Perception, 2005, volume 34, pages 699 – 716

DOI:10.1068/p5411

The rod-and-frame effect: The whole is less than the sum of its parts

Wenxun Li, Leonard Matin
Clarence H Graham Memorial Laboratory of Visual Science, Department of Psychology,
Columbia University, New York, NY 10027, USA; e-mail: WL18@columbia.edu; matin@columbia.edu
Received 13 May 2004, in revised form 15 October 2004; published online 25 May 2005

Abstract. Since the discovery of the influence of the tilted frame on the visual perception of the orientation perceived as vertical (VPV), the frame has been treated as a unitary object — a Gestalt. We evaluated the effect of 1-line, 2-line, 3-line, and 4-line (square frame) stimuli of two different sizes, and asked whether the influence of the square frame on VPV is any greater than the additive combination of separate influences produced by the individual lines constituting the frame. We found that, for each size, the square frame is considerably less influential than the additive combination of the influences of the individual lines. The results conform to a mass action rule, in which the lengths and orientations of the individual line components are what matters and the organization of the lines into a square does not — no higher-level Gestalt property is involved in the induction effect on VPV.

1 Introduction

In 1948, Witkin and Asch published four classic articles describing a series of experiments regarding perception of the vertical that began with a redoing of Wertheimer's (1912) tilted-mirror experiment (Asch and Witkin 1948a). They went on to examine the perception of the vertical in a tilted room (Asch and Witkin 1948b) and in complete darkness (Witkin and Asch 1948a), and closed the series with what has become the classical 'tilted-rod/tilted-frame experiment' (Witkin and Asch 1948b). In a fifth article, Witkin (1949) carried this work further by employing a variably tilted chair that rotated the subject around a horizontal axis in the median plane, independently of the orientation of the tilted room. This body of work brought the importance of visual influences on egocentric space perception to the fore, establishing them as of central interest to subsequent generations of workers.

1.1 *The rod-and-frame effect (RFE)*

The large square frame of Witkin and Asch (1948a) has become institutionalized as the exemplar of a visual 'frame of reference' and numerous experiments have been conducted with it, ranging from experiments concerned with the basis for egocentric space perception to experiments on the relation between space perception, personality, and cognitive style. The essence of the RFE is that, when an observer views a truly vertical rod within a roll-tilted square frame in otherwise total darkness, the rod appears roll-tilted in the direction opposite to the roll-tilt of the frame and, in order for the rod to appear vertical, the observer sets it in the same direction as that of the frame [figure 1; visually perceived vertical (VPV) setting]. Although not new (Helmholtz 1867/1962; Müller 1917; Kleint 1937), the use of the variably oriented rod set to appear vertical, in conjunction with a variably oriented visual field, has provided the basis for the methodology involved in nearly all subsequent work on the perception of the ›vertical and horizontal. The large individual differences among subjects in susceptibility to roll-tilted visual fields in the original work, coupled with considerable stability in the magnitude of the individual observer's RFE and the high correlations with closely related spatial tasks, led Witkin and his colleagues during the twenty years following the original work to pursue a theoretical approach that viewed individuals

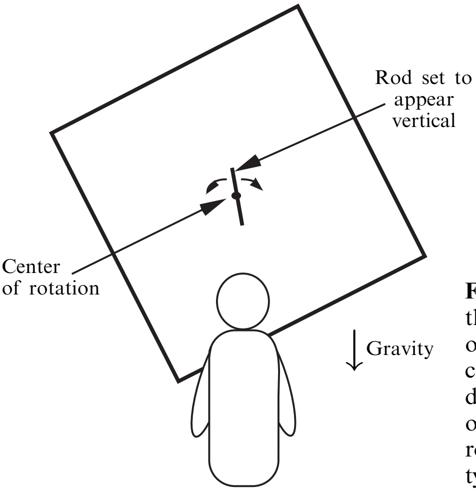

Figure 1. A sketch of the arrangement for generating the classical rod-and-frame effect (RFE). The RFE occurs when an observer views a truly vertical rod centered within a roll-tilted large square frame in total darkness, the rod appears roll-tilted in the direction opposite to the roll-tilt of the frame; in order for the rod to appear vertical (VPV setting) the observer typically sets it in the same direction as the frame.

as field-dependent or independent, respectively, depending on whether they manifested large or small RFE magnitudes. This theoretical approach held that the difference in performance was a manifestation of a bipolar cognitive/personality trait that was a consequence of the extent to which the individual took a global or analytic approach in dealing with the spatial tasks (eg Witkin et al 1954; Witkin 1977; Witkin and Goodenough 1981; Bertini et al 1986; Wapner and Demick 1991; Hudson et al, in press). Significant experiments that demonstrated large influences of visual/vestibular interactions in perceptual phenomena (eg Dichgans et al 1972; Dichgans and Brandt 1974; Held et al 1975) subsequently figured prominently in Witkin's later statements. In his last published work, he stated: "It now seems possible that what we earlier designated an articulated-global field approach consists of two separate though related functions: reliance on vestibular or visual-field referents and cognitive restructuring" (Witkin and Goodenough 1981, page 47). That this was essentially Witkin's view at the time he died in 1979 was noted by his close colleague in a symposium to Witkin's memory (Goodenough 1986).

This latter view, in which the rod-and-frame illusion is treated as a set of phenomena whose determinants lie largely within more primitive neurophysiologically based special systems regulating space perception, has become the common approach to studying a number of large-field spatial illusions in several different dimensions since the 1970s (Dichgans et al 1972; Dichgans and Brandt 1974; Mittelstaedt 1986, 1988; Matin and Fox 1989; Matin and Li 1992, 1994b, 1995, 1999, 2000, 2001; Hudson et al 2000, in press; Li et al 2001). The major basis for the large individual differences in dependence on the visual field can be interpreted as differences in the extent to which the influences are weighted toward vision or toward a body-referenced mechanism(1) separately from theories concerning higher-level cognitive/personality traits. Such a variation in weighting also accounts well for the fact that the magnitudes of these illusions are less than the magnitudes that would result if the visual field alone controlled perception, since in the latter case one might expect the illusion magnitude to equal the magnitude by which the stimulus orientation was changed; however, illusion magnitudes are invariably smaller than the change in stimulus orientation leading to the illusion.

(1) The term 'body-referenced mechanism' was introduced by Matin and 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 retinal local-sign information from the target employed to measure the discrimination itself.

Virtually all of the subsequent work with the rod and frame has been directed at analyzing the basis within the visual stimulus for the influence of the frame on VPV, and this is what the experimental work in the present paper is about, as detailed following a brief review of some previous work with the rod and frame that is relevant here.

There was some concern initially with whether the influence of the square frame on VPV is based on the characteristics of the retinal image of the frame or on aspects of the appearance of the frame to the observer. This concern was first expressed by Witkin and Asch (1948b, page 767), who noted that in some of their experiments in which the subject and the frame were both tilted at 28° some subjects perceived the tilted square as "... an upright diamond, or a diamond tipped slightly toward one side" and that "although not investigated systematically, it was established that many Ss who set the rod in the direction of body tilt and away from frame tilt" did report this perception (also see page 772). Having measured rod settings opposite to frame tilts of between 22.5° and 45°, Wenderoth (1977) also suggested that "the visual system does seem to treat some clockwise-tilted squares as counterclockwise-tilted diamonds". [Also see Radner and Gibson (1935) for perceptual measurements of the appearance of tilted squares.] However, as the result of several later experiments in which the size of the frame and distance of the frame were varied, Ebenholtz and his colleagues (Ebenholtz 1977, 1990; Ebenholtz and Benzschawel 1977; Ebenholtz and Callan 1980) concluded that, although larger frame sizes produce larger effects, the effects depend on retinal size and not on apparent or phenomenal size. Ebenholtz and Glaser (1982) also showed that the effectiveness of the frame did not depend on whether the rod and frame shared the same depth plane or were presented in different, nonparallel depth planes. In still other experiments, Ebenholtz (1985, 1990) reported smaller rod-and-frame effects under high-blur than under low-blur conditions. Although not specifically oriented to deal with the issue whether the appearance of the frame or its retinal characteristics were significant in the determination of the influence of the frame, the results with blur are readily reconcilable with the retinal side of things.

