Available online at www.sciencedirect.com

SCIENCE DIRECT®

Vision Research 45 (2005) 2037–2057

Vision Research

www.elsevier.com/locate/visres

Visually perceived vertical (VPV): induced changes in orientation by 1-line and 2-line roll-tilted and pitched visual fields

Wenxun Li *, Leonard Matin

Clarence H. Graham Memorial Laboratory of Visual Science, Department of Psychology Columbia University, Schermerhorn Hall, New York, NY 10027, USA

Received 5 September 2003

Abstract

We report a series of nine experiments which show that a single roll-tilted line in darkness induces changes of the orientation perceived as vertical (VPV) that are similar in magnitude and direction to those measured by Witkin and Asch (1948a) [Studies in space orientation. I. Perception of the upright with displaced visual fields. *Journal of Experimental Psychology*, *38*, 762–782] with the classical square 4-sided frame, and we describe the configuration-independent mass-action rules by which the influences of the individual lines influences are combined. Clockwise (cw) and counterclockwise (ccw) orientations of a line produce cw and ccw displacements of the VPV setting, respectively, with effect magnitude increasing approximately linearly with line orientation (e.g., a 66.25°-long line at 25° horizontal eccentricity that varies in roll-tilt through ±13.2° around vertical generates a systematic variation in VPV over ±7°). The slope of the VPV-vs-roll-tilt function increases with line length along a negatively accelerated exponential function (length constant = 17.1°). The influences of two bilaterally symmetric lines combine linearly and algebraically and the combined influence is linearly related to the sum of the VPVs for the 1-line components with a slope equal to 0.91 for short lines and 0.66 for long lines; thus, VPV for short lines manifests nearly complete additive summation, but for long lines, the 2-line VPV is nearer to the average of the VPV values for the two components measured separately. The effectiveness of the conjunction of two line segments within a visual scene does not depend on their separate orientations, only on their sum. Individual lines from pitched-only planes or from combinations of such planes generate identical influences to those generated from lines in frontoparallel planes with the same image orientations at the eye of the observer (their "retinal orientations"). Retinal orientation is the key to the induction of VPV change independently of the line's plane of origin.

Keywords: Visually perceived vertical; Space perception; Spatial orientation; Linear summation; Egocentric localization; Spatial Induction

1. Introduction

In a classic series of articles Witkin and Asch brought the study of the visual perception of egocentric spatial orientation into the arena of modern science. They manipulated the orientation (roll-tilt) of the field of view, first, by replicating Wertheimer's experiment with the subject viewing the visual field presented by a tilted mirror (Asch & Witkin, 1948a; Wertheimer, 1912), then by having the subject view a large well-illuminated roll-tilted room containing furniture attached to the floor and walls that filled the field of view while the subject remained erect in physical space (Asch & Witkin, 1948b), and then by roll-tilting a large luminous square frame in the subject's frontoparallel plane in otherwise total darkness (Witkin & Asch, 1948). The main psychophysical measurement was the subject's setting of a rod within a frontoparallel plane to appear vertical (we refer to this as a VPV setting). Tilting the view in the mirror, rotating the room, or rotating the frame from an orientation in

* Corresponding author. Tel.: +1 212854 4325; fax: +1 212854 3609.
E-mail addresses: wl18@columbia.edu (W. Li), matin@columbia.edu (L. Matin).

0042-6989/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2005.01.014

which the main lines in the visual field deviated from an erect orientation relative to gravity typically resulted in the physically vertical rod appearing to deviate from vertical in the direction opposite to the tilt of the field of view; for the rod to appear vertical, it had to be set to a roll-tilt within the frontoparallel plane in the same direction as the field of view. Asch and Witkin (1948a) stated, "The present experiment has provided striking evidence of the predominance of the visual framework over postural factors in perception of the upright". They drew similar conclusions in their subsequent articles. The conclusion has held up remarkably well. The substantial involvement of the body-referenced mechanism[1] has also been made clear along with the contribution by the visual field to VPV (see Gibson & Mowrer, 1938), and the work by Witkin and Asch (see particularly, Witkin, 1949) and subsequent work has helped to delineate the body-referenced mechanism's contribution in relation to influences from the visual field (Bauermeister, 1964; Chelette, Li, Esken, & Matin, 1995; Dichgans, Held, Young, & Brandt, 1972; Dichgans & Brandt, 1974; DiZio, Li, Lackner, & Matin, 1997; Higashiyama & Koga, 1998; Held, Dichgans, & Bauer, 1975; Howard & Childerson, 1994; Li, Dallal, & Matin, 2001; Mittelstaedt, 1986, 1988, 1992, 1997; Schöne, 1964; Trousselard, Cian, Nougier, Pla, & Raphel, 2003; see Howard, 1982; Howard & Templeton, 1966 for earlier summaries).

