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6. AUTHOR(S)
Leonard Matin

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The Trustees of Columbia University in the City of NY
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110 Duncan Avenue Room B115
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Report # 004

VISUAL PERCEPTION OF ELEVATION

AASERT AWARD: F49620-93-1-0563

Professor Leonard Matin
Department of Psychology
Columbia University
Schermerhorn Hall
New York, NY 10027

26 January, 1998

Final Report for Period 1 September, 1993 - 31 August, 1997

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Program Manager: Dr. William Roach
Department of the Air force
Bolling Air force Base, DC 20332

ABSTRACT

The 17 graduate and undergraduate students whose work was supported by the AASERT award participated to various degrees in different phases of the research. Several, more extensively involved, regularly joined in laboratory meetings, ongoing discussions, and formulation of research designs and plans in addition to participating in the construction of apparatus, and collection and processing of experimental data. Others were essentially focused on data collection and processing. The experiments were all concerned with the visual perception of elevation, most particularly with analysis of the significant influence of visual pitch on the elevation of visually perceived eye level (VPEL). An undergraduate's honor's thesis involved measurements of both VPEL settings and manual matches to targets through a range of elevations above and below VPEL, and showed that the influence of the visual field on VPEL was part of a shift of the entire dimension of perceived elevation along with closely related sensorimotor mislocalizations. A graduate student's master's thesis measured the relation between VPEL and the perception of visual pitch over a range of pitches on a large group of subjects; the mechanisms for both are at most minimally connected. The master's thesis is also serving as the basis for his Ph.D. dissertation (in progress).

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PROJECT TITLE: VISUAL PERCEPTION OF ELEVATION

SPATIAL ORIENTATION PROGRAM, DIRECTORATE OF LIFE SCIENCES
DEPARTMENT OF THE AIR FORCE
BOLLING AIR FORCE BASE, DC 20332

Final Report for Period 1 September, 1993 - 31 August, 1997

Principal Investigator: Professor Leonard Matin
Department of Psychology
Columbia University
New York, NY 10027

Date Submitted: January 26, 1998

Status of Effort, Work Accomplished, New Research Findings, Relevance to AF's mission, Publications, Objectives:

This is a final report on the ASSERT award that accompanied our AFOSR research projects originally entitled "Visual Perception of Elevation " during a portion of the 1-year period Sept. 1, 1993-August 31, 1994 (AFOSR-91-0146), and then " Visual Perception of Spatial Location and Orientation" for the remaining period of the first year and during the subsequent 3-year period Sept. 1, 1994 - August 31, 1997 (AFOSR Grant #F49620-94-1-0397). The main purpose of the AASERT grant was to provide support for graduate and undergraduate students to receive training while carrying out research work on the parent grant from AFOSR. During the four-year period considerable assistance was provided for us to carry out the main work of the parent grant and also to extend the research in several very fruitful directions that would not have been possible without the graduate and undergraduate students whose participation was supported by the ASSERT funds. During the four year period 13 undergraduate students and 4 graduate students at Columbia University were supported by the AASERT award for their participation in the research for various periods as workers in the laboratory. The research in which students were involved resulted in a number of full-length articles (we only list those published and in press below; a number of others are in preparation), and abstracts of presentations at meetings. The supported students participated in these, by way of joining in laboratory meetings, discussions, planning of the experiments, and as experimenters collecting and processing data. The major experiments that were carried out during the years of the AASERT award include: (a) Experiments that showed that although both the perception of pitch and the elevation of visually perceived eye level (VPEL) are systematically influenced by the angle of pitch of the visual field, they are governed by separate mechanisms (2, 6, 12, 15, 19, 21, 23, 27); (b) Experiments which determined the rules by which the influences from individual lines combine in determining VPEL; these included 2-line and 3-line combinations (7, 10, 11, 14, 17, 18, 20, 22, 24-26, 29). The major results include finding that the rules of combination for long lines in darkness involve averaging predominantly with a smaller component of additive summation, whereas the influences among individual short lines combine by additive summation. (c) Experiments which have demonstrated that although pitched and rolled lines in darkness exert identical influences on the elevation of VPEL, they do so regardless of whether or not observers can discriminate if they are rolled or pitched (27, 28). (d) Experiments which have demonstrated that the orientations visually perceived as vertical (VPV) and horizontal (VPH) retain their relation although both are systematically influenced by the same rolled lines; these latter lines also influence the physical elevation of VPEL (31).

Two students carried out major projects as theses; neither project is likely to have been done without the financial support to the students provided by AASERT. Copies of both are included with this report. They are both important extensions of our original efforts, have carried us into new intellectual ground, and both are now providing the basis for some significant restructuring of our efforts. Mr. Hudson's master's work has also provided the groundwork for his presently ongoing research, work that appears to be turning into a Ph.D. dissertation of considerable importance.

Mr. Todd Hudson's work (Columbia Univ. Grad. School; MA Thesis and Beyond): Although we have had a number of clear indications that that both the physical elevation of visually perceived eye level (VPEL) and the perception of the magnitude of pitch of a visual field are both systematically related to the physical pitch of the visual environment, we had also carried out two previous experiments that had shown clear separations between the mechanisms controlling the influence of visual pitch on the elevation of VPEL and on the perception of pitch – one experiment with a specially designed stimulus and a second with a visual agnosic – the extent to which the two mechanisms were related was not yet clear. Mr. Hudson measured both VPEL and perceived visual pitch (PVP) across a set of seven visual pitches through a 50° range of pitches on 20 subjects and found that although VPEL and PVP were each linearly related to physical pitch for each subject, and although there were large stable individual differences between subjects, only a very small correlation obtained between the measurements on the two perceptual modalities. This work was carried out in the pitchroom where VPEL was measured in the previously relatively standardized manner and PVP was measured by a visual matching technique with the comparison stimulus a small pitchable target viewed against a normally erect background. In addition to these measurements, measurements were made of performance on the same subjects on three separate tests of cognitive function that were previously reported to correlate strongly with the individual's susceptibility to influence from a rolled visual field on the visual perception of vertical. The tests of cognitive ability were the embedded figures test, the gestalt completion test, and the snowy pictures test. Although some interesting results were obtained with these latter measurements, no indication of any relation to susceptibility to visual influence on VPEL was found. The master's thesis has served as a basis and springboard for a Ph.D. dissertation. Mr. Hudson has now begun work on a new phenomenon that he discovered in some further work with our line stimuli. This is a monocular induction phenomenon ('monocular depth contrast') that is somewhat surprising. It is at least as large an effect as is the classical binocular depth contrast (which we measure also). But, in this case, subjects are able to perceive depth with monocular viewing (9, 30).

Mr. Ezra Robison's Undergraduate Honor's Thesis (Columbia College): From our first observations in the pitchroom in 1985 it was clear that some sensorimotor mislocalizations accompanied the visual mislocalization of visually perceived eye level (VPEL) in the pitched environment, and also that it was likely that the errors of elevation of VPEL pertained to the entire dimension of elevation. However, without a method for making quantitative sensorimotor measurements over a range of stimuli on the appropriate dimension there was no means of determining these things directly. Mr. Robison's Honor's thesis demonstrated the feasibility and utility of having subjects manually match the elevation of the visual target throughout a range of elevations, not only at the elevation of VPEL, and to do so under with the pitchroom at different angles of pitch. The method that was developed worked extremely well and demonstrated first that linear shifts in VPEL with pitch were accompanied by linear shifts in manual settings to the elevation of VPEL and in subsequent experiments that these shifts were accompanied by linear shifts of the entire dimension of perceived elevation along with manual shifts in the elevation of VPEL (8, 11). In addition the methodology was employed in both the entire well-illuminated, complexly-structured pitchroom and in the presence of the pitched-from-vertical 2-line stimulus in otherwise complete darkness; the results in both environments were essentially identical (8, 11). Thus, mislocalizations in vision are accompanied by essentially identical errors in perception of height at the plane of the viewer's body. These experiments have also provided the groundwork for subsequent experiments (in progress) involving measurements of manual settings of elevation to visually mislocalized targets at different distances between the plane of the subject's body and the plane of the visual stimulus; these will inform about a number of things including whether the errors in the pitched environment are due to pitch inducing a rotation of the entire visual field or a simply a change in elevation.

All of the following reports involved work by students supported on the ASSERT award. They were also listed and described in the annual report of the parent grant:

PUBLICATIONS INVOLVING WORK BY STUDENTS SUPPORTED by AASERT AWARD, AFOSR F49620-93-1-0563 (Sept. 1, 1993 - Aug. 30, 1997)

Principal Investigator: Leonard Matin, Columbia University

Full Length Articles: Published and In Press

1. Matin, L., and Li, W. (1995). Light and dark adaptation of visually perceived eye level controlled by visual pitch. ***Perception & Psychophysics,*** **57**, 84-104.

2. Matin, L., and Li, W. (1995). Multimodal basis for egocentric spatial localization and orientation. ***Journal of Vestibular Research,*** **5**, 499-518.

3. Servos, P., Matin, L., and Goodale, M. A. (1995). Visually perceived eye level in a visual form agnosic. ***Neuroreport*****, 6**, 1893-1896.

4. Li, W., and Matin, L. (1996). Visually perceived eye level is influenced identically by lines from erect and pitched planes. ***Perception*****, 25**, 831-852.

5. DiZio, P., Li, W., Lackner, J. R., and Matin, L. (1997). Combined influences of gravitoinertial force level and visual field pitch on visually perceived eye level. ***Journal of Vestibular research*****, 7**, 381-392.

6. Li, W., and Matin, L. (In press). Change in visually perceived eye level without change in perceived pitch. ***Perception.***

7. Matin, L., and Li, W. (In press). Combining influences from lines of different orientation on visually perceived eye level: I. Averaging and summation between two long lines. ***Vision Research.***

Undergraduate and Graduate Theses, Copies Appended

8. Robison, E. (1995). Manual matches to the elevation of visually mislocalized targets. Undergraduate honor's thesis, Columbia University.

9. Hudson, T. (1997). Independence of perceptions of visual pitch (PVP) and visually perceived eye level (VPEL). Master's thesis, Columbia University.

Published Abstracts of Presentations at Meetings and Symposia

10. Matin, L., and Li, W. (1994). Elements and combining rules for the visual influence on egocentric space perception. 35th Annual Meeting of ***the Psychonomic Society***, 26.

11. Matin, L., and Li, W. (1995). The great circle model: combining rules for the elements of visual influence on space perception. ***Investigative Ophthalmology & Visual Science*, 36/4**, S1069.

12. Li, W., and Matin, L. (1995). Influences on visually perceived eye level by tilted lines in a frontoparallel plane. ***Investigative Ophthalmology & Visual Science*, 36/4**, S669.

13. Robison, E., Li, W., and Matin, L. (1995). Manual matches to the elevation of visually mislocalized targets. ***Investigative Ophthalmology & Visual Science*, 36/4**, S358.

14. Matin, L. (1995). Elements and combining rules for space perception: the Great Circle Model. 7th ann. conv. ***American Psychological Society***, 28.

15. Li, W., and Matin, L. (1995). Perceived eye level changes without change in perceived visual pitch. 36th Annual Meeting of ***the Psychonomic Society***, 15.

16. Matin, L., and Li, W. (1996). Similarities between 3D color and egocentric orientation spaces. ***Investigative Ophthalmology & Visual Science*, 37/3**, S519.

17. Li, W., and Matin, L. (1996). Spatial summation of influences on perceived vertical by single tilted lines in a frontal plane. ***Investigative Ophthalmology & Visual Science*, 37/3**, S519.

18. Matin, L., and Li, W. (1996). 3D vector model for egocentric space perception. ***Proceedings in the Society for Neuroscience*, 22**, 884.

19. Hudson, T., Li, W., and Matin, L. (1996). Independence of visually perceived eye level and perceived pitch. ***Psychonomic Society***. 42.

20. Li, W., and Matin, L. (1996). Spatial summation of influences on visually perceived eye level by pitched-from-vertical lines. ***Psychonomic Society***. 43.

21. Hudson, T., Li, W., and Matin, L. (1997). Individual differences in cognitive styles and perception. ***Eastern Psychological Association.***

22. Matin, L., and Li, W. (1997). PDP model for the influence of line orientation on visually perceived eye level. ***Investigative Ophthalmology & Visual Science*, 38/4**, S1008.

23. Hudson, T., Li, W., and Matin, L. (1997). The perception of visual pitch does not determine visually perceived eye level. ***Investigative Ophthalmology & Visual Science*, 38/4**, S1008.

24. Li, W., and Matin, L. (1997). Spatial summation of influences on visually perceived eye level by three differently-pitched lines. ***Investigative Ophthalmology & Visual Science*, 38/4**, S1008.

25. Matin, L., and Li, W. (1997). Summation and averaging of visual influences on VPEL modeled by postsynaptic conductance change in orientation-selective system. ***Society for Neuroscience*, 23**, 175.

26. Matin, L., and Li, W. (1997). Spatial vision: from the stimulus through the single

nerve membrane to perception. 38th *Annual Meeting of the **Psychonomic Society***, 35.

27. Li, W., Hudson, T., and Matin, L. (1997). Pitched and rolled lines which influence VPEL identically are discriminable from each other. 38th *Annual Meeting of the **Psychonomic Society***, 59.

28. Hudson, T., Li, W., and Matin, L. (1998). A possible basis for visual roll/pitch discrimination utilizing the geometric normal. ***Eastern Psychological Association***

29. Matin, L., and Li, W. (1998). Combining orientations for the perception of space. ***Investigative Ophthalmology & Visual Science*, 39/4**.

30. Hudson, T., Li, W., and Matin, L. (1998). Depth contrast effects are not exclusively binocular. ***Investigative Ophthalmology & Visual Science*, 39/4.**

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

Manual matches to the elevation of visually mislocalized targets

Ezra Robison
with the help and supervision of
Wenxun Li
Leonard Matin

Columbia University

ABSTRACT

A subject, monocularly viewing a visual field with the top tilted towards or away from him or her will find that his or her Visually Perceived Eye Level (VPEL) is higher or lower respectively. It was found that information incorrectly obtained by viewing such a tilted field carries over from oral responses (i.e. the light is above my eye) to manual responses (i.e. raising a *yod* or pointer so that its elevation matches that of the stimulus'). Based on this information it was concluded (1) that pointing errors were similar in form to VPEL errors and (2) that the entire visual field was being translated upwards and downwards and being distorted. Matin and Li found that there was a small difference between a full visual field and two vertical lines (1992) and similarly the present study shows that manual matches to visual stimuli were affected less by two lines than by a fully illuminated visual field. It was further found that subjects often pointed too high to the highest stimuli and too low to the lowest stimuli. The yod was shown to be useful for investigating these phenomenon. In the dark there was no difference between monocular view and binocular viewing. There appeared to be an increase in accuracy in pointing to a target when the knowledge of distance to that target was no longer a factor.

INTRODUCTION

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Figure 1

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In figure 1, if the reader foveates the dark circle, then the square appears in the right half of the reader's visual field. If the reader then moves his or her eyes such that he or she is now foveating the light circle, then the square will now appear in the left half of the visual field. The readers should generally agree that the cause of the square's migration from the right to the left is caused by movements of the eyes rather then by movements of the square, but the source of the knowledge that allows the reader to say this is not so clear.

What is generally accepted about the mechanism for this task is that in order to differentiate between these two forms of movement the subject must have extraretinal eye position information (EEPI) to signal when a change in eye position has occurred. If this is the case then comparing changes in eye position with changes in the visual field will reveal whether the eye or the objects in the field or both have moved. Helmholtz, in his Handbook on Physiological Optics, suggested that "in the absence of visual cues, we only know how far we have moved our eyes by judging the effort of will put into moving them" (Helmholtz, 1866 / 1924). EEPI therefore comes from the command to move rather than the movement itself when the retina cannot supply that information. Figure 2A depicts the Outflow Model, in which the 'command source' projects two signals concerning intended movements. One signal is the command to move, sent to the extraocular muscles. The second signal contains information about the intended direction and magnitude of the movement. This signal goes to a comparator, located somewhere in the brain. A third signal containing information about the direction and magnitude of the change of elements in the visual field is sent from the retina to this same comparator. If the direction and magnitude of the change of elements is equal and opposite to the direction and magnitude of the eye movement, then the 'comparator' judges that the movement is internal. If there is a discrepancy between the two possible sources of movement then the comparator judges that the movement is, in part, external.

In 1894, Sherrington announced the discovery of sensory receptors in the extraocular muscles. He labeled these nerves as the source of EEPI (Merton, 1961). In his model, EEPI comes from sensors that detect movement that has occurred rather than from a signal denoting intended movement. Figure 2B depicts the Inflow Model, in which, after moving, the extraocular muscles send information about their new position to this comparator. The comparator also receives information from the retina concerning the displacement of objects in the visual field, and judges motion in the same manner as that of the Outflow model.

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Figure 2

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One major difference between these two models is the expectation of how each will handle the situation in which the eye is moved by an external force. According to the Outflow model, the retinal signal will note a change in position of objects in the visual field that will not be accounted for by any 'will to move.' The comparator will therefore understand the movement to be external. In the Inflow model, the extraocular muscles signal their new position after the eye is moved. The change in eye position is equal and opposite to that of the perceived change of position of the stimulus and the comparator therefore understands that the movement must be in the eye.

In 1961, P.A. Merton found that subjects were unable to foveate on the place where a stimulus had once been in otherwise total darkness. The subject's eyes would move without the subject's knowledge, suggesting that the eye did not have accurate position sense (Merton 1961). Furthermore, in trials where the eyeball was desensitized and sometimes restrained by forceps, subjects were unable to distinguish whether the eye had moved after they had commanded it to move (Merton, 1964).

In 1982, Matin and several colleagues carried out an experiment in which they partially paralyzed their extraocular muscles. It was hoped that this would shed some light on the accuracy of these two models. While partially paralyzed, the subjects reclined, focused on a stimulus and attempted to move their eyes, as shown in figure 3. In darkness, the partial- paralysis caused a remarkable effect. When curare, the paralyzing agent, is applied to the extraocular muscles, they produce some fraction of the neurotransmitter that they would have under normal conditions. Therefore, in order for the eye to move $\theta°$, say 20°, it will need to use enough neurotransmitter to move a larger angle $\phi°$, say 30°. After attempting such a movement, the comparator will think that it has moved $\phi°$(30°), see a change in position of objects in the visual field corresponding to a change of $\theta°$(20°) and conclude that the objects must have moved $\theta° - \phi°$ (10°).

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Figure 3

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What Matin et al found was that, upon asking a reclining, partially paralyzed subject to focus on a stimulus placed at his or her eye level in normal illumination he or she had no problem doing so. However, once the lights were extinguished, the stimulus slowly descended to the floor because of the process described above. With the lights turned on, the stimulus returned to eye level. This process was found to be repeatable (Matin, Picoult, Stevens, Edwards, Young and MacArthur, 1982). It appeared that the presence or absence of a visual field gave clues as to the location of the stimulus (in this case, particularly the vertical position).