Ebenholtz (1990) and his colleagues have also interpreted their results with apparent size and depth to mean that earlier influential theoretical treatment based on an approach derived from Gestalt psychology, as proposed by Koffka (1935, chapters 4–7), did not hold, stating: "the frame does not meet the criteria for a framework for spatial orientation ... since the several different field organizations, implied by the different apparent sizes and the various depth relations between line and frame, yield only a singular effect" (page 235). In addition, they carried out experiments with only the four small corners of the roll-tilted frame visible as the inducing stimulus, and obtained larger influences on VPV than with four small filled circles substituted for the angled corners, although both the corners and circles stimuli produced significantly smaller effects than did the full square. Apparently assuming that the frame, the corners, and the circles were "equivalent form organizations" that should have produced the same magnitude of influence on VPV according to Koffka's theory, Ebenholtz (1990) concluded that this supported his criticism of Koffka's interpretation of the frame as a framework for spatial organization.

In addition to the studies noted above, a number of other studies have manipulated various parameters of the frame in attempts at determining the basis for the influence of the frame on VPV and, on the assumption that the relation of the observer's body relative to gravity was important in determining VPV along with the visual field, have also manipulated the observer's body orientation. These studies have parameterized the separation between the rod and frame, the area of the frame, and the length of the rod, separately, together, and in conjunction with other measures of frame size; these manipulations of the rod and frame have frequently been modulated by body tilt or head tilt (eg Ebenholtz 1977, 1985; Wenderoth 1977; Mittelstaedt 1986, 1988; Zoccolotti et al 1993; Higashiyama and Koga 1998; Poquin et al 1998). We are not concerned with the influence of the body-referenced mechanism in this article: our experiments treat it as a constant parameter for each of the two experiments reported below, although its influence may be slightly different in each experiment as a consequence of differences in weighting with the small and large visual inducers that we employ here.

1.2 *The angle function with full and partial frames*

The first report of an attempt at measuring the influence of the frame across a range of roll-tilt orientations was by Beh et al (1971), whose measurements extended over a 90° range. They interpreted their results as containing two cycles of illusion magnitude within the 90° orientation range, with peaks at 45° intervals and with illusions of one sign peaking at roll-tilts of 15° and 60° and of the opposite sign peaking at 30° and 75°; they inferred a 45° cycle length for illusion magnitude, implying eight peaks over a 360° range, and from this proposed the "major axis hypothesis'. This hypothesis suggests that "illusions always occur in the direction of whichever 'major axis' of the inducing figure is closest to true (gravitational) vertical, where a major axis is defined as any axis of bilateral symmetry of the inducing figure ..." (Wenderoth and Beh 1977, page 59); thus their major axes include the two diagonals of the square in addition to axes in the directions of the lines forming the square. Their subsequent work with right-angle 2-line stimuli yielded angle functions that did not support this hypothesis, although the authors attempted to buttress it with additional assumptions and hypotheses (Wenderoth 1977; Wenderoth and Beh 1977). In more recent work with the full square frame, Spinelli et al (1991) reported experiments in which they measured a single cycle of illusion-magnitude variation over a 90° range of orientations, with each of three frame sizes—6, 10.5, and 47.5 deg—implying a four-cycle sinusoidal function over 360°, in disagreement with the eight-cycle function in some of the Wenderoth work; the magnitude of the function increased systematically with frame size.

A major focus in the work of both the Wenderoth and Ebenholtz laboratories, as well as all subsequent work until recently, has been on the configuration of the frame as a unitary stimulus. This focus is exemplified by the major-axes hypothesis of Wenderoth; their use of hexagons and triangles as framing figures was part of their attempt at examining the frame-as-form as the basis for the influence. Ebenholtz's use of the corner angles and circles was also aimed at finding the aspect of the square form that could be implicated in the influence on VPV.

Entangled with the emphasis on the frame as an entity in itself was the separable view that the axes defined by the outline of the square frame were surrogates for the vertical and horizontal of physical space. This latter emphasis involves a set of assumptions that underlies all research with the frame, derived from Koffka (1935) and beginning with the original Witkin and Asch work. Here the fundamental basis for the influence of the frame on VPV lies in the fact that the main dimensions of the frame are linked and orthogonal, and that, when the square frame is erect, these main dimensions parallel the vertical and horizontal of physical space and of visually perceived space as well; hence, when the frame is tilted relative to gravity it may exert an influence on the perception of other objects in the visual field that would lead perception to apprehend the main directions of physical space as tilted in the directions of those of the frame; in the extreme, the perceptual system may treat the main dimensions of the frame as those of physical space.

If the latter view is taken seriously, a decomposition of the frame into its four individual lines and an examination of the separate influences of the lines should be revealing. Although both the Wenderoth and Ebenholtz laboratories were searching for the basis of the influence of the frame on VPV, as noted above, the emphasis of their investigations was on the configurational or field-organizational aspects of the frame and their analyses into components, and from that point of view they made some measurements of the '2-line stimulus' (Wenderoth) and the 'corners' stimulus (Ebenholtz), but did not pursue the dissection to the level of the single line. Recently, we have carried the analysis of the influence of the frame to the level of the single line and have measured the systematic variation produced by line orientation and length, and the rules by which the influences of single lines are combined. In the first set of experiments (Li and Matin 1998a, 1998b), we measured the angle function for VPV and VPH (visually perceived horizontal) under the influence of a 2-line stimulus centered on a fixation point in the midsagittal plane in which two 64 deg long parallel lines were separated by 50 deg (each line 25 deg from the fixation target). The 2-line stimulus was presented at each of twenty-four different orientations within a 180° semicircle (since each orientation on the other half-circle duplicates the angle in the first half-circle, only 180° are needed to cover the full 360°). The average results are closely fitted by a sinusoidal function, with positive peaks at 22.5° and 112.5°, negative peaks at 67.5° and 157.5°, and zeros at 0°, 45°, 90°, 135°, and 180° (= 0°); thus there are four cycles of illusion magnitude over the 360° circle. The results of the VPV and VPH measurements were virtually indistinguishable, with the influence for a given inducer orientation indistinguishable between the two discriminations, thus indicating that the orthogonal relation of VPV and VPH is retained across a broad range of conditions, in which the absolute magnitudes of VPV and VPH vary widely as a consequence of the substantial influence of the inducing stimuli. The angle function for VPV shown by these results is similar to the one measured for the full square by Spinelli et al (1991), but differs from the one by Beh et al (1971), although it is also similar to some of the later results of Wenderoth (1977) with parallel 2-line stimuli.

In the second set of experiments (Li and Matin 2005), we measured the influences of 1-line inducing stimuli and their combinations as 2-line stimuli with the orientations of individual lines varying over a ±15° range of roll-tilts; these measurements were made separately with 66.5 deg long and 12 deg long inducing lines at 25° horizontal eccentricities. Each set of 1-line results mapped a portion of the sinusoid for the 1-line stimulus that closely fitted a portion of the previously measured function with the 2-line stimulus, with smaller peak effects for the smaller and less eccentric inducing lines. In addition, whereas 2-line combinations of the short (12 deg long) stimuli manifested magnitudes of summation that were close to complete linear additivity, 2-line combinations of the 66.5 deg long stimuli manifested magnitudes of summation that were close to algebraically linear averaging; summation in each case was linear with the sum of the orientations of the two lines and algebraically additive across the entire range of orientations and orientation combinations [eg the sum of the VPVs for the two lines at 15° counterclockwise (ccw) and 5° clockwise (cw) was indistinguishable from the sum of the VPVs for the two lines at 10° ccw and 0° (upright)]. This linear additivity between the separate influences of the individual members of a 2-line stimulus suggests the possibility that the total influence of the entire square frame may be a simple consequence of the action of its individual constituent lines and of a similar 'mass action' law of combination rather than of any particular characteristics of the frame related to its configuration. The present experiments were carried out to examine this possibility quantitatively.

2 Methods

Two experiments were conducted. They differed in only one respect: in experiment 1, the inducing lines were 48 deg long ('long lines'); in experiment 2, the inducing lines were 16 deg long ('short lines').

