Lateral Congruence of Eye and Hand Improves Physical Matching during Estimation of Line Length

by

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ABSTRACT

This study considers judgements of the length of parallel lines which recede in depth from normal viewers. The intention is to clarify neuropsychological models of variation in spatial representation, in terms of sensorimotor action, attention, and visual perception. Milner, Harvey, Roberts, & Forster (1993) suggest that subjective space could be progressively compressed towards the left, especially for those with right hemisphere brain damage. Findings of Heilman, Chatterjee & Doty (1995) could be interpreted as endorsing this effect for normals who binocularly perceive straight lines in left space as looking smaller than lines in right space during judgements of receding line length. The current study replicates and extends this finding, with right side lines being accurately recreated in left space, but left side lines recreated shorter (underplaced) in right space. There is no combined effect of monocular sighting eye dominance and visual angle of retinal image upon binocular line length recreations. Comparison between binocular and monocular findings only support a cyclopean binocular viewpoint for near lines. For far lines, congruent (ipsilateral) eye and hand together recreate accurate line lengths while incongruent (contralateral) eye and hand is influenced by retinal image (indicating misperception of line orientation and/or depth). This evokes Berner and Berner's (1953) crossed (eye and hand) dominance syndrome. The flexibility of the binocular controlling eye may be complemented by an unexpectedly variable monocular sighting eye performance independent of the avowed monocular sighting eye dominance or hemispatial origin of the eye/hand combination. Instead, more accurate perception of line orientation in farther space occurs when both required body systems are those yoked to the same lateral hemispace. This supports previous findings of lateral congruence (Burden et al., 1985) between multiple body-based maps and lateral hemispace.

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CHAPTER I

INTRODUCTION

Judgements of the length of parallel lines may indicate lateral (left/right) differences in spatial attention, gradient, or representation, when the adjustment line is placed on the opposite side of the body as the comparison line.

Judgements of the lengths of straight lines has played a prominent role in psychophysics from its earliest beginnings. Line length perception can be affected by many variables, such as exposure duration (Jaeger & Kraemer, 1980), spatial frequencies (Schor, Heckmann & Tyler, 1989), and field of exposure (Mandes & Strauss, 1984). Reliability has been high (.89) on retesting separated by a day (Landau, Buchsbaum, Coppola, & Sihvonen, 1974). Yet very few studies (an exception is Heilman et al., 1995) have examined judgements of lines in the third dimension, i.e., lines which recede from the viewer. Monocular viewing eye effects have been described in terms of either laterality (left or right viewing eye) or sighting eye dominance (left or right eye dominance). But these viewing conditions have not always been satisfactorily separated from one another.

Viewing Condition

It is established that the visual fixation point has the same visual direction (location in the visual field) for both eyes and is seen as a single point (or pattern or feature) (Dodwell, 1970). Panum's fusional area is an extension of the space surrounding the fixation point. Any feature which lies within this region will create a single percept during binocular viewing. Despite much investigation, there are still two major theories competing to account for the existence of Panum's area. One posits that the two monocular views fuse into a single percept. The other theory posits that the view of one eye (the non-dominant sighting eye) is suppressed during potentially ambiguous sighting tasks. While neurophysiological evidence supports fusion (Barlow, Blakemore & Pettigrew, 1967 as cited in Dodwell, 1970, p. 144), suppression will occur for double images occurring outside Panum's area (Hochberg, 1964, as cited in Dodwell, 1970, p.

153). When an image is suppressed, it is typically that of the non-dominant sighting eye. The binocular visual alignment of any two objects placed at different depths in front of an observer will have to be made in terms of one eye (the sighting dominant eye) to counter double vision (separate and simultaneous images from both eyes occurring for any viewed object not lying on Panum's area - where all images are fused images)[1]. Right eye sighting dominance is the more common manifestation for 65-70% of the population (Porac & Coren, 1981). Many studies have found either superior right-eye reaction times to visual stimuli or better target recognition (Porac & Coren, 1979; Sampson & Horrocks, 1966; Sampson & Spong, 1961, 1962). If suppression occurs, it is predicted that most people will suppress the left eye's image in favour of the right eye's image.

Divisions of Space.

The literature reveals that space is represented differentially in the brain. One such manner is along the mid-sagittal vertical plane (into left and right hemispace) and another is along any radial axis (into near and far space).

Some evidence indicates a dissociation between the representation of peripersonal space (nearer to the body) and extrapersonal space (farther from the body). Peripersonal (near) space has been defined as that space which is within arm's reach (grasping or reaching range) (Brain, 1941, as cited both in Shelton, Bowers & Heilman, 1990 and in Halligan & Marshall, 1991; Kant (as cited in Grusser, 1983); Robertson & North, 1993; Shelton et al., 1990, p. 196). Not all research into near and far space differences is designed to take advantage of this proposed division of radial space. For instance, manual line bisection studies necessarily exclude any space beyond the reach of the participants (examples: Mennemeier, Wertman, & Heilman, 1992; Shelton et al., 1990), while pointing line bisection studies may include space beyond the reach of the participants (Examples: Halligan & Marshall, 1991; Milner, Brechmann, & Paglianini, 1992).

The within-grasp/beyond-grasp division of space is supported by neurophysiological research in monkeys. Some multi-modal neurons in area 7b (parietal cortex) only respond as objects are placed within a few cm of the body surface (cutaneous receptive field) (Leinonen, Hyvarinen, Nyman, & Linnankoski, 1979; Leinonen & Nyman, 1979). These neurons project to the arcuate sulcus, which is also organized to respond according to far space (anterior arcuate sulcus) or to near space (posterior arcuate sulcus) (Rizzolatti et al., 1981, cited in Mennemeier, Wertman, & Heilman, 1992).

Halligan and Marshall (1991) provide neuropsychological support for the visual dissociation between near and far space in a case study with a right hemisphere infarct of the middle cerebral artery (including posterior parietal cortex). This patient, performing (pointing) line bisection tasks, showed a severe left hemispace neglect only in near space (~45 cm), without neglect in far space (~244 cm) nor any personal neglect of his own body parts. Various authors suggest that there is normally a preferential attention for near space (de Gonzaga Gawryszewski et al., 1987; Meador, Meador, Loring, Lee, et al., 1990), although Shelton et al. (1990) propose that "attention is preferentially distributed away from the body during visual exploration" (p. 204) while tactile exploration brings attention towards the body.

Lateral hemispace compares the space on the left and right side of the mid-sagittal plane. There are different ways in which this left/right aspect may be defined. The mid-sagittal plane may be considered either in relation to the body (Bisiach, Capitani, & Porta, 1985; Mark & Heilman, 1990; Ventre, Flandrin, & Jeannerod, 1984), in relation to the head and eyes (Bradshaw, Nettleton, Nathan, & Wilson, 1983), or in relation to all three (Meador, Loring, Bowers, & Heilman, 1987; Pierson, Bradshaw, & Nettleton, 1983, p. 469).

In contrast to lateral hemispace, lateral visual hemifield is exclusively defined in relation to the point of eye gaze (fixation). Head and body alignment creates alignment of hemispace and visual hemifield only when eyes gaze directly in front of the body. As visual gaze moves, either left or right, the alignment shifts between body-based hemispace and eye-based visual hemifields. In the experiments of the current study, hemispace is defined with reference to an alignment of both body and head (because participants' heads are always facing directly forward) during freely moving eye gaze. This study will examine, and predict differences in, lateral hemispace perception of line length.

Hemineglect is the neuropsychological term for neglect of one hemispace (usually the left) which frequently accompanies hemiplegia (paralysis of usually the left, but sometimes the right, side of the body). Hemineglect of left hemispace typically occurs after infarction of the middle cerebral artery of the right hemisphere; damaging the parietal region. Different techniques have been used to study hemineglect. Tactile line bisection is one common technique. It involves using the hand to indicate the perceived centre of varying lengths of rod. Non-tactile visual line bisection tasks have also been used to examine hemineglect in brain-damaged (Butter, 1992; Carlomagno et al., 1993; Milner, Harvey, Roberts, & Forster, 1993) and normal participants (Mark & Heilman, 1990; Nichelli, Rinaldi, & Cubelli, 1989). Fewer studies (Bradshaw, Bradshaw, Nettleton, 1989; Heilman, Chatterjee, & Doty, 1995) have examined hemispace using line length judgements (visual or otherwise).

Subtle signs of lateral hemispace neglect also occur in normal people (Bowers & Heilman, 1980). The direction of the neglect is commonly reversed in normal people, with right space being neglected rather than left space. .This right space neglect is termed pseudoneglect.

Heilman, Chatterjee, and Doty (1995) considered both near/far and left/right types of space division when researching pseudoneglect in line length judgements. They reported differential lateral hemispheric preferences in length judgements of straight lines receding in depth. Contrary to the usual fronto-parallel (coronal) plane configuration they worked with pairs of lines placed "perpendicular to the coronal plane and [both] parallel to [and equidistant from] the midsagittal plane" (see Figure 1). Participants, who freely inspected the lines binocularly, showed consistent bias in selecting the longer line from a pair of lines of nearly equal length (170 mm vs. 172 mm) presented in left and right extrapersonal [far] hemispaces (~110 cm away). Participants judged lines presented in left hemispace to be shorter than lines presented in right hemispace. Heilman et al.

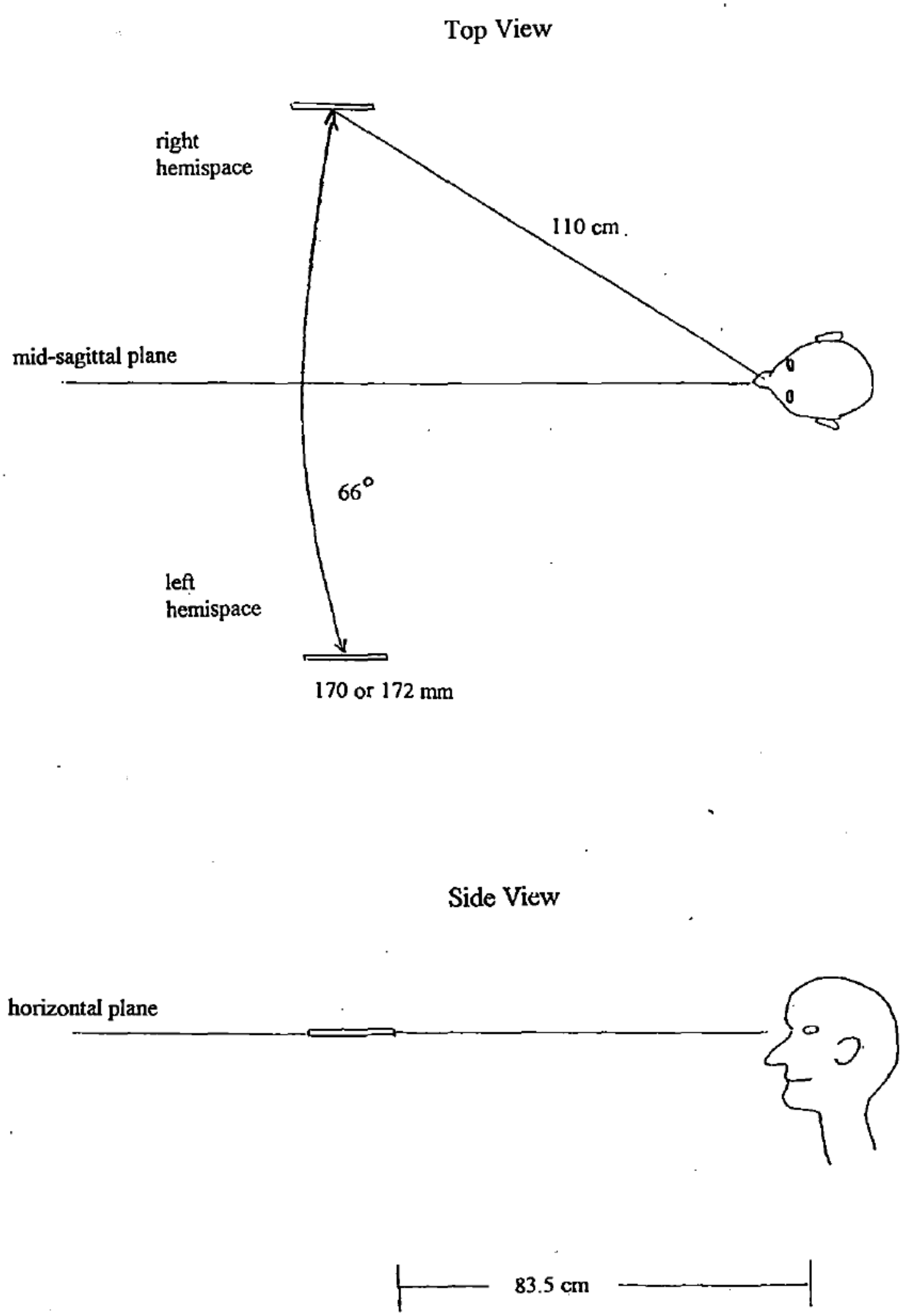


Figure 1. Line configuration for Heilman et al. (1995).

explained this in terms of differential hemispheric preference for attending to near or far space (see Figure 2):

> "when looking leftward to view a radial line [presumably at its centre], the part of the line closest to the body projects to the right half of the retina and the part of the line farthest from the body projects to the left half of the retina. When looking rightward, the opposite occurs. Each half of the retina projects to the hemisphere on the same side. If the left hemisphere directs attention toward peripersonal [near] space and the right hemisphere directs attention toward extrapersonal [far] space, then... when participants look rightward, attention should be directed toward the ends of the lines." (p. 59).

Their predictions were based upon assumptions from the literature indicating right hemisphere preference for processing distal vision (for example, during face recognition) and for left hemisphere preference in processing proximal spatial information (for example, during handwriting):

> "In regard to visually mediated cognitive activities, the left hemisphere seems to be dominant for functions such as reading, writing, and working with tools or objects. The right hemisphere appears to be dominant for recognizing faces, emotional features, and expressions and for performing topographic analysis. Whereas most often the visual cognitive activities performed by the left hemisphere take place in the space close to the viewer (peripersonal space), most of the visual cognitive activities mediated by the right hemisphere take place in space farther from the viewer (extrapersonal space)" (P. 58)."

While it is established that left hemisphere/right visual field shows superiority in processing printed words (Chiarello, Richard, & Pollock, 1992; Eng & Hellige, 1994; Koenig, Wetzel, & Caramazza, 1992) and the right hemisphere/left visual field shows superiority in recognizing faces (Bennett, Delmonicao, & Bond, 1987; Magnussen, Sunde, & Dyrnes, 1994), Heilman et al.'s (1995) interpretation of the accompanying mechanisms for near or far space preferences are not as thoroughly supported. Their model explains perception arising when fixation is always at midline, despite allowing their participants to freely scan the lines. De Gonzaga Gawryszewski, Riggio, Rizzolatti, & Umilta (1987) report that many authors (Eriksen & Hoffman, 1973, 1974; Hoffman,

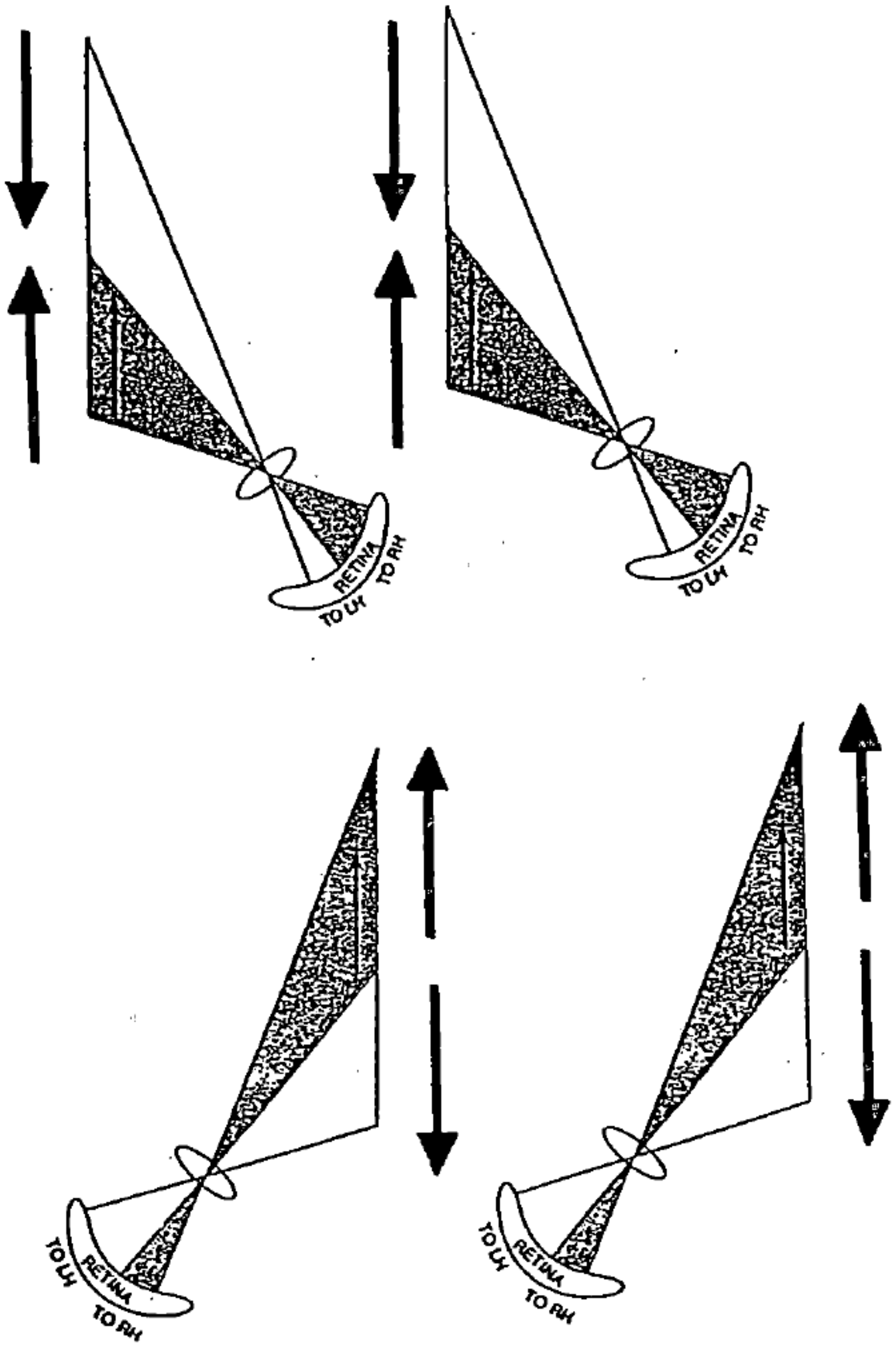


Figure 2. Perceived line length according to Heilman et al.'s (1995) theory of differential hemispheric preference for attending to near or far space.

1975; Posner, Snyder, & Davidson, 1980) have shown that visual attention can be shifted throughout the visual field independently of fixation point.

The current study presents an original model, in competition with Heilman et al.'s (1995) model, which predicts more detailed effects for perception of line length by considering both near and far space (see Figure 3). Participants will adjust the length of a line on one side of their body until it "looks to be the same" as a comparison line placed on their other side. Heilman has previously experimented upon the dissociable effects of near/far space (Mennemeier, Wertman, & Heilman, 1992) but without establishing near and far lines as within and beyond grasping range distances. In the Heilman et al. design, however, no lines were presented in near space, and it is not known whether they would predict left/right perceptions to differ according to distance of the lines from the viewer.

Retinal Image and Size Constancy

Retinal Image is the visual angle (in degrees) subtended on the retina by a visual image. Perfect Size Constancy[2] occurs when an object's size is correctly perceived despite changes to the retinal image arising from changes in distance (Sekuler & Blake, 1990). Size constancy may be demonstrated by physical matching, which is the experimental re-creation of some aspect of a comparison object, achieved through manipulation of an adjustable object. As an object's distance increases from an observer, the multiple available depth cues lose their effectiveness. Three monocular cues that are available in the current experiment are accommodation (variation in the eye's focal distance made by temporary changes in the shape of the lens), linear perspective (convergence of lines that makes a two-dimensional representation of a scene appear to be three-dimensional) and texture gradients. Two major binocular cues are convergence (the angle formed at the object by the foveal lines of sight - Gulick & Lawson, 1976, p. 250) and disparity (differences in the retinal images of the two eyes caused by their horizontal separation). When depth cues are reduced, length judgements tend to be made in terms of the retinal image (Holway & Boring, 1941). With more complete depth cues, length judgements become more constant and approach physical matches (i.e. in this case, an accurate reproduction of the length of the comparison line). The use of an

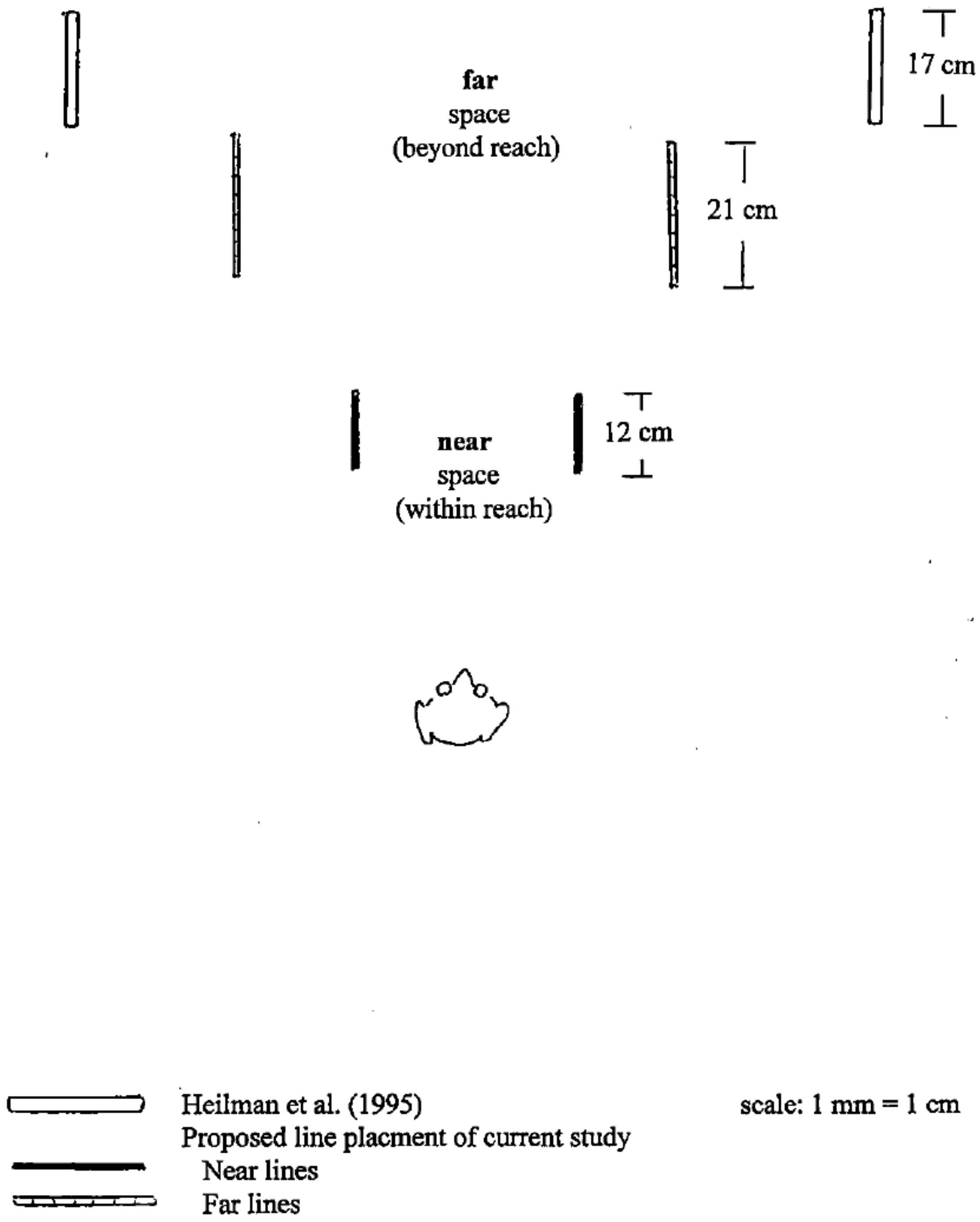


Figure 3. Comparison between line configuration of Heilman et al. (1995) and proposed set-up for Experiment 1.

artificial pupil (which is viewing through a pinhole)(Holway & Boring, 1941; Rix, Tyer, & Pasnak, 1983) or monocular viewing (Ireson & McGurk, 1985) typically demonstrates a decrease in constancy effects similar to those of stimulus impoverishment such as reducing the light and removing contextual information.