This experiment demonstrated the importance of visual fields. In the absence of a visual field, the faulty EEPI signals indicated that the stimulus was near to the floor. In the presence of a visual field, faulty EEPI signals were entirely ignored. To further investigate the role of visual fields on the spatial perception of stimuli, Matin and Fox (1989) introduced the visually perceived eye level (VPEL) task. In this task, the subject is shown a stimulus that is arranged to be directly in front of him or her, but not necessarily at eye level. The subject then instructs the experimenter how to move the stimulus until it appears to be at his or her eye level. Matin and Fox sought out the relationship between angle of pitch and VPEL. No VPEL tasks had ever been run before, but other experiments had demonstrated the effect of changes in the visual field on perceived vertical (Witkin, 1948; Ebbenholtz, 1985; Mittlestadt, 1986). Many studies have found that, in the dark, the accuracy of subjects' perception of vertical is usually within 1° (Howard, 1966). Similarly, in the dark, normal subjects are able to perform this task fairly accurately (Matin & Fox, 1989). Using a pitchroom which is designed to rotate the visual field as a prism would, with the center of rotation at the subject's eyes, Matin and Fox demonstrated that a pitched, illuminated visual field affects VPEL. When the top of the visual field is tilted towards the subject (also referred to as positive pitch, figure, 4a) VPEL is higher. When the top of the room is tilted away from the subjects (also referred to as negative pitch, figure 4b), VPEL is lower (Matin & Fox, 1989).

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Figure 4

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The pitchroom has this effect on VPEL because of the way that the subject determines VPEL. When a subject is asked to make a VPEL judgment, the only information available to him or her is how the body is oriented with respect to gravity and how the body is oriented with respect to the visual field. Because of various laws of physics, these two sources of information have long enjoyed a close relationship whereby objects in our visual field are most likely to be either parallel or perpendicular to gravity, This relationship is so strong that the perceptual system is more sensitive to lines of these two orientations than to oblique lines (Howard, 1966). Similarly, it is expected that one's orientation to gravity will be the same as one's orientation towards the visual field. Both of these sources of information play such important roles during the VPEL task that the final judgment is always a compromise between the two conclusions that one would arrive at using each source individually. When the room is pitched 30°, VPEL is generally pitched between 15° and 25° (although never less than 0° or more than 30°).

Matin and Li further demonstrated that the same effect could be elicited from a visual field consisting of only two luminous lines (Matin & Li, 1992a), or even one luminous line (Matin & Li, 1994a). By using oblique, erect lines that cast retinal images identical to those of the pitched, vertical lines, Matin and Li were able to show that the effects were caused by the intersection of the Great Circle containing the lines' image with the Central Vertical Retinal Meridian[1] (Matin & Li, 1992b; Matin & Li, 1994b).

Recently, reports have emerged of phenomenon among subjects with blindsight where oral responses are not equivalent to manual responses (Weiskrantz, Warrington, Sanders & Marshall, 1979; Goodale, Jakobson, Milner, Perrett, Benson & Hietanen, 1994). Although there has been some evidence that the effects of the pitchroom on manual responses were similar to its effects on oral responses, it was necessary to test this in a more formal setting. Therefore, experiment 2 was performed, in which subjects were asked to match the vertical position of stimuli at various angles of pitch. It was hoped that this would demonstrate that the pitchroom has the same effect on manual responses as it does on oral responses. Experiment 1, actually performed after experiment 2, was used to demonstrate that the method of pointing used in these experiments was providing reasonable data. Impetus for this experiment came from evidence that accuracy of pointing used in these experiments was not as high as that of the VPEL task used in previous experiments.

Initial evidence that the pitchroom would exert a similar effect on manual responses came from informal settings where individuals seated within the pitchroom (pitched 30°) set a target at perceived eye level and were then asked to reach out with their hands and interrupt the beam from the laser creating the stimulus. Invariably, people who were told that the path of the light was horizontal expected to cut off the light by putting their hands in the vicinity of their eyes. Similarly, Goodenough et al noted that manual judgments of perceived vertical were similar to those of non-manual responses (Goodenough, Oltman, Sigman, Rosso & Mertz, 1979).

Based on these findings, subjects were asked to point, one at a time, to an array of lights, centered about VPEL, at each of six angles of pitch. Since VPEL is linearly related to pitch of a visual field, the heights of these five points also varied from condition to condition. Additionally, informal experiments have revealed that the perceived height of a person standing in front of a pitched visual changes with changes in pitch. Someone in front of a negatively pitched field may

1 analogous to the prime meridian on a globe.

appear to be seven feet tall. In front of a positively pitched field he may appear to be standing in a hole. It was hoped that by studying the manual matches to the array of five visually perceived stimuli at each pitch it could be seen whether the field of vision appears to be expanding and contracting or whether these comments are just a consequence of the translations of visual field associated with changes in pitch.

Unfortunately, the inclusion of pointing in this paradigm introduces many new opportunities for error and therefore confounds the data. Daniel Bullock and Stephen Grossberg's Vector Integration to Endpoint (VITE) model for pointing will be useful in addressing these various problems (Bullock and Grossberg, 1989).

This model consists of four subunits: the GO signal, the Present Position Command (PPC), the Target Position Command (TPC), and the Difference Vector (DV). The GO represents the will or motivation to move. The PPC and TPC contain the coordinates of the hand and stimulus respectively and the DV is the difference between the PPC and the TPC. In the VITE model, the act of pointing can be seen as an iterative set of operations in which the PPC is instructed to move in the direction of the DV (towards the TPC) until the DV is equal to 0. A neuronal population in the motor cortex of rhesus monkeys has been identified which responds specifically to the direction of a target during pointing tasks (Georgopoulos, Kalaska, Caminiti & Masses, 1982; Georgopoulos, Schwartz & Kettner, 1986). These findings support the idea that the sensory motor system points using vector maps.

This model, however, more accurately describes a reaching procedure than a pointing procedure for several reasons. For one thing, this model assumes that it is possible for the DV to reach 0, whereas in a pointing task, it is very likely that this is impossible. If a similar mechanism is responsible for pointing, here are two possible modifications that would incorporate this kind of task into the model. Given a set of constraints (the length of the arms in the case of this experiment, the fact that all manual localization is done in one dimension while visual localization is done in three dimensions), either the DV is minimized or some intermediate point is identified as representing the 'correct spot' by virtue of the fact that is in the right direction. This spot becomes the new TPC and the process is completed as described above.

In the present set of experiments, the GO signal is given by an instruction from the experimenter, the TPC is initially a target on the opposite wall and the PPC is the subject's hand, holding the pointer. Because the subject's hand is constrained such that it can only move in one dimension, the DV can never be set to zero. However, there is a point where the DV is minimized and perhaps this can be thought of as the new TPC.

Other problems are raised. In order to estimate the height of a visually perceived target in space using one's hand, the subject must first locate the target in space visually. As has been shown, there is some error introduced at the perceptual stage (Matin & Fox, 1989). Then coordinates in external space must be converted into coordinates in internal space so that proper commands can be issued to the motor system. Soechting and Flanders reported that the majority of error occurs during this stage (Soechting & Flanders, 1989). Also, Merton demonstrated that there was error associated with manual localization on the same order of magnitude as that of visual localization (Merton, 1961). It has been stated that on many manual tasks, vision of the arm improves (Sivak and MacKenzie, 1990), even if only at the beginning of the experiment (Prablanc, Echallierm, Komilis & Jeannerod, 1979). Although this experiment never involves pointing with a visible hand, it is important to note that the specific lack of visual guidance during this task could be introducing additional error. By contrast, fixation on the target (which is present in every pointing-to-visual- stimulus task in this experiment) has been shown to improve accuracy (Biguer, Jeannerod & Prablanc, 1982).

A further problem arises specifically from the fact that these experiments are carried out monocularly. Perceived distance has not been known to play a role in the VPEL task, however, points elsewhere in the visual field are likely to be affected by incorrect judgments of distance. As is seen in figure 5, if the subject mislocalizes such a point, it is difficult to differentiate between errors in judging the angle α and errors in judging the distance d. Reports have been made that direction is more accurately judged than distance (Soechting & Flanders, 1989; Sivak & MacKenzie, 1990) however it is not at all clear that these results are generalizable. If errors are being made in judging the distance, this is an additional problem because there is no clear answer as to how distance evaluations are made. Experiments involving the study of distance perception often contain more questions about the accuracy of depth perception than possible mechanisms. Wallach and Norris favor accommodation as the primary depth cue (Wallach & Norris, 1963). Grossberg favored convergence over retinal cues (Grossberg, 1993) but others have rejected the notion that distance perception can be achieved with any accuracy at all (Heinneman, Tulving & Nachmias, 1957; Foley, 1980). Because of the general feeling that binocular vision improves perception of distance, experiment 3 was designed to compare monocular and binocular vision on this task. Experiment 4 investigated this problem by using two different experimental designs for pointing at the same targets, one which involves making the vertical estimation which has been used in the previous three experiments and one which only requires the subject to point in the direction of the target so that distance is no longer an issue.

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Figure 5

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METHOD

Subjects

All four experiments used subjects who were associated with Columbia University. Their ages ranged from 19 to 40. Some subjects participated in more than one experiment. The breakdown of subject by experiment was as follows:

Experiment 1 (7): SA, VC, AD, NL, WL, NR, ES

Experiment 2 (13): SA, VC, GD, AD, NL, WL, GP, LP, NR, ES, JS, RS, JW

Experiment 3 (7): SA, VC, AD, NL, WL, NR, ES

Experiment 4 (8): SA, TC, MJ, CL, WL, ZM, GT, ST

In experiment 2, subject JS began the experiment but did not complete it. His data was not used in calculating averages although some observations were made based on the sessions he did complete.

Some subjects (n=5) were chosen because they currently worked in Professor Matin's laboratory at Columbia, some (n=15) volunteered. All subjects were paid an hourly rate. Subjects who had worked in the lab prior to these experiments had some experience with VPEL related tasks. The volunteers were naive. 8 of the 20 subjects were women. Two subjects were left-handed: VC used her left hand throughout the experiments but because of the technical difficulties in the fourth experiment, TC had to use her right hand. Information about dominant hand was not used to draw conclusions in this experiment.

The first and third experiments both used the same seven subjects, all of whom participated in the second experiment. The fourth experiment used eight subjects, three of whom had participated in earlier experiments.

Subjects' heights ranged from 5'1" to 5'11". Four subjects in the second experiment (SA, AD, NR and ES) participated in both conditions in which the visual field was fully illuminated and conditions in which the entire visual field consisted of two vertical lines (see below). Four subjects (VC, NL, WL and JW) only participated in the full-room condition and four (GD, GP, LP, RS) only participated in the two line condition.

Design

These experiments' purpose was to measure the relationship between the pitchroom's effect on oral responses and the pitchroom's effect on manual responses. Therefore, we compared VPEL to manual to visual matching (MVM) as both were affected by the angle of pitch (pitch). VPEL was defined as the height of a stimulus when the subject is content that it is at his or her eye level. True eye level is defined as the plane, perpendicular to gravity, that passes through the subject's eyes. VPEL is measured in degrees visual angle. This is defined as the degrees in $\angle SRV$, as seen in figure 6a. $\angle SRV$ is defined by the two vectors, **v** and **t**. Vector **t** passes through the subject's retina (R) and a point (S) on the opposite wall such that line RS is perpendicular to gravity. Vector **v** passes through the subject's retina (R) and the point where he or she set the stimulus during the VPEL task (S'). MVM is defined as the height of the yod (see materials, below) when the subject is asked to match his or her index finger to the height of a stimulus. MVM is measured as the degrees in ∠SRV, as seen in figure 6b. ∠SRV is defined by the two vectors, **h** and **p**. Vector **h** passes through the subject's index finger (H) and a point on the opposite wall (S) and is perpendicular to gravity. Vector **p** passes through the subject's retina (R) and point S. MVM_{TEL} is defined as the special case of MVM in which the stimulus is specifically set to the height of the subject's True Eye Level (TEL). MVM_{VPEL} is defined as the special case of MVM in which the subject is pointing to a light that he or she just set so that it matched his or her VPEL. Kinesthetically Perceived Eye Level (KPEL) is defined as the height of the subject's index finger when the subject sets the yod to his or her own eye level with his or her eyes closed. It should be noted that KPEL is also measured in in degrees visual angle despite the fact that it does not involve any visually perceived stimuli. This is done so that comparisons can be made between MVM tasks and KPEL tasks. For the sake of the first experiment, a mislocalization of x centimeters is equivalent in degrees to a mislocalization of the same amount of centimeters on the MVM_{TEL} task. The act of taking MVM or KPEL measurement will be referred to as 'pointing'. Pitch is defined as the angle defined by the ceiling of the pitchroom (see materials, below) and a plane parallel to the floor. Our convention is that negative angles of pitch represent conditions in which the top of the rear wall is tilted away from the subject (also referred to as top-backward) and that positive angles of pitch refer to conditions in which the top of the rear wall is tilted towards the subject (top-forward).

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Figure 6

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After each trial, VPEL and MVM was recorded in centimeters and the converted into degrees visual angle using the following equation:

$$\text{VPEL or MVM} = \arctan (1/[(D/H) - \tan \theta] \qquad (1)$$

where H is the distance from the actual location of the stimulus to the perceived location of the stimulus, θ is the visual pitch and D is the distance from the subjects eye to the visual field in the plane of true eye level (not necessarily the shortest line). Since the length of the normal from the subject's eye to the visual field was kept constant at 100 cm, D could be calculated as

$$D = 100/\cos\theta \qquad (2)$$

These two equations can be derived from basic geometric principles. One degree visual is equal to about two and a half centimeters around the vicinity of true eye level.

Materials

The pitchroom used in these experiments is the same as the one that Professor Leonard Matin has used in his previous experiments (Matin, 1989, 1992). It is approximately 150 cm x 190 cm x 225 cm in size. In the full room condition, the brick-patterned wall papering (with some irregularities) is visible to the subject on three walls, not including the rear wall. The ceiling is visible but not the floor. In two-line conditions, the entire visual field consisted only of two vertical, luminescent, lines. While in the room, the subject sits in a chair with his or her chin in a chin rest. The subject wears a cape around his or her neck that is designed to block the subject's view of the floor.

The yod used for pointing consists of a relay rack with a platform attached to the inside of the track on which the subject may rest his or her index finger (see figure 7). The platform is attached to the track by magnets which serve a dual purpose. They allow the subject to move the platform with relatively little resistance and to leave the platform in a fixed position when he or she is done moving it. The latter action allows the height of the platform to be read off of a tape measure running vertically along side of the track. The subject wears an eye patch over the eye that is ipsilateral to the hand he or she is using to make MVM judgments. The eye patch also serves two purposes. The first is to eliminate any binocular cues that the subject may have otherwise received. The second is to remove any visual cues that the sight of the yod may have offered. The stimuli were provided by a low powered He-Ne laser from behind the subject in experiments 1, 2 and 3. In experiment 4, stimuli were produced by LEDs. The color of the stimulus was always red.

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Figure 7

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In the second condition of visual field, two vertical, parallel, 140 cm luminescent lines, 92 cm apart were inserted onto the rear wall of the pitchroom using velcro. In this experiment, these two lines served as the entire visual field.

No additional equipment was used in experiments two and three, but experiment four also used the scleral search coil for pointing. This consisted of a contact lens was attached to the subjects' index fingers while they held on to a pole. Subjects were able to rotate their hands around the pole in order to point toward stimuli and press a button to signal that they had completed the task. A computer recorded the angle of their finger after the button was pressed.

Procedure

For the first experiment, the pitch room was always in complete darkness. Subjects were asked to grasp the yod in such a way that their index fingers were on top of it. Subjects were asked to point twenty times to their own TEL (KPEL trials) and twenty times to a stimulus which was set to be at the same height as their TEL (MVM_{TEL} trials). Subjects did not know that these stimuli were set at TEL. The initial position of the yod alternated between above TEL and below TEL throughout all four experiments, but only in the first experiment was the data analyzed by initial condition.

The subject's TEL was measured before and after each session in each experiment by matching the laser with the corner of the subject's eye (while he or she sits with his or her chin in the chin rest). The first session of the second experiment was a calibrating session, in order to find how much effect the pitch room had on each individual subject[2]. Therefore, the session consisted of six experimental conditions (-30°, -20°, -10°, 0°, +10° and +20°) with control conditions in total darkness at the beginning and end of the session. A trial consisted of two tasks. First, the subject set the target so that its height matched his or her VPEL by issuing instructions to the experimenter. Second, the subject pointed to the target by manually raising or lowering the yod so that the height of his or her index finger matched the height of the stimulus, now set to VPEL.

2 In Matin and Fox, (1989) among other places, it is noted that some individuals are affected more by the pitch room illusion than others. The slope of the best fitting line for VPEL as a function of pitch ranged from +0.45 to +0.78.

Four trials are preformed during each condition. For each subject, experimental conditions were tested in a random order.

The second part of the second experiment was divided into two sessions because of lengthiness. In these sessions, the trials during experimental conditions only involved MVM measurements. A set of five targets centered around VPEL (with the other four stimuli being ±10 and ±20 cm above VPEL) were shown one at a time to the subjects. This means that the target heights themselves changed from condition to condition. When VPEL was above TEL, the targets were all placed higher. When VPEL was below TEL, the targets were all lower (see figure 8).

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Figure 8

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No VPEL measurements were taken until the end of the session. These four final VPEL measurements were taken to look for across session variation as well as to insure that the range of heights of stimuli still applied to the subject. Otherwise, these sessions consisted of three experimental conditions (the six experimental conditions divided randomly) with control conditions in total darkness at the beginning and end of each session. In these two sessions, each condition consisted of making fifteen MVM measurements, three at each of five different stimulus heights. VPEL for each pitch was found by creating a regression line based on the data taken from the first session.

Originally, the order in which the fifteen stimuli appeared in any given condition was purely random. But in the middle of the data-collecting period this system was changed so that now the stimuli appeared in blocks of five, each block containing each of the five different possibilities, in order to test for the confounding influences of practice and fatigue. Another mid-process addition was an additional KPEL measurements before and after each session.

Additionally, these experiments were set up to investigate the phenomena that led a subject to perceive the height of a person, standing in front of a pitched visual field, to expand. In order to further study this effect, we will define Ψ as the slope of the regression line of MVM as a function of actual height of stimuli in that condition. It is assumed that if Ψ increases, it is because the targets, whose distance from one another remain constant, appear farther apart.

The third experiment consisted of the subject making 15 MVM measurements (3 measurements at each of 5 heights, appearing in randomized blocks) in three different conditions. The subjects made judgments using each eye monocularly and binocularly. The order of these three conditions was also randomized. Afterwards, four VPEL and four KPEL measurements. All measurements were taken in total darkness.

The fourth experiment involved subjects pointing to a set of three stimuli that were separated by 30 cm, centered at TEL. The increased space between the stimuli was to accommodate the higher standard deviation associated with the new method of pointing. Using this method, 1° of error is equal to about 1 millimeter. In this experiment, subjects were asked to point at stimuli both in the same way as in the other three experiments and by holding on to a rod and rotating their fingers until they were pointing in the right direction. Under these conditions, accuracy was measured by comparing the direction in which they pointed to the correct direction from their finger to the stimulus as opposed to the other method in which accuracy was found by comparing the height of the yod when the experiment was finished with the height of the stimulus. Subjects pointed six times to stimuli at each of three heights. Subjects were asked to put their finger in a horizontal position before and after pointing by holding onto the rod in order to check for any constant errors created by a natural bias or an improper attachment of the coil to the finger.

RESULTS

The Hypothesis

The hypothesis being tested throughout these four experiments is based on previous experiments performed by Dr. Leonard Matin. If a subject perceives his or her eye level to be below TEL, then all stimuli which appear above VPEL should cause the subject to point above TEL. Similarly, stimuli which appear below VPEL will cause the subject to point below TEL. If this is the case, in conditions in which VPEL is translated downward (negative pitch) all stimuli will appear to be translated upwards because of the change in distance from the stimulus' height to VPEL. In conditions in which VPEL is translated upwards (positive pitch) all stimuli will be translated downwards. More specifically, the hypothesis states that errors in pointing to these stimuli should be equal in magnitude to errors in VPEL at any given pitch.

