to have the same mechanism (Hotopf & Hibberd, 1989; Ninio, 2014). Such variants include amputations of lines, replacements of lines by dots, replacement of lines by subjective contours (Tibber, Melmoth, & Morgan, 2008), figures emphasizing perspective cues (Gillam, 1971) and horizontal rotation of the Poggendorff figure itself, which shows a smaller bias than the upright version (Hotopf & Hibberd, 1989). In this paper we renounce the term 'illusion' in favour of 'bias' and we refer to the 'P-bias' as any bias in the perception of collinearity in the same direction as that seen in the traditional, upright 4-line Poggendorff figure. A simple mnemonic for remembering the direction of the P-bias is that it is in the direction expected if the left-hand pointers in Fig. 1 are mentally rotated to appear more orthogonal to the parallel. It must be emphasized that this is merely a convenient description of the bias, not an explanation. An alternative description is that the virtual angle between the two intersection points is mentally rotated in the anticlockwise direction, making the right-hand pointer appear displaced upwards. If the pointers are replaced with circles (c.f. Figs. 4 and 11 below) this allows us to describe a bias using the same metric as a P-bias.

A large variety of values for the P-bias are reported in the literature. Sometimes the effect is reported in terms of the apparent displacement, in units of DVA (degrees of visual angle) of one of the pointers from the point of true collinearity (e.g. Hamburger, Hansen, & Gegenfurtner, 2007). If the origin of the P-bias is a mispointing by one or other of the pointers (e.g. Hotopf & Hibberd, 1989; Ninio, 2014; Ninio & O'Regan, 1999) the DVA measure will vary with the pointer angle and the separation of the parallels. An alternative measure is the apparent rotation of one or both of the pointers (in radians or deg) inferred from the shift expressed as DVA. Using this measure, Morgan (1999) reported P-biases in the region of 5 deg. (0.0873 rad); Hamburger et al. (2007) report DVA shifts for one pointer in the Method of Adjustment of ∼1 deg DVA. Using the information that the DVA between the verticals was 3.1 deg and the angle of the pointer 52.5 deg (K. Hamburger, personal communication) their shift can be expressed as a mispointing of 6.9 deg, similar to that in Morgan (1999).

The P- bias almost certainly has several distinct causes (Hotopf & Ollerearnshaw, 1972; Hotopf, Ollerearnshaw, & Brown, 1974).

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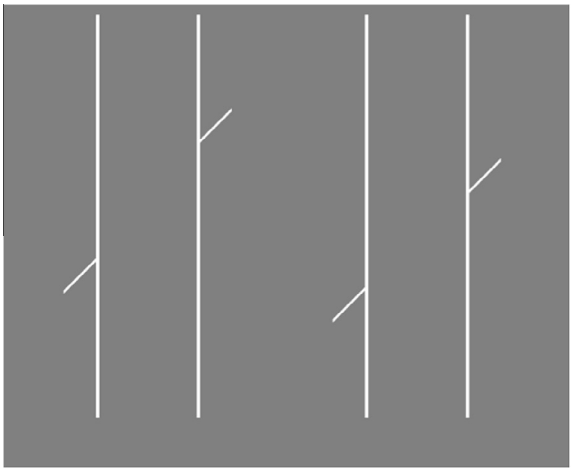

Fig. 1. The figure shows examples of stimuli used to measure the Poggendorff perceptual bias. The observer's task (2AFC) was to decide whether the oblique pointers were more aligned in the left-hand figure or on the right. In the example shown the pointers in the left-hand figure are closer to physical alignment, but a perceptual bias (the Poggendorff effect) makes them appear less aligned. In the experiments both stimuli could be given a pedestal misalignment (the same for both figures) to which was added a test misalignment for one of the figures, randomly left or right. Thus the test stimulus could be either closer to alignment or further away, depending on the pedestal level.

Some insight into the possible causes of the bias can be gained by stating the computational requirements of a distant alignment task (Morgan, 1999). These include (1) measuring the orientation of the two obliques and determining that they are the same, (2) locating the proximal terminations of the pointers (i.e. their terminations on the inducing line) (3) measuring the orientation of the virtual line between the two proximal pointer terminations and, finally (4) comparing the results of steps (1) and (3). Biases in (1) may arise from cross-orientation inhibition (Blakemore, Carpenter, & Georgeson, 1970). Biases in (2) have been predicted from optical (Glass, 1970) and neural (Morgan, 1999) blurring. Biases in (3) could arise from unknown causes, including one that Hotopf and Hibberd (1989) call the 'horizontal bias alignment effect'. Biases in (4) have not been previously considered, and we keep with this tradition.