There will always be a difference between physical matches and retinal (visual angle) matches during monocular viewing in the current study. This occurs because it is the nasal midpoint, and not the viewing eye, which lies directly between the comparison and adjustment lines. For near lines, the ipsilateral line retinal image (5.9 degrees) will be only 78% the contralateral line retinal image (7.7 degrees) (see Figures 4 and 5). Conversely, if the ipsilaterally viewed line length is increased until both lines yield identical retinal images, then the ipsilateral line becomes 17% longer than the contralateral line. Judgements may be matching in either length or retinal image (or neither), but they cannot match in both length and retinal image at the same time. For the far lines of this study, the ipsilateral line (2.9 degrees) will create an image of only 68% the retinal image of an equal line presented contralaterally (4.3 degrees). Conversely, if the ipsilaterally viewed far line length is increased until both lines yield identical retinal images (of 4.3 degrees), then the ipsilateral far line would become 70% longer than the contralateral line[3].

Retinal Image and Eye Dominance Model.

Under binocular conditions people will base judgements on either both eyes at the same time or only one eye. Objects within the eyes' depth of field will be viewed as a single fused image. They are sure to fall within Panum's fusion area. Objects that extend beyond this depth of field will create double (unfusable) images. The present experiment investigated vision under these circumstances, when the lines produced retinal images of different sizes in each eye (see Figure 6). The key question was this: do people make line length judgements based on the images from both eyes, or only from one eye, and if only one, which one?

A line which recedes in space and is placed towards one side will create different-sized images for each eye: The image in the contralateral eye is larger (has more

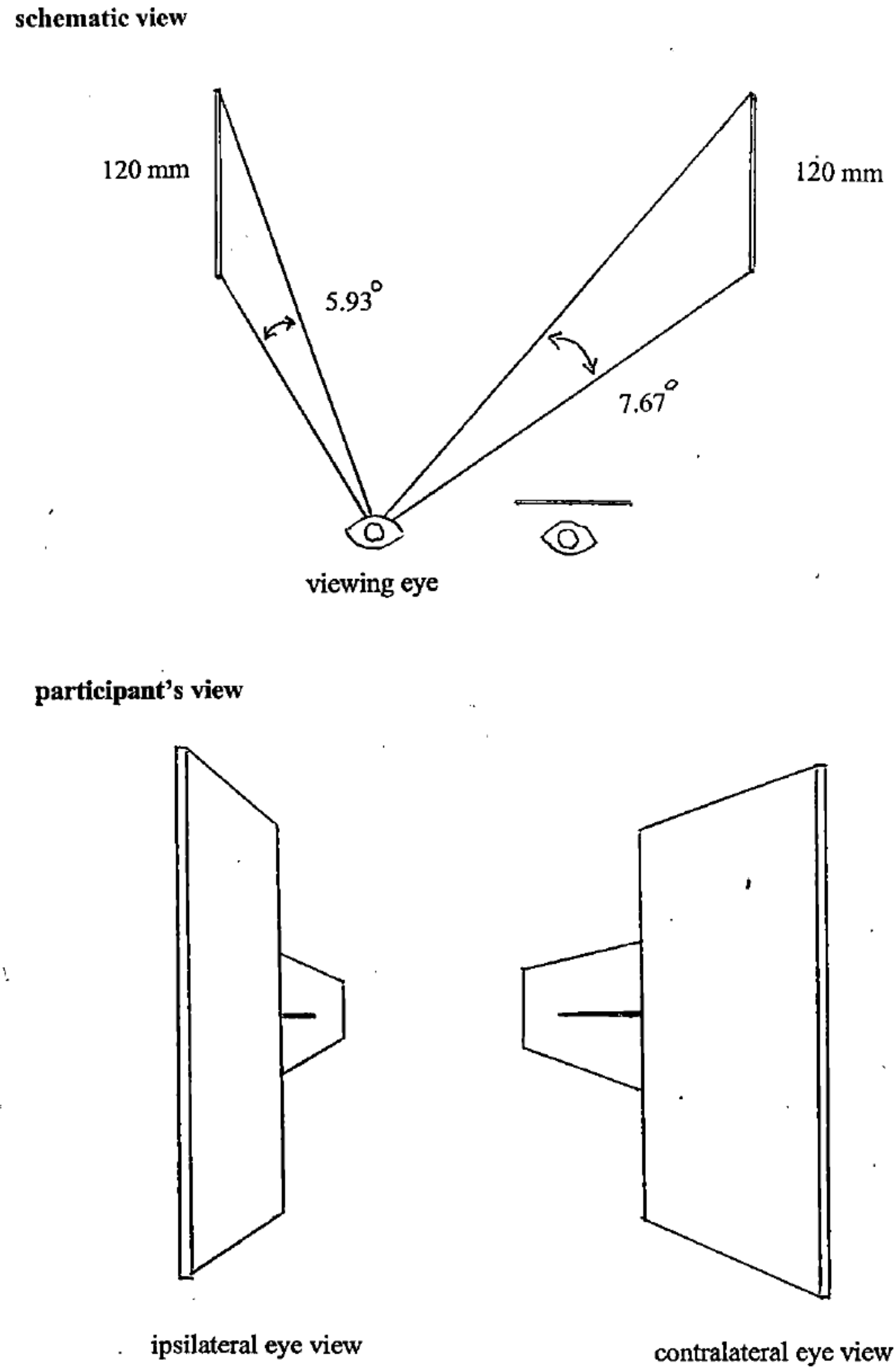
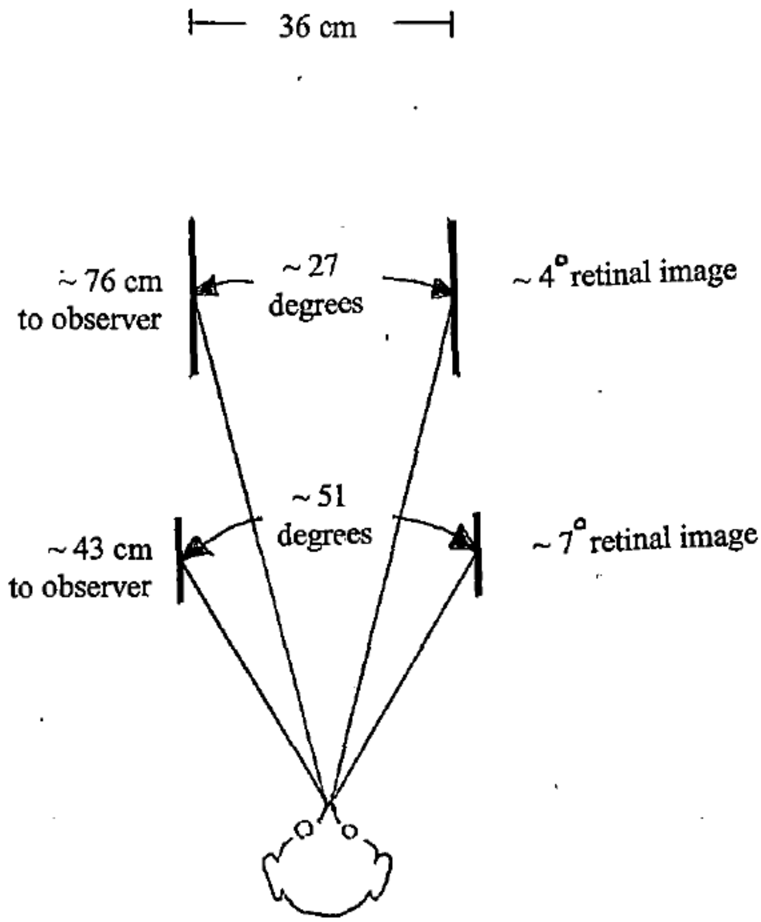


Figure 4. Illustration of the inability to match the length of the retinal images when matching the physical length of the lines, by a single viewing eye.



scale: 1 mm = 1 cm

Figure 5. Adjustment arm configuration for experiment 1.

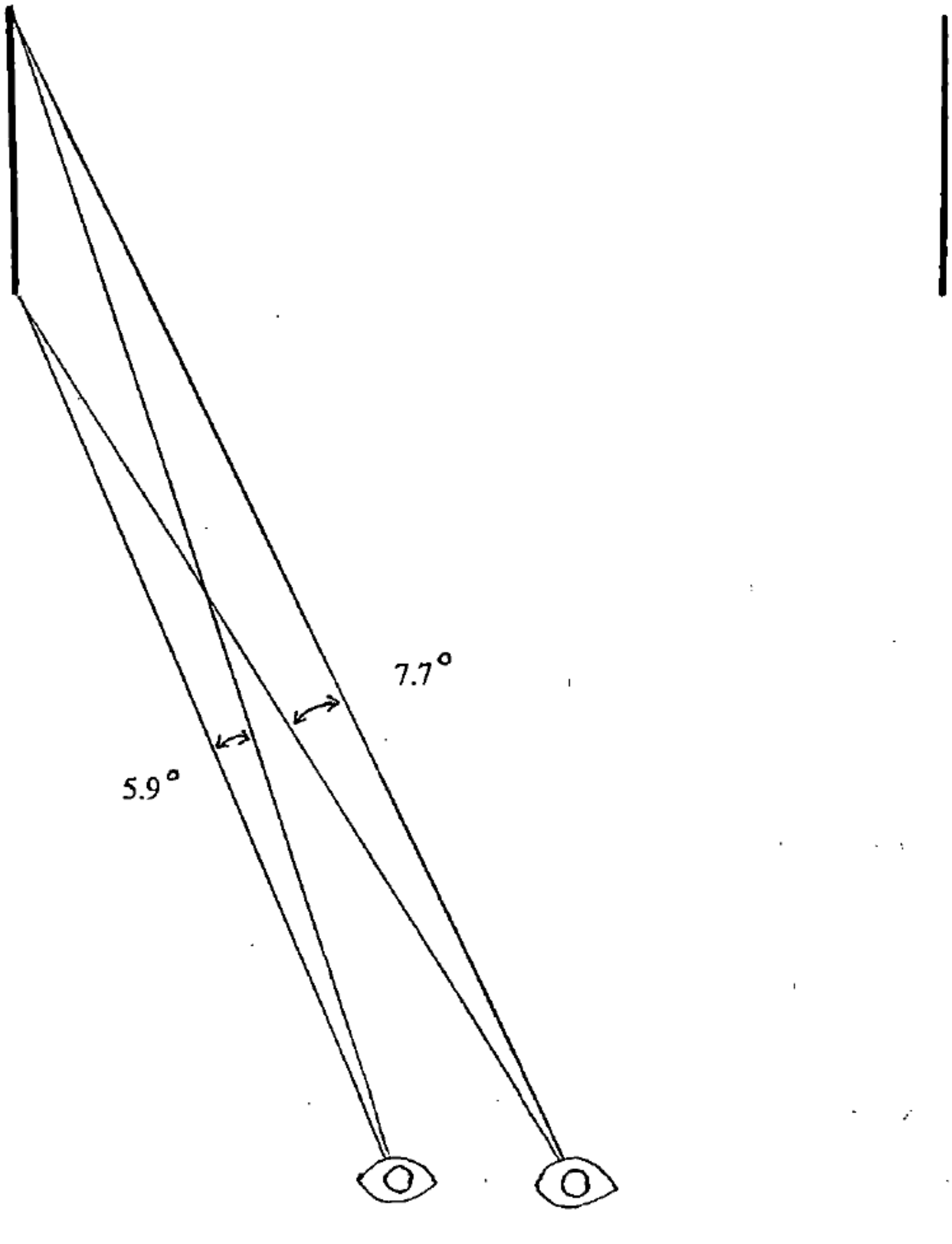


Figure 6. Lines of the current experiment will create larger retinal images in the contralateral eye than in the ipsilateral line. Values are given for near lines.

degrees) (see Figure 6). When two such lines are being compared, the judgement could be based on a computed mathematical average of the line length from both eyes. This would essentially be equivalent to the view of a single, midline, "cyclopean" eye. Alternatively, the lines could be judged on the basis of images in only one eye. Theoretically, when only one eye is being used for judgements, the judgement will be similar to that made under the condition where only that eye is available for seeing (the case where one eye is occluded). Under such a monocular viewing condition, depth cues would be reduced, and line length judgements would have to be based largely on the retinal image size of the line itself (Holway & Boring, 1941). Under such circumstances the retinal image of the contralateral line is longer than that of the ipsilateral line. If a participant is asked to make two line lengths equal by adjusting one, they should adjust it such that the line contralateral to the eye is physically shorter than the ipsilateral line, producing equal length retinal images (see Figure 7).

However, it is also possible that participants could use monocular depth cues to accurately assess the depth and orientation of the lines and take this into account when making line length judgements. Under these conditions participants might be able to make accurate physical matches of one line to the other (see Figure 4).

There are three strategies possible under binocular viewing conditions. First, participants could be adjusting on the basis of a cyclopean eye. This would lead to accurate physical matching. Second, participants could adjust based on the view from only one eye, but taking depth cues into account (perhaps even stereoscopic depth cues) and again accurately match the line lengths. Third, they could be adjusting based especially on retinal images of the line in only one eye, leading them to match the images. This would lead the line contralateral to the controlling eye to be set shorter. There is a further prediction that this binocular controlling eye would be the same as the monocular dominant eye under monocular viewing conditions, such as those which require a single sighting eye (e.g. looking into a telescope, bottle, or keyhole).

It is predicted that the dominant sighting eye will have greater influence on line length judgement than the other eye. It is therefore predicted that people with right

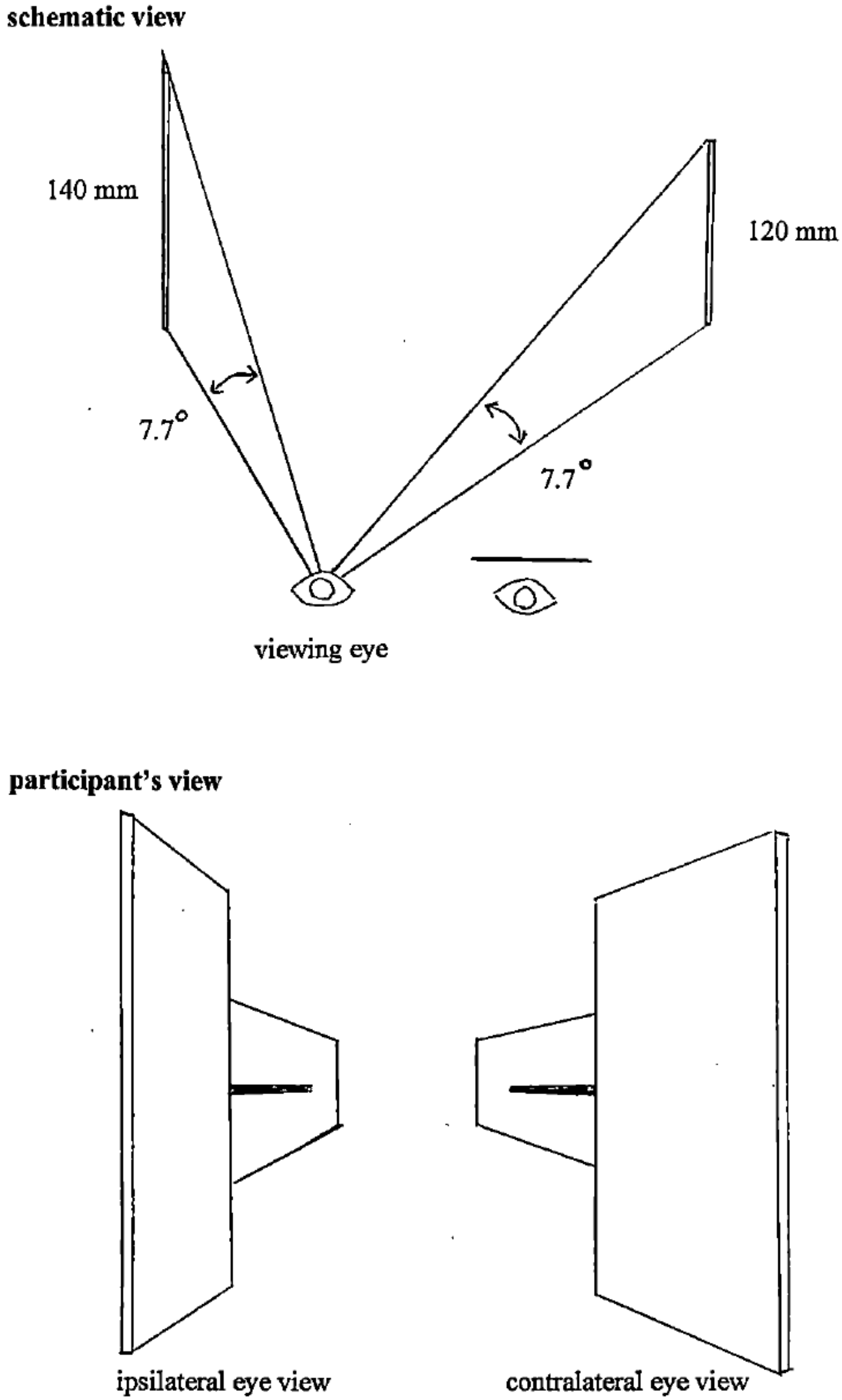


Figure 7. Illustration of the inability to match the physical length of the lines when matching the length of the retinal images, by a single viewing eye.

sighting dominance, viewing two lines of equal length, will perceive the line on the left side to be longer than the line on the right side (see Figure 8). This is because the line on the left side will project a longer retinal image than the line on the right side. The findings of Heilman et al. (1995) conflict with this prediction. They found contralateral lines to be judged shorter than ipsilateral lines. Whether this is due to differences in dominance (i.e. by including some participants with left eye dominance), or to some other circumstance, is not known.

In sum, under binocular viewing conditions, use of a cyclopean eye should lead to accurate matching of line lengths. Use of only one viewing eye, but incorporating depth cues will produce the same result: accurate matches of line length. However, use of only retinal images of the line length from a single eye will result in a mismatch, such that the contralateral line will be perceived as longer and therefore set shorter. This binocular condition could well match the asymmetries which might be observed under monocular viewing conditions.

In accordance with these ideas, this experiment assessed line length judgements under monocular and binocular viewing conditions. This was done by presenting two parallel lines receding in depth/space with the left line or right line fixed as the standard and having the participant adjust the other line until both lines "looked to be the same". Participants were asked to do this on both sides, and also in near or far space (far space was defined as being beyond arm's length/reach).

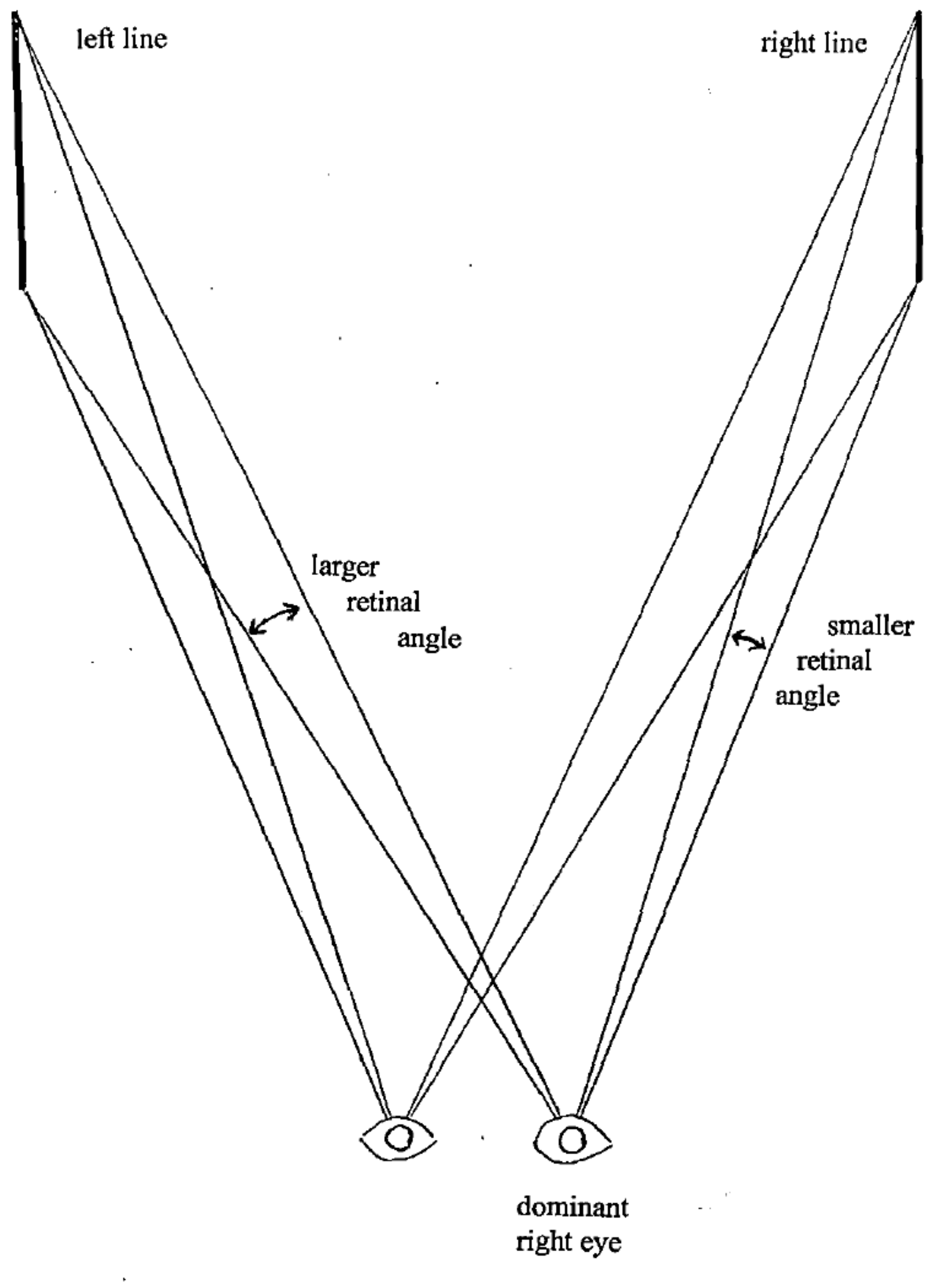


Figure 8. An indication of how retinal image and eye dominance may cause longer perception of left hemispace lines.