Before embarking on the process of showing that the result of pointing to stimuli in a pitched field is any different then the result of pointing at stimuli in non- pitched fields, it is important to demonstrate that the yod is an effective mechanism to use in the study of perceived elevation. There are two basic errors that the yod could be introducing: a consistent bias in one direction and decreased reliability from trial to trial. Indeed there does appear to be some bias, although not very much. Almost all subjects, when pointing to their own eye level (KPEL task) in total darkness, pointed too high. The average mislocalization in the first experiment was 2.4° ± 1.8° (5.5 cm ± 4.0 cm). This error may have arisen from a number of sources. The subjects may have been setting the yod, rather then their index fingers, so that its height was equal to their own eye levels. There may have been some error introduced in moving the yod because of the resistance caused by the magnets holding the yod in its track. Or the problem could have been related to the calibration of the apparatus. In any case, the bias was consistent but small, less than the length of a nose, and therefore not deemed a serious problem. Reliability errors were not found to be as large. The average standard deviation in the KPEL task was 0.43° ± 0.21°(1.0 cm ± 0.5 cm), less than the bias introduced.

Another concern was that the perceived elevation of stimuli, as measured by the yod, would be dependent on the initial position of the yod. However, it is seen that KPEL trials in which the yod started above TEL and KPEL trials in which the yod started below TEL produced very similar results. With the yod below TEL, the mean KPEL was 2.4° ±3.16°, with the yod above TEL, the mean KPEL was 2.3° ± 1.43°. The mean difference between conditions with the initial position of the yod above TEL and conditions with the initial position of the yod below TEL was 0.1° ± 1.13° and in 5 out of 7 subjects, the individual mean difference was less than the standard deviation.

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Table 1

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Using visually perceived stimuli instead of kinesthetically perceived stimuli had a noticeable effect. The average standard deviation on the MVM_{TEL} task was 0.94° ± 0.55° (2.5 cm ± 1.4 cm), about twice that of the KPEL task, but still acceptable. When the yod started below TEL, the mean MVM_{TEL} was 2.0° ± 1.69° and when the yod started above TEL, the mean MVM_{TEL} was 2.1°± 1.43°. The mean difference between initial positions of the yod was <0.1° ± 0.94°, giving very strong evidence that initial position of the yod played very little role in the subjective estimation of heights of stimuli, whether they were visually perceived or kinesthetically perceived. The standard deviation across subjects on the MVM_{TEL} was much larger than the standard deviation across subjects of KPEL (5.67° as compared to 3.47°) accentuating the fact that the addition of vision into the procedure caused more individual variation. Individual data on the differences between these two localization tasks is listed above in table 1.

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Table 2

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Table 2 shows that the difference between KPEL trials and MVM_{TEL} trials is very closely related to VPEL (r=.889; n=7). The current hypothesis being tested in these experiments would predict this result. Further, the observed relationship between KPEL and MVM_{TEL} agreed with the hypothesis. Subjects who had a natural bias to perceive VPEL above TEL pointed to visual stimuli at TEL as if they were below TEL. Subjects who had a natural bias to perceive VPEL below TEL pointed to visual stimuli at TEL as if they were above TEL. Note that the difference between MVM_{TEL} and KPEL was generally greater than VPEL.

Experiment 2

In the first session of the second experiment, subjects were asked to instruct the experimenter to move a stimulus up or down until the subject perceived it to be at eye level. After the subject was satisfied that the stimulus was at eye level, he or she was asked to point at it (MVM_{VPEL}). The graph of VPEL as a function of pitch turns out to look like that of Matin's previous VPEL studies (Matin 1992a; Matin 1992b; Matin 1994a) as is seen in figures 9 and 10. The function is linear with a slope of 0.69 in fullroom condition and 0.61 in twoline condition. Also shown in these 2 figures are the slopes of MVM_{VPEL} as a function of visual pitch. The slopes of these two lines are 0.00 and 0.06 respectively.

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Figures 9, 10

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In previous experiments, Matin had found that the effect of the two-line condition was slightly less than that of the fullroom condition. This was also found to be the case in the first session of the experiment, whether comparing the mean of the four subjects who participated in both conditions or the mean of all 8 subjects in each condition. Means and standard deviations for slopes are found in table 3.

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Table 3

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The subjects, satisfied that they had set the stimulus to eye level always pointed around the height of their TEL. The mean mislocalization of MVM_{VPEL} from TEL was $0.0° \pm 1.91$ for fullroom experiments and $0.0° \pm 1.62$ for the twoline experiment. It is impossible to tell from the data whether subjects were pointing to the height of the stimulus or where they knew their TELs to be. Although this data is inconclusive, it is important that subjects pointed inaccurately in this manner. The rest of the procedure that follows is dependent on the assumption that perceptual errors caused by the pitchroom will carry over to the motor system. It is interesting to note that, on average, subjects pointed closer to TEL on this task than on the KPEL task. There is no easy explanation for this.

Once it has been established that subjects were able to use the yod to point reliably to one visually perceived stimulus, it is important to show that subjects were pointing to different stimuli in a predictable manner. In total darkness, subjects were asked to point at stimuli that appeared in five different locations, 0, ±10, ±20 cm away from VPEL. Under these circumstances, there was a reasonably high correlation between the true height of these stimuli and MVM values ($r=.791$; $n=960$). Subjects pointed higher at higher stimuli and lower at lower stimuli although, not with great accuracy.

The data from lit conditions (fullroom and twoline) did agree with the hypothesis. As seen in figure 11, when the

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Figure 11

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pitchroom was pitched -30°, VPEL was low enough so that the stimuli which the subjects were asked to point at were always below TEL. Nevertheless, the subjects point to those lights that were above VPEL as if they were above TEL and they pointed to those lights that were below VPEL as if they were below TEL. These results support the hypothesis. Because VPEL has been shifted down in this condition, MVM for all stimuli are above actual stimuli height. These results were found to be duplicatable in any condition of pitch for either fullroom (see figure 12) or twoline (see figure 13) conditions.

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Figure 12, 13

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Because the array of stimuli that the subject was asked to point at was always centered around VPEL, subjects always pointed to the same location, despite the fact that VPEL varied from condition to condition, signifying that the actual heights of the stimuli varied from condition to condition. Figure 14 demonstrates that, although the region in which the visual targets can be found varies from condition to condition (dark bars), the range to which the subjects pointed remained constant (light bars). The subject RS consistently pointed to a smaller range of heights than the stimuli themselves covered, showing very little variation from condition to condition. Far more common, subjects like SA pointed to a larger range of heights than the stimuli covered.

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Figure 14

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This was taken to mean that the amount of expansion was constant and therefore independent of pitch. However, when Ψ was plotted as a function of pitch, either in degrees or centimeters their turned out to be a second order relationship between them (see figure 15). Maximum expansion was observed to occur when the room was erect (no different than any other visual stimuli that one encounters) with expansion decreasing as the magnitude of pitch was increased.

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Figure 15

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In experiment 3 there was little difference in accuracy noted between conditions in which subjects used monocular or binocular vision. With monocular vision the average error (in either direction) was $5.84° \pm 4.36°$. With binocular vision the average error was $5.26° \pm 3.91°$. Although binocular measurements had a slightly higher accuracy, it is evident that having binocular vision did not give any additional information towards locating visually perceived stimuli. Paradoxically, there did seem to be a slightly larger Ψ in binocular vision than in monocular vision, 2.56 ± 0.59 as opposed to 2.20 ± 0.71 ($p > .10$).

In experiment 4, standard deviation for measurements taken using the scleral search coil were typically higher than standard deviations using the yod leading to a greater average error in estimating the direction in which stimuli appeared than in estimating the height of these same stimuli. This could well be attributable to the nature of the movements. An error of 3° using the scleral search coil means that the tip of the index finger was 3 millimeters away from the place representing accurate pointing. Using the yod in this condition, an error of 3° means setting the index finger close to 7 centimeters higher or lower than the spot that would represent accurate pointing. Under these circumstances it is difficult to say that subjects were any less accurate with scleral search coil than they were with the yod. In fact it certainly seems as if they were more accurate. Further, the expansion associated with the yod was much greater than that of the scleral search coil. Differences between the pointing with the yod and pointing with the scleral search coil are seen in table 4, below.

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Table 4

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DISCUSSION

The data from experiment 1 suggests that some error is introduced into the pointing process either during the perceptual stage or in the communication between the perceptual and motor stages. Subjects were able to locate their own TEL which they perceived kinesthetically with greater accuracy than they were able to locate a stimulus on the opposite wall which they perceived visually. Errors introduced in the MVM_{TEL} are in most cases, in the direction predicted by mislocalization of VPEL. It is possible that the lower standard deviation associated with KPEL is due to the proximity of the target (the physical eye as opposed to a target located 1 meter away at eye level) but this cannot be concluded from the data.

More importantly, this experiment demonstrates that the yod is providing reasonably accurate records of subjects' estimations of heights of stimuli. The measurements made using the yod were not affected by initial condition, but were affected by VPEL biases. Those subjects who were known to estimate their VPEL to be below TEL pointed to objects in the visual field as if they were higher and vice versa. The yod therefore provides us with a reasonable method of measuring perceived elevation of visually perceived stimuli.

While we cannot hope for conclusions to be made about the process of pointing itself based on these, experiments, some observations may be made. In the introduction, two mechanisms for pointing were proposed based on the VITE model. In the first, subjects found the minimum DV and in the second, subjects identified a new target in space as representing a position between the TPC and the PPC. When using the yod, since all pointing tasks were specifically constrained to take place in one dimension, there was only one position in which the hand could be pointing in the right direction. However, since it was not easy to locate this position most subjects performed a set of actions that looked as if their goal was to find a minimum. They moved their hands up and down, judging when they had gone too far and turning around, until they were satisfied that no point in the immediate area was better. However, in situations in which there are an infinite number of positions that are in the right direction, it would make more sense to begin by identifying a new target that represents pointing in the right direction. A few subjects appeared to be doing this, locating a point on the track and moving their hand right to it. Conversation with subjects who appeared to be using these two methods of pointing did not reveal anything.

The data from experiment 2 shows conclusively that manual responses, made using the yod, were both accurate and affected by the pitchroom in the same manner as the oral responses made during the VPEL task. Although the translation associated with the MVM task was larger than the translation associated with the VPEL task, the translation of the MVM measurements was always in the predicted direction and had a linear relationship with the amount of pitch. Therefore, it appears that the effects that the pitchroom exert on the visual field will be the same, independent of the method of measuring them. This means that it is possible to examine what is happening to the visual field when the room is pitched, especially with regards to the comments mentioned in the introduction - namely that at a normal sized person standing in front of a visual field that was pitch negatively would appear to be taller.

Two likely explanations of this phenomenon are that (1) There is a linear relationship between angle of pitch and expansion of visual field with negative pitches causing more expansion than positive pitches, or (2) The fact that a person appears to be seven feet tall or standing in a hole is entirely related to the perceived relationship between the viewer and the viewee, and that expansion is a constant, independent of angle of pitch. The second theory would explain why people may appear to be seven feet tall but never appear to be four feet tall. It is possible that these comments were made based on one specific part of the viewed person's body, for example, the eyes. If the viewer perceived the viewee's eyes to be elevated (as are all objects in front of a negatively pitched visual field) then the idea that the viewee had grown may have seemed a reasonable explanation to the viewer. Likewise, the idea that the viewee was standing in a hole may have seemed the best way to explain that the viewee's eyes now appear lower than they had. It is possible that expansion does not enter into the explanation of these comments at all. The data supports the latter explanation, but not for the reason expected. The average expansion at -30° pitch is not much greater than the average expansion at +20, suggesting that estimations of the viewee's heights was entirely dependent on translation as a function of pitch. However, expansion was not a constant, but rather had a second-order, non-linear relationship with the pitch of the visual field. It is not clear what is causing this effect. One possible explanation is that the geometry of the situation is responsible.

At any given angle of pitch, the degrees visual angle that the array of targets subtends is equal to

$$\operatorname{acos}(x) + \operatorname{acos}(c-x) \qquad (3)$$

where c is the actual range of targets in Euclidian space defined as

$$c = 40 \sec \theta \qquad (4)$$

for any angle of pitch θ, and x is the amount of this range on one side of the normal (as seen in figure 16). By setting the first derivative of equation (3) equal to 0, one finds that a maximum visual angle occurs when $x = c/2$, or in other words, when the center of the range of targets coincides with the normal. Since VPEL is always at the center of the range of targets, this would mean that VPEL would have to coincide with the normal from the eye to the visual field. In order for that to happen, the slope of VPEL as a function of pitch has to equal 1 (otherwise VPEL will fall short of the normal) and that never happens, except when there is no pitch and VPEL is close to 0°. This shows that the amount of visual angle subtended by the range of targets will only be at a maximum at 0° and will be smaller at every pitched condition. The range will therefore appear smaller in pitched conditions, yielding the parabola seen above.

However, this assumes that all subjects set their VPEL to TEL in an erect visual field. This is not the case, with individual subjects having individual biases. Subjects whose bias leads them to set their VPEL 10° lower at -10° pitch will see the largest of stimuli at that condition. This explains why their is some slight fluctuation as to where the peak of the parabola occurs.

The data from experiment 3 showed that little accuracy was gained by performing the task using binocular vision. It was hoped that the results from this experiment would lend evidence towards the question of whether the accuracy of these pointing tasks was dependent upon the subjects perception of the distance to the target. If authors such as Heinneman, Tulving & Nachmias and Foley are correct, then the subjects received no better idea of the distance from themselves to the stimulus in binocular conditions than they had in monocular conditions. There is clearly some difference between the two conditions because all subjects showed a larger expansion of visual field in the binocular conditions but it is not clear what could be causing this effect.

The data from experiment 4 suggests that the lack of knowledge of distance during these tasks is important. Although subjects were less accurate in identifying the direction of visually perceived targets using the scleral search coil, they pointed to a range that was much closer to being correct than when they estimated the height of the stimuli using the yod. It is assumed that the task of determining the direction of a target does not involve any a priori knowledge of the distance to that target, as does the task of determining the height of this target. If this assumption is correct than it is reasonable to conclude that the uncertainty in estimating distance is in part responsible for the expansion.

Furthermore, there does seem to be some relationship between the distance to a target and the accuracy and Ψ associated with tasks involving the yod. When subjects were performing KPEL tasks, where the target was right next to their head, standard deviations were at their lowest. Pointing at visually perceived targets, 1 meter away (such as in experiments 1-3) caused much larger standard deviations. The largest standard deviations associated with using the yod came from experiment 4, in which targets were now 1.3 meters away. Furthermore, as more information was available for estimating distance, Ψ decreased. It was smallest in conditions where a visual field was present, larger in darkness and larger in experiment 4 where targets were 1.3 meters away, than in experiment 2, where targets were 1 meter away. Although these experiments were not set up to show these differences significant, it is hoped that future experiments will do so.

GLOSSARY

Ψ - The slope of MVM as a function of actual height of stimulus, used to measure the amount of perceived expansion occurring when a subject views a visual field with visually perceived targets in it

DV - Difference Vector; to be set to zero during pointing in VITE model

EEPI - Extraretinal Eye Position Information; necessary for judging the difference between movements in the visual field and movements of eye.

fullroom - The condition in which the subject is able to see the fully illuminated pitchroom while making judgments

GO - the GO signal; signaling onset of pointing procedure

KPEL - Kinesthetically perceived eye level; the height of the yod when the subject is satisfied that his or her hand is at true eye level

MVM - Manual visual matching; the height of the yod when the subject is satisfied that he or she has set it so that its matches that of a stimulus

MVM_{TEL} - Manual visual matching to a stimulus set at true eye level

MVM_{VPEL} - Manual visual matching to a stimulus set by the subject to appear at true eye level

pitch	- the amount of rotation, towards or away from the subject, of the visual field
pointing	- estimating the height of a stimulus
PPC	- Present Position Command; representing the hand in the VITE model;
TEL-	- True eye level; defined as the plane, perpendicular to gravity, passing through the retina
TPC	- Target Position Command; representing the target in the VITE model;
twoline	- conditions in which the subject only sees two vertical, luminescent lines while making judgments
VITE	- Vector Integration to Endpoint; Daniel Bullock and Stephen Grossberg's model for pointing.
VPEL	- Visually Perceived Eye Level; defined as the height of a stimulus when a subject believes that it and the subject's eye define a line perpendicular to gravity.
yod	- a wooden platform in held into a relay rack that the subject moves up and down while pointing

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Figure Legends

Figure 1 If the reader foveates the dark circle, then the square appears in the right half of the reader's visual field. If the reader then moves his or her eyes such that he or she is now foveating the light circle, then the square will appear in the left half of the visual field. The readers should generally agree that the cause of the square's migration from the right to the left is caused by movements of the eyes rather than movements of the square.

Figure 2a This is Helmholtz's Outflow model in which the common center sends a signal α, to the extraocular muscles to move and an identical signal β, to the comparator, reporting the magnitude and direction of the intended move. After the movement, the retina sends a signal, γ, reporting the change in visual field. If the displacement in objects as reported by γ differs from the displacement of objects as predicted by β, then the brain believes that external movement has taken place.

Figure 2b This is Sherrington's Inflow model. The difference is that after receiving the movement command α, the extraocular muscles send their new position signal β, which is compared with the retinal displacement signal γ.

Figures 2a and 2b are adapted from Matin, 1986.

Figure 3 In darkness, the partial- paralysis caused a remarkable effect. When curare, the paralyzing agent, is applied to the extraocular muscles, they produce some fraction of the neurotransmitter that they would have under normal conditions. Therefore in order for the eye to move $\theta°$, say 20°, it will need to provide enough effort to move a larger angle $\phi°$, say 30°. After attempting such a movement, the comparator will think that it has moved $\phi°$(30°), see a change in the position of objects in the visual field corresponding to a change of $\theta°$(20°) and conclude that the objects must have moved $\phi° - \theta°$ (10°).

Figure 4 These figures show the direction that the side wall of the pitch room is tilted with respect to the direction of gaze of the subject and the direction of gravity. 4a shows the room pitched topforward (or positively) and 4b shows the room pitched topbackward (or negatively).

Figure 5 These figures show the two kinds of errors that would lead to the same error if a subject was trying to match the height of his or her index finger to the height of a stimulus. If the subject were incorrectly judging the direction of point h (say α' instead of α) as in figure 5a or incorrectly judging the distance to point h (say d' instead of d) as in figure 5b, then the subject could arrive at a height corresponding to h' instead of h. Under the conditions of the first 3 experiments reported here, it is impossible to differentiate between these two types of errors during the pointing procedure.

Figure 6 VPEL is measured in degrees visual angle. This is defined as the degrees in $\angle$SRV, as seen in figure 6a. $\angle$SRV is defined by the two vectors, **v** and **t**. Vector **t** passes through the subject's retina (R) and a point (S) on the opposite wall such that line RS is perpendicular to gravity. Vector **v** passes through the subject's retina (R) and the point where he or she set the stimulus during the VPEL task (S'). MVM is defined as the height of the yod (see materials, below) when the subject is asked to match his or her index finger to the height of a stimulus. MVM is measured as the degrees in $\angle$SRV, as seen in figure 6b. $\angle$SRV is defined by the two vectors, **h** and **p**. Vector **h** passes through the subject's index finger (H) and a point on the opposite wall (S) and is perpendicular to gravity. Vector **p** passes through the subject's retina (R) and point S.