2.1 *General*

In each experiment, measurements of VPV settings were made in the presence of each of eight inducing line configurations as shown in figure 2a for the 48 deg long lines and in

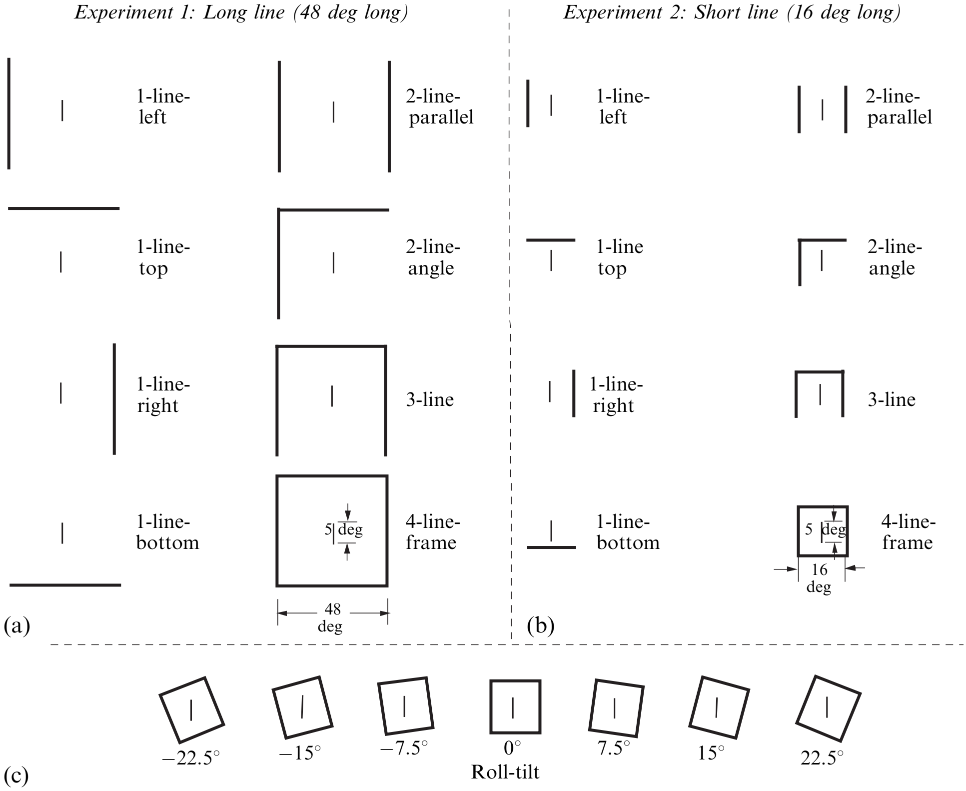

Figure 2. The erect version of the configuration for each of the eight conditions in each of the two experiments. The visual angle of each of the inducing lines in each configuration was (a) 48 deg in experiment 1 ('long line'), and (b) 16 deg in experiment 2 ('short line'); the test line was 5 deg long in each experiment. We refer to the configurations as 1-line-left, 1-line-top, 1-line-right, 1-line-bottom, 2-line-parallel, 2-line-angle, 3-line, and 4-line-frame. (c) The influence of each of the inducing configurations on visually perceived vertical (VPV) was measured with each configuration at each of seven orientations in the frontoparallel plane; the orientations ranged from being roll-tilted 22.5° counterclockwise to 22.5° clockwise around an axis centered at eye level in the midfrontal plane of the viewing eye of the subject.

figure 2b for the 16 deg long lines. Each configuration is displayed together with the 5 deg long rod that was set to appear vertical according to the subject's instruction. The rod is shown in figure 2 as vertical and the configuration is displayed in its erect or horizontal orientation. We refer to the eight configurations by the names indicated in figure 2: 1-line-left, 1-line-top, 1-line-right, 1-line-bottom, 2-line-parallel, 2-line-angle, 3-line, and 4-line-frame. Although the configurations in figures 2a and 2b are displayed in the erect or horizontal orientation in order to display the configurational property (number of lines and their arrangement relative to each other), as shown in figure 2c, each of these eight configurations was presented at each of seven roll-tilts. These roll-tilts were 22.5° ccw (−22.5°), 15° ccw (−15°), 7.5° ccw (−7.5°), upright (0°), 7.5° cw (+7.5°), 15° cw (+15°), and 22.5° cw (+22.5°). All seven roll-tilts for a given induction configuration were presented in the same session and in a given session only one configuration was employed.

In each trial of each of the two experiments, the monocularly viewing subject, seated straddling a stool with head stabilized by a chin-rest, viewed the visual field which consisted of one of the eight configurations at one of the seven orientations. The visual field was in darkness that was total with the exception of the visible presence of the inducing stimulus and the test line that was 5 deg long × 5.6 min of arc wide, centered in the median plane of the viewing eye at eye level; both were located within a frontoparallel plane at 1 m from the subject. Viewing was always with the right eye, vision in the left eye was occluded by an eye patch.

2.2 *Stimulus display*

Each of the inducing configurations consisted of strips of phosphorescent tape that received a brief exposure (~2 min) to normal room illumination at the beginning of each experimental session; this was refreshed for approximately 30 – 60 s following each set of four VPV measurements. Each of the 48 deg long × 5.6 min of arc wide strips was 99.4 cm × 0.2 cm; each of the 16 deg long × 5.6 min of arc wide strips was 28.4 cm × 0.2 cm; the luminance of the strips was approximately 0.01 mL (EG&G photometer/radiometer 550). The inducer strips were mounted on separate plastic bars that could be attached by Velcro to three large stand-alone wheel-mounted vertical boards. The boards were physically lined up to form a unified frontoparallel plane. The test line was mounted on its own plastic bar that was itself mounted on the middle board with its center on the central point of a large machined protractor (tick marks on the protractor were separated by 0.25°; readings were to the nearest 0.25°); rotation of the test line was linked to rotation of a large pointer whose alignment with the tick marks provided the angular readings; test-line rotation could be performed freely around the center of the line. The line(s) constituting the inducer configuration was (were) placed across the appropriate segments of the three boards.

When an inducing line was erect, the middle point of the line was at 26.4° horizontal eccentricity relative to the center of the test line which lay in the midsagittal plane of the subject's viewing eye for the 48 deg long line, and was at 8.1° horizontal eccentricity for the 16 deg long line; when an inducing line was horizontal, the middle point of the line was at 26.4° vertical eccentricity relative to the center of the test line for the 48 deg long line, and was at 8.1° vertical eccentricity for the 16 deg long line. For both the long and short inducing lines, the rotation from the original erect or horizontal orientation was around a horizontal axis on the midsagittal plane of the subject's viewing eye at true eye level. Thus, all seven roll-tilts for each of the sixteen induction configurations remained on the same frontoparallel plane. (That is, if the 1-line-right inducing stimulus was rotated ccw 90°, it would become the 1-line-top stimulus; if it was rotated ccw 180°, it would become the 1-line-left stimulus.) The 2-line, 3-line, and 4-line stimuli were constructed by proper combinations of the four 1-line inducers. At the beginning of the session, by adjustments of the stool and chin-rest, the frontal plane of the subject's body was set parallel to the plane containing the test line and the inducer configuration; when the subject's fixating eye was horizontal and the direction of gaze was parallel to the body's midsagittal plane, the eye was centered on the centers of the test line and inducer configuration.

2.3 *Procedure*

The same general procedure was followed in the two experiments. A method of adjustment with hunting was employed for the setting of the test line. A trial began with the subject's eyes closed, and following the experimenter's setting of the test line to an orientation that was well out of the region of uncertainty for a VPV setting, the subject was instructed to open his/her eyes, fixate the center of the test line, and report whether it needed to be rotated to the left or right in order to appear vertical (to appear at VPV); immediately after reporting, the subject closed his/her eyes, whereupon the experimenter reset the test line by a variable amount and instructed the subject to open his/her eyes again and report on the orientation of the test line relative to VPV again. This sequence was repeated until the subject indicated that the test line was oriented at VPV. Four such settings were made before proceeding to another inducer orientation. Two of each set of four trials began with the initial orientation of the test line far counterclockwise relative to true vertical, two began at a clockwise orientation far from vertical; the four starting orientations were sequenced in ABBA order. The seven orientations of the configuration examined in a session were sequenced by an independent random order in different sessions in each experiment; different random orders were employed for different subjects. The order of the sessions in which these configurations were employed was also separately randomized for each subject. The value of VPV employed as the setting for a given inducer orientation, for a given subject, for further analysis was the mean value of the VPV settings on the four trials. In each session, with only the test line visible, a series of four trials was run prior to the seven main conditions, and a second four-trial series was run following the seven main conditions ('dark VPV' measurements). All of the conditions of experiment 1 (48 deg long lines) were completed for a given subject before that subject was run in experiment 2 (16 deg long lines).