CHAPTER II

METHOD

Experiment 1.

Participants.

Participants were 32 undergraduate students volunteering for partial credit in introductory psychology. Each potential participant was assessed to determine the side of the monocular sighting dominant eye by a 3-item questionnaire (see Appendix A). Only those who preferred at least 2 of the 3 items with either left or right eye were declared strongly sighting-eye dominant and were included. Inclusion of equal numbers of left and right eye dominant sighters was made to determine whether any sighting eye effects are due to the sighting dominance or merely the left or right eye. Only those participants with stereovision, as indicated by modified Frisby test, were included. Since all line length judgements were made manually, participants' handedness may have accounted for some variation in the judgements (i.e. the non-dominant hand, being not as well controlled as the dominant hand, may have yielded greater variability than the dominant hand). All participants completed a 7-item handedness preference inventory (see Appendix B) to examine this possibility.

Procedure

Judgements of line lengths in depth were made under binocular and monocular exposure. Participants were allowed free inspection during the experiment and encouraged to scan particularly along the lengths of each line and between the comparison and adjustment lines. In right and left hemispace conditions, participants were instructed to extend or retract the length of an adjustment line (beginning with zero length) until it "look[ed] to be the same" as a 120 mm comparison line located identically in contralateral space (see Figure 9). This wording (phenomenal instruction) was chosen to encourage participants to match the line lengths according to "an immediate impression of how the stimulus looks to the subject" (Kaess, 1980, p. 477) (i.e. emphasizing neither objective size nor perspective size). Both lines were placed in either near or far space (~43 cm from between-the-eyes to mid-line for near conditions, and

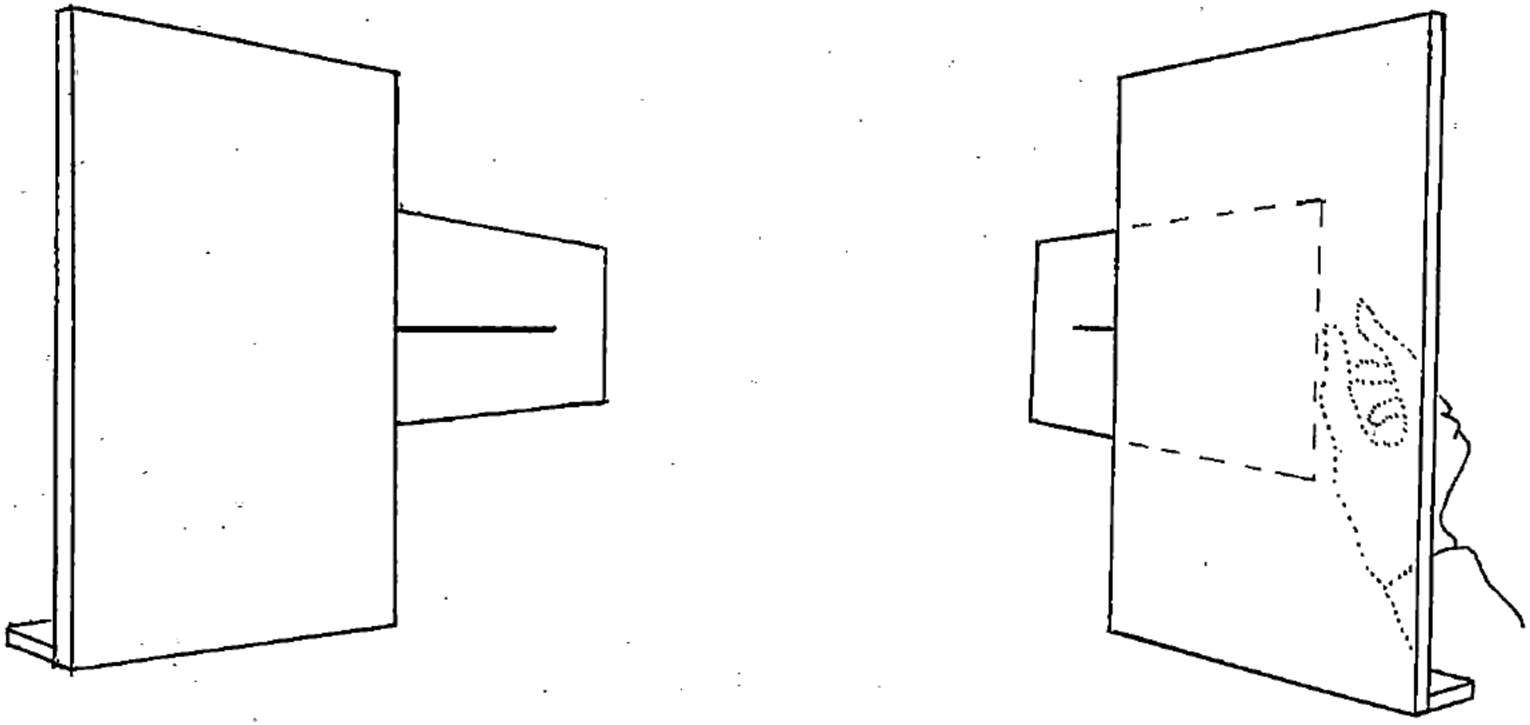


Figure 9. Participant's view of set-up (for near-line pairs, right-arm adjustment) for Experiment 1.

~76 cm from between-the-eyes to mid-line for far conditions, see Figure 5). This arrangement ensured that the distal lines extended completely beyond the arm reach of all participants, and that the proximal lines extended completely within the arm reach of all participants. Near lines subtended 7.67 or 5.93 degrees of retinal image for contralateral and ipsilateral viewing eyes, respectively. Far lines were expected to subtend 7.33 or 6.61 degrees of retinal image for contralateral and ipsilateral viewing eyes, respectively[4]. These four retinal image measurements were calculated from the approximate dimensions of the apparatus set-up, using an estimated mean of 65 mm as the distance between the eyes. All lines were black, 1.6 mm thick, and mounted on white paper sheets. Room illumination was provided by four 40-watt white fluorescent light bulbs placed in the ceiling directly over the apparatus.

Four adjustable arm locations were created by crossing two independent variables. Distance (of line pairs) is one of the variables, with near and far line pairs. Side of Adjustment is the other variable, with lines being adjusted on both left and right sides (approximately 32 cm apart) of the participant's body. Each participant was tested individually, sitting at a table covered with black felt. Participants' chins were placed on a chin rest equidistant between pairs of lines and at a height resulting in line placement at eye-level. This arrangement attempted to ensure that lines were placed in the horizontal plane at eye level, and would not yield perspectives slant cues. Participants' eyes were approximately 31 cm from the frontoparallel plane from which the near lines emerged. Participation order was self-determined by individual times on a sign-up sheet, resulting in no control over order according to eye dominance (the only non-assigned variable).

Each participant first made two binocular adjustments and then four monocular adjustments in one of the two line-pair distance conditions before doing the same for the remaining distance condition (see Appendix C). Binocular adjustments were always made first in order to prevent any monocular viewing effects from contaminating future binocular adjustments. Conversely, while no control was used to ensure that binocular viewing effects did not contaminate the monocular adjustments, it was assumed that such contamination would be less likely. This was because unusual (monocular) viewing circumstances were assumed to be much more likely than normal (binocular) viewing circumstances to contaminate later adjustments. Odd numbered (ascending condition) participants extended the adjustment arm line lengths while even numbered (descending condition) participants retracted the adjustment arm line lengths. Order of the distance condition was pseudorandomly alternated throughout the ranks of participants. Side of arm adjustment order was evenly alternated throughout the ranks of participants. Monocular viewing eye order was also evenly alternated throughout the ranks of participants. All ascending condition line increments extended away from the participant while all descending condition line decrements retracted towards the participant (see Figure 10). At the beginning of each ascending condition trial, the adjustable arm line was

not yet visible. Each participant extended the arm, introducing and then increasing the length of the adjusted line (see Figure 9). At the beginning of each descending condition trial, the adjustable arm line was extended by the experimenter to a length of 200 mm. Each participant then retracted the adjustment arm, decreasing its length until both lines "look[ed] to be the same".

Participants were told, before the binocular adjustments, to resist the urge to close one eye (which could have made the task easier by removing potential diplopia). During binocular viewing, participants wore goggles without any lenses. After recording the first binocular adjustment in mm from a scale on the back of the adjustable arm, the experimenter set that arm to 120 mm, which then served as the comparison line for the second binocular adjustment. As part of this procedure, the arm was first moved completely into the apparatus to obscure the relation between the participant's previous setting and the 120 mm comparison standard. For ascending condition participants, the experimenter then pushed the <u>contralateral</u> arm into the apparatus so that its line length reduced to zero. For descending condition participants, the experimenter then extended the contralateral arm so that its line length became 200 mm. The participant then made the second binocular adjustment, which was also recorded by the experimenter. The first four monocular judgements followed, with the participant wearing goggles which

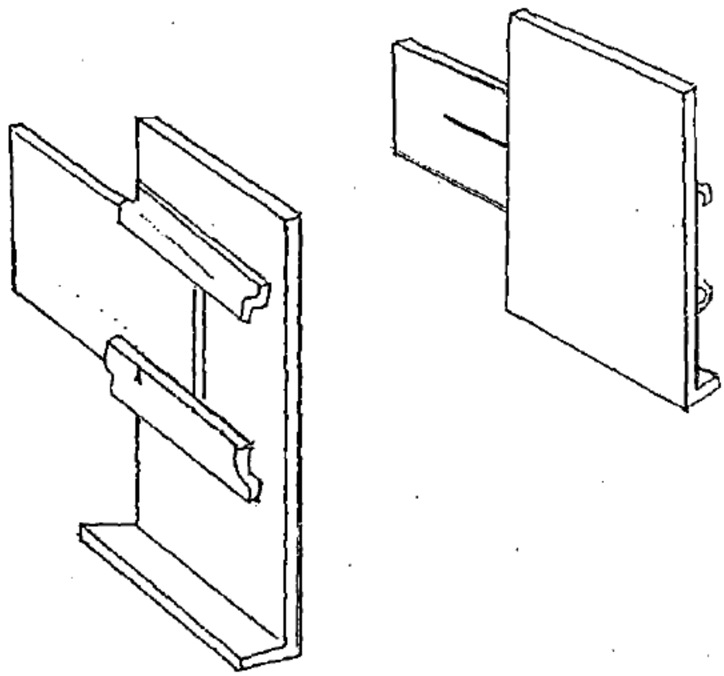


Figure 10. Position of apparatus adjustment arms for Experiment 1.

occluded either the left or right eye with a paper-covered plastic lens. The first two monocular adjustments used one eye, and the next two adjustments used the other eye. The order of eye occlusion was alternated with every four participants per eye-dominant group. The same pair of lines as with the binocular adjustments, either near or far, was involved in the first four monocular adjustments. The line apparatus was exchanged for the remaining six adjustments. The entire procedure was repeated for this remaining condition of line-pair distance, for a total of 12 adjustments per participant.

Data Analysis

Various repeated measures multivariate analyses of variance (MANOVAs) were performed on the data of Experiment 1. The first two MANOVAs used monocular data, while the third used only the binocular viewing data. The type 1 error rate was set at .05. Main effects are described before interactions. T-tests were performed where indicated by overall between-groups significance in the MANOVAs.

Note: MANOVAs that included both monocular and binocular viewing were deemed inappropriate, because expected differences between monocular and binocular results would probably have overshadowed other differences in any potential interactions.

Experiment 2

Participants

Thirty-two participants were chosen with the same criteria as in Experiment 1.

Procedure

Participants directed extensive adjustments of the 4 location of line lengths by using the staircase version of the method of limits in psychophysics (Cornsweet, 1962). Instead of having participants making the manual adjustments of line length, the experimenter repeatedly adjusted the experimental line length while the participants decided whether the adjustment line or the comparison line was shortest (forced choice). Each successive adjustment should have approached the participant's psychophysical point of subjective equality (PSE). Half of the participants made judgements from an ascending condition and half from a descending condition. Approximately 16 adjustments were made per viewing condition and ascending (or descending) condition, to provide each recorded estimation of length. Step sizes begin at 30 mm, and were reduced each time a participant made 2 reversals of choice. Step sizes decreased as follows: 30, 20, 10, 5, 3, 1 mm. A total of about 192 judgements resulted in 12 recorded measurements for each participant.

CHAPTER III.

RESULTS

Experiment 1

Table 1 reports the mean settings (mm) for 24 viewing conditions. Table 2 reports these same values as percentages of the length of the comparison line. These percentage terms allow for comparison of near and far line results.

Monocular MANOVAs

The first monocular MANOVA had three within-subjects factors and two between-subjects factors. Within-subjects factors were Distance (near/far), Adjustment Side (left/right), and Ipsilateral/Contralateral (eye/hand) Adjustment. Between-subjects factors were Arm Direction (ascending/descending) and Sighting Eye Dominance (left/right). Four main effects occurred: Distance ($F(1,28) = 23.73$, $MSe = 2483$, $p < .001$), Adjustment Side ($F(1,28) = 6.57$, $MSe = 1850$, $p < .016$), Arm Direction ($F(1,28) = 10.05$, $MSe = 3905$, $p < .004$), and Ipsilateral/Contralateral (eye/hand) Adjustment ($F(1,28) = 86.35$, $MSe = 22641$, $p < .001$)(see Table 3). There was no main effect of Eye Dominance ($F(1, 28) = 0.26$, $MSe = 389$, $p > .50$). Near adjustments (98.7% of comparison line) physically matched the comparison line length ($t(127) = -1.54$, $p < .127$) while far adjustments (91.8%) resulted in significantly shorter lines than the comparison line length ($t(127) = -4.82$, $p < .001$). Left side adjustments (97.64%) physically matched the comparison line length ($t(127) = -1.64$, $p < .103$) while right side adjustments (92.3%) resulted in significantly shorter lines than the comparison line length ($t(127) = -4.97$, $p < .001$). Ascending adjustments resulted in shorter lines (90.1%) than descending adjustments (98.2%). Contralateral adjustments (e.g. using right eye to make left side adjustments, or using left eye to make right side adjustments) resulted in shorter lines (85.5%) than ipsilateral adjustments (104.4%). Contralateral adjustments (85.5%) were shorter than comparison line length ($t(127) = -12.75$, $p < .001$), while ipsilateral adjustments (104.4%) were longer than comparison line length ($t(127) = 3.14$, $p < .002$).

The second MANOVA differed from the first MANOVA by replacing

Table 1

Mean Adjustments (mm) according to Adjustment Side, Viewing Eye, Distance, and Arm Direction

Ascending Adjustments

	Adjustment Side					
	Left			Right		
Viewing Eye	left	both	right	left	both	right
Distance (size of line)						
Far	207.6		171.4**	155.2**		199.2
(210 mm)		**202.3(*)**			**198.4***	
Near	107.2*	105.4**	98.2**	102.3		
(120 mm)		**113.6***		**112.9***		

Descending Adjustments

	Adjustment Side					
	Left			Right		
Viewing Eye	left	both	right	left	both	right
Distance (size of line)						
Far	223.6		197.6*	164.1**	224.2	
(210 mm)		**218.4***		**207.9**		
Near	129.4		116.6	107.8**		132.7*
(120 mm)		**124.2**			**120.6**	

Key: Significantly different from comparison line length (210 mm for far lines, 120 mm for near lines):

** $p < .001$

* $p < .05$

Binocular means are printed in bold.

Table 2

Mean Adjustments (as Percentage of the Comparison Line Length) according to Adjustment Side, Viewing Eye, Distance, and Arm Direction

Ascending Adjustments

	Adjustment Side						
	Left				Right		
Viewing Eye	left	both	right		left	both	right
Distance							
Far	98.9		81.6**	73.9**	94.9		
		96.3(*)				**94.5***	
Near	107.2*	87.8**	81.8**	102.3			
		94.6*				**94.1***	

Descending Adjustments

	Adjustment Side						
	Left				Right		
Viewing Eye	left	both	right		left	both	right
Distance							
Far	106.5		94.1*		78.1**	106.8	
		104.0*			**99.0**		
Near	107.9		97.2		89.8**	110.6*	
		103.5				**100.5**	

Key — Significantly different from comparison line length (of 100%):

** $p < .001$

* $p < .05$

Binocular means are printed in bold.

Table 3
Summary of Monocular MANOVA Main Effects with One-Sample t-tests

	Mean adjustment length					
	mm	percent of comparison length	significance	effect size	observed power	two-tailed significance of one-sample t-test for physical matching
Arm Direction			.004	.264	.863	
ascending	148.6	91.1				.001
descending	162.0	98.9				.455
Distance			.001	.459	.997	
near	117.7	98.1				.127
far	192.9	91.8				.001
Adjustment Side			.016	.190	.695	
left	160.0	97.6				.103
right	150.5	92.3				.001
Eye			.001	.755	1.000	
left	151.8	93.0				.001
right	158.7	96.9				.018

Ipsilateral/Contralateral (eye/hand) Adjustments with Monocular Viewing Eye (left/right). Adjustments using the left eye (93.0%) resulted in significantly shorter lines than right eye adjustments (96.9%) ($\underline{F}(1,28) = 6.58$, $\underline{MSe} = 148$, $\underline{p} < .016$), although both were significantly shorter than the comparison line length ($\underline{t}(127) = -4.14$, $\underline{p} < .001$; $\underline{t}(127) = -2.39$, $\underline{p} < .018$).

Binocular MANOVA

A third MANOVA was performed on the binocular data only. It contained two within-subjects factors, Distance (near/far) and Adjustment Side (left/right), plus two between-subjects factors, Sighting Eye Dominance (left/right) and Arm Direction (ascending/descending). The only significant finding was a moderate main effect of Arm Direction. As with monocular results, ascending adjustments (94.9%) resulted in significantly shorter lines than descending adjustments (101.73%) ($\underline{F}(1, 28) = 28.09$, $\underline{MSe} = 53$, $\underline{p} < .001$). One-sample t-tests qualify this finding. Ascending adjustments resulted in significantly shorter lines than comparison lines ($\underline{t}(63) = -5.85$, $\underline{p} < .001$), while descending adjustments were not significantly different from the comparison lines ($\underline{t}(63) = 1.67$, $\underline{p} < .099$).

Additional one-sample t-tests were performed on binocular results against the comparison line length standards (see Table 4). Overall, binocular means (98.3%) were not different from the comparison line length ($\underline{t}(127) = -.66$, $\underline{p} < .510$). Right side lines were shorter (97.0%) than the comparison line (i.e. physical matching), while left side lines were not significantly different (99.6%) from the comparison line ($\underline{t}(63) = -3.00$, $\underline{p} < .004$; $\underline{t}(63) = -.36$, $\underline{p} < .721$). Although there was no main effect of Distance, nor an interaction between Distance and Adjustment Side, there was an interaction between Distance and Adjustment Side for t-tests against comparison line length (physical match). Only the far lines were placed significantly shorter than physical match on the right side (left: $\underline{t}(31) = .31$, $\underline{p} < .901$; right: $\underline{t}(31) = -2.56$, $\underline{p} < .016$) (as was the case for the far lines of Heilman et al., 1995), whereas the near lines were non-significantly placed shorter than physical match on the right side (left: $\underline{t}(31) = -.54$, $\underline{p} < .591$; right: $\underline{t}(31) = -1.75$, $\underline{p} < .090$) (see Table 4).

Table 4
<u>One-Sample t-tests of Binocular Means against Comparison Line Lengths</u>

Comparisons	Means (mm)	Percentage of Comparison Line Length	Two-tailed Significance
Overall	162.3	98.3	.510
Left side	164.6	99.6	.721
Right side	159.9	97.0	.004
Near	117.8	98.2	.120
Far	206.7	98.4	.101
Near left side	118.9	99.1	.591
Near right side	116.8	97.3	.090
Far left side	210.3	100.2	.901
Far right side	203.1	96.7	.016

<u>Note</u>. Right side is underplaced, while left side is not significantly different from physical matching. Splitting this by Distance, these differences remain significant only for <u>far</u> lines (as was the case for the far lines of Heilman et al., 1995), while both <u>near</u> lines are not significantly different from physical matching.

Paired t-tests showed that neither near nor far line adjustments differed according to left and right sides (near: $t(31) = .74$, $p < .467$; far: $t(31) = 1.87$, $p < .071$), although far line adjustments were close to significance.

Comparisons to Theoretical Predictions. Figure 11 shows that while binocular means lie between monocular means (Prediction A), they do not lie exactly between them, as would be expected of a cyclopean eye. The binocular means tend to lie closer to the monocular mean of the ipsilateral viewing eye (the eye with the sharpest viewing angle) (see Table 5). Only the far binocular means lie significantly beyond the halfway distance between their two monocular means (see Figure 11). One interpretation is that cyclopean viewing occurs only for binocular viewing of near lines.

However, this interpretation should be tempered by the findings that descending near (and also descending far right side) binocular means are also not significantly different from physical comparison line lengths (see Table 2 and Figure 12). That is, while the near binocular means lie halfway between their two monocular means, both binocular and ipsilateral monocular near means also lie close to the physical comparison line length. Therefore, the interpretation of cyclopean viewing effect for near lines may be reconsidered as follows. Both binocular and ipsilateral monocular adjustments appear to result in physical matching. In contrast, the contralateral monocular adjustments result in lines that are shorter than physical matching. These contralateral monocular adjustments also fall between (are significantly different from) either physical matching or retinal image matching (see Table 2 and Figure 13). This is only weak support for Prediction C: that retinal image matches would occur for monocular viewing.

There was no interaction between binocular Eye Dominance and Adjustment Side ($F(1, 28) = 0.85$, $MSe = 90$, $p > .25$). This indicates no support for Prediction B that lengths contralateral to the dominant eye (99.1%) would be shorter than lengths ipsilateral to the dominant eye (97.5%) during binocular adjustments. While left side lengths are placed longer (99.6%) than right side lengths (97.0%), regardless of eye dominance, this is not significant ($F(1, 28) = 2.42$, $MSe = 90$, $p > .10$).