Figure 7 This figure shows a subject pointing at a target using the yod. Because the yod is situated in a tall narrow relay rack, it is impossible for the yod to move in any direction except up or down. The yod is attached to the relay rack by magnets. The subject is never able to see his or her hand or the yod.

Figure 8 This figure demonstrates the fact the heights of the targets that the subjects points to change from condition to condition. When the top of the field of vision if pitched towards the subject (positively pitched conditions), VPEL is above true eye level and consequently, each individual target is higher than when there is no pitch. When the top of the field of vision is pitched towards the subject (negatively pitched conditions), VPEL is below true eye level and consequently, all of the individual targets are lower than when there is no pitch.

Figures 9 and 10 These two graphs show the relationship between VPEL and orientation of pitch, for fully illuminated conditions (figure 9) and conditions in which the entire visual field consists of two vertical lines (figure 10). All graphs represent the average of eight subjects. Under both conditions, when the room is pitched positively, VPEL is above TEL. When the room is pitched negatively, VPEL is below TEL. Also shown on these graphs are the results of the MVM_{VPEL} trials. Accurate pointing would consist of the two lines coinciding. Because subjects were satisfied that they had set the targets to their own eye levels, they always pointed around TEL.

Figure 11 This graph shows the average MVM of eight subjects to targets during the two-lines condition with the room pitched -30°. All of these targets appeared below TEL yet subjects pointed to those targets appearing above VPEL (the top two points on the graph) as if they appeared above TEL. They pointed to those targets appearing below VPEL (the bottom two points on the graph) as if they were above TEL.

Figures 12, 13 These two graphs show how the angle of pitch affects MVM measurements. When the room is negatively pitched, VPEL is below TEL and subjects point too high at all stimuli. When the room is erect, VPEL is close to TEL and subjects point fairly accurately. When the room is pitched positively, VPEL is above TEL and subjects point too low at all stimuli. This is not to say that subjects are pointing to different places at each condition. The experiment was set up so that subjects would see the stimuli appearing in the same place each time. Therefore, subjects pointed to the same set of places during each condition. Just as before, when subjects pointed to their TEL after instructing an experimenter to set a target to VPEL, the subjects found the targets to be in the same place each time as long as its distance from VPEL remained constant.

Figure 14 This figure graphically represents two subjects' data on the second experiment. The black bars represent the actual range of heights that the targets covered at each condition for these two subjects. The gray bars represent the the range of heights that the subjects pointed to while trying to estimate the heights of these targets. The top subject, RS, had a tendency to point to a smaller range than the points themselves actually covered. She showed this behavior in both dark and lit conditions. The bottom subject, SA, pointed to a larger range of heights than the targets themselves covered. Notice that the ranges of both subjects change very little from condition to condition, varying less than the actual heights of the targets.

Figure 15 Although it is not obvious from the past three figures, there is a non-linear relationship between pitch and Ψ. However, the largest expansion occurs when the room is erect, with expansion decreasing in both directions.

Figure 16 This figure shows how visual angle decreases for pitched conditions, when the range of the targets is constant at 40 centimeters. Visual angle is equal to the arc cosine of the arc cut out by x and c-x for any given angle of pitch, θ. A maximum visual angle occurs for when x = c-x, which is to say, when the center of c is on the normal from the eye to visual field. Since VPEL is always the center of the range of targets, this would mean that VPEL fell on the normal, or that the slope of VPEL as a function of pitch was equal to 1, which never happens. Therefore, when the field is pitched, the amount of arc subtended by the targets is always less than the maximum possible for all conditions except 0°, in which VPEL tends to hover about 0°. Therefore, one should expect the largest perceived range of targets when there is no pitch of the field and consequently Ψ should be at its highest.

Table 1: This table shows the mean settings in KPEL and MVMTEL tasks broken down by the initial position of the yod (above or below true eye level) and the standard deviation of these settings (n=10). It also shows the mean and standard deviation of the difference between initial position. All measurements are in degrees visual angle.

subject		below	stdev	above	stdev	mean b-a	stdev b-a
SA	kpel	2.2	0.44	3.3	0.27	-1.1	0.51
	mvm	-9.6	2.15	-10.8	1.44	1.1	2.59
VC	kpel	1.5	0.34	1.9	0.31	-0.4	0.46
	mvm	2.1	0.85	3.2	0.96	-1.1	1.28
AD	kpel	4.0	0.37	3.7	0.21	0.3	0.42
	mvm	5.1	0.42	4.7	0.37	0.4	0.56
NL	kpel	6.3	0.93	3.6	0.90	2.7	1.29
	mvm	5.8	1.19	6.8	0.46	-1.0	1.28
WL	kpel	2.2	0.30	2.7	0.38	-0.5	0.49
	mvm	5.6	0.97	6.7	0.86	-1.1	1.30
NR	kpel	-0.8	0.43	-0.7	0.56	-0.2	0.70
	mvm	5.7	0.68	4.4	1.70	1.2	1.83
ES	kpel	1.6	0.32	1.6	0.30	0.0	0.44
	mvm	-0.4	0.86	-0.6	1.25	0.3	1.52
mean	kpel	2.4	0.45	2.3	0.42	0.1	0.62
	mvm	2.0	1.02	2.1	1.01	-0.0	1.48

TABLE 2. This table shows the difference between KPEL trials and MVM_{TEL}. The correlation between KPEL and MVM_{TEL} was .889. All measurements are in degrees visual angle.

Subject	KPEL	Stdev	MVM(TEL)	Stdev	Difference	VPEL
SA	2.8	0.86	-10.2	3.27	13.0	6.9
VC	1.7	0.61	2.6	1.69	-0.9	4.0
AD	3.8	0.54	4.9	0.73	-1.1	0.5
NL	5.0	2.12	6.3	1.67	-1.3	0.5
WL	2.5	0.66	6.2	1.71	-3.7	-1.0
NR	-0.8	0.88	5.0	2.37	-5.8	-3.1
ES	1.6	0.55	-0.5	1.89	2.1	1.6
mean	2.4	0.89	2.0	1.90	0.3	1.3

Table 3. This table demonstrates the difference between fullroom and twoline conditions in the VPEL task by comparing mean slope of VPEL as function of pitch. The mean slopes of the subjects who participated in both conditions are compared in the first row. The mean of the slopes of the eight subjects from the fullroom is compared to the mean of the slopes of the eight subjects who participated in the twoline condition in the second row.

Subjects	n	mean fullroom	stdev	mean twoline	stdev
Subjects who participated in both conditions	4	0.60	0.19	0.55	0.17
All subjects from each condition	8	0.69	0.19	0.61	0.18

Table 4. This table demonstrates some of the differences between using the scleral search coil to estimate the direction of visually perceived stimulus and using the yod to estimate the height of the same stimulus. The search coil appeared to be slightly less accurate than the yod but this result was not significant. The search coil was found to have a smaller Ψ than the yod ($p < .01$).

	Search Coil		Yod	
	Mean	Std Error	Mean	Std Error
Absolute Error	10.6	2.45	7.1	1.77
Ψ	32.2	3.11	47.5	3.39