2.4 *Subjects*

The same four erect subjects participated in all sixteen conditions of the two experiments. With the exception of the senior author, the subjects were Columbia University undergraduates who were paid an hourly wage for participating; recruitment and the experimental protocol met the requirements of the human subject committee at Columbia University.

3 Results

The results for the two experiments averaged across the four subjects are plotted in figure 3 as the VPV setting versus the roll-tilt of the inducing stimulus. The four 1-line conditions are plotted in figure 3a for the 48 deg long inducing stimulus and in figure 3c for the 16 deg long inducing stimulus. The four multiline conditions are plotted in figure 3b for the 48 deg long stimulus and in figure 3d for the 16 deg long stimulus. The slopes (best-fitting straight line) of all of these functions are displayed in figure 4a for the 48 deg long inducing stimulus and in figure 4b for the 16 deg long inducing stimulus. The standard deviation for the four trials at each of the seven orientations in each of the eight conditions was calculated for each subject separately. No important differences were found among them; the average standard deviations were 0.53° and 0.67° in experiments 1 and 2, respectively. The average standard deviations for the dark values (averaged across measurements at the beginning and end of the sessions) were 0.65° and 0.68°, respectively; these are similar to, but somewhat smaller than, numerical values of the variability measures with the adjustment method first reported by Neal (1926).

For each of the two inducing-line lengths, the slopes are indistinguishable for the 1-line versus roll-tilt functions in figure 4 for the four differently located inducing lines, with the four conditions for the 48 deg long line averaging 0.25 and the four conditions for the 16 deg long line averaging 0.13. We note, without further comment, two small differences among the results for the 1-line conditions: nearly all of the VPV values for the bottom inducing line are below those for the other three 1-line conditions across the seven roll-tilts at each line length in figure 3, and the slopes for the bottom and top (near-horizontal) lines in figures 4a and 4b are slightly (but not significantly) smaller than those for the left and right (near-vertical) lines.

More noteworthy is the fact that the slopes of the multiline configurations displayed in figures 4a and 4b are all larger than those for the 1-line inducers, with the slope values rising more rapidly with the number of lines for the 16 deg long inducer than for the 48 deg long inducer. The slope for the 3-line configuration is smaller than the slope for the full frame in each case, and the slopes for both 2-line configurations are still smaller with no difference between the 2-line-angle and 2-line-parallel configurations.

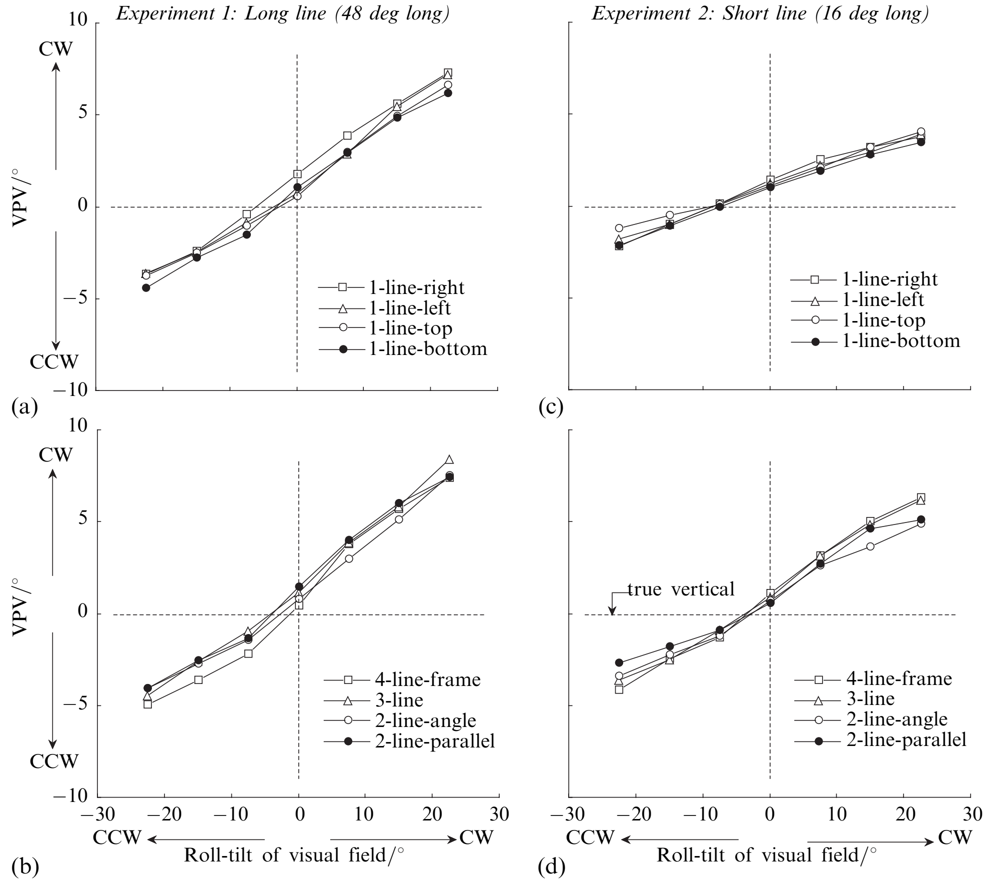

Figure 3. Visually perceived vertical (VPV) plotted (average of four subjects) against the roll-tilt for each of the eight inducing configurations in each of the two experiments. The results for each of the four 1-line configurations are displayed in panels (a) and (c) for experiments 1 and 2, respectively. The results for each of the four multiline configurations are displayed in panels (b) and (d) for experiments 1 and 2, respectively. The dashed vertical and horizontal lines in each panel represent true vertical for the inducing stimulus and for the subject's setting of the test line, respectively. CW: clockwise; CCW: counterclockwise.

The y-intercepts of all sixteen of the best-fitting straight lines to the average results in the four panels of figure 3 are positive, with values ranging from 0.7° to 1.7° and an average value of 1.15°, containing no obvious pattern. For three of the four subjects, values given had a small positive bias in all conditions; the fourth subject had a slightly negative bias in all conditions.

In figure 5 the slope of the VPV versus roll-tilt function is plotted against total line length for each of the eight inducer configurations; it is seen that the slope increases smoothly along a negatively accelerated exponential with a space constant of 31.9 deg across both the 16 deg long and the 48 deg long lines. Although the differences in slopes between short-line and long-line experiments is complicated by the difference in retinal eccentricity between the short-line (8.1° eccentricity) and long-line (26.4° eccentricity) stimuli, we have measured similar differences in slope between short (12 deg long) and long (66.5 deg long) lines when both were located at 25° horizontal eccentricity (Li and Matin 2005); it is likely that the slope difference is a general one for length. However, in the earlier experiments, where length was varied systematically at the single eccentricity, the space constant was only 17.1 deg, considerably smaller