This can be seen by examination of individual case's difference-scores (between

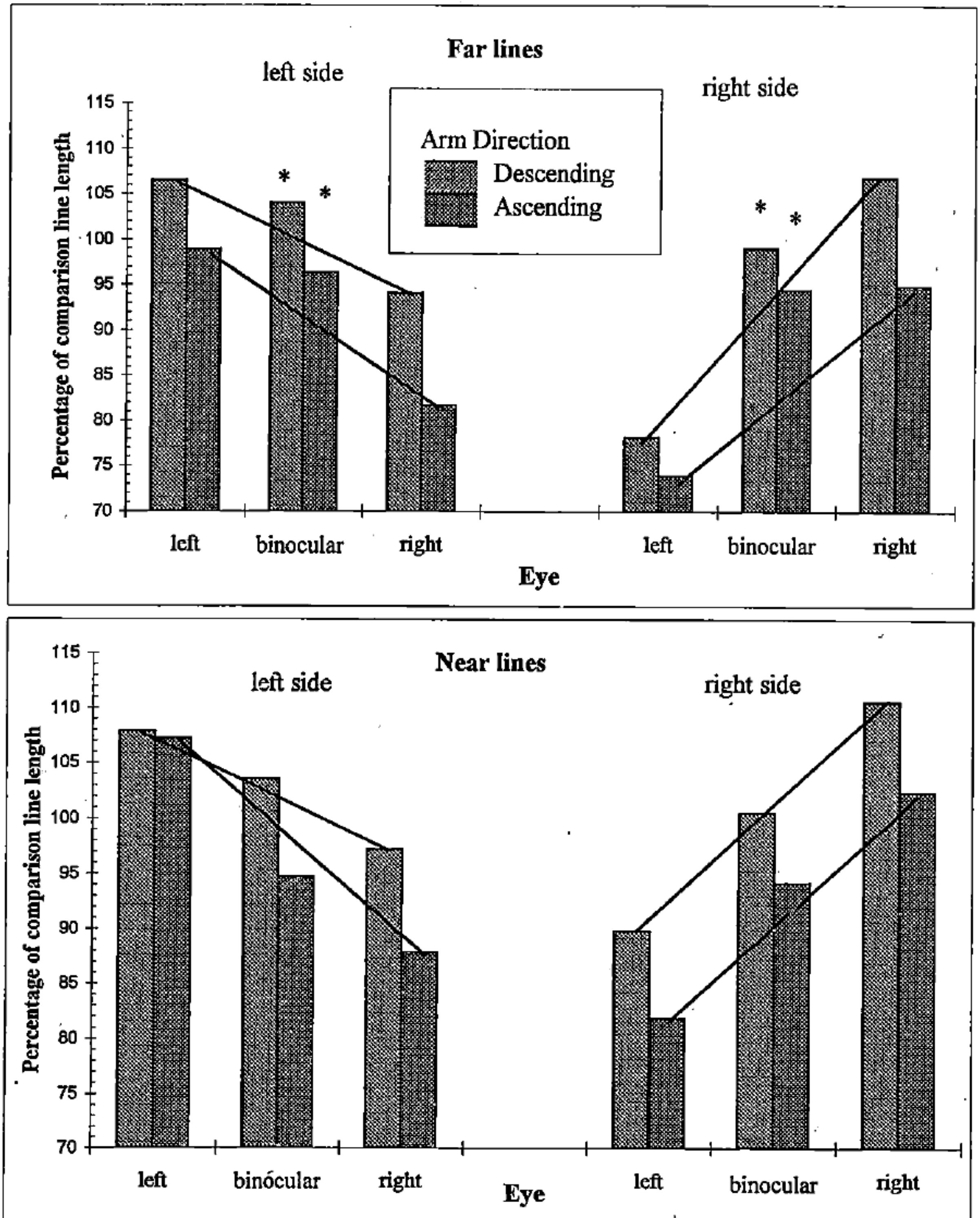


Figure 11. Comparison between monocular and binocular means (as percentage of comparison line length) according to Adjustment Side, Viewing Eye, Distance, and Arm Direction. Near binocular means lie halfway between monocular means while far binocular means lie closer to ipsilateral monocular means (* indicates a significant difference from the point halfway between the monocular means, $p < .05$).

Table 5

Amount (in Percentage of the Distance between the 2 Monocular Means) that the Binocular Judgements Approach Ipsilateral Eye/Hand Monocular Judgements

Ascending Participants:

Adjustment Side			
left side	right side		
84.8*	98.1*	far space	position of line pairs
35.2	60.1	near space	position of line pairs

Descending Participants

Adjustment Side			
left side	right side		
80.0*	72.9*	far space	position of line pairs
59.0	51.4	near space	position of line pairs

One-sample comparisons against halfway (50%) between the 2 monocular means.
* significantly different from halfway ($p < .05$).

Note: Only the far binocular means lie significantly beyond the halfway distance between their two monocular means (see Table 6).

Table 6

One-sample T-test Comparisons between 2 Monocular Means' Halfway Distance and Binocular Means (as Percentage of Comparison Line Length)

Ascending Judgements

Distance	Adjustment side: left	Adjustment side: right
far	90.3	84.4
	96.3*	**94.5***
near	97.5	92.1
	94.6	**94.1**

Descending Judgements

Distance	Adjustment side: left	Adjustment side: right
far	100.3	92.5
	104.0*	**99.0***
near	102.5	100.2
	103.5	**100.5**

Note. Monocular halfway comparison distances are in normal print. Binocular means are in bold. All far binocular means are significantly closer to ipsilateral monocular means than they are to the halfway (cyclopean) distance between ipsilateral and contralateral monocular means (*$p < .05$). No near binocular means are significantly different from the halfway (cyclopean) distance between ipsilateral and contralateral monocular means.

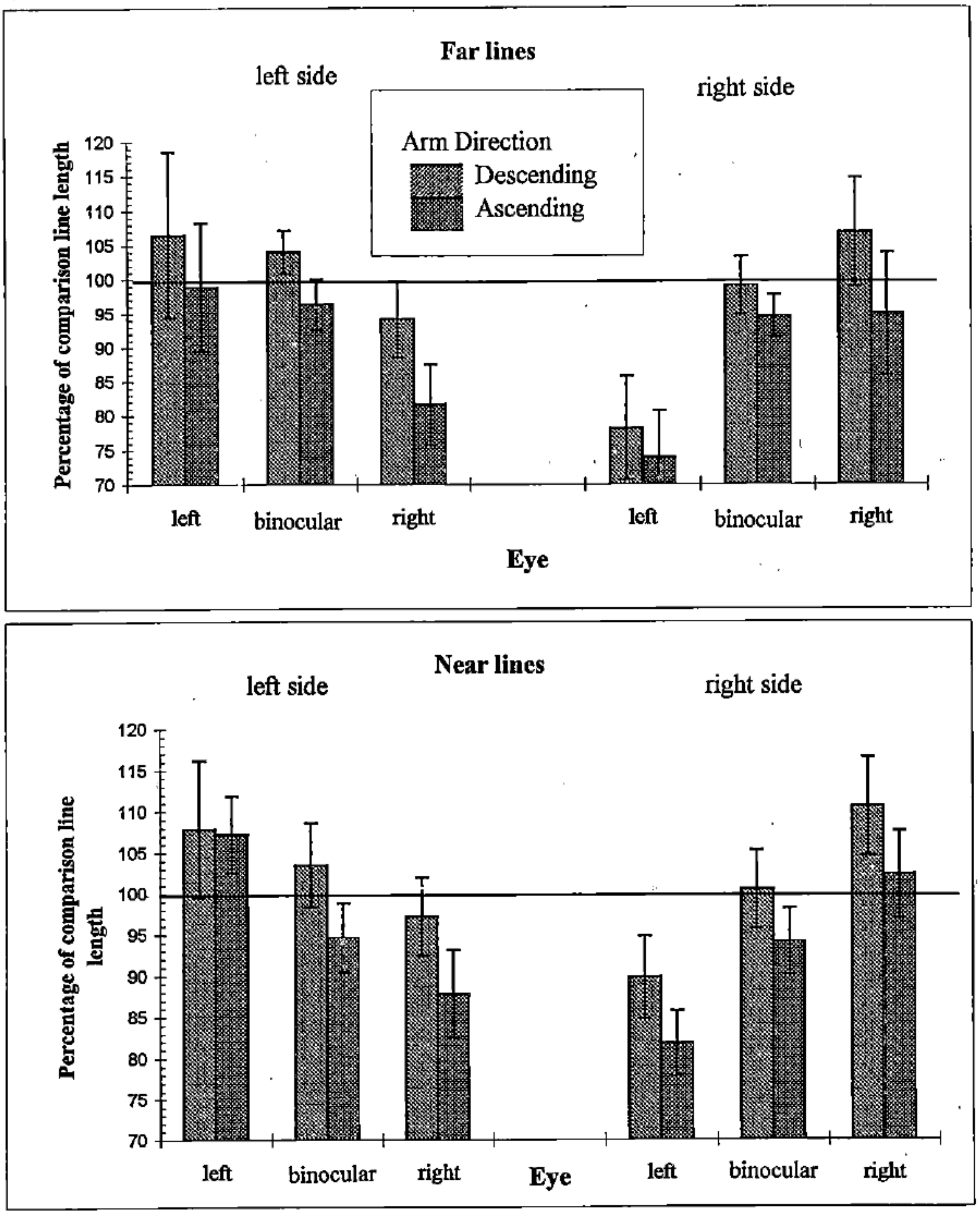
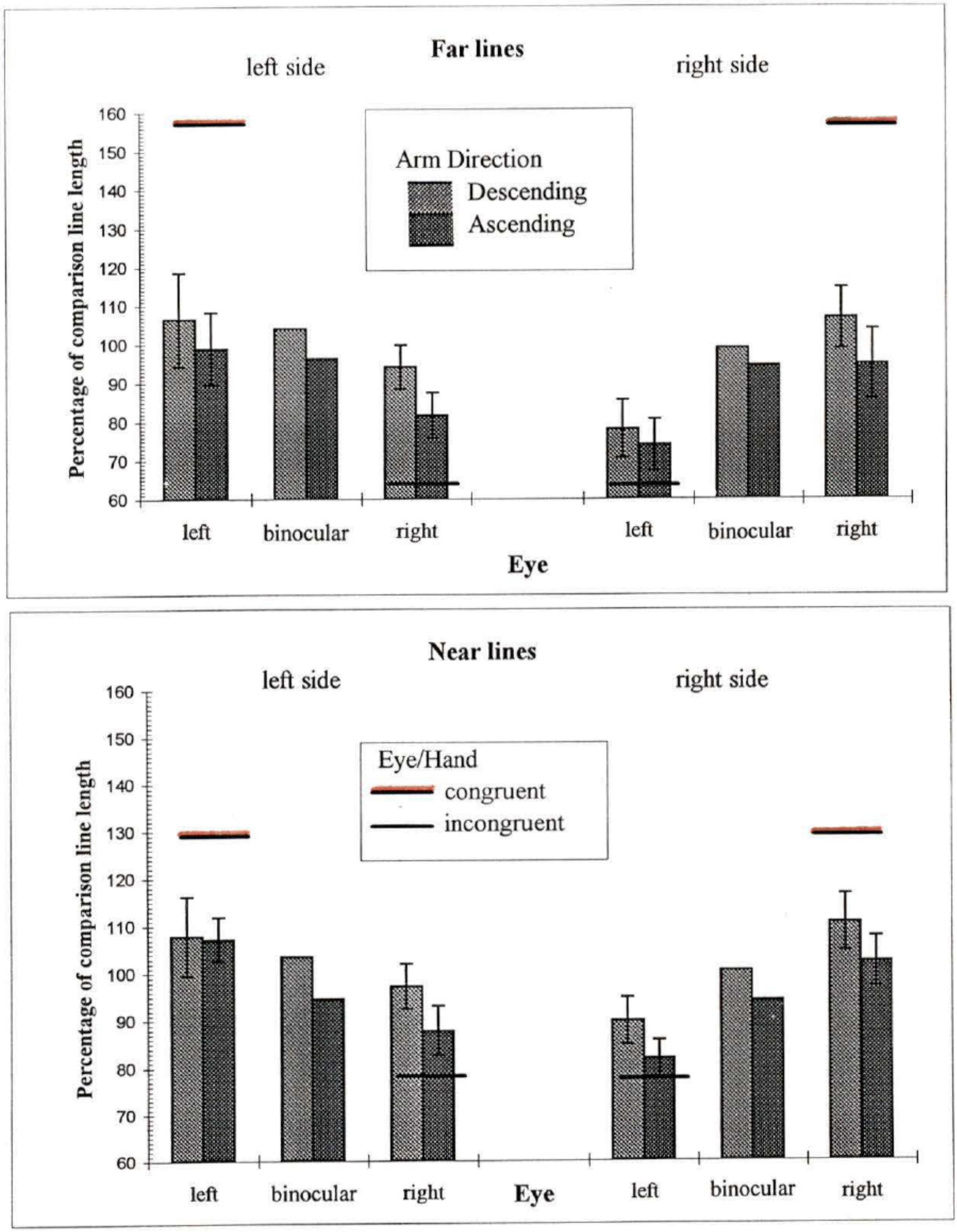


Figure 12. Physical matching (as percentage of comparison line length) according to Adjustment Side, Viewing Eye, Distance, and Arm Direction. Error bars represent 95% confidence intervals against physical match (100% comparison line length). Ipsilateral monocular means and binocular means lie close to comparison line length for both near and far lines.



retinal image match

Figure 13. Retinal image (visual angle) matching (as percentage of the comparison line length) of viewing conditions according to Adjustment Side, Viewing Eye, Distance, and Arm Direction. Retinal image contributes less to mean judgements than does physical matching (see Figure 11). Note: Error bars represent 95% confidence intervals against physical match (100 comparison line length).

left and right sides) (see Figure 14). Support for the Retinal Image and Eye Dominance Model (Prediction B) would have been revealed as positive difference scores for right-eye dominant participants (cases 1-16), and negative difference scores for left-eye dominant participants (cases 17-32). Instead, there was an insignificant overall longer placement of left side lines than right side lines (-3.92 mm difference). Neither near lines nor far lines were placed significantly longer on the left side ($p > .25$). The conclusion is that the wide range of binocular differences according to both viewing Distance and Adjustment Side are not due to retinal image in conjunction with eye dominance.

There is an interesting, unexpected finding for some of the descending adjustments. There are four viewing condition adjustment means which correspond to the distance from the eye (ipsilateral or contralateral) to the farthest end of the comparison line (near or far) (see Figures 15 and 16). Three of the 16 monocular means (of Table 2) fall within 1 mm of these values (see Figure 17). All three means are for Descending condition far lines (see Table 7).

Experiment 2

Staircase

The second experiment replicated Experiment 1, except that participants no longer used their own hands to make physical adjustments during line length estimation. Instead, the experimenter made a series of gradually finer adjustments (Staircase procedure) in response to participants' estimation of the "smaller" of the two lines. Approximately 18 adjustments were made to yield each recorded value. Pilot testing indicated it too unwieldy to try to record every adjustment (approximately 10,000 were made during Experiment 2).

This implementation of the Staircase procedure meant that once the first direction change had been made (as a result of overshooting the point of subjective equality, or PSE), any three or more adjustments in the same direction would indicate inconsistent performance (by reversing the direction of an earlier estimation). Such unexpected inconsistencies occurred sporadically for many of the participants towards the end of

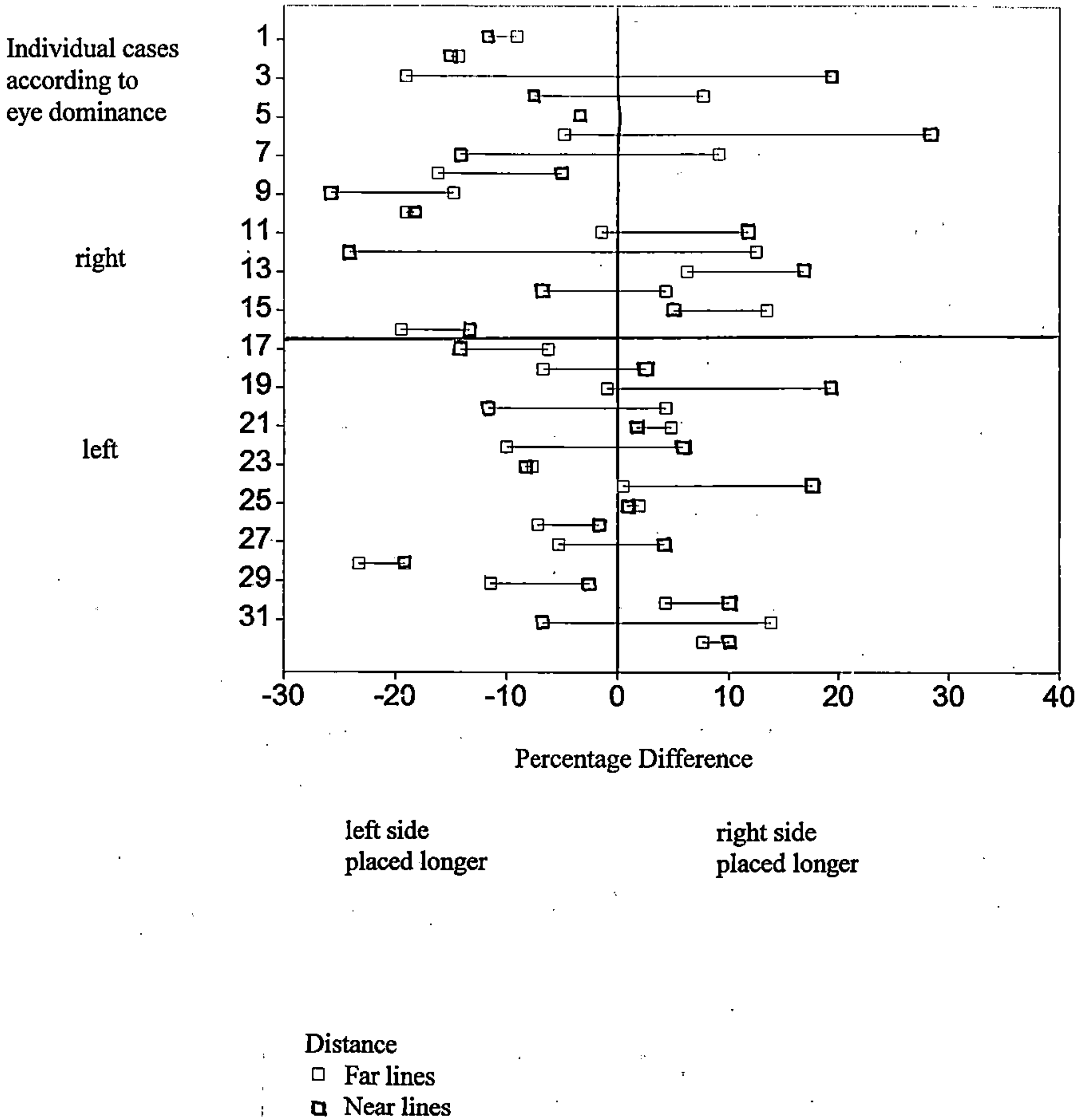
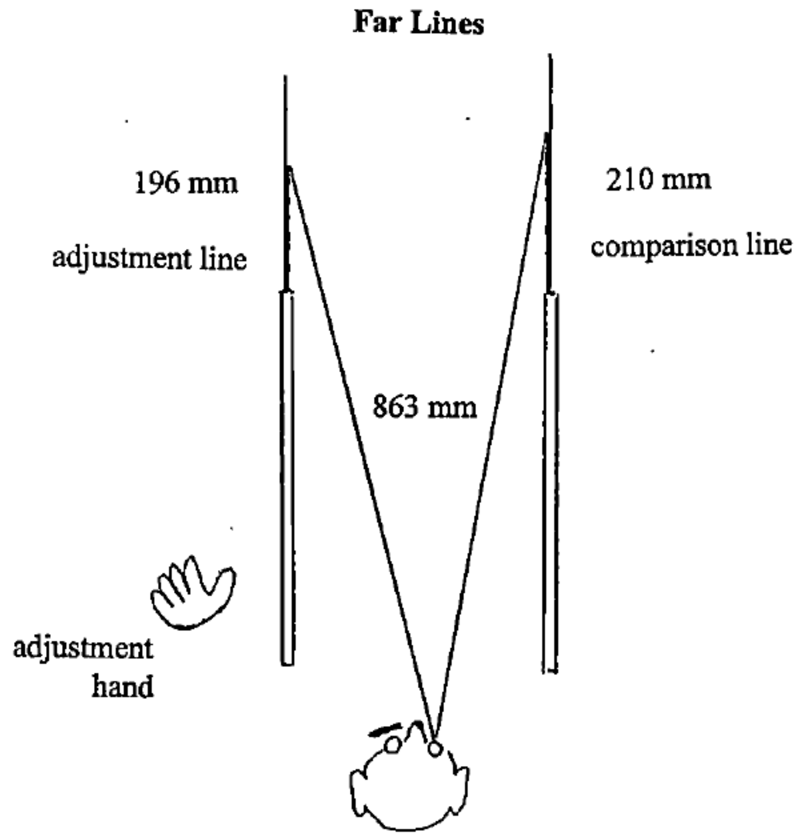


Figure 14. Individual case's binocular differences (in percentage of the comparison line length) between left and right sides, for both near and far distances. Support for the Retinal Image and Eye Dominance Model would have been revealed as positive difference scores for right-eye dominant participants (cases 1-16), and negative difference scores for left-eye dominant participants (cases (17-32). Instead, there is an overall negative value (-3.92 mm difference), indicating a nonsignificant trend towards longer placement of left side lines.



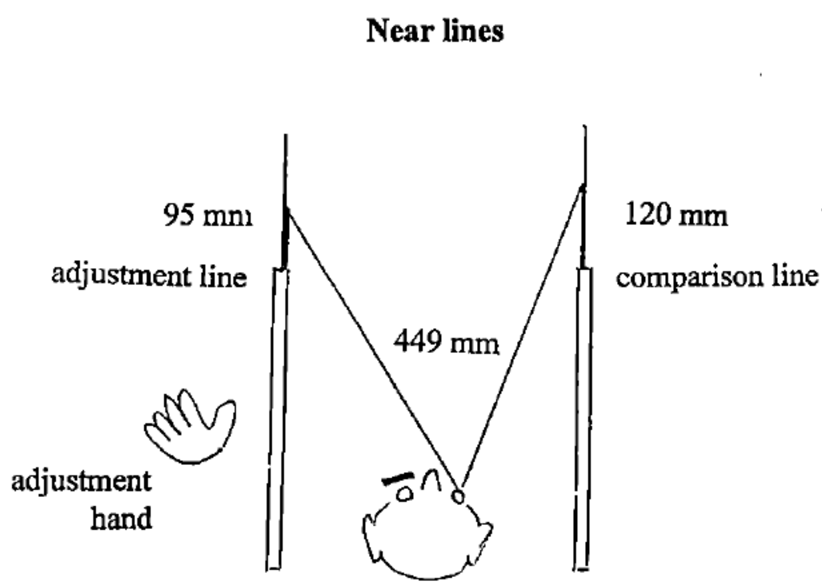
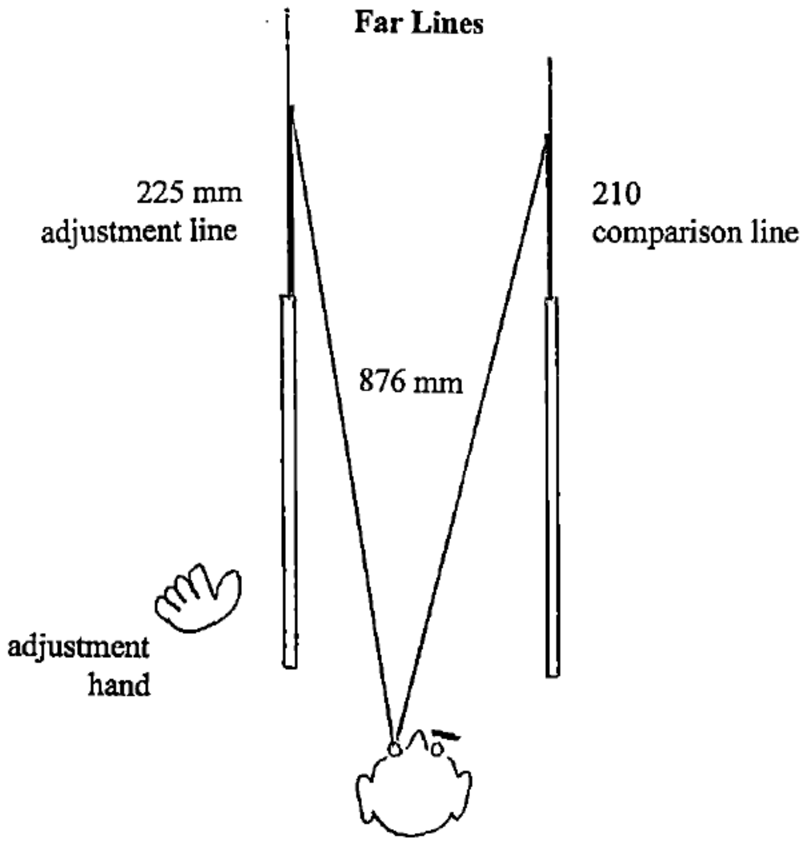


Figure 15. Generation of expected values based on equal distance from one eye to farthest end of both lines for incongruent eye/hand adjustments.