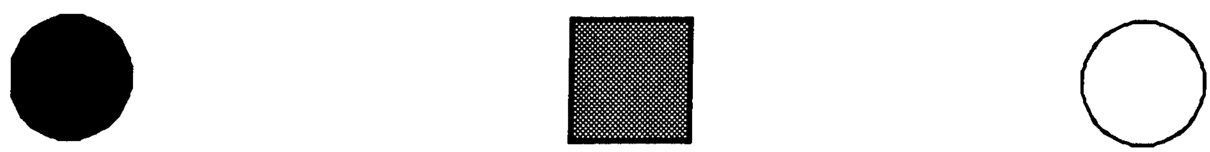


Figure 1

Helmholtz's Outflow Theory

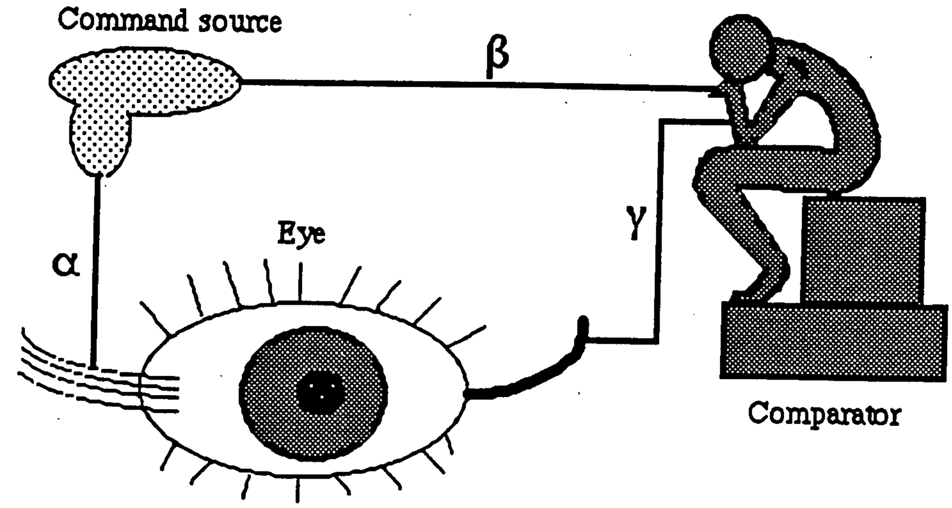


Figure 2a

Sherrington's Inflow Theory

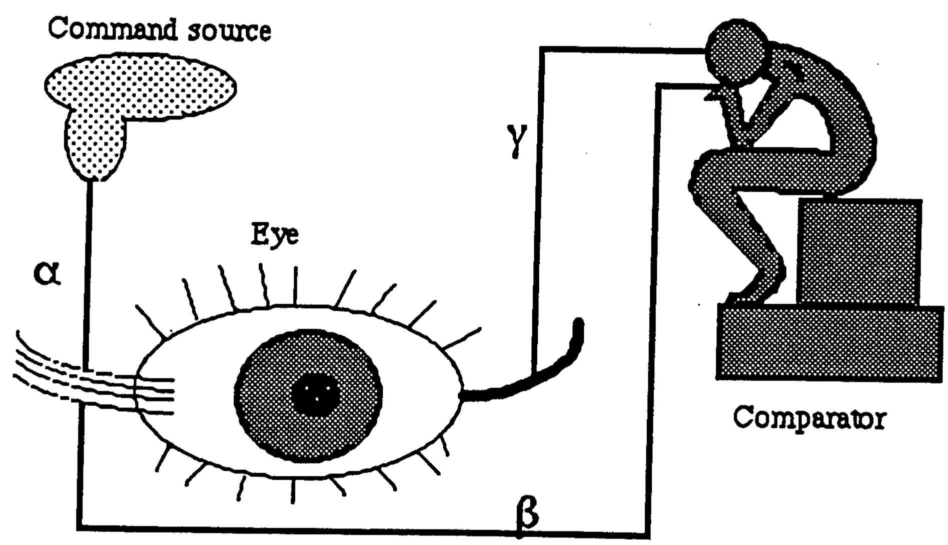


Figure 2b

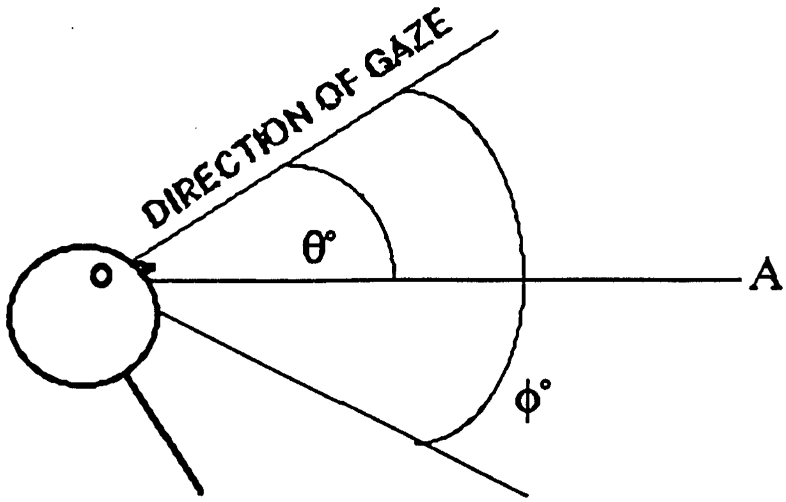


Figure 3

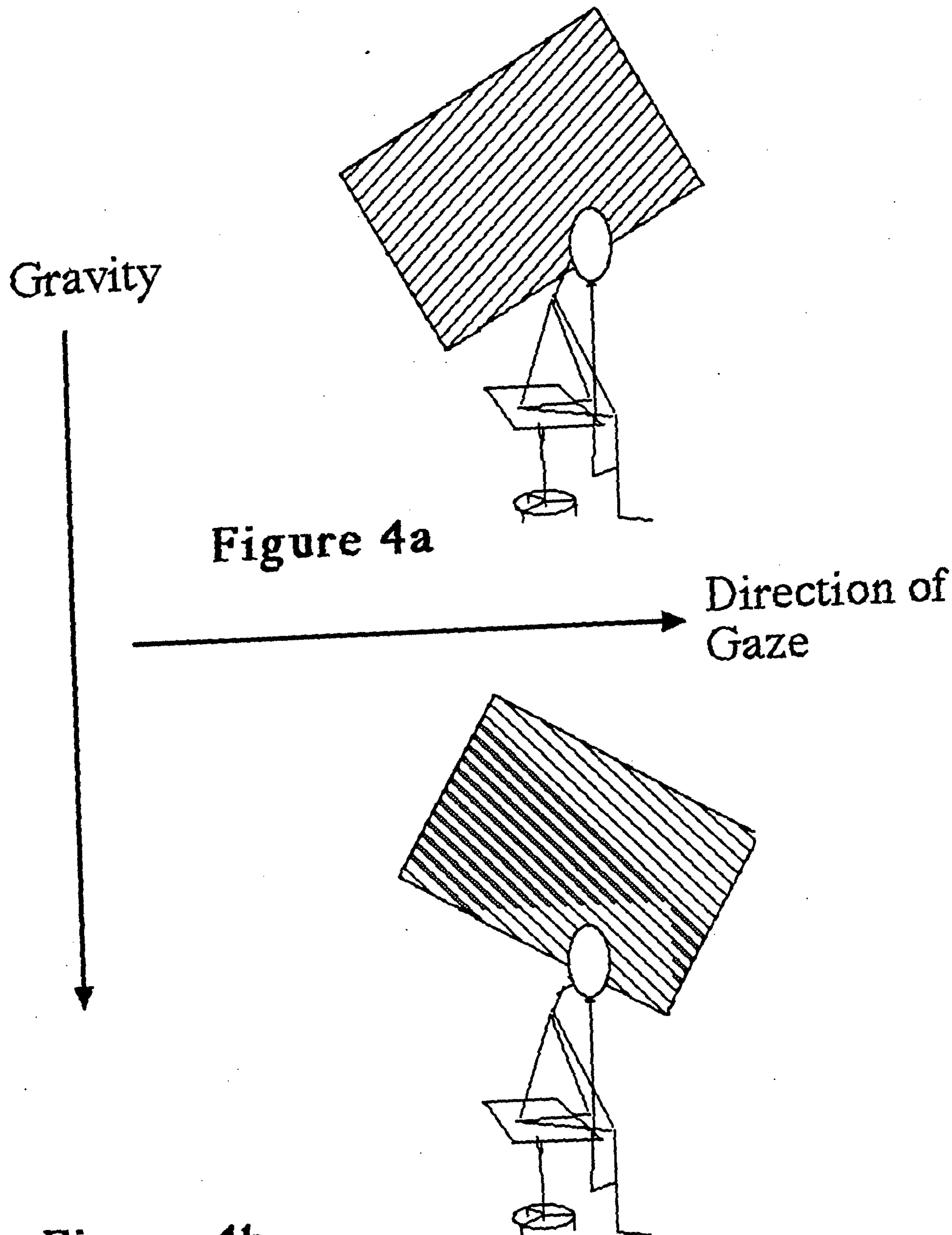


Figure 4a

Figure 4b

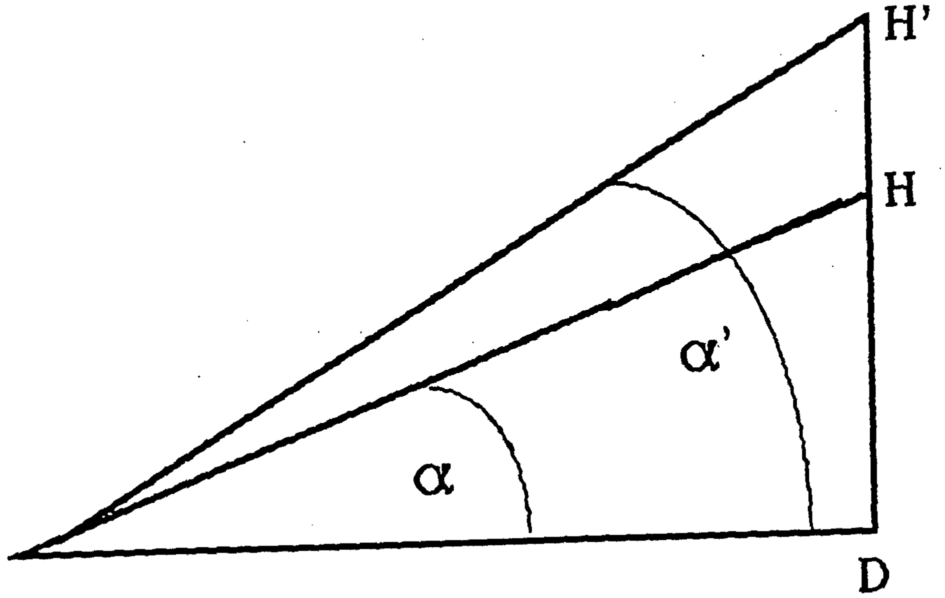


Figure 5a

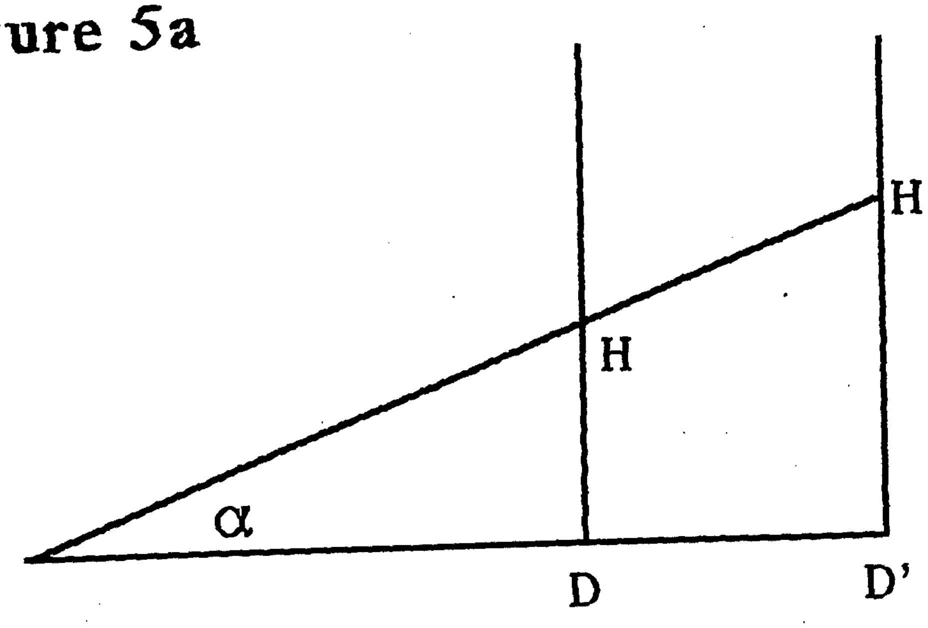


Figure 5b

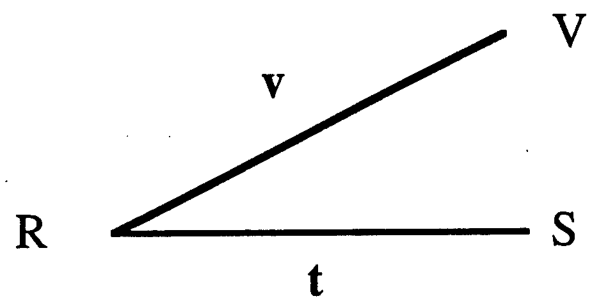


Figure 6a

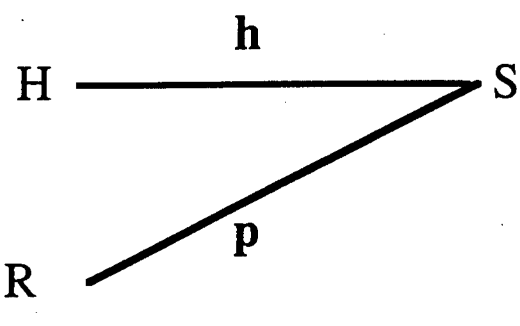


Figure 6b

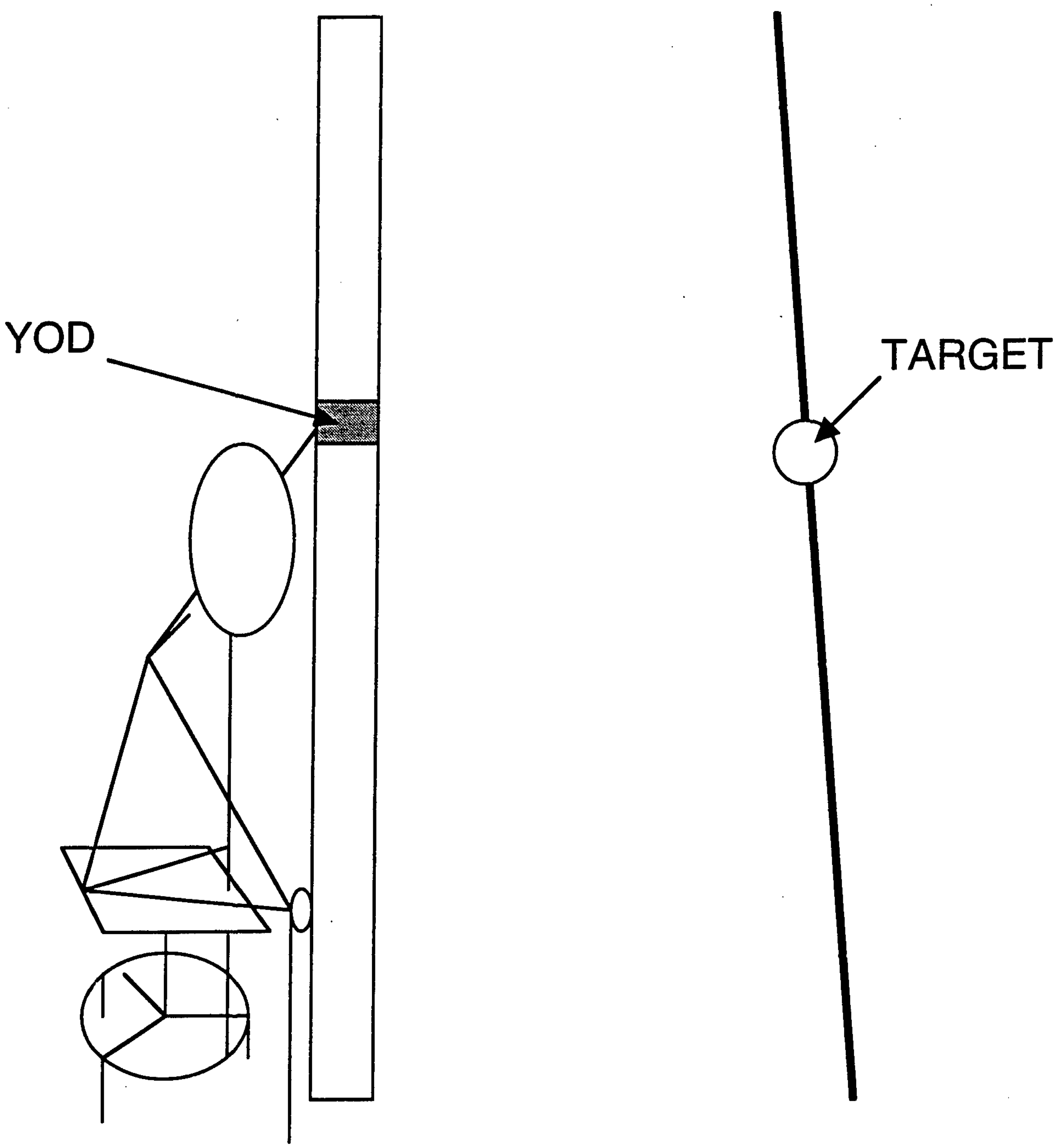


Figure 7

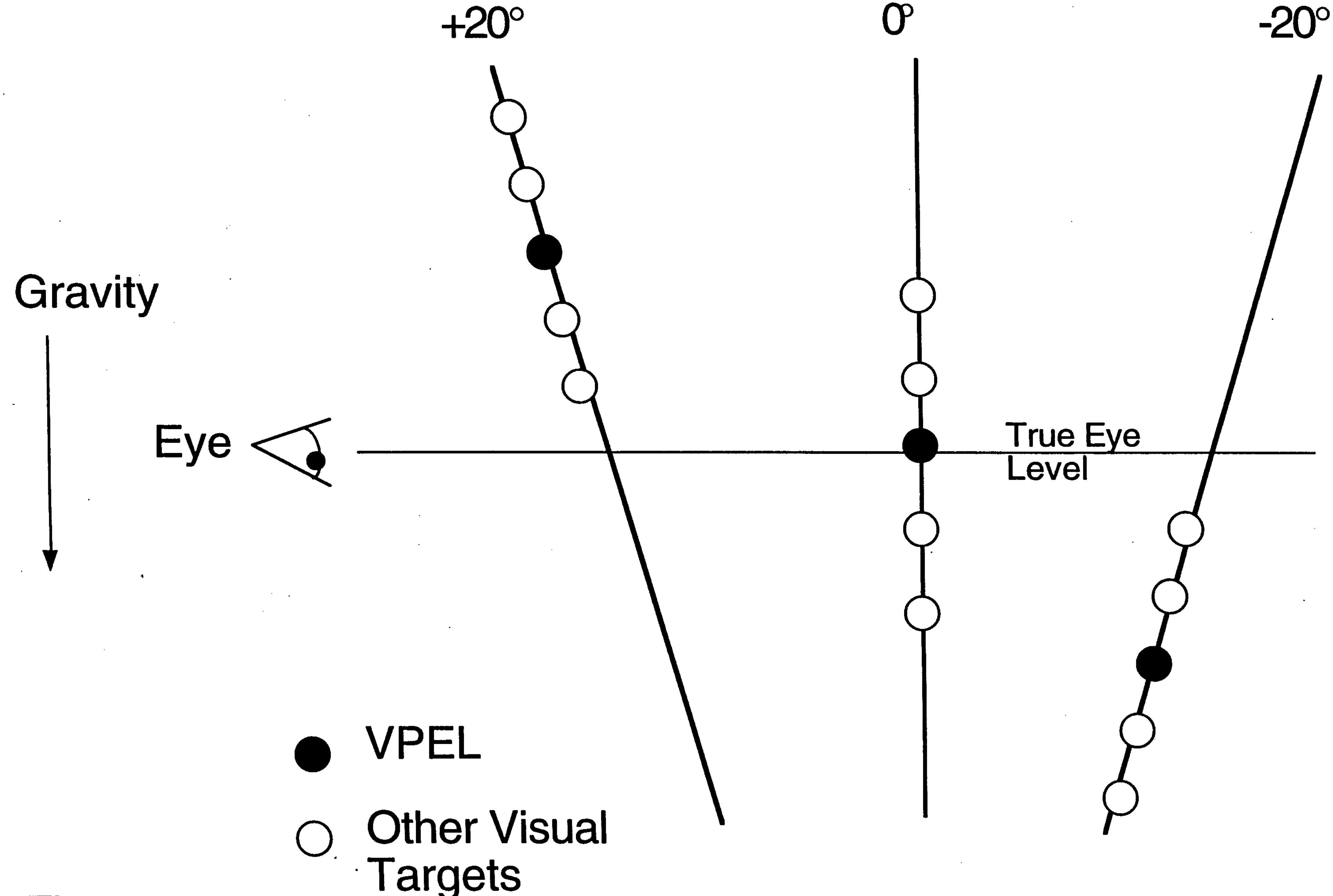


Figure 8

Pointing to Visually Perceived Eye Level (VPEL)
in a Fully Illuminated Visual Field

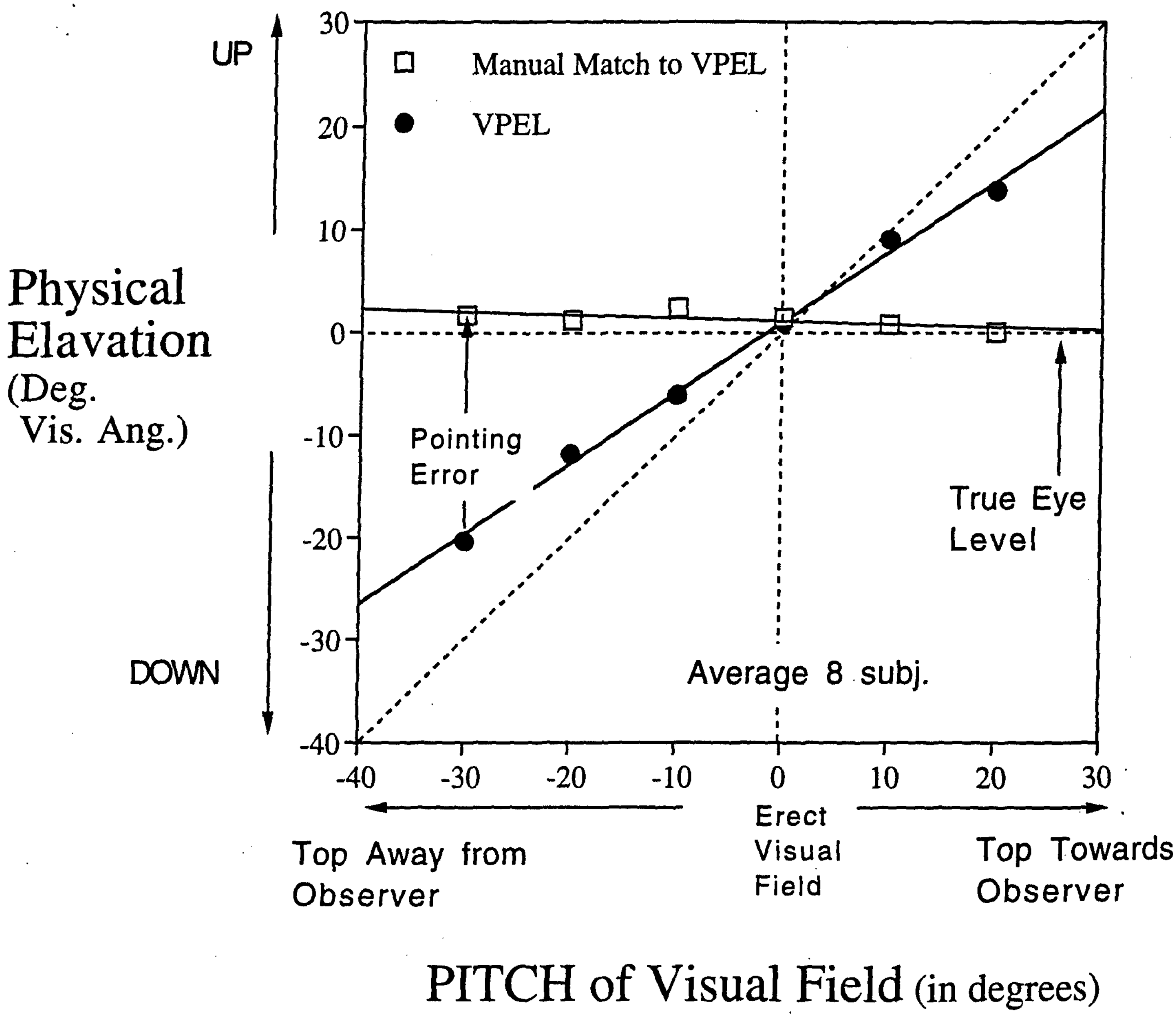


Figure 9

Pointing to Visually Perceived Eye Level (VPEL)
in a 2-line Visual Field

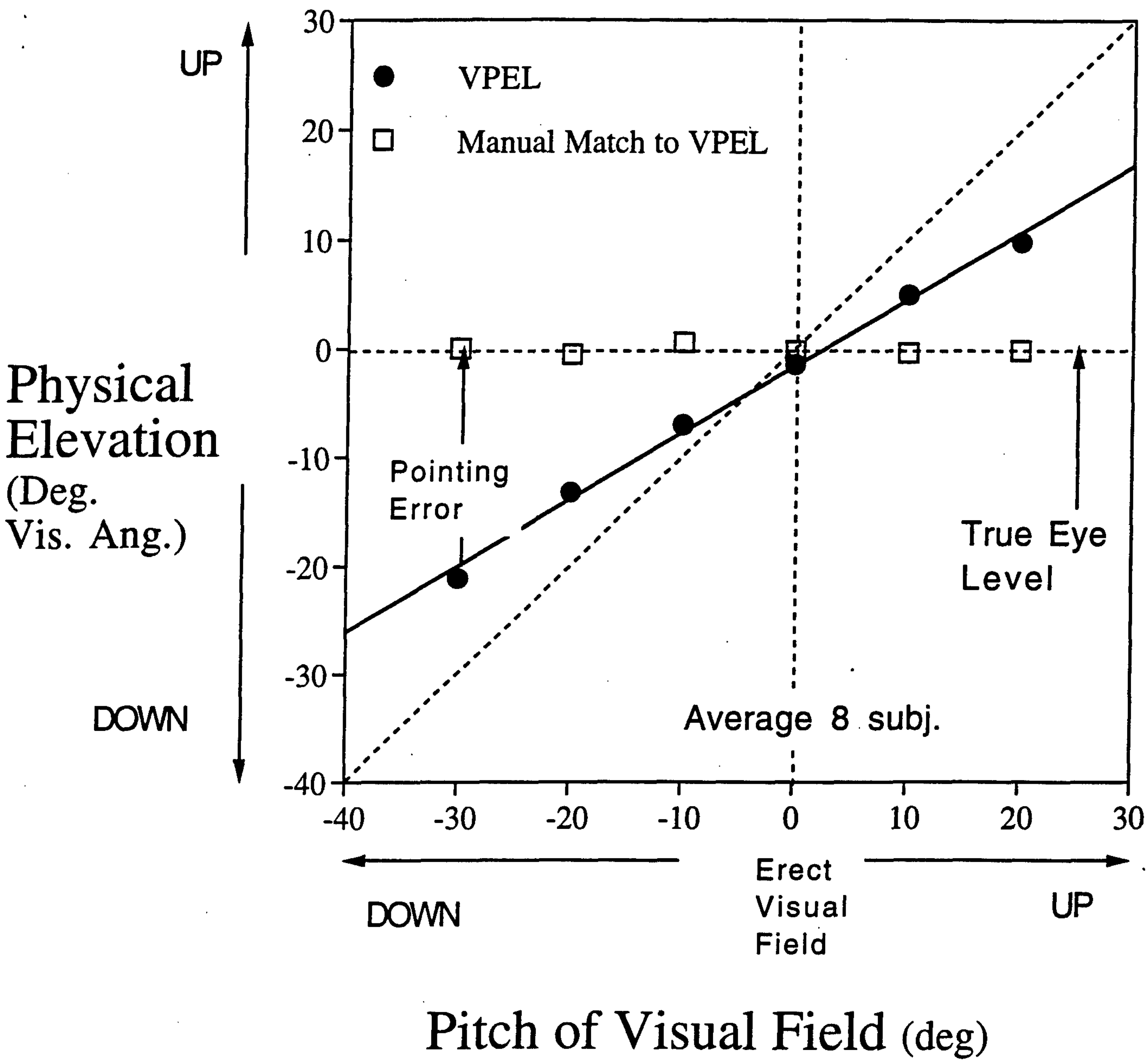


Figure 10

Pointing to Visual Target at Different Elevations
(In 2-line Visual Field, pitched -30°)

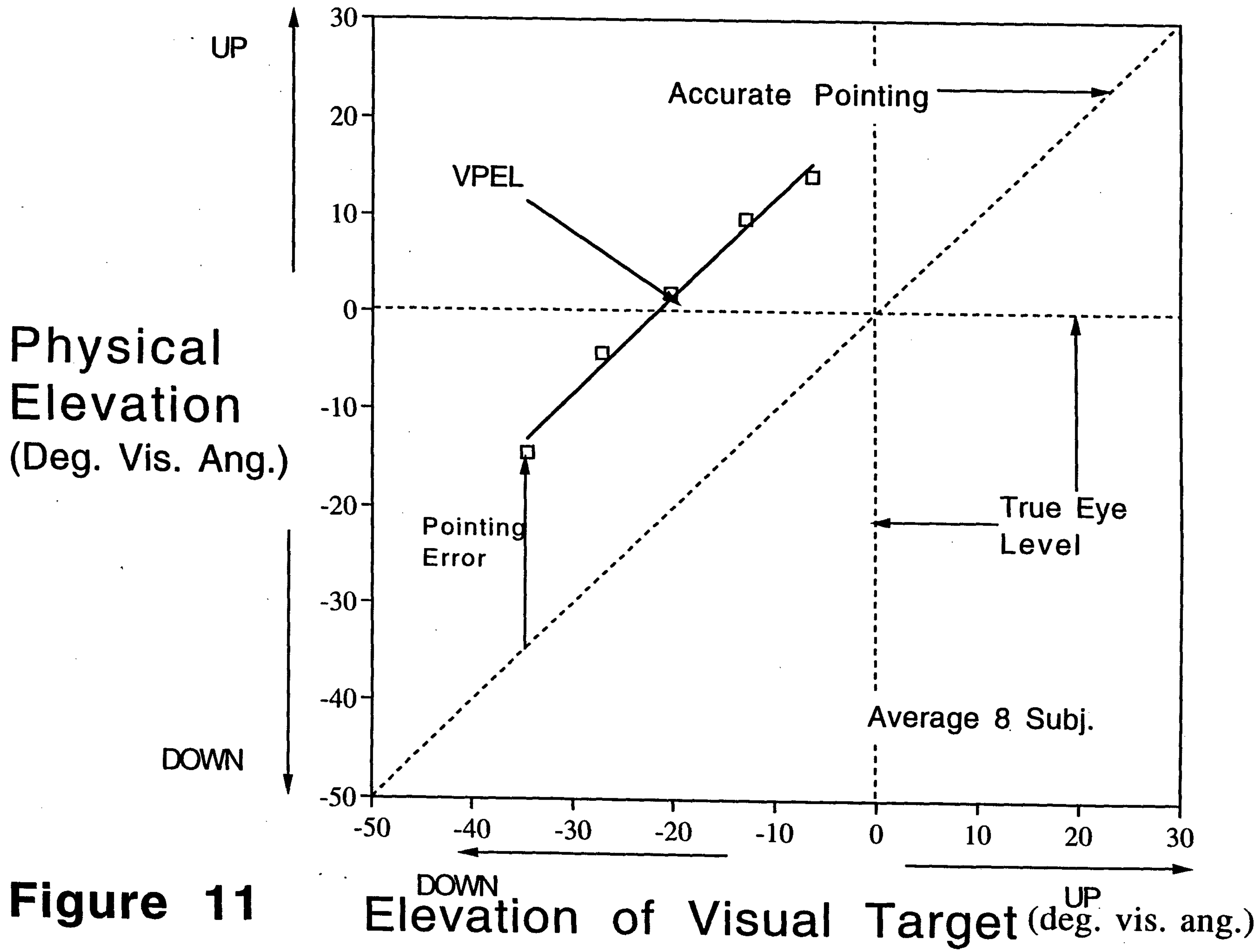


Figure 11

Pointing to Visual Target at Different Elevations
(In Fully Illuminated Visual Field)