An alternative to this Cartesian approach is to consider an analogue process of extrapolation, which bridges the gap between the parallels by linking together local units that have the same orientational specificity as the pointers, and which are preferentially linked in a direction that is similar to that of their local specificity. Such a linking has previously been postulated as an 'association field' (Field, Hayes, & Hess, 1993) or as a 'collector unit' (Morgan & Baldassi, 1997; Morgan & Hotopf, 1989) to explain the Fraser 'twisted cord' effect, and the appearance of 'spiderweb' lines in grids and lattices. This kind of explanation differs from the Cartesian in that it does require spatial position of features to be made explicit or compared, but as we shall see, it is logically difficult to distinguish from the Cartesian model in any particular case with purely psychophysical data.

In this paper, we concentrate on biases in Steps 1, 2 and 3. Biases in location of the intersection points could result from neural blurring in first (Glass, 1970) or second-order filters (Morgan, 1999) that place the centroid of the blurred intersection inside the acute angle. One line of evidence supporting blurring is that increased optical blurring or low-pass filtering enhances the magnitude of the P-bias in the Poggendorff figure, as well as in its acute-angle and obtuse-angle amputated versions (Morgan, 1999). Evidence for a location shift was also found (Morgan, 1999) using the rather difficult task of matching the perceived orientation of the virtual line between the two intersections to that of a grating.

In the present experiments we measure the P-bias in various configurations using a 2AFC task designed to distinguish a genuine perceptual bias from a response bias or deliberate criterion shift (Morgan, Melmoth, & Solomon, 2013). The task is explained briefly in the legend to Fig. 1. Its essence is that the offset from collinearity in the test figure is added to a pedestal in both test and comparison figure, so that it can either reinforce or counteract any perceptual bias depending on the pedestal level, which is varied over trials and is unknown to the observer. Thereby, the observer is prevented from feigning a perceptual bias by a strategy such as 'response on left button if unsure' or 'respond to test if unsure' (Morgan, Dillenburger, Raphael, & Solomon, 2012). The task is a genuine 2AFC, as opposed to the Method of Single Stimuli (Morgan, Watamaniuk, & McKee, 2000b), with which it is frequently confused (e.g. Taya, Adams, Graf, & Lavie, 2009).

We used the 2AFC task because we thought it important that participants should be unable to infer the true point of collinearity in the figures from repeated trials. Learning of this kind may explain the decrement in biases that is commonly reported with the Geometric Illusions over time (e.g. Predebon, 2006). Since we intended to use the same participants over a large variety of conditions, we were concerned to avoid this learning. Using the Method of Single Stimuli it is difficult to choose the range of values with which the participant is presented. If the range is centered around true alignment, the observer can soon infer a bias from their distribution of responses between the two buttons and adjust accordingly (Morgan, Watamaniuk, & McKee, 2000a); if one the other hand, it is centered around the putative Point of Subjective Equality there is a risk of *petitio principii.* The Method of Adjustment, which is probably the most widely used method in the field (e.g. Blakemore et al., 1970; Morgan, 1999; Ninio & O'Regan, 1999; Predebon, 2006; Weintraub, Krantz, & Olson, 1980) avoids this difficulty, but allows the observer some degree of experimentation with the figure, in conjunction with scanning eye movements, which may not be altogether desirable. In our 2AFC Method the observer never knew which of the two figures was in reality 'more aligned', and any perceptual bias would have no effect on the distribution of responses between the two categories 'left more collinear' or 'right more collinear'. Pilot studies (Morgan, Grant, Melmoth, & Solomon, 2015) showed that the Method produced stable results over repeated testing.

Five experiments will be reported:

1. Measurement of the basic P-bias by pointer collinearity.
2. Measurement of positional bias in proximal pointer terminations.
3. Measurement of bias in pointer orientation (Blakemore et al., 1970).
4. Measurement of the spatial integration region for orientation at the proximal pointer terminations.
5. Measurement of the P-bias without pointers.

2. Materials and methods

2.1. Apparatus and stimuli

In experiments carried out in City University London, stimuli were presented on the LCD display of a MacBookPro laptop computer with screen dimensions 33×20.7 cm (1440×900 pixels) viewed at 0.57 m so that 1 pixel subtended 1.25 arcmin visual angle (VA). The background screen luminance was 50 cd/m^2. In Cologne, stimuli were presented on the screen of SONY Trinitron monitor with resolution 1400×1050 pixels and viewed at 75 cm so that 1 pixel subtended 1.33 arcmin. The background screen