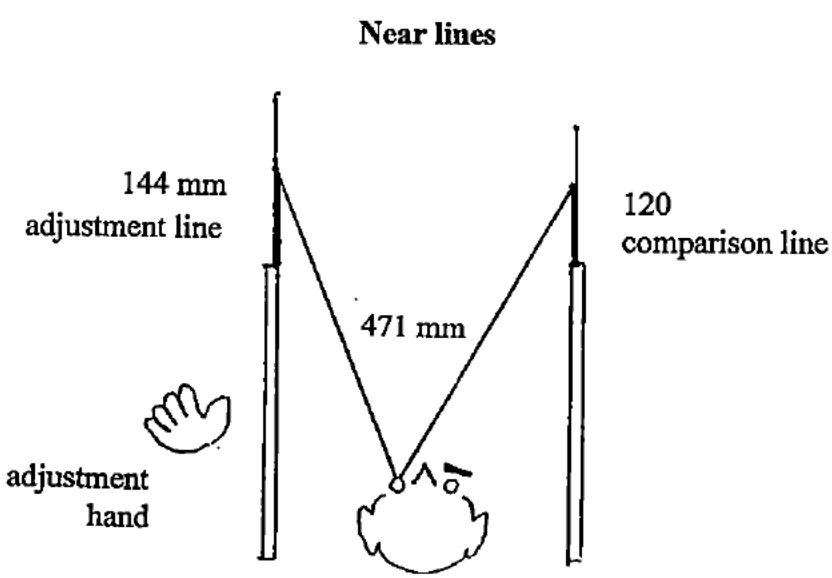
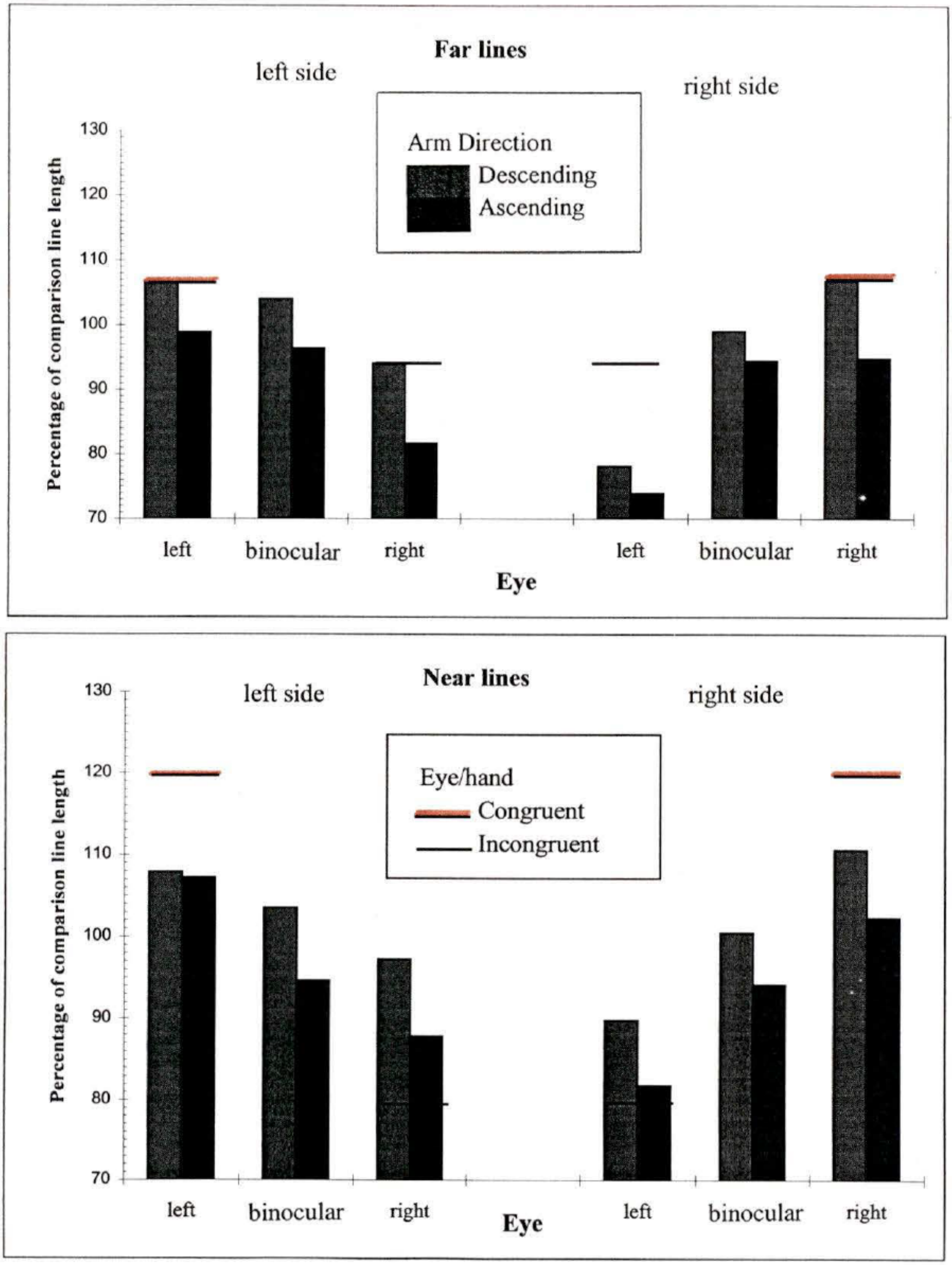


Figure 16. Generation of expected values based on equal distance from one eye to farthest end of both lines for congruent eye/hand adjustments.



—— match of distances to farthest end of both adjustment and comparison lines.

Figure 17. Matching distance from eye to farthest end of lines according to Adjustment Side, Distance, Arm Direction, and Eye/Hand Congruence.

Table 7

Difference (mm) between Mean Adjustment Line Distance (from Eye to Farthest End of Line) and Comparison Line Distance (from Eye to Farthest End of Line)

Ascending condition

	Adjustment Side			
	Left		Right	
Viewing Eye	Left	Right	Left	Right
Eye/Hand	Congruent	Incongruent	Incongruent	Congruent
Distance				
Far	-17.4	-24.6	-40.8	-25.8
Near	-36.8	10.4	3.2	-41.7

Descending condition

	Adjustment Side			
	Left		Right	
Viewing Eye	Left	Right	Left	Right
Eye/Hand	Congruent	Incongruent	Incongruent	Congruent
Distance				
Far	-1.4	1.6	-31.9	-0.8
Near	14.6	21.6	12.8	-11.3

each recorded estimation, while adjustments were being made in ever smaller increments (5 mm, 3 mm, or 1 mm). Participants would occasionally require six, seven or eight adjustments in the same direction; causing the PSE to "drift" considerably from where it had just been placed (i.e. the PSE could drift 15-20 mm from a location that had been consistently located from increments as small as 5 and 10 mm). As a result of unsystematic documentation of this unexpected inconsistency, the Experiment 2 results were deemed to be unreliable and were not subjected to statistical analyses[5].

CHAPTER IV

DISCUSSION

This study was designed to consider length judgements of parallel lines which receded in depth from normal viewers. The intention was to clarify neuropsychological models of variation in spatial representation, in terms of motor action, attention, and visual perception.

The effects of matching the appearance of pairs of receding lines may be summarized as follows: (1) Binocular lengths lay between monocular lengths, as predicted; (2) Near binocular lengths lay exactly between monocular lengths, as described by a cyclopean viewpoint; but (3) Far binocular lengths lay unexpectedly close to ipsilateral monocular; (4) All binocular lengths lay close to physical match (comparison line length); (5) Monocular ipsilateral eye/hand (congruent) lengths also lay closest to physical match, although also significant towards retinal image match; (6) Monocular contralateral eye/hand (incongruent) lengths lay farther from physical match, towards retinal image (though closer to physical match); (7) Binocularly-viewed lines contralateral to the sighting-dominant eye were unexpectedly <u>not</u> perceived longer (not placed shorter) than those lines contralateral to the non-dominant eye; instead, (8) Left side lengths were placed longer than right side regardless of monocular eye dominance, although this was significant only for monocular viewing.

<u>Cyclopean Effect and Crossed Dominance</u>

The first prediction (Prediction A) compared monocular and binocular mean judgements. It generally stated that the binocular length perception of such lines would lie <u>somewhere between</u> the two monocularly perceived lengths. If the binocular judgements lie precisely between the two monocular judgements then a <u>cyclopean</u> viewing effect is occurring. A preliminary interpretation of the current findings is that such a cyclopean effect appears for near lines, but not for far lines (see Figure 11, Table 5 and Table 4).

However, additional tests have shown that three descending binocular means are also not significantly different from physical comparison line length (see Table 2). The near cyclopean viewing effect may be reconsidered as follows. Both binocular and ipsilateral monocular adjustments create physical matching (i.e. lines equal in length to the comparison line). In contrast, contralateral monocular adjustments result in shorter lines which fall between (are significantly different from both of) the two effects of physical matching and retinal image (see Table 2 and Figure 13). Prediction C had stated that the removal of binocular depth cues would result in a greater dependence on retinal image than on physical matching when making line length judgements. This prediction is supported by incongruent (contralateral) eye/hand adjustments, but is not supported by results of congruent (ipsilateral) eye/hand adjustments. All eight congruent condition means are nowhere near matching according to retinal image, while only 2/8 of these conditions differ from physical matching (see Figure 13). In contrast, the incongruent (contralateral) eye/hand combinations lie between the standards of physical matching and retinal image matching. These experiments had been designed to exaggerate the importance of retinal images above other monocular depth/orientation cues. Yet retinal image is never the strongest determinant of line matchings. Physical matching is decidedly the more important effect for congruent (eye/hand) monocular matching (as it is, more expectedly, during binocular matching). The placement of incongruent monocular matching halfway between physical matching and retinal image matching expected values may be considered <u>less accurate</u>, regardless of criteria. Recall that the wording of instructions to participants had been purposefully vague to encourage either one or the other effect to occur (not expecting results to lie between these two effects). What precedent exists for this difficulty with incongruent eye/hand matching? Berner and Berner (1953) summarize 20 years of opthalmological case-work by reporting on over 600 children and adults in connection with the following constellation of commonly-noted symptoms:

> "[This constellation of symptoms] begins in early childhood with the slow development of motor coordination, often accompanied by speech hesitations or frank stammering. At school age the children show poor visual imagery and memory, and reversals in reading and writing patterns, sometimes

> including complete mirror writing. Very poor reading and spelling are the outstanding difficulties. Nervous fatigue accentuates the problem. In more mature life the combined appearance of ocular discomfort, nervous disorganization, and disruption of established reading habits suggests a similar pattern of later origin." p. 603.

This pattern is associated with crossed dominance; "the fact that the dominant (sighting) eye is on the side of body opposite to the preferred hand." This conclusion is echoed by later work of Benton (1968). Berner and Berner (1953) also describe a lack of correlation between monocular and binocular eye dominance:

> "As binocular vision develops, it becomes habitual to use two eyes as a unit for visual perception. But within the pattern of binocular vision there is rivalry between the two eyes, and one eye controls binocular perception. This eye we have called 'the controlling eye'. The other eye plays an assisting, rather than an equal, role. The eye which controls binocular perception is not necessarily the eye with which the person sights. The sighting, or dominant, eye is selected for an essentially monocular act; the controlling eye gains its mastery within the pattern of binocular vision. The dominant eye is stable from early life, but the controlling eye can be shifted, as the binocular pattern is easily influenced by changes in vision, or controlled by training." p. 604. [Emphasis mine.]
>
> "It will often happen that an eye with relatively less visual acuity, as measured monocularly on a Snellen chart, performs noticeably better in picking out the dots on binocular targets, indicating that there is a strong demand for this eye to lead the binocular vision pattern." p. 605.

This finding has relevance for the current study. Participants' sighting eye dominance had been assigned according to self-reported monocular preferences. Berner and Berner's results may well explain the lack of Eye Dominance effects (with 16 participants each of left and right eye sighting dominance). While Heilman et al. (1995) also found no effect of Eye Dominance, only five of their 11 participants were left-eye dominant (and it is not known what type of eye dominance evaluation was employed). Note also the claim that the binocular controlling eye may be easily shifted. The current study confirms with examples of every possible pattern of binocular differences according to both viewing Distance and Adjustment Side (see Figure 14). Some unknown factor has created a wide variety in the binocular controlling eye. The current results suggest that the accuracy of line length judgements is adversely affected by incongruence of the motor (hand) and perceptual (monocular sighting eye) elements. This general effect is more flexible than Berner and Berner's syndrome, in that it is independent of hand dominance, monocular sighting eye dominance, or binocular controlling eye dominance. A tentative explanation may lie in better eye/hand (perceptual/motor) performance resulting when the eye and hand from the same side of the body work together. This is reminiscent of the Simon effect, where responses tend to be faster when the responding hand and the stimulus both lie in the same (lateral) position in space (the hand-hemispace spatial-compatibility effect of Bradshaw et al., 1994). This effect occurs when tasks have responses which are defined in spatial terms. Two types of codes are described. One is task relevant and specifies the spatial position of the response, while the other is task irrelevant and specifies the anatomical identity of the effector. Bradshaw et al. report that overall RTs (reaction times) are consistently longer when stimulus and hand are crossed (lie in the same hemispace) than when they are uncrossed. They maintain that this crossed-arm effect is a type of Simon effect that is caused by a task-irrelevant response code (Hommel, 1993 as cited by Bradshaw et al., 1994). They also predicted that longer stimulus-onset-asynchrony (SOA) allows attention to be diverted to the correct location, thus resolving any coding conflicts. "If the hand-hemispace compatibility effect depends on a conflict between the (relevant) code of the anatomical identity of the hand and the (irrelevant) code of the hemispace the hand occupies, its magnitude should decrease as the SOA becomes longer" (p. 173). Bradshaw et al. did find this result when SOAs surpassed 300 ms, indicating a conflict between incongruent stimulus/hand hemispace (which dissipates between 200 and 300 ms). The interpretation was that 300 ms of attention to the correct (stimulus/response) hemispace allowed enough time to program the contralateral hand to respond before the stimulus appeared.

In contrast, the current study's hemispace incongruence is not between stimulus and responding hand, but between viewing eye and responding hand/adjustment side.

Neither is there dissipation of the current study's effect of hemispace incongruence. A few seconds of adjustment time does not eliminate poor performance for incongruent eye/hand adjustments. The current effect might be termed an "eye-hemispace spatial-compatibility effect". If any explanation is to made in terms of shifting attention, it would be that attention divided among the body's lateral parts results in miscalibration between perceptual and motor activity. Any detailed model of such superior performance from congruent eye and hand must await further investigation.

Previous studies have documented that congruent hand/hemispace conditions (i.e. each hand working on its usual side of the body) yield faster reaction times or fewer errors (Bradshaw, Bradshaw & Nettleton, 1989; Bradshaw et al., 1994; Riggio, de Gonzaga Gawryszewski, & Umilta, 1986). These studies have not considered hemispace lateralities (i.e. ipsi or contra) in terms of eye location.

Arm Direction and Distance to Farthest Ends of Lines

Participants placed the length of the adjustment line by either increasing (starting from zero length) or decreasing the length of the adjustment line until it "looked the same as" a comparison line. This resulted in the study's purest main effect (i.e. occurring in all MANOVAs, but not appearing in any interactions) of ascending adjustments falling short of the comparison line length while descending adjustments fell close to comparison line lengths (see Table 3).

An interesting pattern occurs for certain descending monocular means. Three of these eight means (Distance by Eye/hand congruence) fall within 1 mm of the farthest end of the adjustment line at the same distance from the viewing eye as the farthest end of the comparison line (see Figures 17, 15, and 16). It may be speculated that the farthest end of all adjustment lines (both near and far) in this study is more salient because only this end changes in length (and position). The near ends of lines always remained at the same distance (and position) from the viewer. It appears that one monocular strategy in making the lines "look the same" was to ensure that the salient (farthest) line ends were equidistant from the viewing eye, rather than to match line lengths according to either physical match or retinal image. This new, previously unreported strategy could be termed a Distance-to-End strategy.

Such findings occurred for three descending, far conditions and for one ascending, near condition (see Figure 17). One crucial difference between ascending and descending trials is that only ascending trials could allow tactile-proprioceptive feedback to augment the visual information. For example, if one were to extend the adjustment line a distance of 12 cm, that same distance would also be moved by the adjusting hand, and could be available (consciously or not) to inform the participant of the length of the adjusted line. However, this could not occur for descending trials, where retraction of the adjustment line would be accompanied by a different distance travelled by the adjusting hand. For example, retracted placement of the adjustment line to a length of 12 cm would require a hand movement of either 18 cm (for far lines) or 8 cm (for near lines). Instead, participants were obliged to rely more upon visual information to make far line comparisons. This fits with the findings of Shelton, Bower, & Heilman (1990) in their study of radially receding rod bisection. Their participants erred by visually bisecting rods away from their body, but also erred by tactually bisecting rods (when blindfolded) towards their body. Their interpretation was that "normally attention is preferentially distributed away from the body during visual exploration but distributed towards the body during tactile exploration." The complementary interpretation of the current study is that necessity of visual reliance for far line comparisons resulted in directing attention towards the farthest ends of lines (which, presumably, already provided the more salient information). This attention was relaxed for near line comparisons (despite far ends retaining their most salient status) which allowed tactile-proprioceptive feedback to inform the adjusted line lengths. This is not the whole story, for the comparison line lengths could never provide tactile proprioceptive feedback. As well, this effect only occurs for 3/8 of the descending conditions (see Figure 17).

This finding of shifting attention away from the body occurs despite concurrent adjustment arm manipulation which always must occur in near space (because the hands cannot reach beyond near space). However, Robertson and North (1993) support this in reporting an improved attention towards left visual space which "spread also to far space, and was not confined to reaching space, suggesting that the left sides of personal, reaching and far spatial representations may have been synchronously activated."

This interpretation of the Distance-to-End effect should be considered with caution. It may be better to interpret this effect also in terms of eye/hand crossed dominance. Notice that the congruent eye/hand condition provides two quite different standards of distance to farthest ends of lines, for far and near lines. The expected value for far lines is 107% of comparison line length, while the expected value for near lines is 120% of comparison line length (see Figure 17). Descending congruent condition judgements are all about the same (left or right, near or far). However, these judgements for far lines match the distance-to-end expected value (107%), but do not match the expected value for near lines (120%). From the left/right similarities, one might reasonably conclude that whatever determines the descending congruent condition judgements remains consistent across distance. Yet only the two far congruent condition judgements fit their distance-to-end expected value (see Figure 17). Both of the near congruent condition judgements are quite disparate from their distance-to-end expected value. It must be either (1) explained why the matching of distance to farthest line ends occurs only for far congruent descending lines and not near lines, or (2) concluded that the matching of distance to farthest line end does not really explain any of the congruent eye/hand findings, but occurs merely as a coincidence for the two far congruent conditions. Physical matching seems to be a better explanation (see Figure 12) for congruent (ipsilateral) condition judgements (descending, and even more so for ascending), than is a matching of distance to farthest line ends effect.

The expected values of distances to farthest ends of lines for incongruent eye/hand conditions are 93% for far lines and 79% for near lines (see Figure 17). The Distance-to-End effect does not strongly explain incongruent eye/hand judgements (approximating only 2/8 of these means). However, neither do the remaining two pure effect models (physical matching, and retinal image matching) seem able to explain incongruent eye/hand judgements (either descending or ascending) (see Figures 12 and 13). Instead, it may be emphasized that the incongruent conditions result in a poorer approximation of physical matching than do the congruent or binocular conditions.

Binocular adjustments involve four distance-to-end values. It is impossible for a single eye to match distance-to-end values during binocular viewing. However, a pair of equal but opposite distance-to-end values will occur for the two eyes if physical matching occurs during binocular adjustments. This makes it impossible to determine whether binocularly-driven physical matching arises merely from distance-to-end matching (albeit, from two pairs of equal, but opposite, distances), or arises from a more complete perception of both lines' length and orientation.

All told, there is such great individual variability in the individual binocular judgements that every model under consideration is supported by a minority of certain cases (see Table 8). The most common pattern is the left-side overplacement found by Heilman et al. (1995), explaining between 19-34% (6 or 11 cases) of the cases (see Figure 14). The most parsimonious interpretation suggests a mild neglect of left space, reminiscent of the stronger left space neglect common to those with right hemisphere brain damage. The next most common pattern supports the proposed Eye Dominance and Retinal Image Model, which explains as many as 22% of the cases (7 cases), although none of them explained by only one model. However, neither of these two models explains a majority of the cases, and they overlap in explaining 5 of the same (left-eye dominant) cases. An additional model of this thesis, the Depth Cue model (see Appendix D), uniquely accounts for 19% (or 6) of the cases. Another 16% (or 5 cases) of the cases support the (right space) pseudoneglect previously reported in normal people. Beyond these four models, another 28% (or 9 cases) of the cases remain unexplained.

The only clear conclusion is that there is too much variety in binocular judgements to be explained by any single model. A recommended next step is to examine whether individual participants are truly consistent in their binocular perceptions of lateral line length (i.e. by testing participants twice, at a one-week interval).

Maximum Alignment Effects

Recall that lateral hemispace may be defined either in relation to the body, the

Table 8.

Models Associated with Binocular Results of Individual Participants.