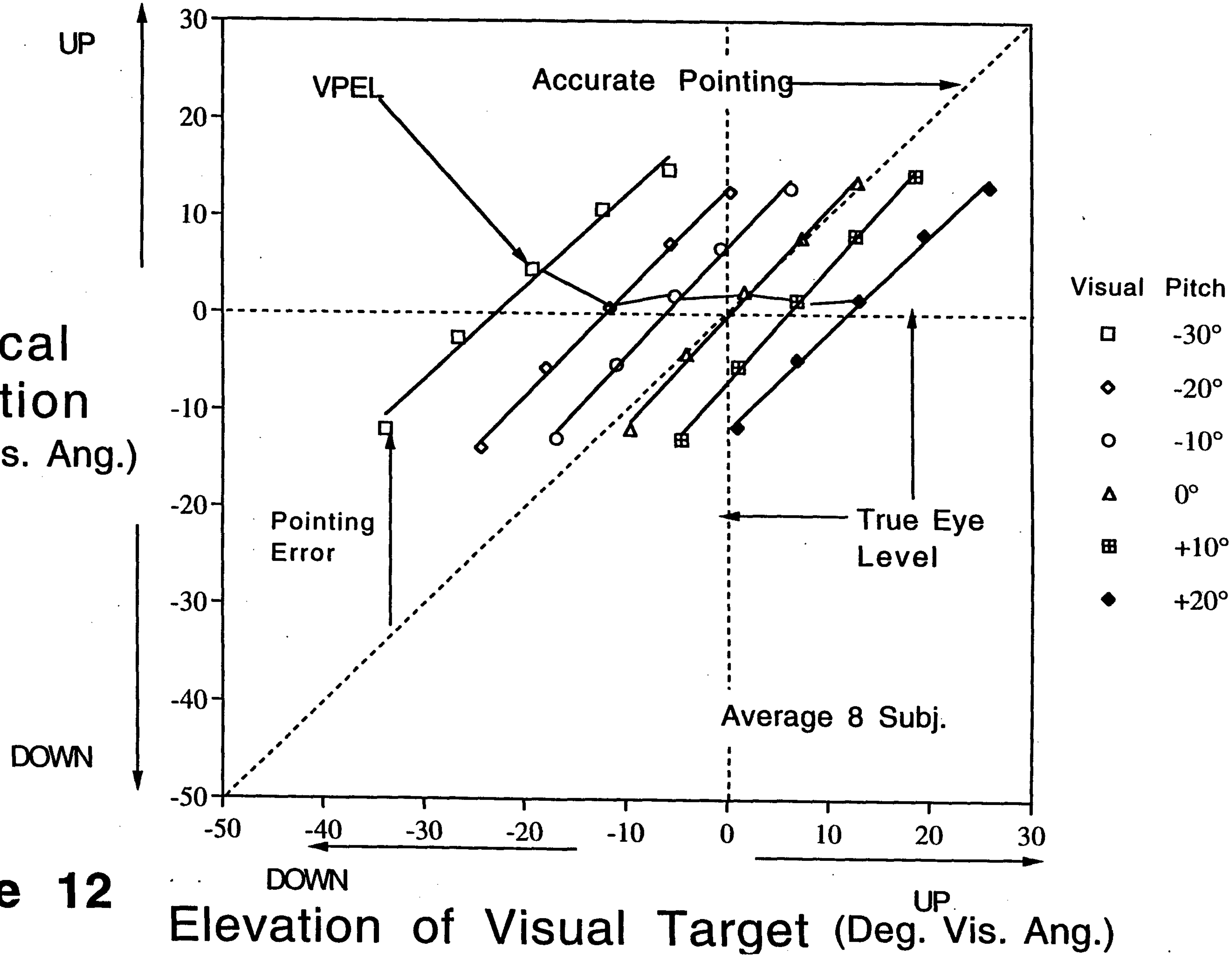


Figure 12

Pointing to Visual Target at Different Elevations
(In 2-line Visual Field)

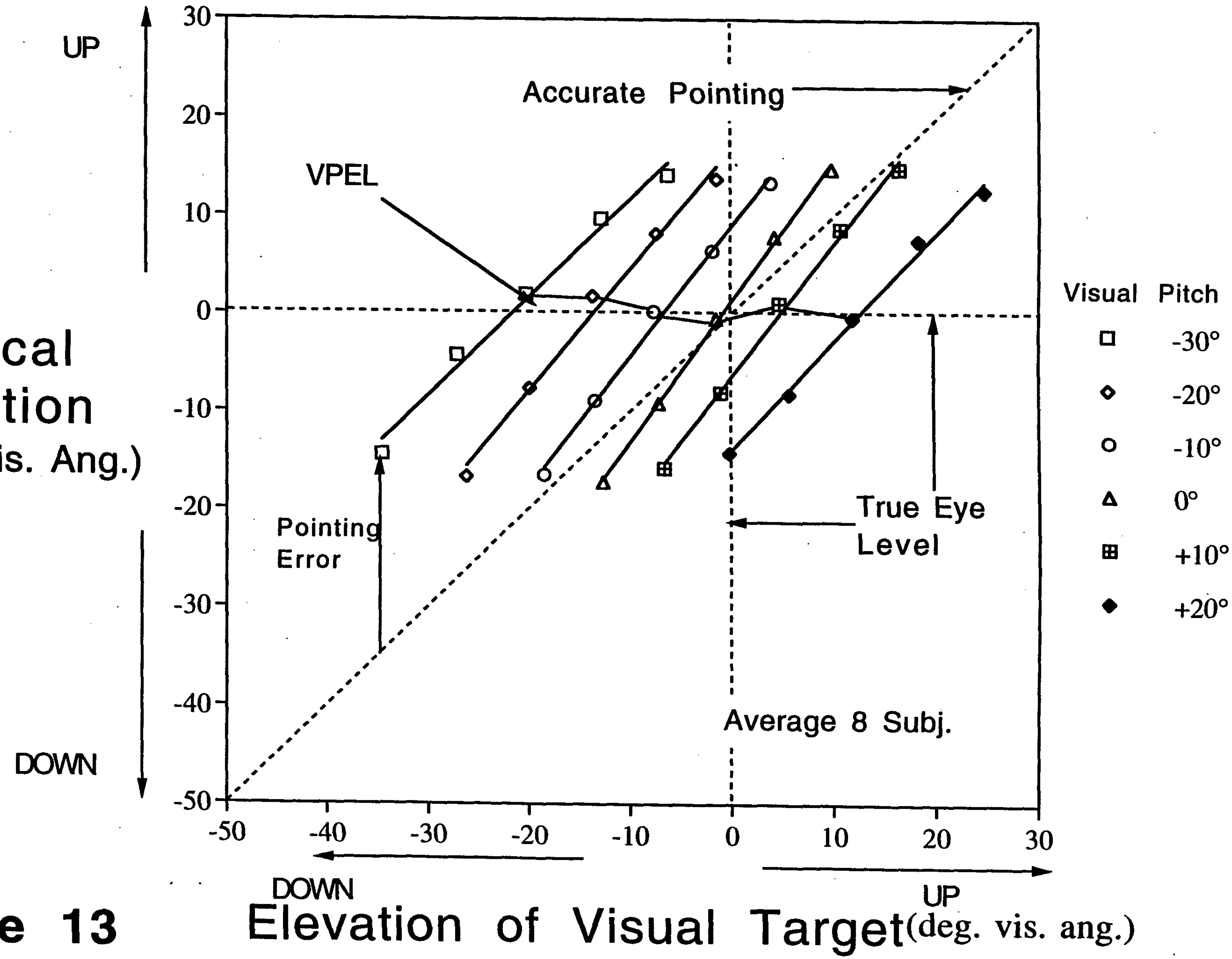
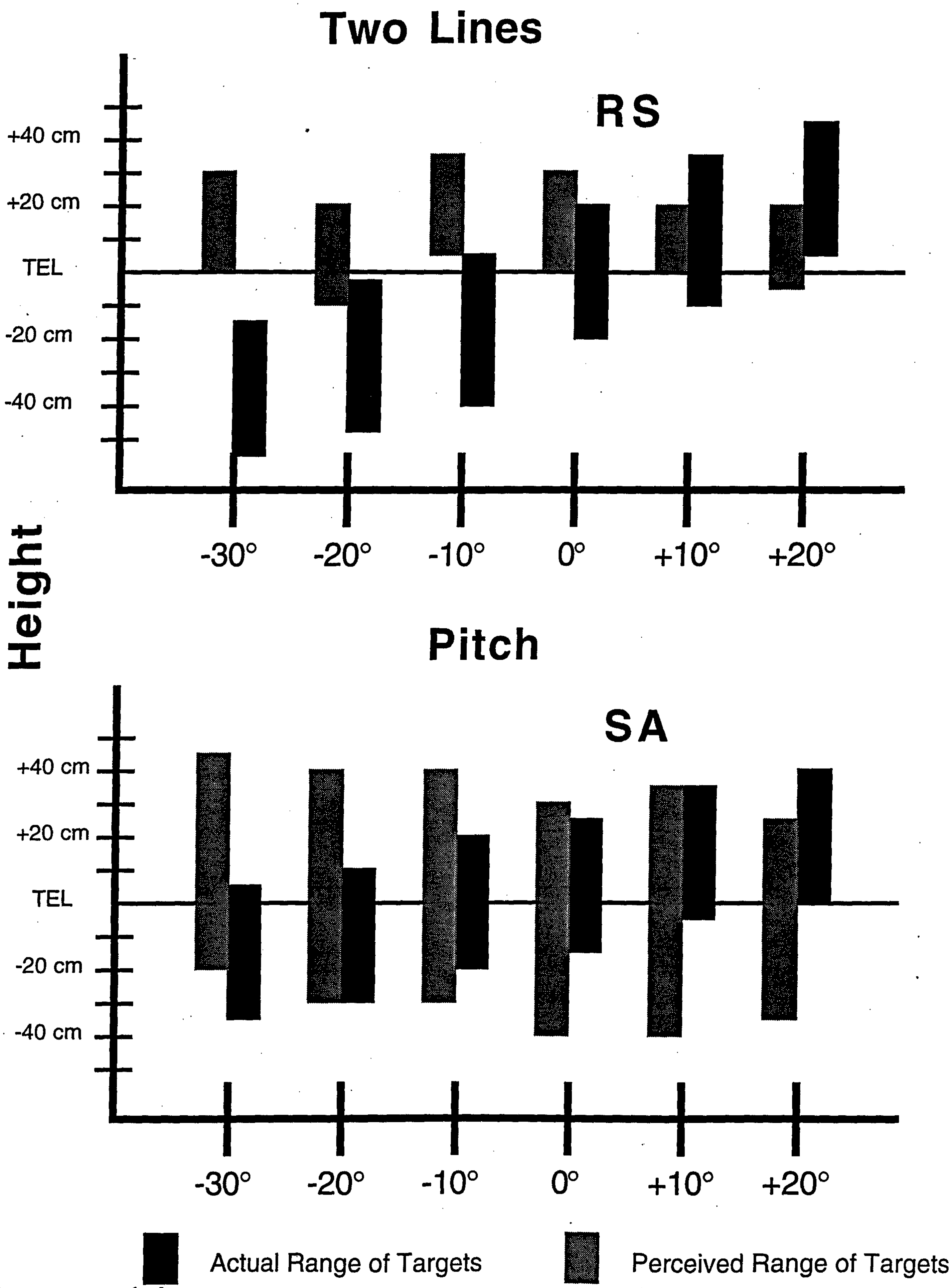


Figure 13



Two Lines
RS
+40 cm
+20 cm
TEL
-20 cm
-40 cm
-30°
-20°
-10°
0°
+10°
+20°
Height
Pitch
SA
+40 cm
+20 cm
TEL
-20 cm
-40 cm
-30°
-20°
-10°
0°
+10°
+20°
Actual Range of Targets
Perceived Range of Targets

Figure 14

Ψ as a Function of Pitch of Visual Field

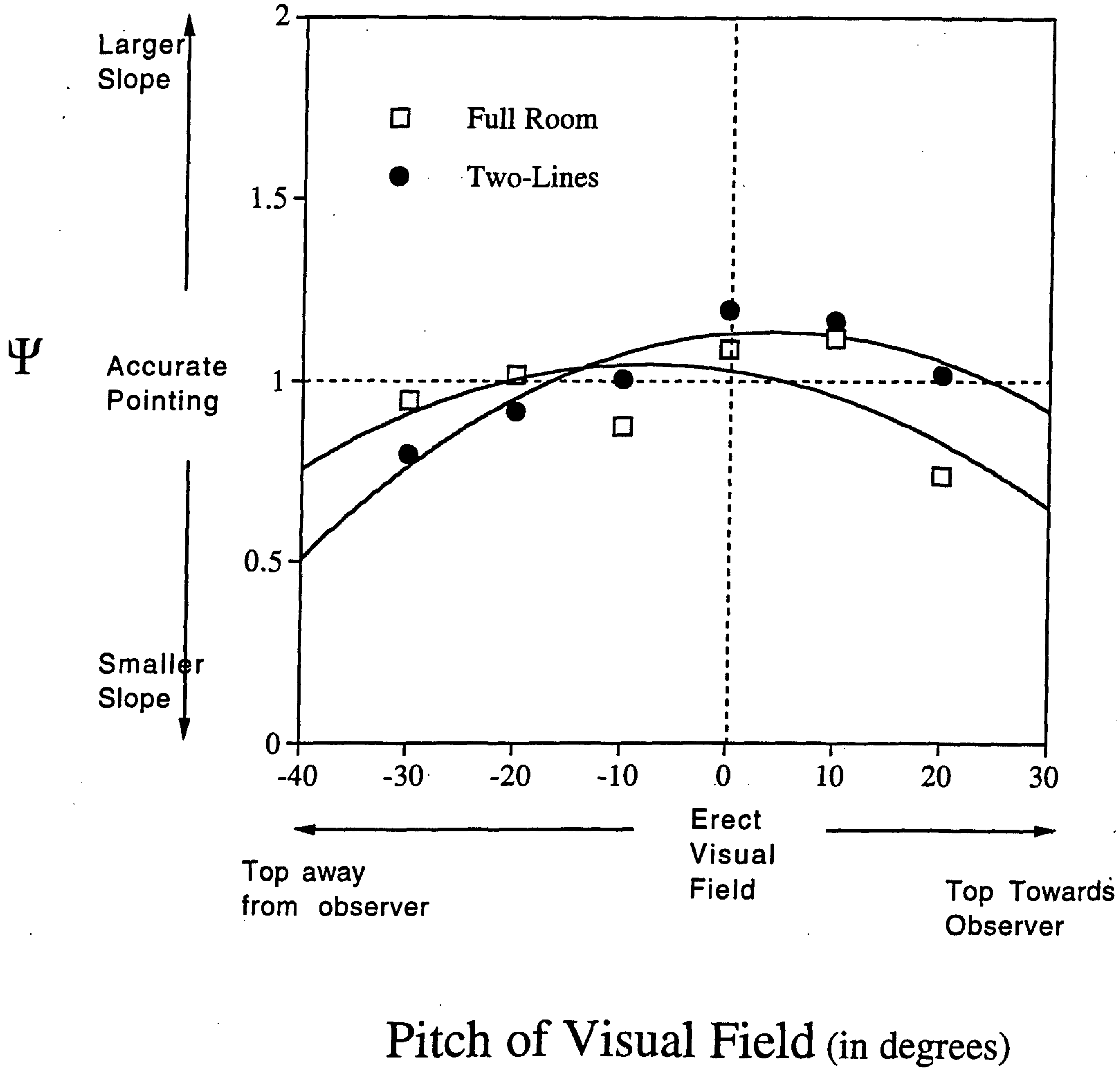


Figure 15

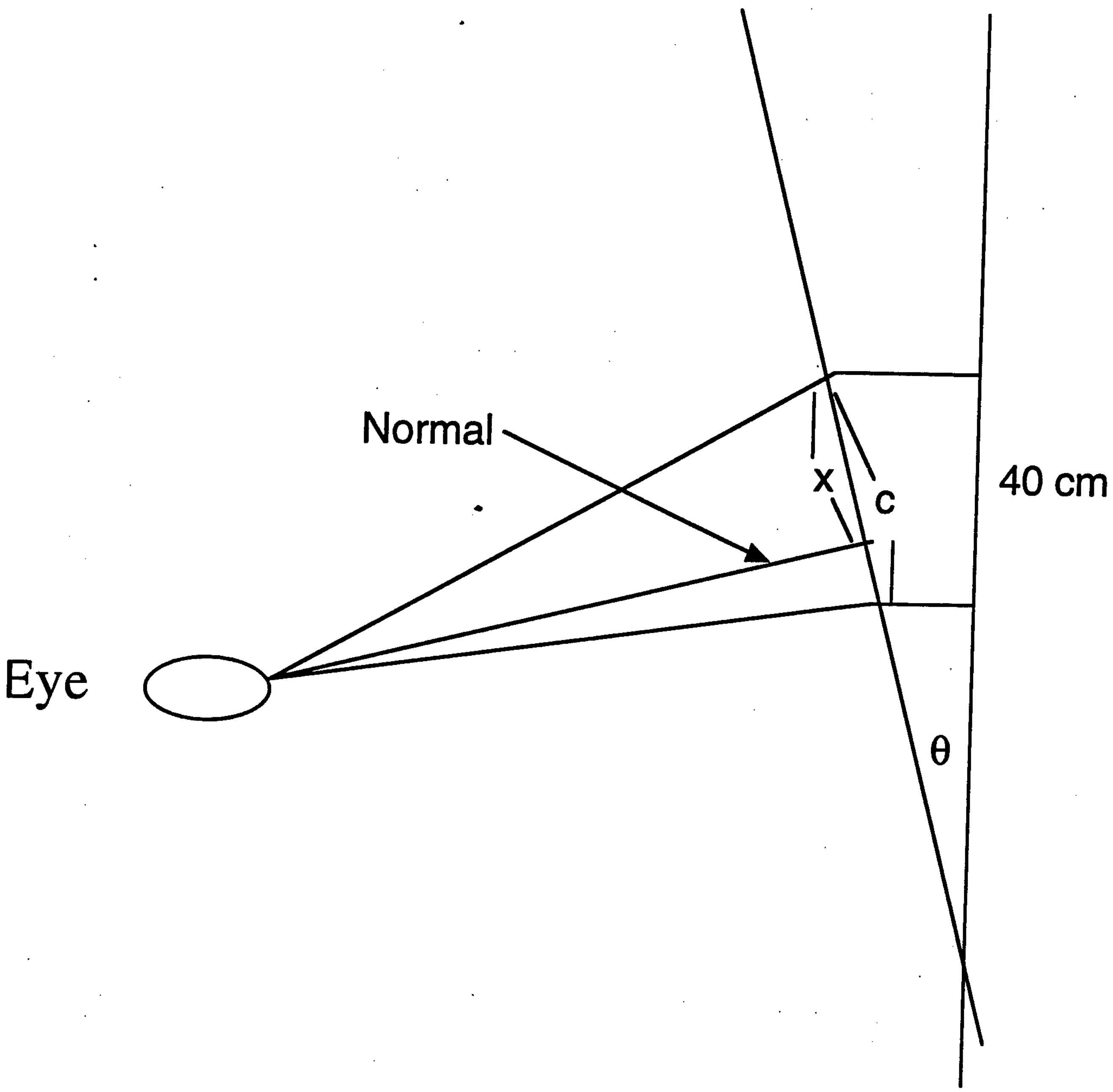


Figure 16

CORRIGENDA

While the conclusions I reached in my sketchy mathematical proof that the parabolic effect of the pitchroom could be entirely caused by the geometry of the situation appear to be correct, the math I used to arrive at them was most certainly incorrect. That's what I get for throwing something additional into my paper at 4:00 am the night before. What follows is a correct proof:

With c being equal to the range of the targets *in the plane of the pitched visual field* and x being the distance from the point where the normal (from the eyes to the visual field) intersects the visual field to one extreme of c, the degrees visual angle ($^{\circ}va$) subtended by the range of visual targets can be given as:

$$^{\circ}va = \text{arc tan}\,[x/100] + \text{arc tan}\,[(c-x)/100]$$

The maximum amount of $^{\circ}va$ can be found by setting the first derivative of this equation equal to zero as follows:

$$^{\circ}va' = 1/[1 + (x/100)^2] - 1/[1 + (\{c - x\}/100)^2] = 0$$

$$1/[1 + (x/100)^2] = 1/[1 + (\{c - x\}/100)^2]$$

$$1 + (x/100)^2 = 1 + (\{c - x\}/100)^2$$

$$x/100 = \{c - x\}/100$$

$$x = c - x$$

$$x = c/2$$

In other words, $^{\circ}va$ is maximized when the normal falls right in the middle of c. Since the middle of c is VPEL for all conditions, $^{\circ}va$ is maximized when VPEL occurs at the normal. Since the slope of VPEL as a function of pitch is always less than 1, this does not occur except at an erect field (discounting natural biases). Therefore, the largest $^{\circ}va$ would be expected in an erect field, predicting a maximum expansion to occur here.This shows that this bizarre parabola located around p47, is merely a facet of the geometry of the experiment.

Independence of Perceptions of Visual Pitch (PVP) and Visually Perceived Eye Level (VPEL)

Todd Erik Hudson

Submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Faculty of Pure Science, Columbia University.
1997

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ABSTRACT

Section I

Psychophysical measurements of the elevation of Visually Perceived Eye Level (VPEL) and of Perceived Visual Pitch (PVP) were made on 20 subjects viewing a variably pitched room over the 50° pitch range from -30° to +20°. Although VPEL and PVP were each linearly related to physical pitch for each subject, there were large stable differences among subjects. Contrary to the expectation of an inverse relation between the slopes of the VPEL/pitch and PVP/pitch functions, the correlation across subjects was near zero.

Section II

Although setting the elevation of a visual target to appear at eye level (VPEL) in a pitched visual field and a rod to appear vertical (VPV) in a tilted visual field (classical Rod-and-Frame Test) both require perceptual "disembedding", the correlation between VPEL and performance on the Embedded Figures Test (EFT) is insignificant. Thus, the global field dependent / independent style believed to underlie the significant correlation between VPV and EFT cannot account for VPEL performance.

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Independence of Perceptions of Visual Pitch (PVP) and Visually Perceived Eye Level (VPEL)

Section I

Egocentric visual spatial orientation requires that organisms utilize observer-relative coordinates to localize external objects. One of the main dimensions of egocentric visual space is observer-relative elevation; the elevation of an object or target relative to some point of reference on the observer. An obvious point of reference is the observer's eye. Elevation relative to the observer's eye is specified in angular coordinates, with the line of visual direction perpendicular to gravity as the reference direction. Any point along this reference line (points in visual space which have zero angular deviation from the reference line) are at True Eye Level (TEL; see Figure 1a). Points which are above or below TEL (points which have some angular deviation above or below the reference line) are specified in terms of their angular separation from the line of TEL. The Visually Perceived Eye Level (VPEL) discrimination is a measure of observer-relative elevation. In the VPEL discrimination, observers are required to set a target to the elevation perceived as lying along the line of TEL. VPEL is the orientation of the imaginary line connecting the eye to the target (see Figure 1a). As with any orientation in egocentric space, VPEL must be measured relative to some reference direction. Therefore, VPEL is specified relative to TEL, as shown in Figure 1a.

Another dimension of egocentric visual space is observer-relative pitch; the pitch of an object or plane relative to the pitch of an observer. The Perceived Visual Pitch (PVP) discrimination is a measure of perceived observer-relative pitch. It is measured as the angular deviation of a variable plane from the orientation of the observer. In the special case of an observer oriented to gravity, it is possible to measure PVP relative to gravity (see Figure 1b). In general, PVP is measured by matching the orientation of a variable plane to that of a fixed standard plane[1]. Subjects are instructed to orient the variable plane to the same orientation relative to themselves as the orientation of the standard plane. Because PVP is the plane of *relative* orientation, it can only be specified relative to the reference orientation, the orientation of the observer (see Figure 1b).

The settings of a target to Visually Perceived Eye Level (VPEL) change linearly as a function of the pitch of the visual field within which the target is presented. In the pitchroom, the setting of elevation at which subjects set a target to appear at eye level generally averages near 0.6 of the angle of the pitch of the visual field (Matin & Fox, 1989; Matin & Li, 1992a, 1994a). The Perception of

[1] It is also possible to measure PVP by setting a variable orientation plane to the orientation of the observer (in the special case of an erect observer, this corresponds to setting the plane to the erect (unpitched) orientation.

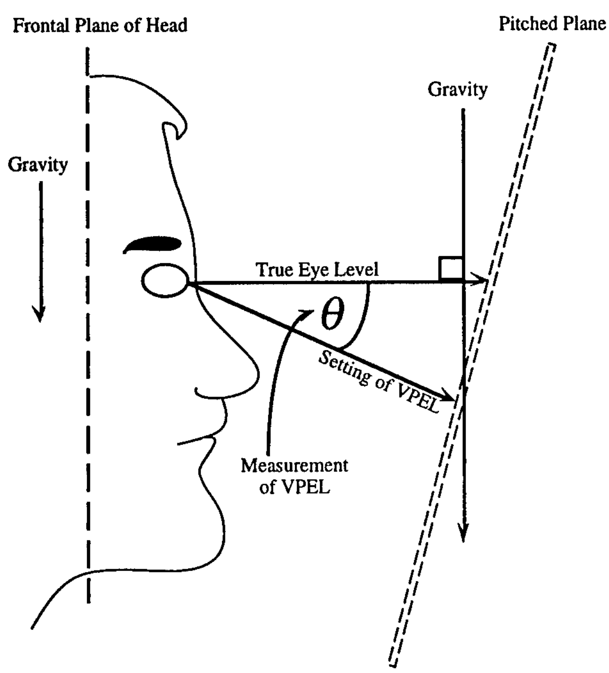


Figure 1a. Schematic of an observer, indicating a possible setting of VPEL within a pitched visual field and the corresponding measurement of the setting relative to the visual norm of the subject's TEL.

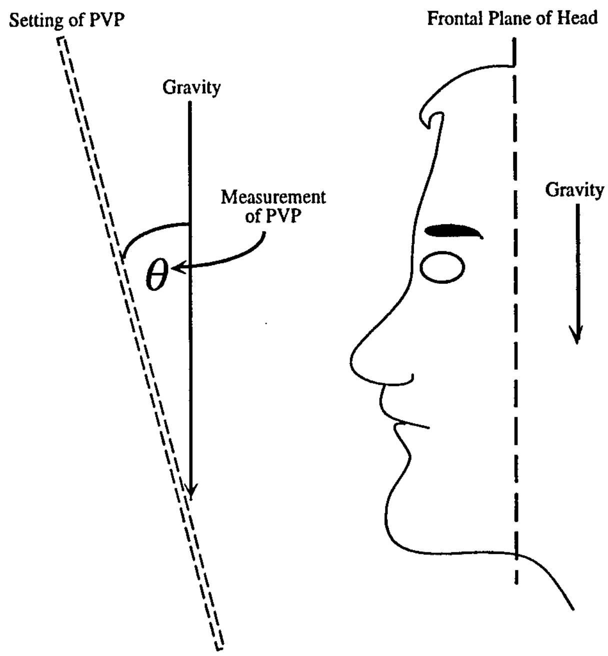


Figure 1b. Schematic of an observer, indicating a possible setting of PVP and the corresponding measurement of the setting relative to the orientation of the observer, and therefore the direction of gravity.

Visual Pitch (PVP) also changes linearly as a function of the pitch of the visual field (Clark, Smith, & Rabe, 1955; Epstein & Mountford, 1963; Flock 1964a; Freeman, 1965a, 1965b, 1966a, 1966b; Smith, 1956, 1959, 1964), but has been most commonly reported to be matched to pitch at between 0.2 and 0.7 of the physical pitch settings of a standard (Flock, 1965). As both VPEL and PVP are positive linear functions of pitch, they will be correlated across a range of pitches. This suggests the possibility that either PVP discriminations require eye level information, or that VPEL discriminations require visual pitch information (Flock, 1964a, 1964b, 1965; Freeman, 1965a, 1966a, 1966b; Perrone 1980, 1982), or both. In any of these cases, the two discriminations could be outputs of the same processing system, as shown in Figure 2.

In the present paper we will explicitly consider two cases in which the two discriminations are outputs of a single mechanism. In the first, VPEL is derived from the same information (retinal and/or extra-retinal) which is presumed to underlie the PVP discrimination (pitch information). In the second, PVP is derived from the same information (retinal and/or extra-retinal) which is presumed to underlie the VPEL discrimination (eye level information).

Case 1: VPEL Discrimination Requires Pitch Information

The angular distance between the normal line of visual direction to the pitched visual field (N), and the True Eye Level of an observer (TEL; defined as the direction perpendicular to gravity intersecting the eye) is equal in magnitude to the pitch of the visual field (see Figure 3a). It is possible, therefore, that an observer locates eye level within a pitched environment using pitch

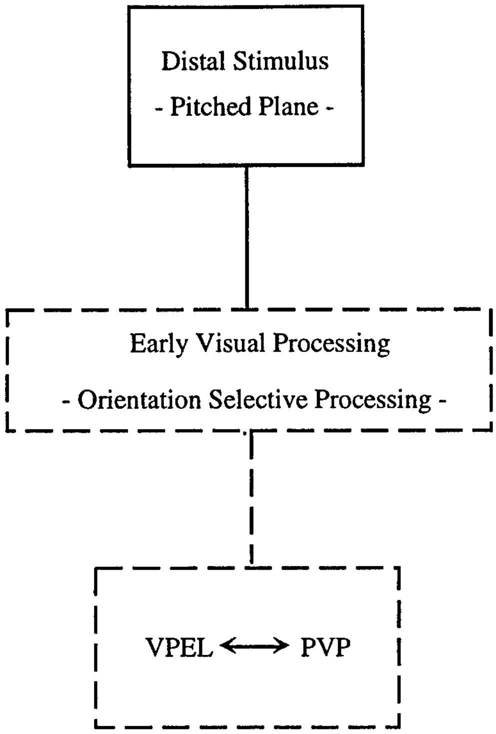


Figure 2. Diagram of a unitary processing system which computes both Visually Perceived Eye Level (VPEL) and Perceptions of Visual Pitch (PVP).

information. In the presence of a pitched visual field, observers make non-veridical VPEL discriminations of some constant fraction of the pitch of the field. If accurate VPEL discriminations require pitch information, we would expect individual differences in the accuracy of VPEL discriminations to be determined by individual differences in the magnitude of the scaling constant producing (scaled) pitch information.

Several examples should serve to illuminate the nature of the scaling constant, and the relationship between pitch information and VPEL. A scaling constant of 1 would produce pitch information equal to the physical pitch of the visual field, θ. Observers would therefore be expected to set VPEL the full angular distance from N to TEL, producing veridical VPEL discriminations. A scaling constant of 0 would produce pitch information equal to an unpitched environment (erect visual field). Observers would therefore be expected to produce VPEL settings which do not differ from N. A scaling constant intermediate between 0 and 1 would produce pitch information somewhat less than θ. A constant of about 0.4 would produce the classic VPEL to pitch function whose slope has been found to be about 0.6 (e.g., Matin & Fox, 1989; Matin & Li, 1992a, 1994) in the pitchroom. In all cases, the scaling constant specifies the expected proportion of the pitch of the visual field by which VPEL will differ from N. Because VPEL is an error measure, VPEL will be equal to the difference between pitch information and θ. This is shown graphically in Figure 3a, in which the pitch information, indicated by W', produces a VPEL discrimination that differs from TEL by $\theta - \gamma$. The difference between the pitch information and the physical pitch (θ), the angular distance from W' to W, is equal to the error in the VPEL discrimination, the angular distance from VPEL to TEL. Similarly, the difference in the angular distance from W' to its erect position (parallel to the direction of gravity) is equal to the angular distance from VPEL to the normal from the observer to the wall (N). This leads to the equation:

$$VPEL = \theta - (\gamma) \qquad (1)$$

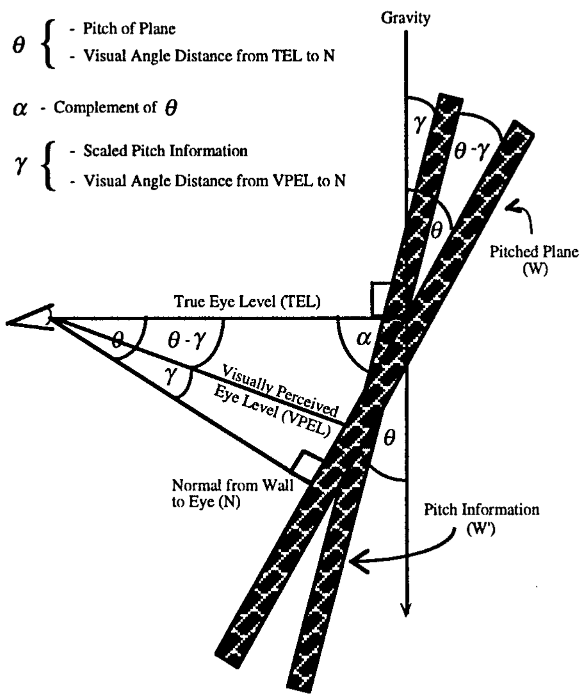


Figure 3a. Schematic of the geometric relationships between Visually Perceived Eye Level(VPEL) and scaled pitch information (W'). θ is the physical pitch of the plane, as well as the angular distance from True Eye Level (TEL) to the Normal (N) from the pitched plane to the observer's eye. The ratio of γ to θ is the scaling constant for pitch information.
* Pitch information has no real physical location. It is added here to show the location of the pitched visual field that would have produced the pitch information (with: $1 \geq$ scaling constant ≥ 0), had the scaling constant been 1.

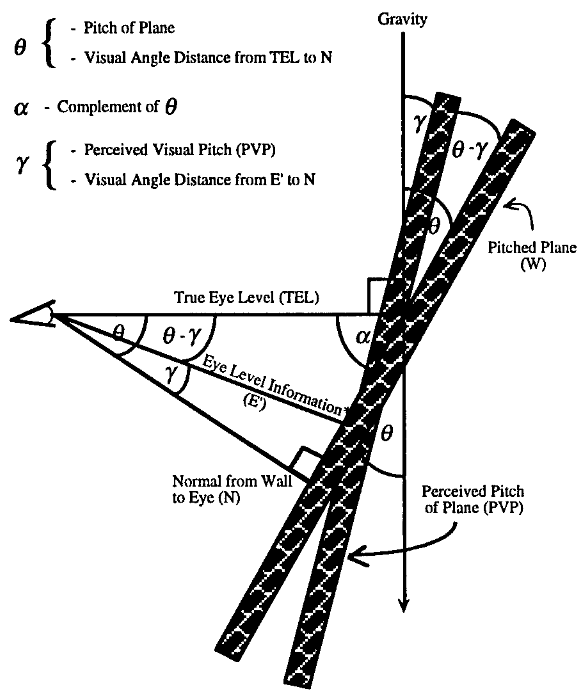


Figure 3b. Schematic of the geometric relationships between Perceived Visual Pitch and scaled eye level information (E'). θ is the physical pitch of the plane, as well as the angular distance from True Eye Level (TEL) to the Normal (N) from the pitched plane to the observer's eye. The ratio of γ to θ is the scaling constant for eye level information.
* Eye level information has no real physical location. It is added here to show the location of the pitched visual field that would have produced eye level information (with: $1 \geq$ scaling constant ≥ 0), had the scaling constant been 1.

Case 2: PVP Discrimination Requires Eye Level Information

The pitch of a plane (defined as the dihedral angle between a frontoparallel plane and the pitched plane) can be specified by the visual angle distance from the observer's eye level to the normal from the plane to an observer's eye, shown in Figures 3a, b, & c as N to TEL, or θ. If accurate PVP discriminations require eye level information, we would expect individual differences in the accuracy of PVP discriminations to be determined by individual differences in the magnitude of the scaling constant producing (scaled) eye level information; that is, the extent to which eye level information differs from N. A scaling constant of 0 would produce eye level information which does not differ from N. Observers would therefore be expected to produce PVP settings which form a dihedral angle of 0° with the frontoparallel plane, regardless of pitch. A scaling constant of 1 would produce eye level information which differs from N by θ. Observers would be expected to produce PVP settings which form a dihedral angle with the frontoparallel plane equal to θ, or veridical PVP discriminations. A scaling constant intermediate between 0 and 1 would produce eye level information which differs from N by less than θ, producing the classic underestimations of the pitch of the visual field found in most studies of pitch perception (e.g., Braunstein, 1968; Clark, Smith, & Rabe, 1956; Flock, 1964a, 1965). In all cases, the scaling constant specifies the expected proportion of the angular distance from N to TEL by which PVP is expected to differ from the frontoparallel plane.