The square roll-tilted frame was originally employed by Witkin and Asch as a reduced and readily manipulable surrogate for the normal visual environment. However, since that work, the basis for the influence of the frame has also become a subject of study in itself. The nearly invariable use of the square frame as an entity whose parameters were varied while retaining its squareness and its closed figural character in a very large number of studies indicates the frame's treatment as a unitary gestalt; an emphasis on the configurational aspects of the square frame has been at the center of substantial research efforts in several laboratories concerned with the basis for the frame's influence: Witkin and Asch first suggested that the perceptual ambiguity of the physically tilted square—it sometimes appeared as a tilted diamond and at others as a tilted square—had a bearing on the VPV settings; a similar view regarding the frame's appearance as a diamond was later expressed by Wenderoth and Beh (1977), and Wenderoth (1977, 1982). As an interpretation of experiments in which the orientation of the frame was systematically varied, Beh, Wenderoth, and Purcell (1971) had proposed a "main axes hypothesis" which stated that VPV settings were biased in the direction of the main axes of the inducing frame where "main axes" included all axes of symmetry of a frame, including the main diagonals of the square frame, not only the two axes parallel to the sides of the frame. They continued to explore this with triangles and hexagons as inducing figures in experiments measuring VPV, originally reporting support for it (Beh & Wenderoth, 1972), and subsequently reporting mixed support for the hypothesis from work with partial frames (2-line-angle and 2-line-parallel stimuli) in Wenderoth and Beh (1977) and Wenderoth (1977). In work centered on other configurational aspects of the frame, Ebenholtz and his colleagues replaced the entire tilted frame with its four corners or with filled circles at its corners (Streibel, Barnes, Julness, & Ebenholtz, 1980), and from small effects with corners only they concluded that Koffka's theory (1935) regarding field organization in perception, as applied to the square frame's influence on VPV, did not hold.

A sizable number of studies manipulated the parameters of the frame as a unitary stimulus, including the separation between rod and frame both within the frontoparallel plane and in depth, the orientation of the frame, the area of the frame and the length of the rod, separately, together, and in conjunction with other measures of frame size, and/or in conjunction with variation of body tilt or head tilt (e.g., Ebenholtz, 1977, 1985; Ebenholtz & Benzchawel, 1977; Gogel & Newton, 1975; Poquin, Ohlmann, & Barraud, 1998; Wenderoth, 1977; Zoccolotti, Antonucci, & Spinelli, 1993). Spinelli, Antonucci, Goodenough, Pizzamiglio, and Zoccolotti (1991) systematically varied the orientation and size of the frame over a 90° range and described their angle functions as a weighted sum of the relative amplitudes of the first two Fourier components and also reported reduced effects with smaller frames. Ebenholtz and his colleagues had further demonstrated that the influence on VPV was due to retinal size, not perceived size (Ebenholtz, 1977; Ebenholtz & Callan, 1980). In addition to the numerous explorations of these and other parameters, the square frame was treated as the concrete embodiment of the concept of frame of reference and become the focus of numerous experimental and theoretical articles in space perception, in cognition, and in the study of connections between cognition and personality where it has become known as the rod-and-frame test (e.g., Bertini, Pizzamiglio, & Wapner, 1986; Goldstein & Chance, 1965; Hudson, Li, & Matin, 1997; Hudson, Li, & Matin, submitted for publication; Linn & Peterson, 1985; Sherman, 1969; Wapner & Demick,

[1] The term 'body-referenced mechanism' was introduced (Matin & Fox, 1989) to refer to the combination of all extraretinal influences on the perception of interest—here the visual perception of vertical—including extraretinal eye position information, extraretinal head orientation information (including information regarding the head relative to the body and the head relative to gravity), other effects of gravity on the body, pressure cues from the surfaces of the body, joint receptors, and the vestibular organ; it includes, in addition, the basic local sign information from the visual target employed to measure the discrimination itself. There is some overlap with the term "postural factors" as employed by Witkin and Asch (1948).