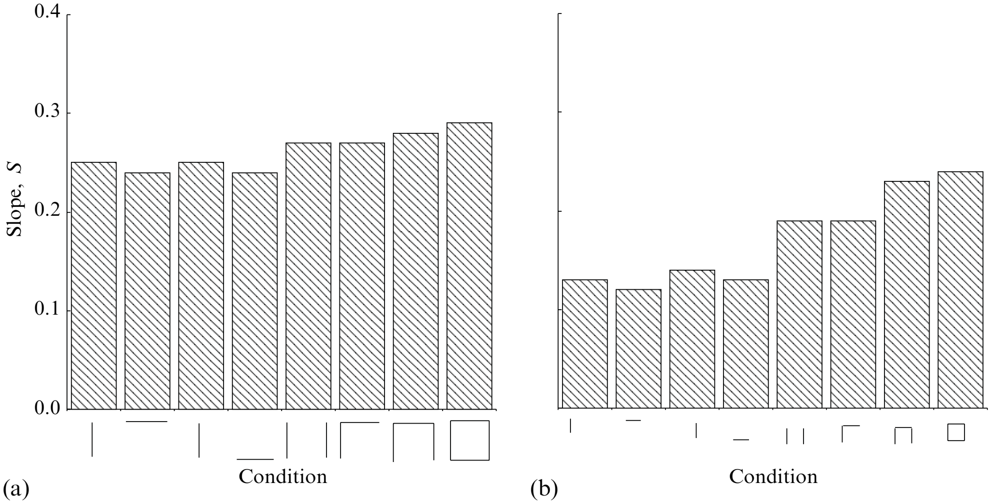

Figure 4. The best-fitting slopes (S) of the VPV versus roll-tilt functions in figure 3. (a) Experiment 1: long inducing line (48 deg long). (b) Experiment 2: short inducing line (16 deg long). The icons under the histograms represent the configuration of the inducing visual field at the horizontal or vertical orientation that was the central value of the seven inducer orientations employed for the displayed configuration. Average of four subjects.

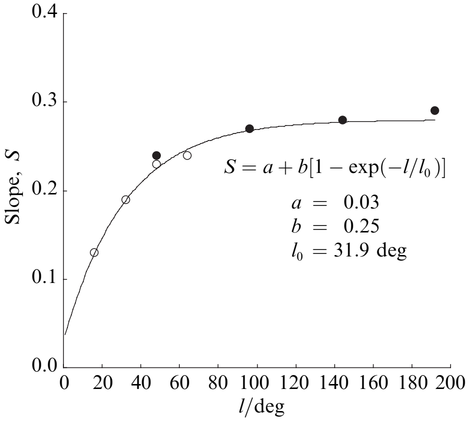

Figure 5. The best-fitting slopes (S) of the VPV versus roll-tilt functions for both the short line and the long line plotted against the total length (l) of all inducing lines in the visual field. The displayed curve is the best-fitting negatively accelerated exponential to the eight slope values averaged across the four subjects. The results for four conditions of the 1-line inducing field and results for two each of the two conditions of the 2-line inducing field are separately averaged.

than the value of 31.9 deg in figure 5. We note that this large space constant is not a consequence of the length or of the eccentricity per se, but is largely a result of the fact that the plot in figure 5 combines results from two exponentials with different asymptotes, one for each of the two line lengths, and in this sense is a consequence of the combined variation of line length with eccentricity.(2)

(2) The space constant for a VPV versus length function of a 1-line inducer at 25° eccentricity was measured at 17.1 deg (Li and Matin 2005), and if the asymptotic magnitude is only slightly less for the less eccentric inducer (as appears to be the case, although complete measurements are not available), regardless of whether the space constant is also 17.1 deg or different, the fit of an exponential to the combined results for the two eccentricities would only be somewhat less good, but the space constant would, of necessity, be larger by an amount that would account well for the difference between 31.9 deg and 17.1 deg. For example, for two exponentials both with space constants of 17.1 deg but different asymptotic magnitudes—values of b in the equation in figure 5 equal to 0.30 and 0.25—the best-fitting exponential for the combination possesses a space constant of 36 deg, more than twice the value of each of the constituent exponentials.

4 Discussion

4.1 *Periodicity in the 1-line results*

It is instructive to plot the 1-line results in a way that treats the orientation of the 1-line inducing stimulus as a continuous variable in the frontoparallel plane without regard to whether it is on the left or right side or above or below the test line. We have done this in figure 7 making use of the circular scale in figure 6. The stimulus variation in the neighborhood of each of the four sets of 1-line stimuli involves the seven equally spaced orientations of the stimulus line that were utilized in the present experiments (tick marks) over the ±22.5° range centered on the vertical or horizontal axis in figure 6. Employing this arrangement we replotted the VPV versus roll-tilt functions displayed in figure 3 separately in figure 7 for the 48 deg long lines and for the 16 deg long lines. They all fall along piecewise periodic segments of the orientation dimension where each of the four 1-line variations occupies one of the rising 45° segments within the 360° range.[3] All of the data for each line length are fitted to the sinusoid, $V_\rho = \beta \sin(\alpha\rho + \phi) + V_0$. In line with our previous findings, where results were obtained on both ascending and descending portions of the sinusoid (Li and Matin 1998a, 1998b), the data are well-described by 4α periodicity ($\alpha = 3.97$ for both long and short lines). Both manifest a small phase shift relative to physical orientation,

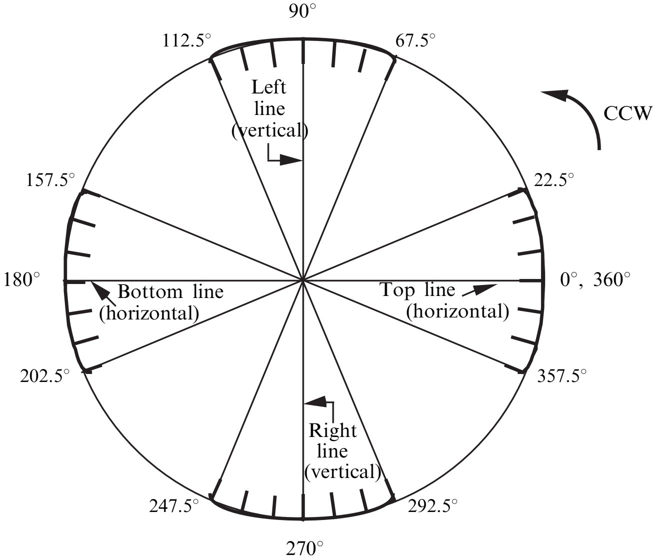

Figure 6. A circular arrangement that treats the orientation of the 1-line inducing stimulus as a continuous variable in the frontoparallel plane relative to physical space without specific regard to its location relative to the test line. The angles (ρ) on the outside of the circle from 0° to 360° represent the orientation within a frontal plane relative to horizontal at 0°. Both the 1-line-top and 1-line-bottom stimuli are horizontal and have been aligned on the 0° – 180° axis; both the 1-line-left and 1-line-right stimuli are vertical and are aligned on the 90° – 270° axis. The specific association in the figure of 0° with top, 180° with bottom, 90° with left, and 270° with right is arbitrary. However, the particular choice provides a circular scale in which the angular measure increases in the usual fashion with counterclockwise (ccw) rotation in the *xy* plane. The stimulus variation in the neighborhood of each of the four 1-line stimuli involves the seven equally spaced inducer orientations that were utilized in the present experiments (shown by the tick marks) over the ±22.5° range centered on its axis.

[3] Although our present measurements were only made on the rising segments of the sinusoid, justification for assuming a complete sinusoid here lies in earlier experiments (Li and Matin 1998a, 1998b) in which measurements were made throughout the entire 360° range and which showed both rising and falling segments of the 4α function as clearly as the present results show the rising segments.