Model	Total Cases	Specific Participants
Eye dominance & retinal image	5-7	13, 15, 17, 23, (26), 28, (29)
Heilman et al. or left hemineglect	9-11	1, 2, 5, (8), 9, 10, 16, 17, 23, (26), 28, (29)
Depth cue	4-6	4, 7, 12, 14, (20), (31)
pseudoneglect	4-5	13, 15, (21), 30, 32
	16-22 / 32	

head and eyes, or to all three together. The implication is that there are separate, but complementary, spatial representations for each system (Meador, Loring, Bowers & Heilman, 1987; Pierson, Bradshaw, & Nettleton, 1983). The current study always aligned the head and the body (but required the eyes to move). Much research indicates that such alignment increases any hemispace effects (presumably because such differences would be shared in common by multiple systems of spatial representation) (Bisiach, Capitani, & Porta, 1985; Burden, Bradshaw, Nettleton, & Wilson, 1985; Butter, 1992; Robertson & North, 1992; Shelton, Bowers & Heilman, 1990; Tressoldi, 1987; Ventre, Flandrin, & Jeannerod, 1984). Conversely, misalignment of head and body is thought to allow any lateral hemispace distortions to be minimized. Perhaps the alignment of head and body in the current study contributed to the strength of the resulting hemispace differences.

Lateral Hemispace Differences

Left side lines were placed longer than right side lines during monocular adjustments. This is the most common finding for line/rod bisection amongst hemineglect patients (Milner, Brechmann, & Pagliarini, 1992), indicating a relative neglect for left hemispace. This is also an occasional finding for normal controls in line/rod bisection studies (Mark & Heilman, 1990) although others (Bradshaw, Nettleton, Nathan, & Wilson, 1985, 1986; Sampaio & Chokron, 1992) report a normal pseudoneglect in the direction opposite (i.e. neglect towards right hemispace) to hemineglect patients (who neglect towards left hemispace).

Such lateral hemispace differences have been variously described as: selective enhancement of perceptual fields (Sampaio & Chokron, 1992), rightward bias (Roeltgen & Roeltgen, 1990), over-evaluation of certain regions of space relative to the body (Nichelli, Rinaldi, & Cubelli, 1989), enlargement and diminution of subjective space (Milner, Brechmann, & Pagliarini, 1992), under-estimation of space (Bradshaw, Nettleton, Nathan, & Wilson, 1985), and distraction for extracorporeal stimuli (Mark & Heilman, 1990).

Care must be taken to acknowledge and avoid the potential confusion when speaking of under-estimation of space. Note that under-estimation of line length indicates over-estimation of space, (and over-estimation of line length indicates under-estimation of space). The current author reserves the term "estimation" for perception, and the terms "placement" or "adjustment" for physical bisections or reproductions of line lengths. Perhaps it is counter-intuitive, but compressed space, where things look smaller (Milner, Harvey, Roberts, & Forster, 1993), actually has a courser grain when represented as a map drawn onto a uniform map of physical space (while expanded [or non-compressed] space has a finer grain) (see Figure 18).

Different Theories of Lateral Spatial Representation

There are different theories which try to explain the nature of human spatial representation, whether it be revealed by studies with hemineglect patients or with normal people. Both types of studies often focus on bisection (either visual or manual) of horizontal extents (either line segments or rods), which frequently reveal lateral (left/right) differences for both types of populations. A common point of theoretical division is whether perceptual or motor aspects are more responsible.

Perceptual Theories

Nichelli, Rinaldi, & Cubelli's (1989) position is that "...we still do not know whether the perceptual representation of a simple horizontal segment is the same across different portions of space and whether it can vary according to changes of the focus of attention" (p. 58).

Milner (1987, as cited in Milner, Brechmann, & Pagliarini, 1992) suggests that patients underscale the leftward extent of lines (bisecting to the right of midline) because less "automatic" attention is paid to the left side (Riddoch & Humphreys, 1983, as cited by Milner, Brechmann, & Pagliarini, 1992). Milner favours a view that subjective space is "progressively compressed" in leftward parts of space. The current study's main effect of shorter right Adjustment Side placements may be interpreted in these terms, whereby a longer line in left hemispace occupies equal amounts of subjective space as a shorter line in right hemispace (see Figure 18).

The current study refines Heilman et al.'s (1995) finding of left side lines placed

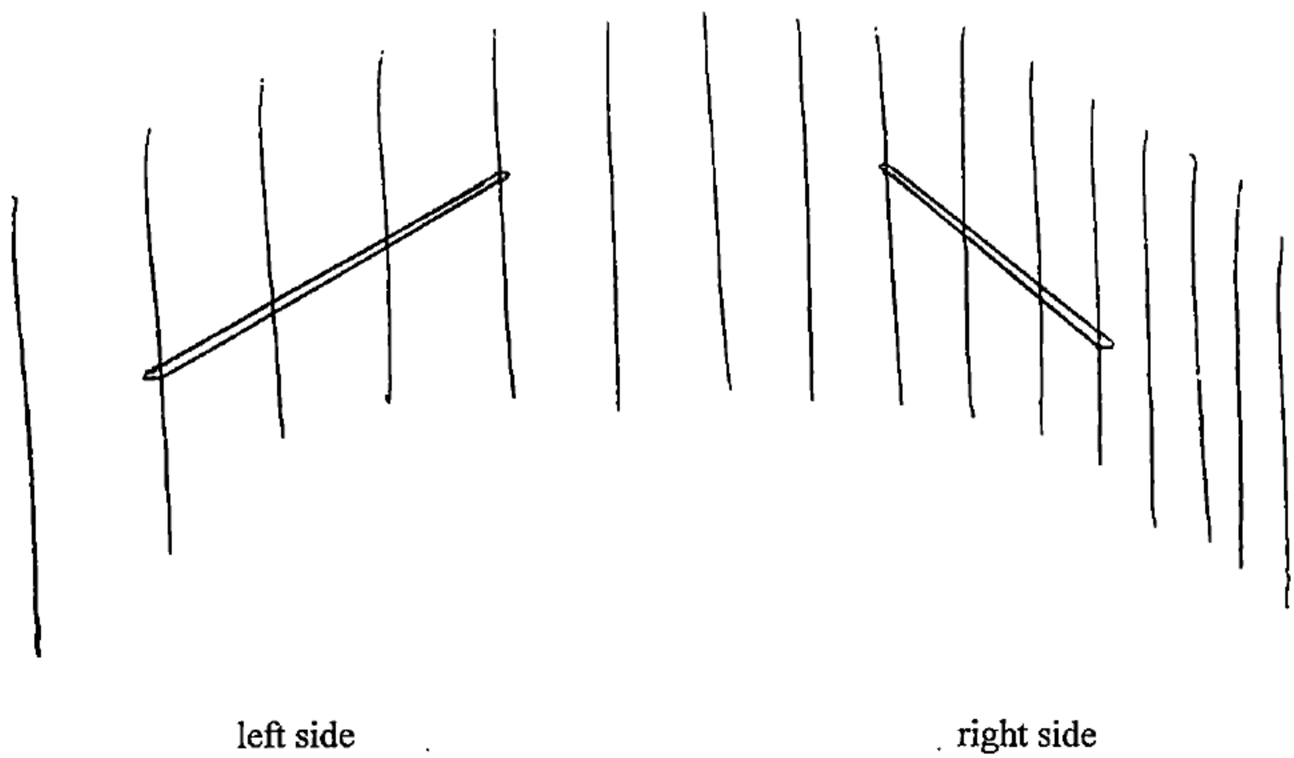


Figure 18. Subjective left/right differences in hemispace applicable in the current experiment. The horizontal distances between the vertical lines represent identical perceptual units of length. The gradual increase in physical distance between the vertical lines towards the left side indicates less compression (or more expansion) of perceptual space towards the left side. The two horizontal lines are perceived as being equal in length because they both extend an equal number of perceptual units (3). This only occurs when the left side line is physically longer than the right side line (which is the same as saying that the right side line is physically shorter than the left side line).

longer than right side lines during lateral comparisons of line length. Left side lines are physically matched with the same length as the right side comparison lines while right side lines are placed significantly shorter than the left side comparison lines (see Table 4). All line length judgements in the current study involve both lateral hemispaces (left and right); one containing the comparison line and the other containing the adjustment line. This begs the question of whether perception in either left or right hemispace may be considered more "accurate" while perception in the other hemispace should be considered either over- or underestimated. The current finding serves as an illustration. Is it possible to determine whether one of the following two interpretations is correct? (1) Perception in right hemispace is essentially "accurate" while the subjective units of perception in left hemispace are larger (i.e. equally long lines in left space are underestimated and overplaced relative to lines in right space). (2) Perception in left hemispace is essentially "accurate" while the subjective units of perception in right hemispace are smaller (i.e. equally long lines in right space are overestimated and underplaced relative to lines in left space). The answer seems to be no, we cannot determine which of these scenarios is more accurate because the comparison is between two subjective perceptions (i.e. there is no possibility for objectively declaring either side to be a "standard" or "accurate" perception, since any length comparisons are necessarily based on subjective perceptions of both lines involved). See Appendix E for details of the full rationale, plus a model which integrates central line bisection within the current experimental paradigm (where two side lines are compared to one placed in front).

As a result of this indeterminacy of an accurate standard of perception, it may be noted that it is equally valid to state such comparative results in either possible manner. For example, Gainotti & Tiacci (1971, as cited by Milner, Harvey, Roberts, & Forster, 1993) report visual shapes on the left tend to be under-estimated in size when compared with similar shapes shown on the right. However, they could just as well claim that visual shapes on the right tend to be over-estimated in size when compared with similar shapes shown on the left. Few authors have noted this interchangeability, while some have even voiced an intuition that one position is correct while the other is unlikely. For example, Milner, Brechmann, & Pagliarini (1992) say "it seems unlikely that the perceived size of attended items would be subject to illusory enlargement, but rather that unattended ones might be subject to subjective diminution." This conclusion does not follow logically.

Motor Theories

Bradshaw, Nathan, Nettleton, Pierson & Wilson (1983) found right-hemispace vibrotactile reaction time superiority to be motor rather than sensory. "It is as if motor (though probably not sensory) attentional processes are better allocated in body space to the right of the midline."

Whether Attention Includes both Perceptual and Motor Components

It is often not clear whether "attention" indicates a perceptual or motor effect. It may not be possible to sensibly separate the two.

Mark and Heilman (1990) found that both hemineglect patients and normal people "have a propensity to orient to or be distracted by stimuli in right hemispace". This occurred in a motor (pointing) bisection study which, however, was not designed to separate motor and perceptual aspects of spatial differences.

Roeltgen & Roeltgen's (1990) findings of more extinction and allesthetic errors (incorrectly identifying which of one's hands had been touched) on the left and faster visual search times on the right give "strong support to the hypothesis that there is asymmetry of lateralized attention in young children", on tactile extinction and visual search tasks, favouring right hemispace (p. 35). Tactile and visual components seem to collude in displacing attention towards right space.

Numerous authors support Rizzolatti et al.'s (1981) premotor theory of neglect (Carlomagno, Parlato, Belfiore, Silvano, Vanderlinden, & Seron, 1993; Milner, Brechmann, & Pagliarini, 1992; Nichelli, Rinaldi, & Cubelli, 1989; Robertson & North, 1993) which is based on studies of frontal and parietal lesions in monkeys. This theory equates the neural representation of space with the neural representation of attention for the same space:

> "We [Nichelli et al., 1989] argue that neurons devoted to directing attention to specific portions of space determine the salience of that part of space and therefore constitute the neural substratum of space representation. We define

> 'spatial representation' as the global pattern of attention distributed over space. Space representation has to be kept distinct from 'perceptual representation', which refers to the result of processing, coding, and interpreting sensory information from an actual stimulus, and from 'mental representation', which refers to the quasi-pictorial building up and manipulation of memory data in the absence of actual stimuli. In this framework spatial representation must be viewed as the background on which the cognitive processes of perceptual and mental representation can be implemented."
>
> "...both length and space effects and the interaction between them is explained by a gradient of distortion in the perceptual representation along the horizontal axis, going from an extreme underestimation of the left-most portions of the line, to a relative overestimation of its right-most portions, while the cue effect is explained by the persistence, in the sound hemisphere, of neurons able to direct attention toward the ipsilesional space and hence, when properly recruited, to at least partially rebalance space representation along the horizontal axis" (p. 68).

Robertson and North (1993) explain Rizzolatti's theory as unifying attention, perception, and motor aspects of spatial representation:

> "...attention is a consequence of activation of premotor neurons, which in turn facilitate the sensory cells functionally related to them. Hence, according to this theory, activating the premotor circuits of the damaged hemisphere may in some way facilitate the sensory cells connected with them, and hence improve perception of stimuli on the neglected side" (p. 293).

The relative contributions of motor/proprioception and visual perception in the current study were to have been discovered by comparing the results of Experiment 1 (motor/proprioception and visual perception) with Experiment 2 (visual perception). Unfortunately, the unexpected "drifting" of various judgements during Experiment 2 preclude a confident analyses of its results. Future work may yet resolve this point.

Future Research

Appendix E suggests a model whereby one might determine a mathematical description of the psychological compression gradient of horizontal space. This might be accomplished by comparing left/right hemispace differences in receding line length judgements (as done in this study) with bisection of horizontal lines in the frontoparallel plane. Success of this model may allow much more precise interpretation of extensive line bisection literature.

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Footnotes

[1]For example, it is impossible to visually align the tips of both index fingers binocularly when one hand is extended and the other is held close. The non-fixated finger, appearing as two separate images, cannot be aligned with the single image of the fixated finger. Only by choosing the image from one eye (the sighting eye) can this problem be solved (see Figure 19). This reliance upon one eye is termed sighting dominance.

[2]The use of straight lines in the current length perception study invokes a combination of size constancy and shape constancy. Size constancy is "the tendency for an object's perceived size to remain constant despite changes in the size of the retinal image of that object as viewing distance varies." Shape constancy is "the tendency for an object's perceived shape to remain constant despite changes in the shape of the retinal image of that object" (Sekuler & Blake, 1990). [Emphasis mine.] The horizontal lines of the current experiment were presented in various horizontal orientations (or slants, according to Pizlo, 1994). The lines seem to straddle both definitions; precisely neither of them, but invoking both size constancy and shape constancy. This is because lines are not saliently amenable to the variation in shape which accompanies the rotation of other objects. Yet lines are still amenable to changing their orientation to the viewer by being rotated in space. The binocular visual images of lines change very saliently along only one dimension (length) under both of the following circumstances: (1) when lines are rotated in the horizontal plane at eye level, (2) as lines vary in distance, without any rotation, from an observer. Salient changes in a horizontal line's length at eye level must be interpreted within a context by an observer. Accurate judgements (comparisons) of the physical lengths of the experimental two lines may reflect either size constancy or shape constancy. Shape constancy would result if line length differences are (incorrectly) perceived as line rotation rather than change in length. This is not very likely in the current study because the apparatus is rigidly anchored and prevents the rotation of lines relative to the viewer. Size constancy will be indicated by physical matching if line length differences are (correctly) attributed as changes in line distance from the viewer, without line rotation. In either case, changes in the retinal image may result in the perception of an object with an unchanging physical length.

The impression of an object's unvarying size (size constancy) indicates that estimation of size is usually not a direct function of the size of the visual image on the retina of the eye. Yet common exceptions in daily life indicate that size constancy does not always occur. Traffic signals or warnings printed on road surfaces for drivers to read are perceived in their familiar shape (shape constancy) rather than as the distortions they really contain. Such instances are created by the retinal image, rather than size constancy.

[3]Brunswik (1929, as cited in Osgoode, 1960) introduced a method of indicating the extent to which perceptual judgements reflect either size constancy (physical matching) effects or retinal matching (visual angle) effects. This Brunswik ratio is $(R - S)/(A - S)$. In terms of the length perception of lines, R is the retinal angle of the

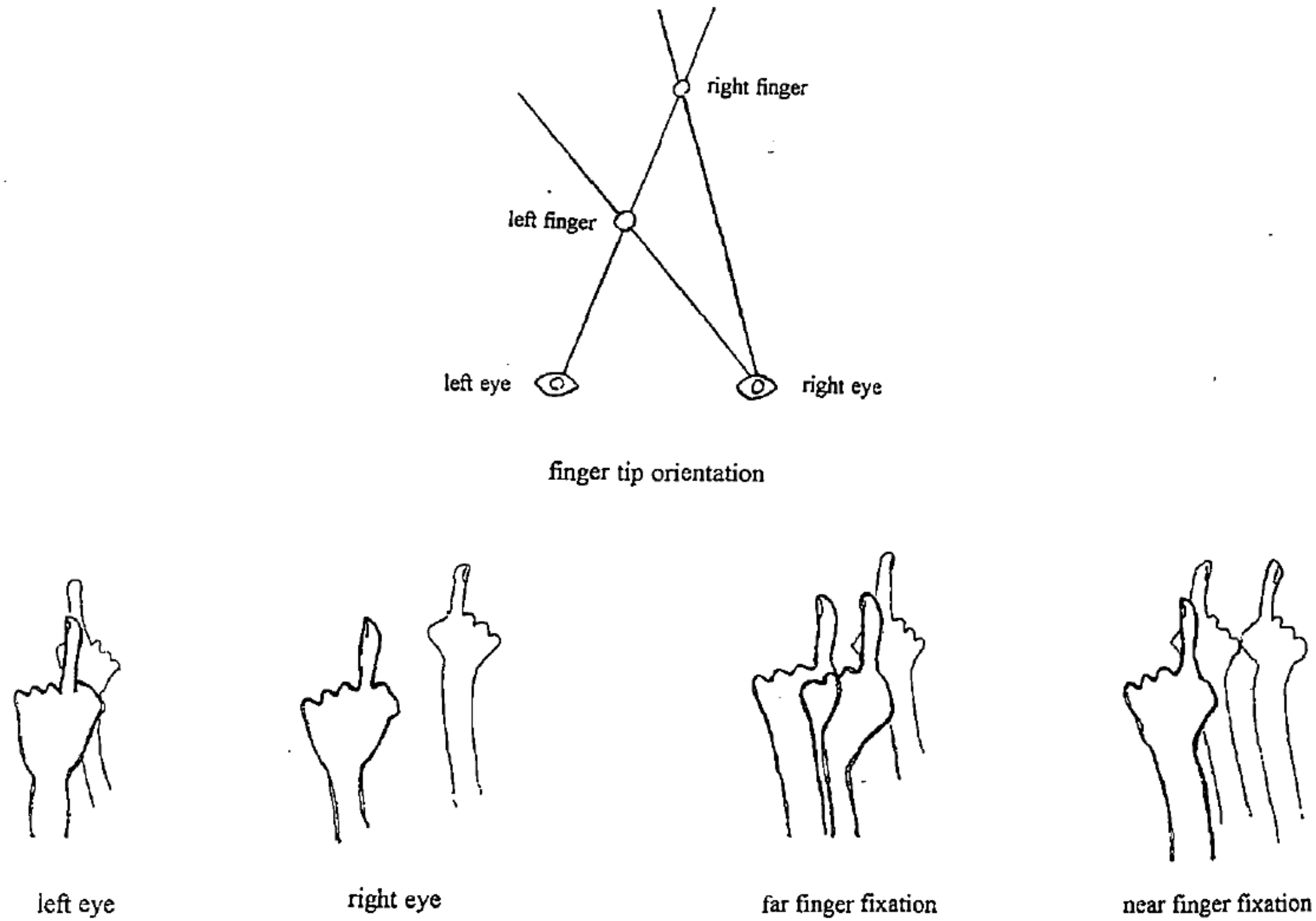


Figure 19. Binocular alignment of objects at different depths in terms of a left sighting dominant eye.

subjective psychophysical judgement, S is the (constant) retinal angle of adjustment line which is equal to the retinal angle of the comparison line, and A is the (constant) retinal angle of the adjustment line when the adjustment line is the same length as the comparison line. Thouless (1931, as cited in Osgood, 1960) expanded the study of constancy across brightness, color, shape and size. Thouless always found his ratios to lie somewhere between pure size constancy (approaching 1.00) and pure retinal image (approaching 0) effects. Later investigators (Holway & Boring, 1941) have found exaggerated size constancy effects (where the ratio exceeds 1.00). The Brunswik ratio is not used in reporting the results of this study because it is not as informative as comparing physical matching directly with retinal matching.

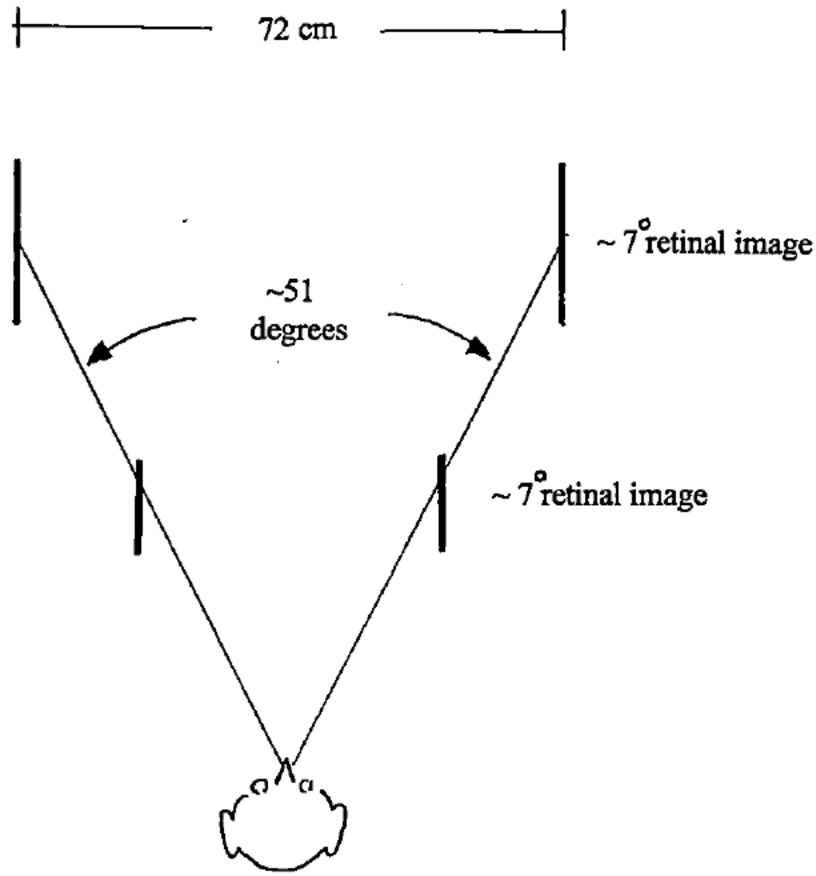
[4]It was not noticed, until after data collection for Experiment 1, that the Far Apparatus lines had been placed too close together during construction. The original design required a separation of 72 cm between left and right sides (see Figure 20). However, only half that distance (36 cm) was inadvertently incorporated in the construction of the Far Apparatus (see Figure 5).

This design resulted in two unintended discrepancies between near and far lines: (1) The angular separation between left and right sides should have been approximately equal (about 51 degrees). This angle was reduced to about 27 degrees for the far lines. (2) The visual angle of the retinal image should have also been approximately equal for both near (6-8 degrees) and far lines (about 7 degrees) but was reduced to about 4 degrees for the far lines.

As well, descending-condition participants were unlikely to make incongruent eye/hand line length judgements according to retinal matches because the initial length of the adjustment line created a retinal image (11%) shorter than the comparison line's retinal image, rather than being (17%) longer, as intended by the experimental design.

[5]Many Experiment 2 (Staircase procedure) participants performed unexpectedly (but not routinely so) by allowing their estimations to "drift" inconsistently from their previous point of subjective equality (PSE). The impression is that this behaviour only happened after the participants passed their discrimination thresholds (i.e. once adjustment magnitudes became so small that they were not discernable, and at a moment when both lines were perceived as being equally long). This threshold would occur between 10 mm and 5 mm, if at all. At this point, it appears that two possible strategies could be employed. Since participants could no longer confidently detect the changes being made, they could alternate (more or less) in their forced choices (of indicating the smaller line). Such a strategy would result in a final, recorded length quite close to their PSE before losing the ability to detect the changes in line length. However, it seems that some participants chose to consistently report one of the lines as being smaller; probably not changing their decision until becoming quite certain once more (as during the earlier, easily discriminable estimations) of an obvious difference between the two lines' lengths. However, the end result of this strategy would be a large drift away from a previously consistent estimation.

This drifting effect could have been avoided had there been indication that such



scale: 1 mm = 1 cm

Figure 20. Proposed adjustment arm configuration for Experiment 1.

an effect might occur. However, none of the consulted staircase-procedure literature warned about such an effect (Cornsweet, 1962; Findlay, 1978; Taylor & Creelman, 1967).

A parallel effect can be observed during the tuning of string instruments. The difference between two widely discrepant musical notes is quickly and easily minimized. However, there comes a point, as the two notes approach their appropriate tuning, that the further required small adjustments allow one to lose the understanding of which direction to continue tuning (i.e. which note is too high and which is too low).

Appendix A

Eye-Dominance Questionnaire

1.	Which eye would you use to look through a telescope?	___ left ___ right ___ either
2.	If you had to look into a dark bottle to see how full it was, which eye would you use?	___ left ___ right ___ either
3.	Which eye would you use to peep through a keyhole?	___ left ___ right ___ either

Appendix B

Hand Preference Questionnaire

1.	Which hand do you draw with?	___ right	___ left	___ either
2.	Which hand do you use to throw a ball?	___ left	___ right	___ either
3.	With which hand do you use a hammer?	___ right	___ left	___ either
4.	With which hand do you use a toothbrush?	___ left	___ right	___ either
5.	Which hand do you use to hold a match when lighting it?	___ right	___ left	___ either
6.	Which hand do you use a screwdriver with?	___ left	___ right	___ either
7.	Which hand do you write with?	___ right	___ left	___ either

Appendix C

Order of all 12 Manual Line Length Adjustments for all 32 Participants of Experiment 1.

	Near Line Pairs		Far Line Pairs		Near Line Pairs	
participant number	binoc	monoc	binoc	monoc	binoc	monoc
R1	L R	DL DR NDL NDR	L R	DL DR NDL NDR		
R2			R L	NDR NDL DR DL	R L	NDR NDL DR DL
R3			L R	DL DR NDL NDR	L R	DL DR NDL NDR
R4	R L	NDR NDL DR DL	R L	NDR NDL DR DL		
R5	R L	DR DL NDL NDR	R L	DR DL NDL NDR		
R6			L R	NDL NDR DL DR	L R	NDL NDR DL DR
R7			R L	DR DL NDR NDL	R L	DR DL NDR NDL
R8	L R	NDL NDR DL DR	L R	NDL NDR DL DR		
R9	L R	NDL NDR DL DR	L R	NDL NDR DL DR		
R10			R L	DR DL NDR NDL	R L	DR DL NDR NDL
R11			L R	NDL NDR DL DR	L R	NDL NDR DL DR
R12	R L	DR DL NDL NDR	R L	DR DL NDL NDR		
R13	R L	NDR NDL DR DL	R L	NDR NDL DR DL		

R14			L R	DL DR NDL NDR	L R	DL DR NDL NDR
R15			R L	NDR NDL DR DL	R L	NDR NDL DR DL
R16	L R	DL DR NDL NDR	L R	DL DR NDL NDR		
L1	L R	DL DR NDL NDR	L R	DL DR NDL NDR		
L2			R L	NDR NDL DR DL	R L	NDR NDL DR DL
L3			L R	DL DR NDL NDR	L R	DL DR NDL NDR
L4	R L	NDR NDL DR DL	R L	NDR NDL DR DL		
L5	R L	DR DL NDL NDR	R L	DR DL NDL NDR		
L6			L R	NDL NDR DL DR	L R	NDL NDR DL DR
L7			R L	DR DL NDR NDL	R L	DR DL NDR NDL
L8	L R	NDL NDR DL DR	L R	NDL NDR DL DR		
L9	L R	NDL NDR DL DR	L R	NDL NDR DL DR		
L10			R L	DR DL NDR NDL	R L	DR DL NDR NDL
L11			L R	NDL NDR DL DR	L R	NDL NDR DL DR
L12	R L	DR DL NDL NDR	R L	DR DL NDL NDR		
L13	R L	NDR NDL DR DL	R L	NDR NDL DR DL		
L14			L R	DL DR NDL NDR	L R	DL DR NDL NDR
L15			R L	NDR NDL DR DL	R L	NDR NDL DR DL
L16	L R	DL DR NDL NDR	L R	DL DR NDL NDR		

adjustment arm manner: odd number participants = ascending; even number participants = descending

L = left side R = right side D = dominant eye ND = non-dominant eye

Appendix D

Depth Cue Model

<u>Summary</u>.

The Depth Cue theory predicts that impoverished depth cues will result in inaccurate perception of the orientation and length of lines which recede in depth from the viewer.

It is assumed that not all portions of any viewed line will be equally attended. Instead, either the left or right ends of lines will be attended more depending on the viewing condition. For lines presented in left hemispace, the left end of the line will be closer to the viewer and the right end of the line will be further from the viewer. This is reversed for lines presented in right hemispace, with the left end of the line being farther from the viewer and the right end of the line being closer to the viewer.

Different portions of receding lines lie at different depths from the viewer. It is assumed that the judged depth of the attended end will erroneously provide most of the depth information which is used in perceiving the orientation of the line.

It is assumed that line length judgements will be based upon retinal image information combined with the depth judgement of only the attended end of the line.

It is assumed (following Heilman et al., 1995) that the left hemisphere is specialized for perceiving visual objects in near space, while the right hemisphere is specialized for perceiving visual objects in far space.

It follows that location of the lines (in either near or far hemispace) will determine whether it is the left end or right end of the line which is especially attended.

End-point fixation allows direct projection of entire length retinal images to a single hemisphere (see Figure D1). It is assumed that such direct projection of a line's entire image is preferred during perception of line orientation and length. During viewing of near lines, left-end fixation would be preferred because it will project the entire line retinal image to the left hemisphere. The corollary preference is that right end fixation of lines during far line viewing will project the entire line length to the right hemisphere.

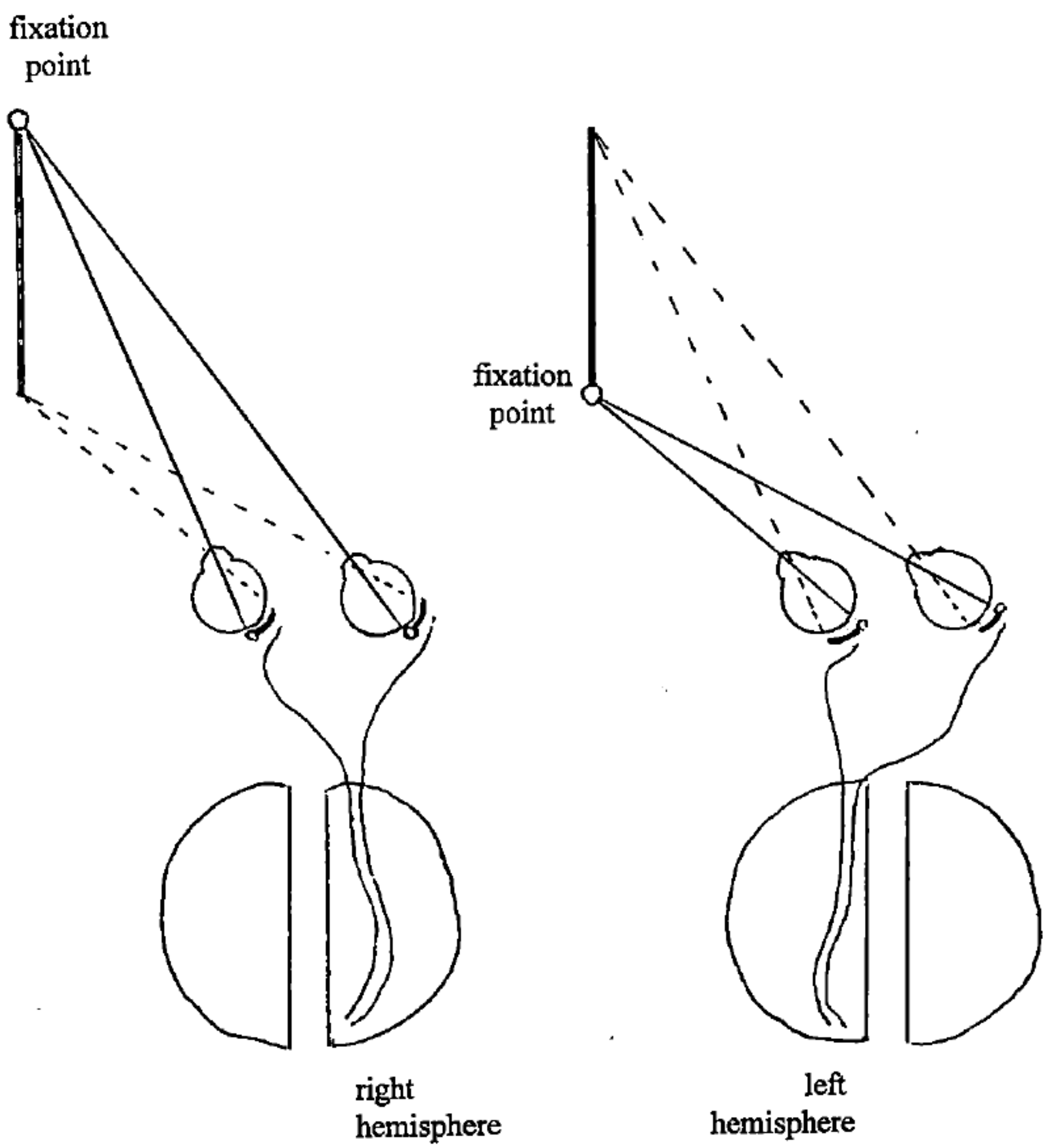


Figure D1. End-point fixation allows direct projection of entire length retinal images to a single hemisphere.

The resulting perceptions of line orientation and retinal image will create perceptions of line length. For near lines, these perceptions of length and orientation are predicted to consist of shorter and closer lines in left hemispace and longer and further lines in right hemispace. For far lines, it is predicted that the opposite will occur. Perceptions of length and orientation will be of shorter and closer lines in right hemispace and longer and further lines in left hemispace (see Figure D2).

Depth Cue Model for Binocular and Monocular Viewing.

There is an alternative model to predict left and right presentation-side differences and near and far space-differences in the perceived length of binocularly observed pairs of lines. As with Heilman et al. (1995), consider two equal lines which are presented "perpendicular to the coronal plane and parallel to the midsagittal plane"; one in each hemifield. Regardless of the place of fixation upon the lines, there will be a slightly different image length on the two retinas. In a full cue situation, there are many depth cues, even during monocular viewing, which indicate that the lines extend forward from the viewer. For example, the width of the line decreases towards the distant end. Accommodation may change as fixation moves from the near to the far end. Convergence changes with the point of fixation. These effects, creating differences between the near and far line ends, increase with the nearness of the lines. Perspective cues occur as lines in the entire viewing area which converge towards the central horizon. Perspective creates a tilt (towards the vanishing point) in the retinal image of horizontal lines placed either above or below eye level. Of all horizontal lines in sagittal planes, only those placed exactly at eye level create horizontal retinal images. The monocular viewing depth cues of line thickness, accommodation, and convergence may differ between the near and far fixation points of any given line. Such depth cues should lose their prominence as the distance increases between the viewed line and the observer (Leibowitz & Moore, 1965). The proposed experimental set-up contains two levels (near and far) of line pair viewing distance (see Figure 3). The Depth Cue model hypothesizes that relative loss of monocular viewing depth cues (for far line pairs compared with near line pairs) will result in a greater dependence upon retinal image information in making

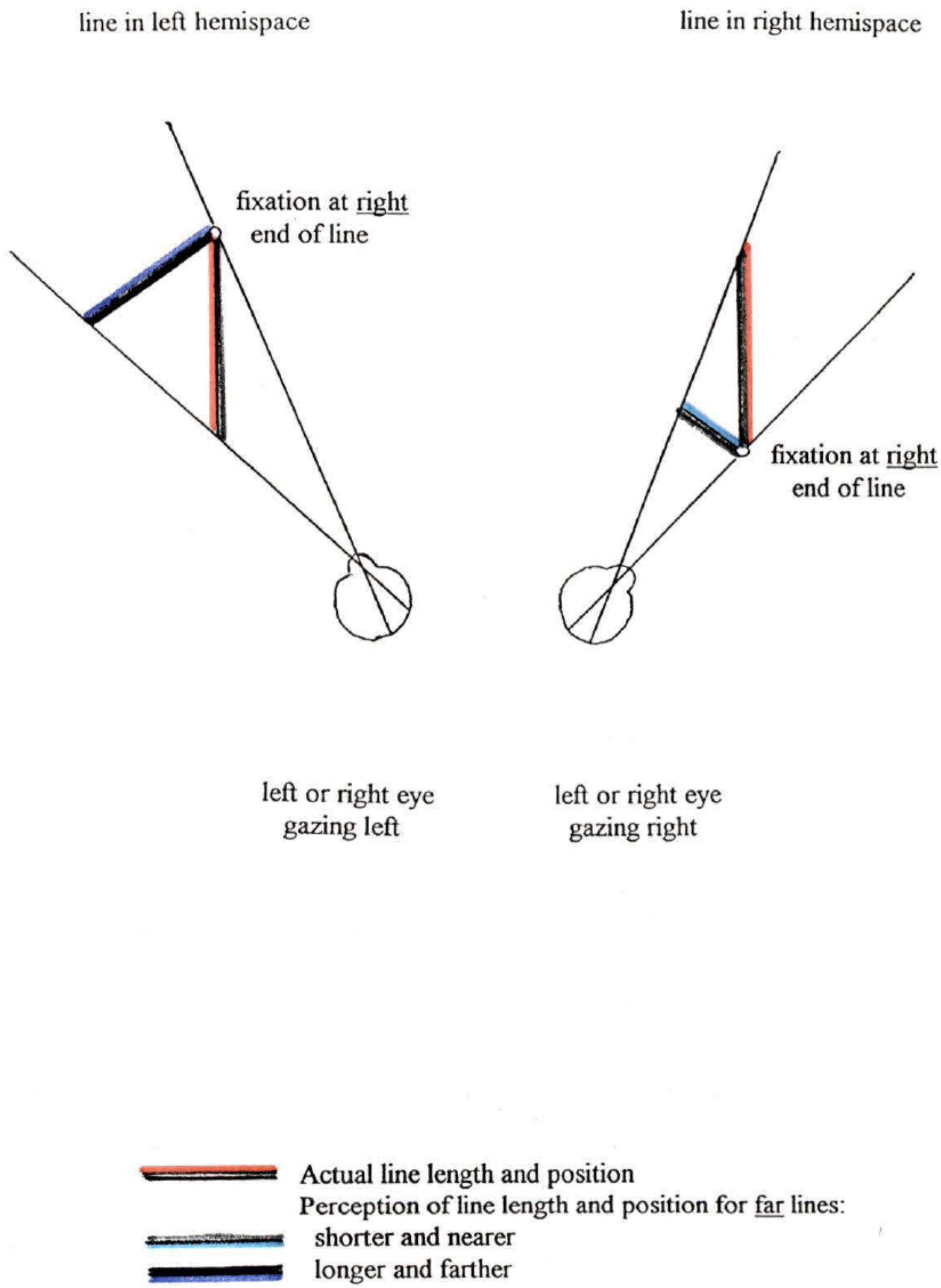


Figure D2. Right hemisphere perception of far (extrapersonal) lines in left hemispace as being further away and longer than lines of identical orientation and retinal image in right hemisphere.

far pair line length judgements.

Note that when participants are free to inspect both lines by moving their fixation along both entire lengths (as in Heilman et al., 1995) the entire image will project to the left hemisphere when fixation happens to be at the far end of the right hemispace line, or when fixation is at the near end of the left hemispace line (see Figure D3). Conversely, a reversal of these fixations will project the entire image to the right hemisphere (with near end fixation of the right hemispace line, and far end fixation of the left hemispace line). These selective projections would occur for either monocular or binocular viewing.

Proprioceptive feedback from eye motion may contribute to judgement of line length (Porac & Coren, 1977; Walls, 1951). It could be hypothesized that scanning the entire line, rather than fixating it, is most useful in line length judgement. However, if visual information of different distances are best processed uniquely by different hemispheres, as is suggested by Heilman et al. (1995), then end-point fixations may be more useful for making line length judgements. It is hypothesized that the resulting projection of a line's entire retinal image directly to the appropriate hemisphere will provide more accurate line length judgements than would the indirect projection of a line's retinal image. Such indirect projection would occur during other-than-endpoint fixations, with partial visual information crossing from the inappropriate hemisphere (through the corpus callosum) to the appropriate hemisphere. This is not to predict that participants will fixate line end-points during a free scanning experiment. Instead, it is hypothesized that the moments of end-point fixation occurring during free scanning provide the most utilized information for making line-length judgements. Alternatively, it is possible that line ends may be attended independently of visual fixation. De Gonzaga Gawryszewski, Riggio, Rizzolatti, & Umilta (1987) report that many authors (Eriksen & Hoffman, 1973, 1974; Hoffman, 1975; Posner, Snyder, & Davidson, 1980) have shown that visual attention can be shifted throughout the visual field independently of fixation point. While attending to (rather than fixating) the near end for lines in one hemispace and to the far end of lines in the other hemispace does not project entire visual images of both lines, in turn, to the same hemisphere, it does emphasize different depths

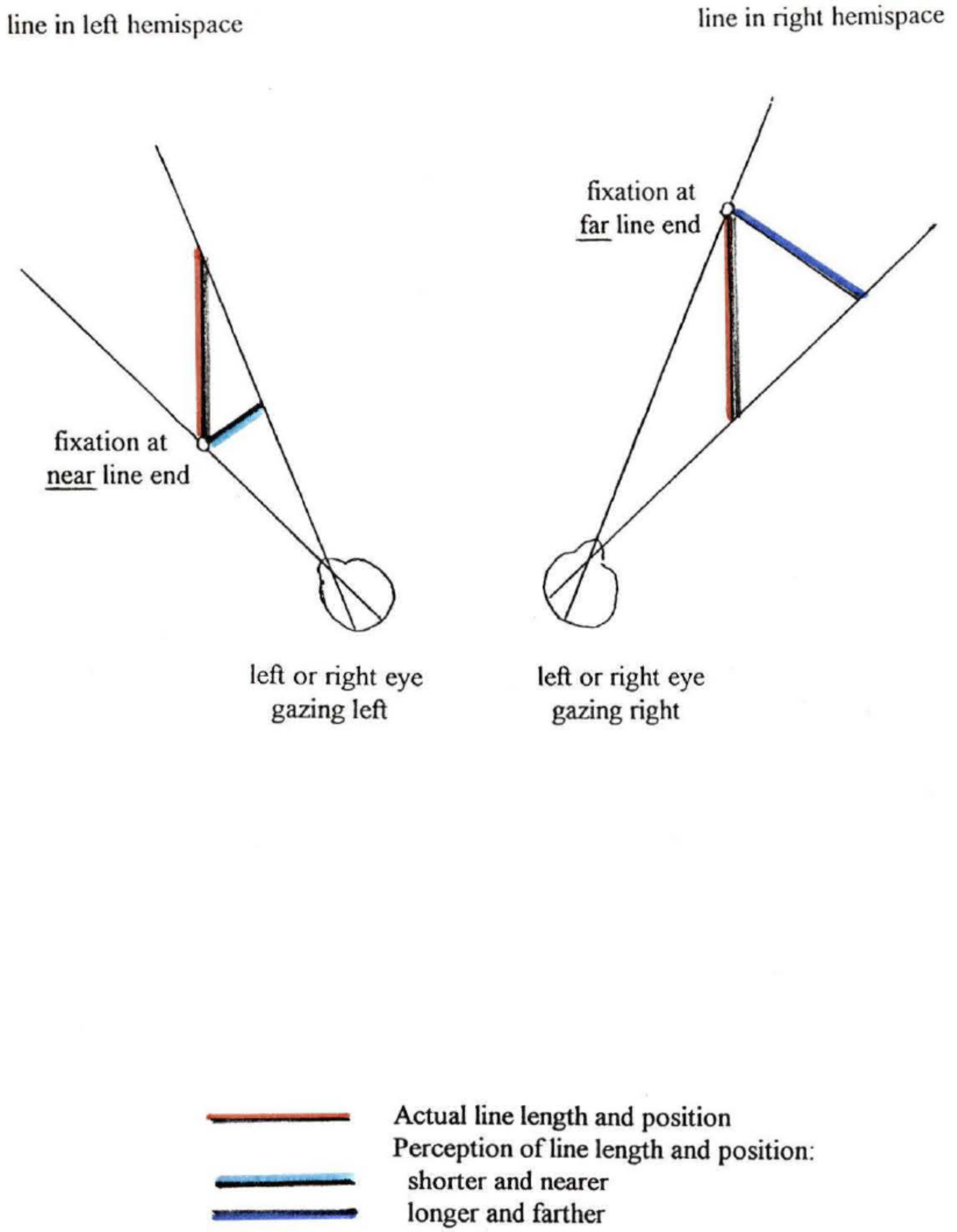


Figure D3. Direct visual projection to a single (left) hemisphere depending upon fixation point and location (hemispace) of line.