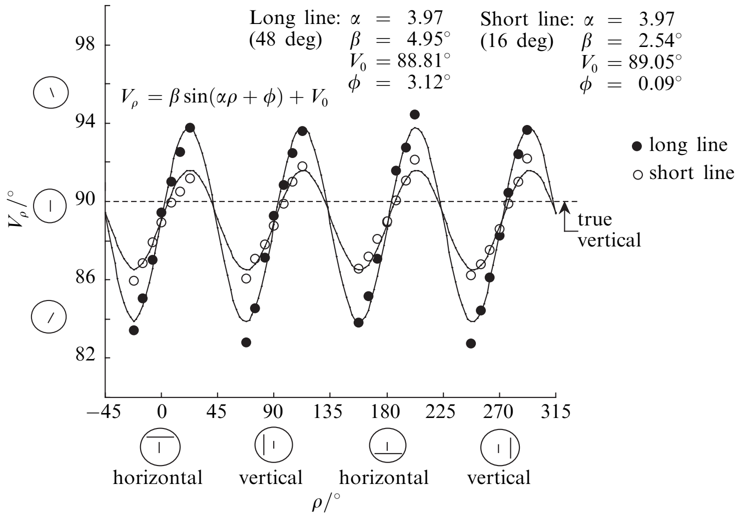

Figure 7. The VPV versus roll-tilt functions (V_ρ) displayed along the circular orientation scale (ρ) described in figure 6. For each line length the results fall along piecewise periodic segments of the orientation dimension; each of the four 1-line variations occupies one of the rising 45° segments within the 360° range. All of the data for each line length are fitted to the sinusoid, $V_\rho = \beta \sin(\alpha\rho + \phi) + V_0$. They are well-described by 4α periodicity ($\alpha = 3.97$ for both long and short lines).

indicated by the deviation of ϕ from vertical (3.12° for the long line, 0.09° for the short line); both manifest a small clockwise displacement from the VPV zero (ordinate equal to 90°) as indicated by the deviations of V_0 from 90° (1.09° and 0.95° for long and short lines, respectively), all of which are small. The near doubling of the amplitude of the 48 deg function ($\beta = 4.95$) relative to that of the 16 deg function ($\beta = 2.54$) is an indication of the negative acceleration of the VPV versus length function (Li and Matin 2005), although in the present case the influence of line length is not separable from the influence of the difference in eccentricity. It is clear that 4α periodicity obtains at both the near (short) and more eccentric (long) inducers.

4.2 *Multiline combinations*

Our main interest in carrying out the present experiments, however, was not in the 1-line stimulus itself, as has been the focus of the discussion to this point, but in how influences on VPV from the individual lines in the square frame combined when multiline pieces of the frame were presented.

4.2.1 *The parallel and 90°-angled 2-line inducing stimuli.* As reported elsewhere (Li and Matin 2005), whether the influence of a 2-line stimulus is larger or smaller than the influence of each of its two component lines and whether it has the same sign as one or both lines depends on the angular relation between the two components. This is not true in the present special cases involving either a 90° or 180° relation between the 2-line components; the use of these special cases, of course, derives from our present interest in assessing how the influence of the square frame is related to the influence of the individual lines that constitute the frame: the individual influences on VPV of two such lines are either equal or near-equal (figures 3, 4, and 7); ie the most counterclockwise member of the seven-orientation set centered on the top line generates an influence on VPV that is essentially indistinguishable from the most counterclockwise member of the seven-orientation set centered on the left line, and both are essentially indistinguishable from the most counterclockwise member of the set centered on the bottom line, as well as the most counterclockwise member of the set centered on the right line; the same relation holds for the second most counterclockwise members of the four 1-line sets, etc. As a result of the special angular relations involved, the influence of each of the 2-line combinations is larger than the influence of either of its components.

The ordinate in figure 8a displays the VPV for the parallel 2-line stimulus plotted against the sum of the individual VPVs for the two component lines; figure 8b displays the analogous results for the 2-line-angle conditions. The results for the 16 deg long and 48 deg long inducers are shown as the open and filled circles, respectively, and the best linear fit for all seven 1-line inducer combinations (least squares) whose equation is given in the figure is displayed for each length. The dashed line and the dotted line in figures 8a and 8b possess slopes of 1.00 and 0.50, respectively; the slope of 1.00 represents what would be complete linear additive summation between the influences of the two individual lines—that is, the case in which the 2-line VPV would equal the sum of the influences from the two individual component lines; the slope of 0.50 represents what would be simple linear additive averaging (since the additional presence of a second line along with the presence of a first line produces no increase in influence beyond that of the first line, such averaging corresponds to 'zero summation').

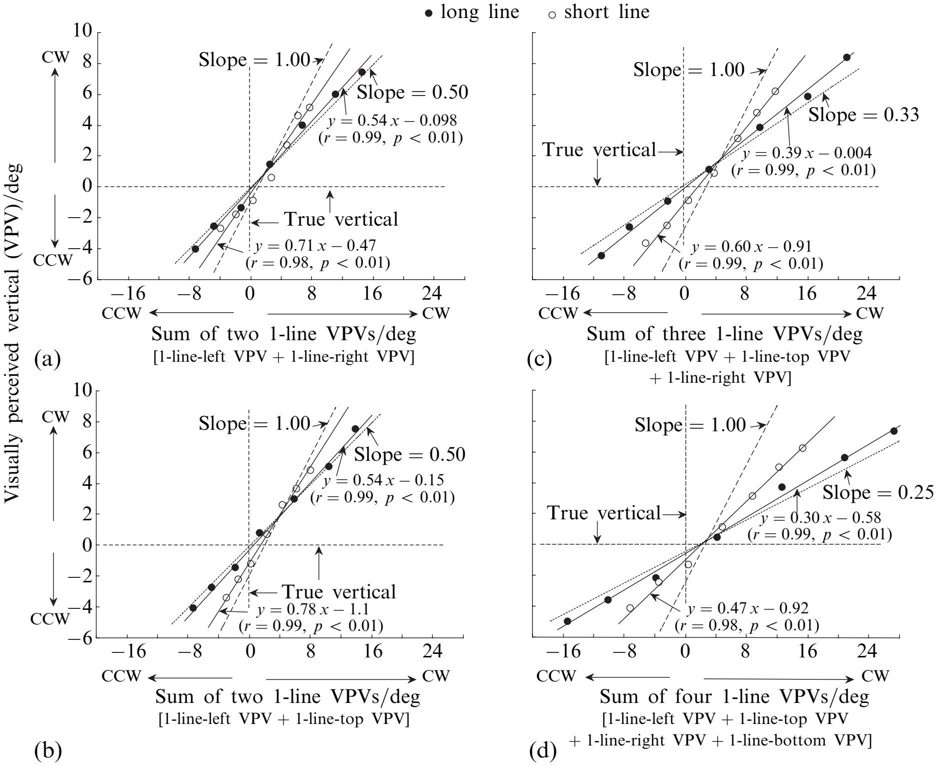

Figure 8. Visually perceived vertical (VPV) for the multiline stimuli plotted against the sum of the VPVs for the constituent lines. Panels (a) and (b) display the relation for the 2-line-parallel and 2-line-angle measurements, respectively, panels (c) and (d) display the relation for the 3-line-frame and 4-line-frame stimuli, respectively. The least-squares best-fitting straight lines, fitted separately for the results with the long line of experiment 1 and the short line of experiment 2, are shown as the continuous straight diagonal lines. The theoretical slope representing complete linearly additive summation is displayed by the dashed line with slope of 1.00 in each panel; the theoretical slope representing linear averaging ('zero summation') is displayed by a value of 0.50 in (a) and (b) for the 2-line stimuli, 0.33 in panel (c) for the 3-line stimuli, and 0.25 for the 4-line-frame stimuli. In each panel, the dashed and dotted lines are placed so as to cross the point of intersection between the best-fitting straight lines to the long-line and short-line data.

Clearly, the slopes of the results in figures 8a and 8b do not reach either complete summation or averaging but are bracketed by the 'complete summation' and 'averaging' boundaries, where the slopes for the short-line inducer equal 0.71 and 0.78 for the parallel and 90°-angled pairs, respectively, and 0.54 for each of the long-line pairs. These results are consistent with those reported by us elsewhere (Li and Matin 2005), where the results with a shorter short line (12 deg long) possessed a slope of 0.91 and results with a longer long line (66.5 deg long) possessed a slope of 0.67. Since the magnitude of summation must, of necessity, decrease systematically with length along the negatively accelerated exponential that characterizes the VPV versus length relation (Li and Matin 2005), the closer approach to full linear summation for the shorter short line in the previous experiments is expected. However, one would also expect a slightly closer approach to averaging in the previous experiments with the longer long line, and this did not occur. There are three additional possible main bases for differences between the present and our other set of experiments in addition to the length difference (48 deg versus 66.5 deg) that together suggest no inconsistency is involved: (a) in the previous experiments, the rotation center for variation of line orientation was fixed at a horizontal eccentricity of 25°, whereas the rotation center in the present experiments was centered in the median plane; (b) in our other experiments, the range of inducer orientations was ±15° around the vertical, whereas in the present case the range was ±22.5° around an axis centered at eye level in the midfrontal plane of the viewing eye of the subject; (c) different subject pools were employed in the two sets of experiments and the range of differences across subjects in magnitudes of the influence is substantial. Nevertheless, differences between the work in the two papers are fairly small, the main results are clearly in line with the other work, and the results with the 3-line and 4-line conditions described below continue to be in line with expectations from the other work.