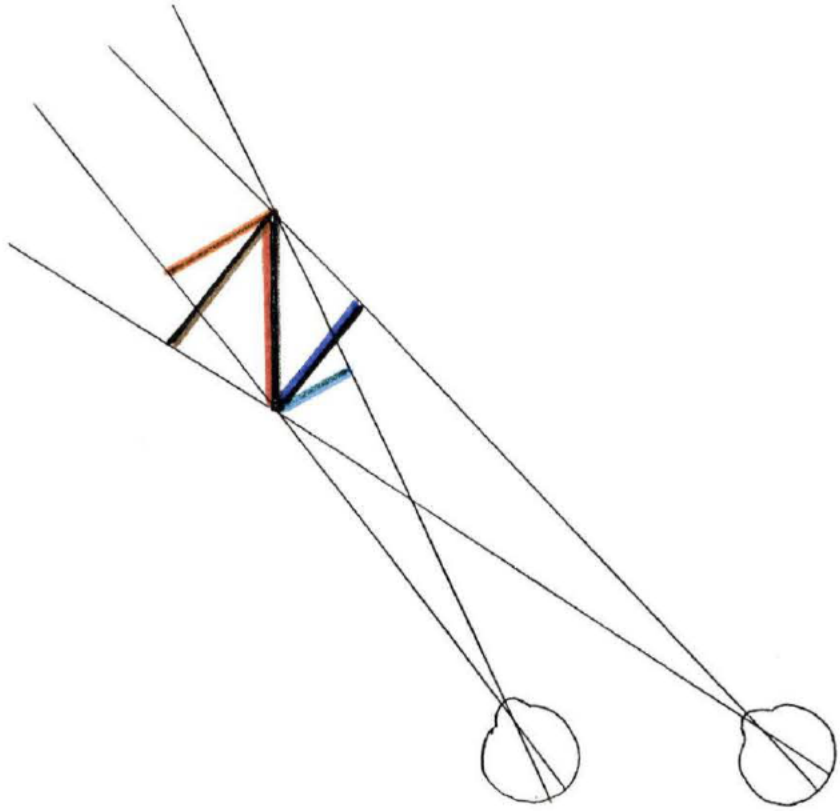
for each line.

The Depth Cue model hypothesizes that the depth information at the fixated end of a viewed line will be especially attended and provide an anchoring depth position to be used in judging line length. It is hypothesized that the location information provided by this anchoring depth position is then used in conjunction with the viewed line's retinal image in creating an illusory perception of that line's position and length (see Figure D4). To the extent that there is depth cue reduction during either binocular or (especially) monocular viewing it is possible that the entire line (especially for far lines) is simply perceived to lie perpendicular to the line of sight (i.e. not to lie in depth). This perceptual illusion would result from failure to detect the different depths at which the different portions of the line lie (i.e. the correct orientation of the line in depth).

This viewing mechanism would result in different line lengths and positions being perceived according to which end of the line is being attended during the judgements. Despite both monocular line percepts extending equal retinal images, the percept formed during far-end fixation would have to be longer than the percept formed during near-end fixation. If a monocular viewing scenario similar to that of Figure D3 holds (with one line being attended upon its far end alternated with the other line being attended upon its near end) then, even with identical (but reversed) retinal images, it is hypothesized that the line attended at its far end will be perceived as being both longer and more distant than the other line (see Figure D5).

This follows Emmert's law, which states that "for a retinal image of given size, the apparent size will, within certain limits, increase with the distance" (Ogle, 1964). The two lines, if under binocular comparison, both extend the same retinal images. These angles are reversed for the two eyes as the gaze alternates between the two lines. I am investigating whether this reversal in the retinal images of the two eyes causes perceptual differences during either monocular or binocular viewing.

Heilman et al. (1995) indicate that the left hemisphere is associated with spatial analysis in the peripersonal (near) field. The current proposal hypothesizes that this is associated with the preferential attending of the left end of proximally viewed objects.



Actual line position and length.
Potential monocular perceptions of line position and length:
Near-end based location.
Right eye.
Left eye.
Far-end based location.
Right eye.
Left eye.

Figure D4. Potential monocular illusions of line position and length.

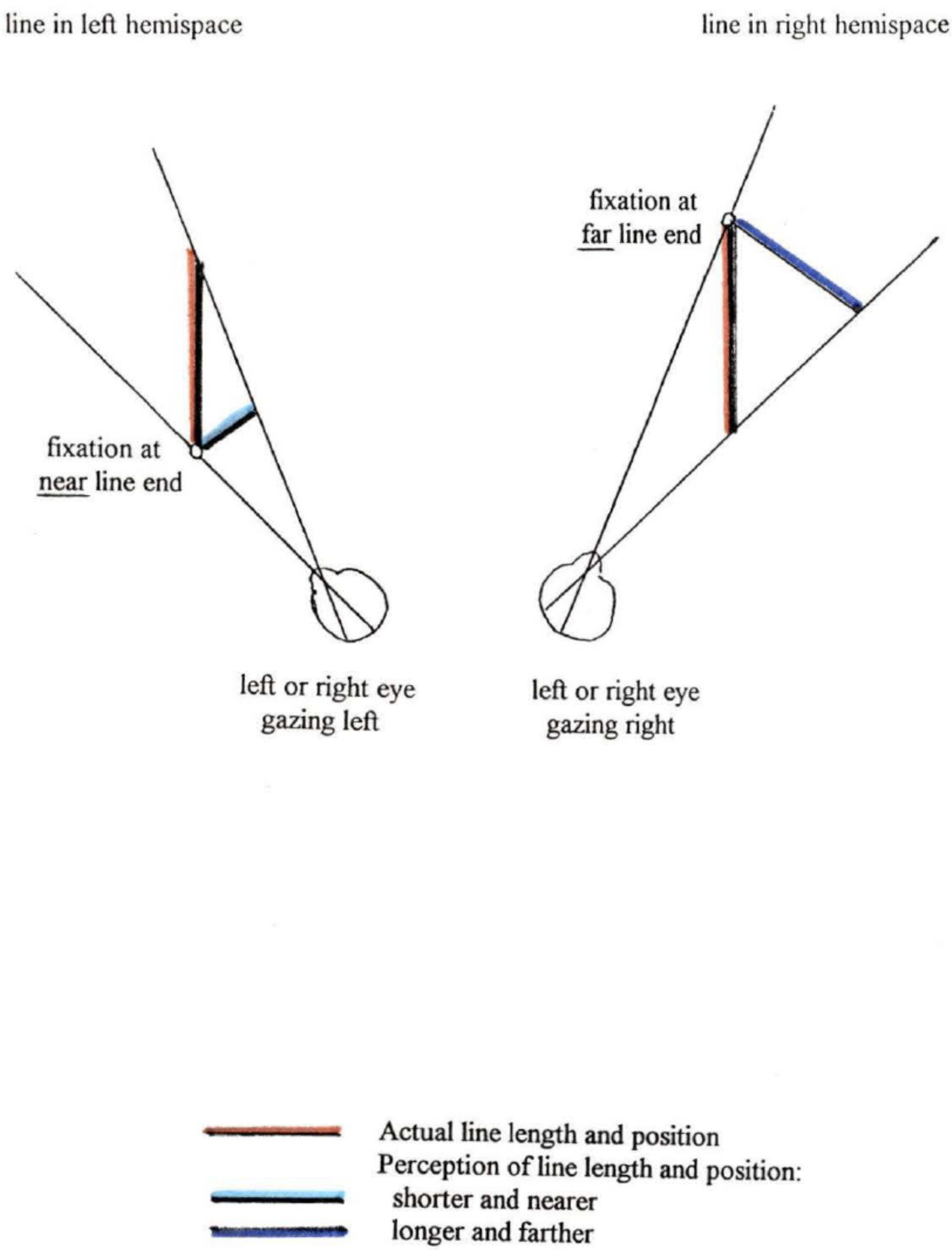


Figure D5. Perception (depending upon fixation point) of length and position of lines with identical retinal images and orientation.

Additionally, it is predicted that depth cues at the attended location, if active, will then influence the left hemisphere perception of near lines in right hemispace as being further away (and therefore longer) than identical lines in left hemispace (see Figure D6). Heilman et al. (1995) did not place test lines in peri-personal (near) space. It seems reasonable to assume that their theory continues to predict over-judgement of right hemispace line length if line pairs are to be placed in peri-personal instead of extra-personal space. Since both models predict the same result, there is nothing to distinguish between Heilman et al.'s (1995) model and the Depth Cue model for line pairs placed in peri-personal space.

But for lines viewed in the extrapersonal (far) field, Heilman et al. (1995) indicate that the right hemisphere is dominant for spatial analysis. The current proposal hypothesizes that this is associated with the preferential attending of the right end of distally viewed objects (see Figure D2). Additionally, it is predicted that depth cues at the attended location, if active, will then influence the right hemisphere perception of extra-personal lines in left hemispace as being further away (and therefore longer) than identical lines in right hemispace. This prediction, being directly contrary to Heilman et al.'s (1995) general prediction and findings of line perception in extra-personal space, will distinguish between their model and the Depth Cue model.

The contributions of accommodation and convergence to binocularly perceived size decrease as the distance increases between the observer and a viewed object. Leibowitz and Moore (1965) determined this relationship for viewing distances of 10, 25, 50, 100, and 400 cm. In Heilman et al. (1995), the difference between the near and far ends of their lines was small. The near end of the lines was about 101 cm from the eyes while the far end of the lines was about 118 cm from the eyes (see Figure 3). If the viewer looked from one end of the line to the other end, there should not have been very much difference in accommodation or convergence.

The near lines of the current proposal should create much larger accommodation changes as the viewers look from one end of the line to the other end. The near end of the lines will be about 29 cm from the eyes, while the far end will be about 44 cm from

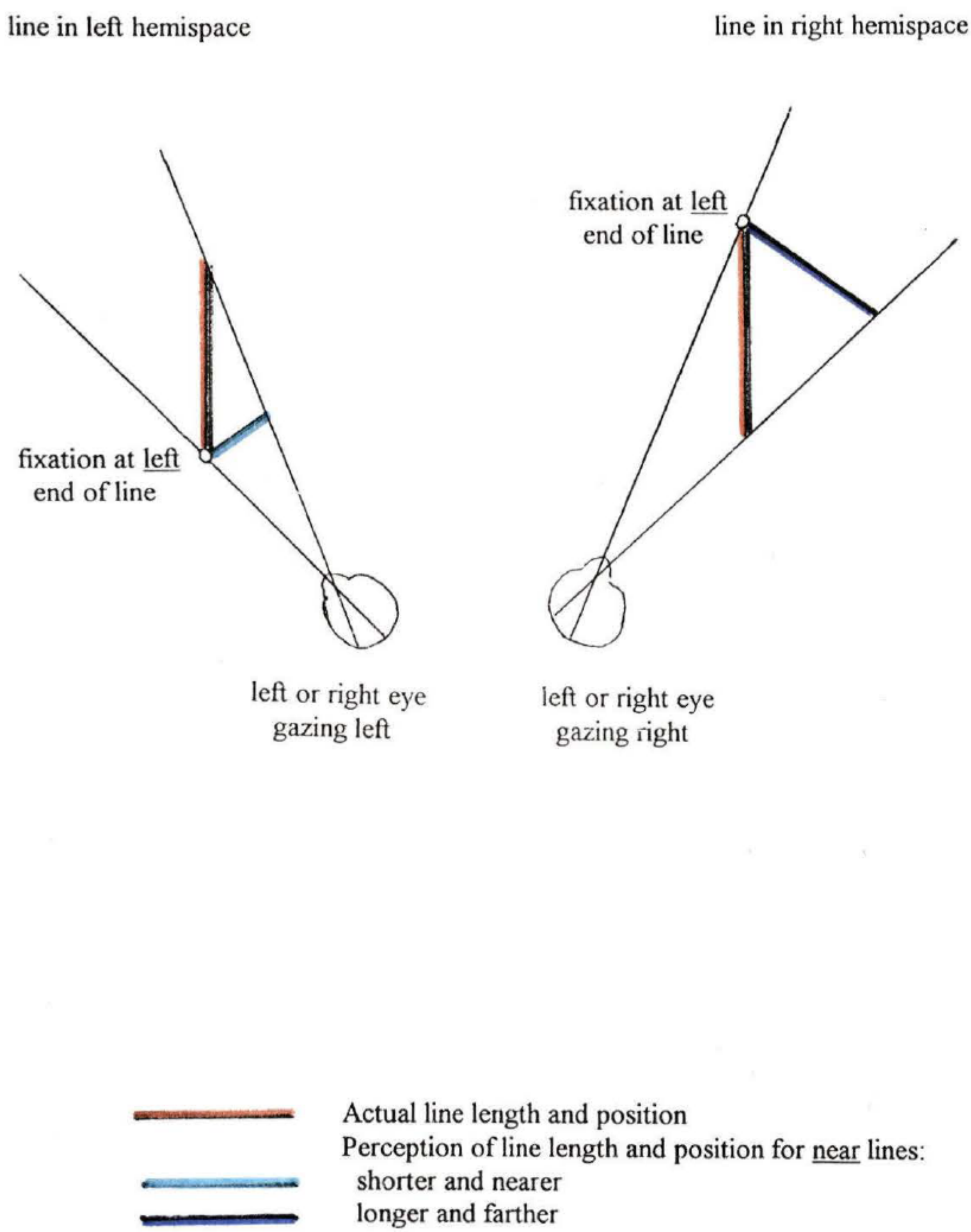


Figure D6. Left hemisphere perception of near (peripersonal) lines in right hemispace as being further away and longer than lines of identical orientation and retinal image in left hemispace.

the eyes. This arrangement will allow for the depth cues of accommodation and convergence to contribute significantly to participants' perception of near line depths, orientations, and lengths.

It is also assumed that there will be a noticeable drop in the utility of accommodation and convergence when viewing the far lines of the current proposal (with near ends about 70 cm from the eyes, and far ends about 82 cm from the eyes). Accordingly, it is predicted that depth cues will be less effective during viewing of far line pairs (i.e., the perceived differences between left and right line lengths should be less for far line pairs than for near line pairs).

The current study examines the perception of line length in depth. Despite the chief dimension being length, the experimental line stimuli are truly multidimensional, with size and position information being provided by line width in addition to line length. Perspective slant (not of the lines, but of the experimental apparatus arms containing the lines) and proprioception are also available to the participants during the experimental manipulations. While no dimension except length is being measured in the current study, it is still proper to think in terms of size constancy (physical matching) effects. This is because any veridical line length judgement cannot be based solely on retinal image (visual angle) information.

In summary, the Depth Cue model makes the following three predictions. It is predicted that depth cues at the left end of viewed lines will influence the left hemisphere perception of peri-personal lines in right hemispace as being further away (and therefore longer) than identical lines in left hemispace. The complementary prediction is that depth cues at the right end of viewed lines will then influence the right hemisphere perception of extra-personal lines in left hemispace as being further away (and therefore longer) than identical lines in right hemispace. Thirdly, it is predicted that depth cues will be less effective during binocular viewing of far line pairs because of diminished salience of accommodation and convergence cues. Accordingly, the difference in perceived differences between left and right lines should be less for far line pairs than for near line pairs.

Appendix E

Implications for Attributing Relative Perceptual Primacy between Left and Right Side Adjustments to a Central Control Line (of proposed Experiment 3)

Both hemispaces (left and right sides) were involved in every estimation of line length for Experiments 1 and 2; one hemispace for the comparison line and the other for the adjustment line. This meant that interpretations of differences between left and right hemispace (or hand) performance could not necessarily separate perceptual from motor aspects. This is why Experiment 2 (Staircase) was incorporated. Its successful completion would have allowed this attribution, regardless of whether differences were found or not between Experiments 1 and 2.

It was generally agreed at the committee proposal meeting that inclusion of Experiment 3 would remove additional confounds present in the first two experiments. Experiment 3 proposed to always use the same, central location for the comparison line. This would have allowed the changing of a single variable between different estimations of line length. Presumably, the results would have then been clearly attributable on the basis of that single variable manipulation. However, the inclusion of the central, horizontal comparison line (midsagittally located in the frontoparallel plane) would have introduced other confounds to negate the benefit of its inclusion in the study. Experiment 1 was designed to replicate the spirit of Heilman et al.'s (1995) feature of placing parallel lines in recession from the viewer, and clearly located in separate lateral hemispaces. The chief goal of this replication was to challenge Heilman et al.'s interpretation of the general literature findings of right hemisphere preference for distal vision and left hemisphere preferences for proximal spatial processing. It was crucial that the current design keep the feature of placing lines in depth from the viewer. This orientation was crucial for eliciting either Heilman et al.'s differential attention to near and far space, or maintaining the current theory's competition between the effects of physical size matching (size constancy) and retinal image matching (visual angle matching). The comparison line orientation of Experiment 3 would not have retained the characteristics required to allow comparison with either Heilman et al.'s (1995) theory or with the current model of retinal image and eye dominance effects. And even though the comparison would be constant throughout, there would have still remained multiple locations for visual attention for any single estimation of line length. Comparisons between estimations in left and right hemispace would still involve three spatial locations (left, right, and central) instead of the intended two. A discussion follows of the implications of trying to explain left/right spatial differences in terms of accurate perception versus over-perception or under-perception of space.

Argument 1. Assuming that central space has **no** left-right gradient bias (which is uncertain).

Experiment 3 had been proposed to explain differences between left and right line length adjustments by creating a situation where both adjustments were made to a single comparison line. With such a design, it was expected that left-right side differences could be clearly attributed to either over-estimations or under-estimations of actual size (and in which hemispace these erroneous estimations occurred). Yet this doesn't seem to be the case.

All models (and Figures) of this Appendix refer to a situation where three lines are judged to be of equal length despite unequal physical line lengths. Models A and B (see Figures E1 and E2) both illustrate the situation where line length judgements on the left side are placed significantly longer than line length judgements on the right side (with left side judgements matching the length of the central comparison line). Yet models A and B (amongst many possibilities) conflict as to whether over-estimation or under-estimation is occurring (along with the appropriate location of the erroneous perceptions).

Model A assumes that the perception of the central comparison line is accurate (see Figure E1). This accurate perception is recreated during left hemispace line placements. The under-placement of line length in right hemispace is then interpreted as a difference between spatial perception (representation?) of right space and a unified left space and central space. The three lines representing perceived line lengths are drawn identically because they represent the "same" perceptual length (as defined by participants' agreement that all three lines are of equal length). However, in right hemispace, the units of perceptual appreciation (whatever this truly means is still quite vague) somehow compress (i.e. they map onto a smaller line length than in the other two spaces). The nature of this compression is unclear. It seems more likely to occur in the horizontal direction than the vertical direction.

Model B assumes that the perception of the line in right hemispace is accurate (see Figure E2). However, perceptual appreciation somehow expands (i.e. maps onto a longer line length) in both left hemispace and in the central space. Once again, the nature of this expansion is unclear. Also, as with Model A, the three lines representing perceived line lengths are drawn identically because they represent the "same" perceptual length.

Three similarities between models A and B

1. The "perceptual appreciation" (psychological judgement of length) is identical between the three locations within a given model. This is defined by participants' agreement that all three are the same length.

2. The perceptual appreciation of left hemispace is identical with the central comparison space.

3. The three physical (mean) line lengths of Model A are identical to their corresponding line lengths of Model B (i.e. right side length is placed shorter than central or left line length for both models).

4. The theoretical unit (whatever that may be) underlying the perceptual appreciation of length in right hemispace is somehow more salient than that of both left hemispace and the central comparison space.

One crucial difference between model A and B

1. It is not possible to determine which region of space should serve as the comparison standard (i.e. which region of space has a "correct" match between its physical lengths and its perceived lengths.) If one is going to determine whether differences in line length judgement reflect over-estimation or under-estimation, then one must begin the process of logical comparison with an a priori definition (assumption) of

one of the three spaces as being "correct". Yet this can only be an assumption and cannot be shown to be fact.

What can be determined from either model A or B

1. Psychological perceptual units of length (whatever these may be in neural or representational or computational terms) are not consistent across all regions of space (these regions being defined in relation to the body).

2. One of these two equivalent situations is occurring, but we do not know which is the better phrasing:

   A. Right hemispace is under-placed (over-estimated) relative to left hemispace.

   B. Left hemispace is over-placed (under-estimated) relative to right hemispace.

3. Psychological perceptual units of length are consistent between central space and left hemispace.

How Models A and B are indistinguishable.

It is not clear how one could tell, from the difference between left and right side adjustments, whether model A or model B is correct, because both models can explain identical physical line adjustments. This design with the central comparison line cannot answer the question.

Argument 2. Assuming central space **does** have left-right gradient bias (which seems probable, from line bisection studies).

Experiment 3 had been proposed to explain differences between left and right line length adjustments by creating a situation where both left- and right-side adjustments were made from a single comparison line standard. With such a design, it was expected that left-right side differences could be clearly attributed to either over-estimations or under-estimations of actual size (and in which hemispace these erroneous estimations occurred).

Models A1 and B1 both illustrate the situation where line lengths on the left side are placed longer than the central comparison line length, and where line lengths on the right side are placed shorter than the central comparison line length (see Figures E3 and E4).

Both models assume that perceptual differences between left and right space continue to extend close to the body's midsagittal axis.

Three predictions which arise from Models A1/B1 but not from Models A/B.

1. Participants should place line lengths in right hemispace significantly shorter than the central comparison line length.

2. Participants should place line lengths in left hemispace significantly longer than the central comparison line length.

3. The ratio of left and right line placements should allow prediction of both (1) the size of the central line which would be judged equal to both left and right lines, and (2) the location (right of centre) where participants perceive the centre of the centre line (see Figure E5 for an illustrated example). [These calculations may be modified to incorporate an assumption of the gradient of space, such as whether the change was uniform or logarithmic (power function).]

Model A1 assumes that only perception of length in right hemispace is accurate (see Figure E3). It also assumes that perceptual appreciation of length in left hemispace is somehow increased when mapped onto visual objects.

Model B1 assumes the opposite; that only perception of length in left hemispace is accurate (see Figure E4). It also assumes that perceptual appreciation of length in right hemispace is somehow decreased when mapped onto visual objects. As with models A and B, the nature of this expansion is unclear.

Three similarities between model A1 and B1

1. The "perceptual appreciation" (psychological judgement of length) is identical between the three locations within a given model. This is defined by participants' agreement that all three are the same length.

2. The three corresponding physical (mean) line lengths within a given model retain these identical relationships: Left side length is placed longer than central length, and right side length is placed shorter than central length, for both models.

3. The theoretical unit (whatever that may be) underlying the perceptual appreciation of length in left hemispace is lesser than that of right hemispace, when both

units are mapped onto physical objects.

One crucial difference between models A1 and B1.

1. It is not possible to determine which region of space should serve as the comparison standard (i.e. which region of space has a "correct" match between its physical lengths and its perceived lengths.) If one is going to determine whether differences in line length judgement reflect over-estimation or under-estimation, then one must begin the process of logical comparison with an a priori definition (assumption) of one of the three spaces as being "correct". Yet this can only be an assumption and cannot be shown to be fact.

What can be determined from either model A1 or B1.

1. Psychological perceptual units of length (whatever these may be in neural or representational or computational terms) are not mapped onto objects consistently across all regions of space.

2. One of these two equivalent situations is occurring, but we do not know which is the better phrasing:

A1. Left hemispace is underestimated (i.e. lines are placed over-sized) relative to right hemispace.

B1. Right hemispace is overestimated (i.e. lines are placed under-sized) relative to left hemispace.

Discriminating between Models A1 and B1.

It is not clear how one could tell, from the difference between left and right side adjustments, whether model A1 or model B1 is correct, because both models can explain the identical pattern of physical line adjustments. This design with the central comparison line cannot answer the question. However, it is possible to discriminate between model(s) A/B and model(s) A1/B1, as follows:

1. Participants should place line lengths in right hemispace significantly shorter than the central comparison line length, for A1/B1. For A/B, participants should place right hemispace lines at the same length as the central comparison line.

2. Participants should agree (or indicate through pointing) that a location, right of

physical straight-ahead, is their perceived centre of the central line. The location of this perceived centre should be predictable from the ratio of a participant's left and right side length judgements.

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