4.2.2 *The 3-line inducing stimulus.* Figure 8c contains the plot for the 3-line stimulus that is analogous to the 2-line plots in figures 8a and 8b. Here, the best-fitting slopes for the relation between the VPV values for the 3-line stimulus and the sum of the VPV values for the three separately measured component lines are 0.60 and 0.39 for the short and long lines, respectively. Thus, the slopes for both lengths have been reduced from their values with the 2-line conditions. For the 3-line case the 0.39 result for the long line is not significantly more distant from 0.33, the 'zero summation' case (averaging), than is the 0.54 from 0.50 in the 2-line case described above; thus, again, the approach to averaging is close for the long line. The 0.60 result for the short line is even further from complete summation (slope of 1.00) than are the 0.71 and 0.78 results for the 2-line inducer, and this is entirely consistent with expectation from linearly additive summation extending to a higher portion of the negatively accelerated exponential for three 16 deg long lines as compared to two lines.

4.2.3 *The 4-line (full square) inducing stimulus.* The results for the full square are entirely consistent with those we have obtained with the 2-line and 3-line inducers by characterizing the influence of a multiline inducer in terms of the relation between its individual line components and the full configuration. The slopes of the 4-line stimulus versus the sum of the individual VPVs for the four individual lines (figure 8d) are 0.47 and 0.30 for the small and the large square, respectively. Here, the zero summation (averaging) result would be a slope of 0.25 and as before the full summation result would be 1.00. Thus, the long-line result for the full square is close to what would be predicted from averaging, and the result for the short-line full square is smaller than either the 2-line or 3-line results but still considerably larger than zero summation; this relation to the 2-line and 3-line results for the long line is as expected, since the total length of the four lines is longer than the total length of the 2-line and 3-line stimuli.

4.2.4 *Summary: multiline configurations.* Thus, each of the relations between the 1-line and multiline stimuli is well-described by the linear relation

$$V'_{\mathrm{m}} = k_1 \sum_{i=1}^{n} V_i + k_2 \,, \tag{1}$$

where V'_{m} and $\sum_{i=1}^{n} V_i$ are the multiline VPV and the sum of the appropriate 1-line VPVs, respectively, and k_1 and k_2 are the slope constant and y-intercept of the linear function relating them. The important differences in results for the different multiline stimuli are reflected in the differences in k_1. In figure 9 a summary is shown of the influences of the 2-line, 3-line, and 4-line combinations compared to that predicted by linearly additive summation of the results for the 1-line stimuli, by displaying the slopes of the multiline VPV versus roll-tilt functions from figure 8 normalized as a percentage of the average of the constituent 1-line slopes (S%). The straight diagonal line representing complete linearly additive summation represents multiples of the 1-line slope corresponding to the number of lines in the configuration. Had there been any increase in the slope of the VPV versus roll-tilt function above that line it could be taken to be a consequence of an influence due to the configuration itself—an interaction—above and beyond the combined influences of the individual line components. The measured values are considerably below this Gestalt prediction region. In fact, the values for the full-square 4-line frame fall on smooth curves along with those from the 1-line, 2-line, and 3-line inducers, with the asymptotic value of the total influence from the combination of individual components of the square frame in figure 9 also lying considerably below the line representing complete linear summation. That line is approached most closely here by the combination of two short lines, and the multiline value deviates more with increase in the number and length of the lines in the combination; the data lie closer to the linear-averaging line than to the complete-summation line.

Thus, although the square frame possesses a distinct qualitative perceptual character ('squareness') that is clearly different from what can be obtained from the sum of its parts and depends on the spatial relation between those parts, influence on the perception of vertical is a quantitative variable whose value is considerably less than the sum of the influences of its four component straight lines. As shown in our other

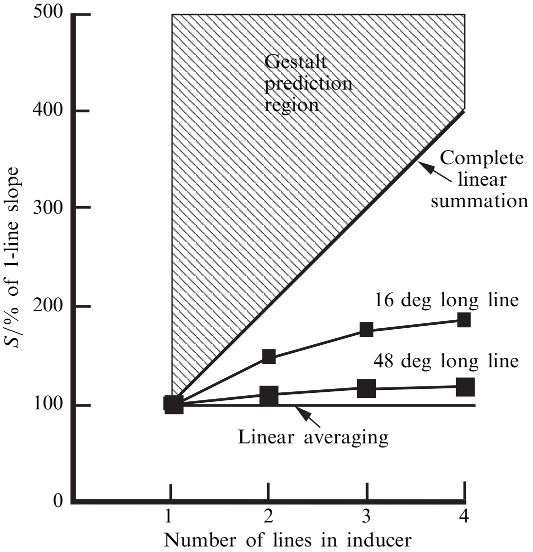

Figure 9. Slope of the VPV versus roll-tilt function (S) as a percentage of the average 1-line slope for all configurations at each of the two inducing-line lengths. The two dark straight lines bracketing the results show the loci for predictions of linear averaging among the individual lines and for complete linearly additive summation. The Gestalt prediction region displays the prediction of 'supersummation', that is the region in which more than complete linearly additive summation among the individual lines might occur (ie where the "whole would be more than the sum of its parts").

report (Li and Matin 2005), and in figures 5 and 8 here, although the sensitivity to induction as measured by the slope of the VPV versus roll-tilt function increases along a negatively accelerated exponential function with total length, the combining rule for the net influence of either 2, 3, or 4 lines is linear and additive as represented in equation (1). Such 'mass action' among individual lines has also been measured for the 2-line stimuli for all combinations of roll-tilt orientations over the range from $+15^\circ$ to -15° centered on the vertical (Li and Matin 2005) and with the same lines at the same 25° horizontal eccentricity for another spatial discrimination, one regarding the visual perception of elevation (Matin and Li 1994a, 1999, 2000, 2001). This allows us to conclude that there is no significant basis for believing that the unique configurational or Gestalt properties of the square frame have any bearing on the influence on VPV, conclusions that are in line with current ideas regarding a fundamental bifurcation in the processing of visual stimulation out of V1 that gives rise to a stream providing 'where' information (the influence on VPV in the present case) to one part of the cerebral cortex and a second stream that provides 'what' information (the perception of squareness of the frame) to another part of the cerebral cortex, ideas that go back to a 1967 symposium (Held et al 1967) in which such views were first delineated (see Jeannerod 1997 for a review and analysis indicating further complexity). It remains to be shown over how broad a range of configurations the configuration independence of the spatial induction we measure on VPV will hold.

Acknowledgment. This work was supported by Grant EY 10534 from the National Eye Institute, NIH.

References

Asch S E, Witkin H A, 1948a "Studies in space orientation. I. Perception of the upright with displaced visual fields" *Journal of Experimental Psychology* **38** 325 – 337

Asch S E, Witkin H A, 1948b "Studies in space orientation. II. Perception of the upright with displaced visual fields and with body tilted" *Journal of Experimental Psychology* **38** 455 – 477

Beh H, Wenderoth P M, Purcell A T, 1971 "The angular function of rod-and-frame illusion" *Perception & Psychophysics* **9** 353 – 355

Bertini M, Pizzamiglio L, Wapner S (Eds), 1986 *Field Dependence in Psychological Theory, Research, and Application. Two Symposia in Memory of Herman A. Witkin* (Hillsdale, NJ: Lawrence Erlbaum Associates)

Dichgans J, Brandt T, 1974 "The psychophysics of visually induced perception of self-motion and tilt", in *The Neurosciences, Third Study Program* Eds F O Schmitt, F G Worden (Cambridge, MA: MIT Press) pp 123 – 129

Dichgans J, Held R, Young L R, Brandt T, 1972 "Moving visual scenes influence the apparent direction of gravity" *Science* **178** 1217 – 1219

Ebenholtz S M, 1977 "Determinants of the rod-and-frame effect: The role of retinal size" *Perception & Psychophysics* **22** 531 – 538

Ebenholtz S M, 1985 "Absence of relational determination in the rod-and-frame effect" *Perception & Psychophysics* **37** 303 – 306

Ebenholtz S M, 1990 "Metamorphosis from rod and frame to visual – vestibular interaction", in *The Legacy of Solomon Asch: Essays in Cognition and Social Psychology* Ed. I Rock (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 233 – 242

Ebenholtz S M, Benzschawel T L, 1977 "The rod and frame effect and induced head tilt as a function of observation distance" *Perception & Psychophysics* **22** 491 – 496

Ebenholtz S M, Callan J W, 1980 "Modulation of the rod and frame effect: retinal angle vs. apparent size" *Psychological Research* **42** 327 – 334

Ebenholtz S M, Glaser G W, 1982 "Absence of depth processing in the large-frame rod-and-frame effect" *Perception & Psychophysics* **32** 134 – 140

Goodenough D R, 1986 "History of the field dependence construct", in *Field Dependence in Psychological Theory, Research, and Application. Two Symposia in Memory of Herman A Witkin* Eds M Bertini, L Pizzamiglio, S Wapner (Hillsdale, NJ: Lawrence Erlbaum Associates)

Held R, Dichgans J, Bauer J A, 1975 "Characteristics of moving visual areas influencing spatial orientation" *Vision Research* **15** 357 – 365

Held R, Ingle D, Schneider G E, Trevarthen C B, 1967 *Psychologische Forschung* **31** 42 – 43

Helmholtz H von, 1867/1962 *Treatise on Physiological Optics* volume 3 (New York: Dover, 1962); English translation by J P C Southall for the Optical Society of America (1925) from the 3rd German edition of *Handbuch der physiologischen Optik* (first published in 1867, Leipzig: Voss)

Higashiyama A, Koga K, 1998 "Apparent body tilt and postural aftereffect" *Perception & Psychophysics* **60** 331 – 347

Hudson T, Li W, Matin L, 2000 "Independent mechanisms produce visually perceived eye level (VPEL) and perceived visual pitch" *Vision Research* **40** 2605 – 2619

Hudson T , Li W, Matin L, in press "The field-dependence/independence cognitive style does not control the spatial perception of elevation" *Perception & Psychophysics*

Jeannerod M, 1997 *The Cognitive Neuroscience of Action* (Cambridge, MA: Blackwell)

Kleint H, 1937 "Versuche über die Wahrnehmung" *Zeitschrift für Psychologie* **140** 109 – 138

Koffka K, 1935 *Principles of Gestalt Psychology* (New York: Harcourt Brace)

Li W, Dallal N, Matin L, 2001 "Influences of visual pitch and visual yaw on visually perceived eye level (VPEL) and straight ahead (VPSA) for erect and rolled-to-horizontal observers" *Vision Research* **41** 2873 – 2894

Li W, Matin L, 1998a "Relations between rolled-induced changes in orientations of visually perceived vertical and horizontal" *Investigative Ophthalmology & Visual Science* **39**(4) S626 (abstract)

Li W, Matin L, 1998b "Visually perceived vertical and horizontal remain orthogonal although both undergo large roll-tilt induced changes" *Abstracts of the Psychonomic Society* **3** 42

Li W, Matin L, 2005 "Visually perceived vertical (VPV): Induced changes in orientation by 1-line and 2-line roll-tilted and pitched visual fields" *Vision Research* **45** 2037 – 2057

Matin L, Fox C, 1989 "Visually perceived eye level and perceived elevation of objects: Linearly additive influences from visual field pitch and from gravity" *Vision Research* **29** 315 – 324

Matin L, Li W, 1992 "Visually perceived eye level: Changes induced by pitched-from-vertical 2-line visual field" *Journal of Experimental Psychology: Human Perception and Performance* **18** 257 – 289

Matin L, Li W, 1994a "The influence of the orientation of a stationary single line in darkness on the visual perception of eye level" *Vision Research* **34** 311 – 330

Matin L, Li W, 1994b "Spatial summation among parallel lines across wide separation (50°): Spatial localization and the Great Circle Model" *Vision Research* **34** 2577 – 2598

Matin L, Li W, 1995 "Multimodal basis for egocentric spatial localization and orientation" *Journal of Vestibular Research* **5** 499 – 518

Matin L, Li W, 1999 "Averaging and summation of influences on visually perceived eye level between two long lines differing in pitch or roll-tilt" *Vision Research* **39** 307 – 329

Matin L, Li W, 2000 "Linear combinations of signals from two lines of the same or different orientations" *Vision Research* **40** 517 – 527

Matin L, Li W, 2001 "Neural model for processing the influence of visual orientation on visually perceived eye level (VPEL)" *Vision Research* **41** 2845 – 2872

Mittelstaedt H, 1986 "The subjective vertical as a function of visual and extraretinal cues" *Acta Psychologica* **63** 63 – 85

Mittelstaedt H, 1988 "The information processing structure of the subjective vertical. A cybernetic bridge between its psychophysics and its neurobiology", in *Processing Structures for Perception and Action* Eds H Marko, G Hauske, A Struppler (Weinheim: VCH) pp 217 – 263

Müller G E, 1917 "Zur Analyse der Gedächtnistätigkeit und des Vorstellungsverlaufs" *Zeitschrift für Psychologie* Supplement **9**

Neal E, 1926 "Visual localization of the vertical" *American Journal of Psychology* **37** 287 – 291

Poquin D, Ohlmann T, Barraud P A, 1998 "Isotropic visual field effect on spatial orientation and egocentric localization" *Spatial Vision* **11** 261 – 278

Radner M, Gibson J J, 1935 "Orientation in visual perception: the perception of tip-character in forms" *Psychological Monographs* **46** 48 – 65

Spinelli D, Antonucci G, Goodenough D, Pizzamiglio L, Zoccolotti P, 1991 "Psychophysiological mechanisms underlying the rod-and-frame illusion", in *Field Dependence – Independence: Cognitive Style across the Life Span* Eds S Wapner, J Demick (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 37 – 60

Wapner S, Demick J (Eds), 1991 *Field Dependence – Independence: Cognitive Style across the Life Span* (Hillsdale, NJ: Lawrence Erlbaum Associates)

Wenderoth P, 1977 "An analysis of the rod-and-frame illusion and its variants", in *Studies in Perception* Eds R H Day, G V Stanley (Perth, Australia: University of Western Australia Press) pp 95 – 141

Wenderoth P M, Beh H, 1977 "Component analysis of orientation illusions" *Perception* **6** 57 – 75

Wertheimer M, 1912 “Experimentelle Studien über das Sehen von Bewegung” *Zeitschrift für Psychologie* **61** 161 – 265

Witkin H A, 1949 “Perception of body position and of the position of the visual field” *Psychological Monograph* **63**(7) 1 – 46

Witkin H A, 1977 *Cognitive Styles in Personal and Cultural Adaptation* volume XI Heinz Werner Lecture Series (Washington, DC: Clark University Press)

Witkin H A, Asch S E, 1948a “Studies in space perception. III. Perception of the upright in the absence of a visual field” *Journal of Experimental Psychology* **38** 603 – 614

Witkin H A, Asch S E, 1948b “Studies in space perception. IV. Further experiments on perception of the upright with displaced visual fields” *Journal of Experimental Psychology* **38** 762 – 782

Witkin H A, Goodenough D R, 1981 *Cognitive Styles: Essence and Origins. Field Dependence and Field Independence. Psychological Issues, Monograph 51* (New York: International Universities Press)

Witkin H A, Lewis H B, Hertzman M, Machover K, Meissner P B, Wapner S, 1954 *Personality through Perception. An Experimental and Clinical Study* (New York: Harper & Brothers)

Zoccolotti P, Antonucci G, Spinelli D, 1993 “The gap between rod and frame influences the rod-and-frame effect with small and large inducing displays” *Perception & Psychophysics* **54** 14 – 19

ISSN 0301-0066 (print)
ISSN 1468-4233 (electronic)

PERCEPTION
VOLUME 34 2005

www.perceptionweb.com