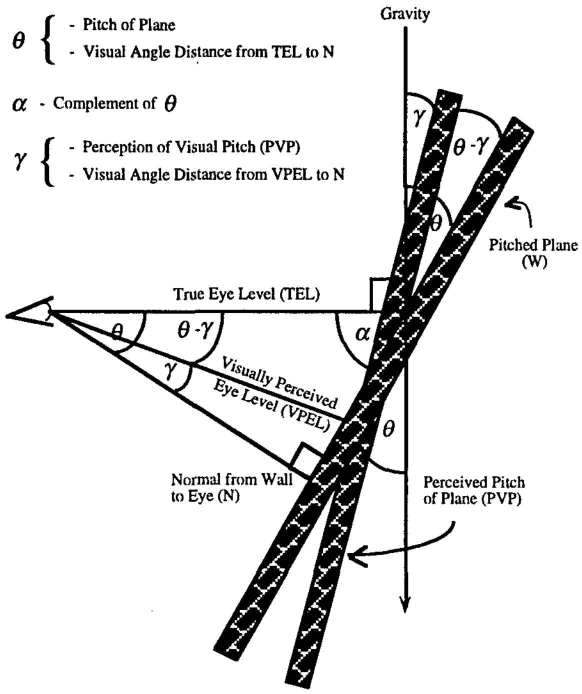


Figure 3c. Schematic of the geometric relationships between Visually Perceived Eye Level(VPEL) and Perceived Visual Pitch (PVP)θ is the physical pitch of the plane, as well as the angular distance from True Eye Level (TEL) to the Normal (N) from the pitched plane to the observer's eye. The ratio ofγ toθ is the scaling constant for pitch information.

These possibilities are shown graphically in figure 3b, where the eye level information, indicated by E', produces a PVP discrimination that differs from W by $\theta-\gamma$. The difference between the eye level information and True Eye Level, the angular distance from E' to TEL, is equal to the error in the PVP discrimination, the angular distance from PVP to W $(\theta-\gamma)$. Similarly, the difference in angular distance from E' to N (γ) is equal to the angular distance between PVP and an unpitched plane (parallel to the direction of gravity). This leads to the equation:

$$PVP = \theta - (\theta - \gamma) \qquad (2)$$

Prediction for the Relationship Between VPEL and PVP

Because we have assumed that a single mechanism may underlie performance on the VPEL and the PVP discriminations, we must suppose that the eye level information used in the PVP discrimination will produce VPEL discriminations, and that the pitch information used in the VPEL discrimination will produce PVP discriminations. From these assumptions, we can make a further prediction concerning the relationship between the PVP and VPEL discriminations. Specifically, by changing (1) and (2) to:

$$VPEL = \theta - (PVP), \qquad (3)$$
$$PVP = \theta - (VPEL), \qquad (4)$$

respectively, we see that both equations make the same prediction. This prediction, shown in Figure 3c, states that the VPEL and PVP discriminations should sum to the pitch of the visual field, or:

$$PVP + VPEL = \theta \qquad (5)$$

Notice also that equation (5) is able to account for veridical discriminations, where VPEL does not deviate from TEL (VPEL = 0 for all pitches), and PVP matches the physical pitch (PVP = θ).

Section II

Individual differences in perceptual discrimination tasks involving disembedding, such as the classical Rod and Frame Test (RFT), have been interpreted as reflecting differences in global information processing style. Accurate performance on these tasks requires that subjects extract, or 'disembed', specified information from highly salient but misleading information in the visual field. In the RFT, subjects are required to set a small movable rod to the vertical within a tilted visual field (usually tilted 28° from the vertical). Subjects will on average set the rod somewhere between true vertical and the tilt of the visual field. Subjects who set the rod to a relatively low proportion of the physical tilt of the visual field are said to be less influenced by the tilted visual field, or less field dependent, than subjects whose settings of the vertical are a greater proportion of the physical tilt (Asch & Witkin, 1948a, 1948b; Witkin & Asch, 1948; Witkin, Oltman, Raskin, & Karp, 1971).

The information processing style of which the RFT is taken to be indicative is said to be global because subjects' relative abilities on a wide range of disembedding tasks, including perceptual (such as the RFT) and cognitive disembedding tasks (such as the Embedded Figures Test, or EFT), were shown to be consistent with one another, indicating the influence of a single global processing style which mediates performance on this class of task (Newbigging, 1954; Witkin, 1950; Witkin, Goodenough, and Karp, 1967; Witkin, Lewis, Hertzman, Machover, Meissner, and Wapner, 1954; Witkin et. al., 1971), such as that shown in Figure 4.

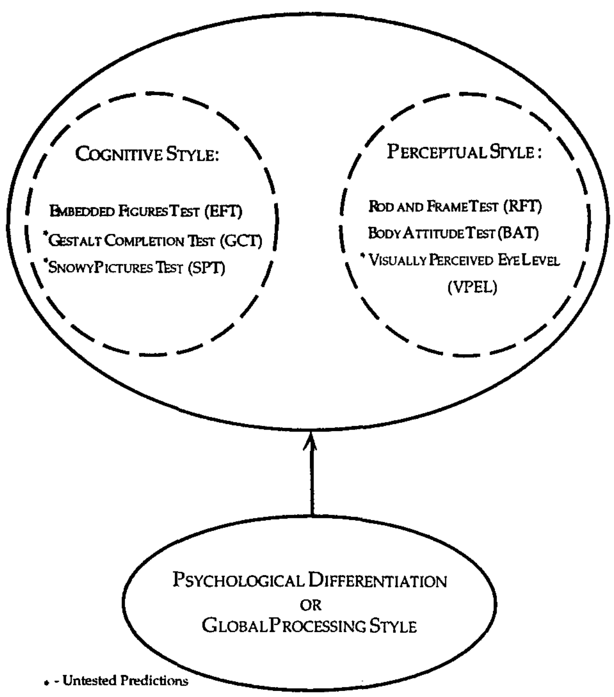


Figure 4. Representation of the suggested relation between global processing style, perceptual style (performance on such tasks as the Rod and Frame Test, the Body Attitude Test, and predicted performance on the Visually Perceived Eye Level discrimination), and cognitive style (performance on the Embedded Figures Test, and predicted performance on the Gestalt Completion Test and Snowy Pictures Test).

The purpose of the present study was to investigate further the claim of a single underlying global style which mediates performance on both perceptual and cognitive tasks requiring disembedding. The Visually Perceived Eye Level (VPEL) discrimination, which meets the requirements for a disembedding task, and has task requirements which are exactly parallel to those of the RFT, has been chosen for comparison with the EFT.

The RFT, which utilizes the Visually Perceived Vertical (VPV) discrimination, requires an observer to set a small rotatable rod within a large, tilted-from-vertical frontoparallel plane to the vertical. VPV changes linearly with the tilt of the visual field, such that clockwise tilts produce clockwise shifts in VPV. The magnitude of the angular shift in VPV has been found to be some constant proportion of the physical tilt of the visual field (Asch & Witkin, 1948a, 1948b; Witkin & Asch, 1948; Matin & Li, 1992b, 1994b, 1995). In order to correctly set VPV within a tilted-from-vertical visual field, the observer must differentiate between true vertical, corresponding to the direction of gravity, and the 'verticals' of the visual field, produced with reference to the main lines of the visual field. These two are always in close correspondence in a carpentered environment, but are discrepant in a tilted environment to a degree equal to the tilt of the visual field (see Figure 5a). The VPEL discrimination requires an observer to locate her eye level within a pitched visual field. It is well known that VPEL changes linearly with the pitch of the visual field, such that topbackward pitches elicit VPEL's below true eye level, and topforward pitches elicit VPEL's above true eye level. The magnitude of the angular shift in elevation corresponding to VPEL has been found to be about 0.6 of the pitch of the visual field in the well illuminated, complexly structured environment of the pitchroom. That is, the best fit line describing average VPEL settings has a slope of about 0.6. There are, however, individual differences in slopes, with values ranging from about 0.1 to 0.8 (Matin & Fox, 1989; Matin & Li, 1992a; 1994a). In order to correctly localize eye level within a pitched visual field, the observer must differentiate between eye level and the normal from the eye to an erect wall (N). These two points are always in close correspondence in a carpentered environment, but are discrepant in a pitched visual field to a degree equal to the pitch of the visual field (see Figure 5b).

It was suggested by Witkin, et. al. (1954) that individual differences in the RFT are due to subjects' interpretations of the visual field. If subjects treat the tilted visual field as upright, then their settings of VPV should parallel the tilted axis of the visual field, as would be the case in an upright, carpentered environment. The error in the VPV discrimination will therefore equal the tilt of the visual field. If subjects treat the visual field as appropriately tilted, they are expected to set VPV as in a tilted environment, which requires them to take tilt 'into account'. These subjects will be expected to make approximately veridical settings of VPV. Of course, it is possible that subjects do not treat the visual field as entirely untilted (upright), or entirely tilted (to the full tilt, θ, of the visual field), but as some scaled combination of the two. In this case, the error in VPV will be dependent upon the scaled tilt. For example, a scaling constant of 0.7 would produce scaled tilt which differed from θ by 0.3 of the tilt of the visual field. These subjects are expected to set VPV to 0.7 of the angular distance from the tilted axis of the visual field to true vertical (an error of 0.3 of θ). Subjects whose scaling constants are close to 1 are considered field independent, because their settings of perceived vertical do not parallel the tilt of the visual field, while those subjects whose scaling constants are close to 0 are considered field dependent, because their settings are approximately parallel to the tilted visual field. Similarly, individual differences in VPEL settings would be due to subjects' interpretations of the visual field. If subjects take the pitched visual field to be erect, then VPEL settings should be at the point perpendicular to the pitched plane (intersecting the eye), or at N (see Figure 5b); the error in the VPEL discrimination will equal the pitch of the visual field. If subjects perceive the visual field as appropriately pitched, then they will be able to 'account for' the pitch of

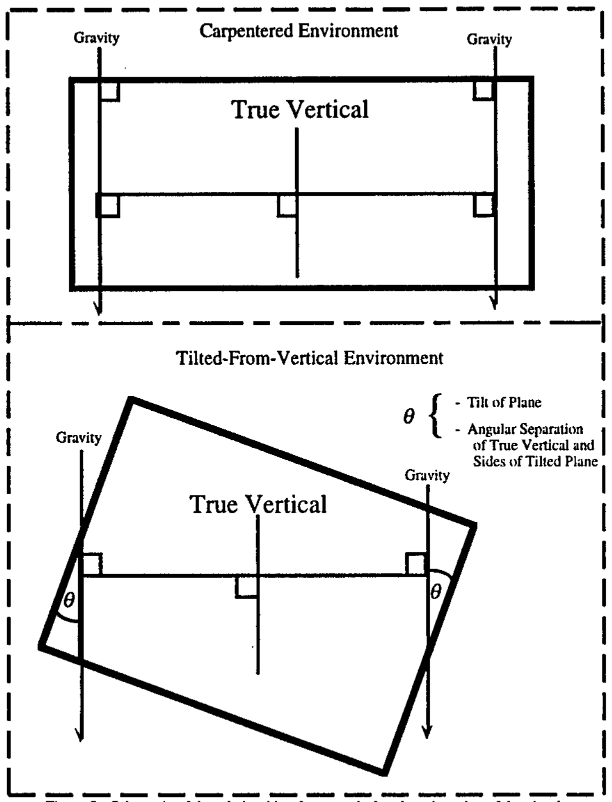


Figure 5a. Schematic of the relationship of true vertical to the orientation of the visual field in both a carpentered environment (upright visual field) and a tilted-from-vertical environment (tilted-from-vertical visual field).

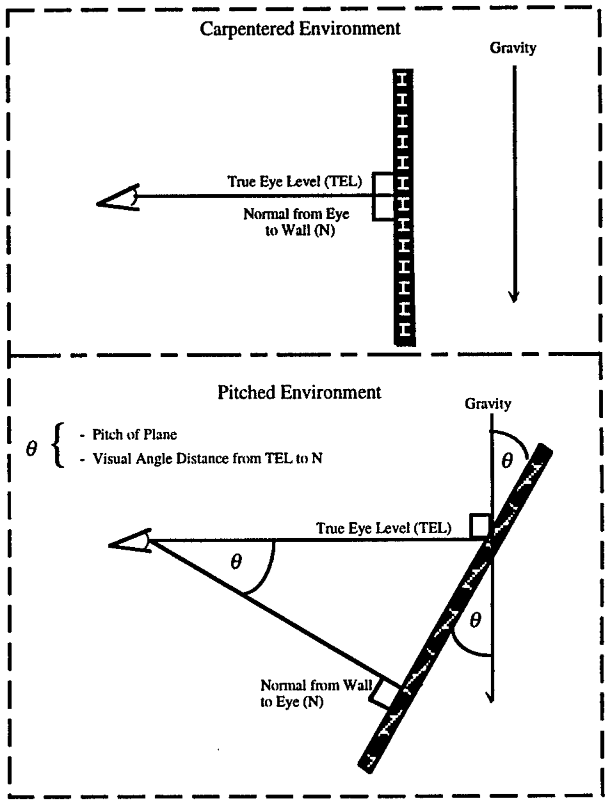


Figure 5b. Schematic of the relationship of the pitch of a visual field to the angular difference between the Normal (N) from the pitched plane to the observer's eye and the observer's True Eye Level (TEL) in both a carpentered environment (erect visual field), and a pitched environment (pitched visual field).

the visual field, and set VPEL at an angular distance from N equal to the perceived pitch (veridical VPEL discrimination). As with VPV, it is possible that subjects do not treat the visual field as entirely unpitched (erect), or entirely pitched (to the full pitch, θ, of the visual field), but as some scaled combination of the two. In this case, the error in VPEL will be determined by the scaled pitch. For example, a scaling constant of 0.4 would produce scaled pitch which differed from θ by 0.6 of the pitch of the visual field. These subjects are expected to set VPEL to 0.4 of the pitch of the visual field distant from N (an error of 0.6 of θ). Subjects who use a relatively large scaling constant are considered field independent, because their settings of VPEL do not correspond to the location of N, while those subjects using a relatively small scaling constant are considered field dependent, because their settings correspond approximately to the location of N (they do not take the pitch of the visual field 'into account').

The comparison task we have chosen is the most widely used and studied of the disembedding tasks, the Embedded Figures Test (EFT). The EFT requires observers to locate previously seen simple shapes within complexly structured designs as quickly as possible. By treating the complex shapes analytically, differentiating between the previously seen form and the extraneous contours that have been added in the complex designs, subjects can identify the previously seen simple forms relatively quickly. Field independent subjects, who are expected to treat the figures relatively more analytically, would require less time to find the simple shapes than would field dependent subjects. Two other cognitive disembedding tasks were used. The Gestalt Completion

Test (GCT) and the Snowy Pictures Test (SPT) both involve the identification of fragmented and/or partially hidden objects, and are similar to the EFT in their disembedding requirements.

It is therefore expected that individual differences in VPEL slopes will result from individual differences in the amount by which subjects scale the pitch of the visual field, and these differences are expected to be directly proportional to EFT scores (as well as inversely proportional to GCT and SPT scores). In other words, VPEL slopes and EFT scores are expected to be positively correlated, and VPEL slopes and number correct on the GCT and SPT are expected to be negatively correlated. Similarly, we expect a negative correlation between EFT scores and number correct on the GCT and SPT.

Methods

There were two separate parts to the study, to be described in Section I and Section II. In Section I, twenty subjects (ten female, ten male) performed both the VPEL and PVP discrimination tasks. In Section II, eighteen of the subjects from Section I (nine female, nine male) performed cognitive tasks, involving the disembedding of objects from a complex scene, and the identification of fragmented line drawings. Section I measures were taken before Section II measures for all subjects.

Section I

Participants

The ages of the subjects ranged from 18 to 33 years; the median age was 23.5 years. This portion of the experiment took approximately 2 hours to complete. Subjects were paid for their participation.

There was a marginal sex difference in the average True Eye Level (TEL) values, (measured from the floor to the outer canthus of the left eye) with the male subjects having TEL's of approximately 3.7 cm ($t(18.21) = -1.879$, $p = 0.076$) greater than the female subjects. These values were not correlated with any of the perceptual or cognitive variables discussed in this paper.

Apparatus

The experiment was conducted in the pitchroom shown in Figure 6. When erect, the far wall of the pitchroom subtended approximately $40^{\circ} \times 40^{\circ}$ of visual angle (at its 185.4 cm viewing distance). The erect pitch match frame (1 meter from the subject, with its axis of rotation 1.17 m above the floor) subtended at most $17^{\circ} \times 19^{\circ}$ of visual angle, and was positioned directly between the subject and one of the walls of the erect exterior room (not shown in Figure 6), such that the visual field of the subject facing the frame was composed mainly of the erect wall of the exterior room.

Procedure

The method of adjustment was used for both the VPEL and PVP discriminations. Measurements were obtained for both VPEL and PVP at:

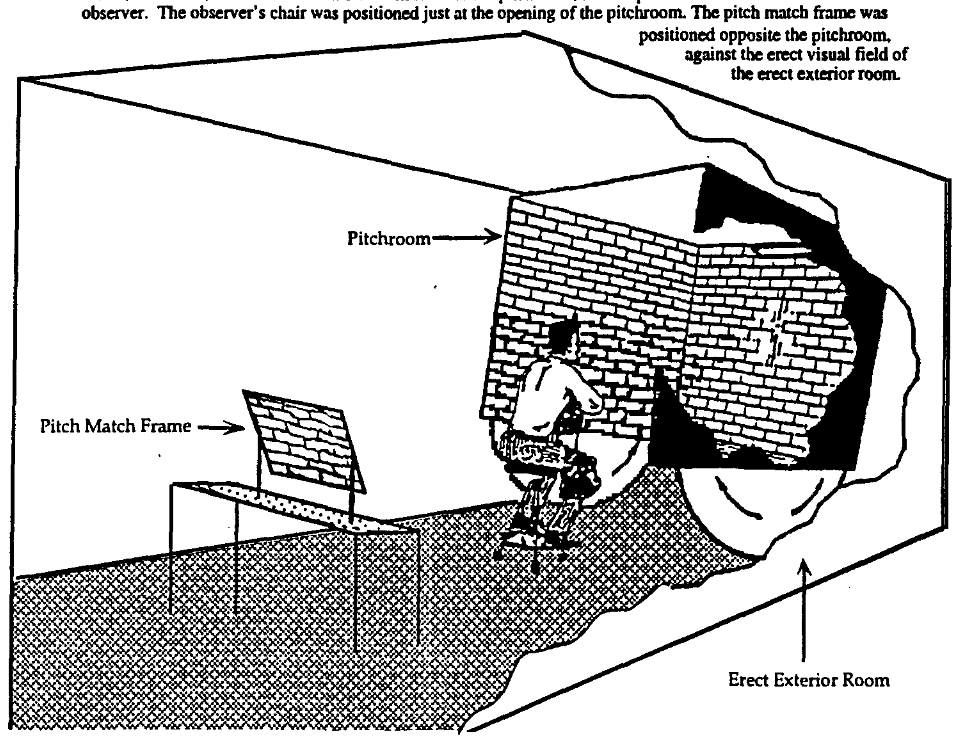
topforward pitches: 10°, 20° in the illuminated pitchroom;

upright pitchroom (0°), with the pitchroom both darkened and illuminated;

topbackward pitches: -10°, -20°, -30° in the illuminated pitchroom.

Each subject's session began and ended with discriminations in the upright (both darkened and illuminated) pitchroom. Intermediate nonzero pitches were presented once each within two blocks. The blocks were separated by discriminations in the erect, illuminated pitchroom. The blocks themselves were composed of the remaining (nonzero) pitches presented in random order, with each subject receiving a new random order. Each pitch was therefore presented twice, once in each block, except for the 0° illuminated pitchroom condition, which was presented three times. Two VPEL and PVP discriminations were obtained for each presentation of each pitch, making 4 measurements of each discrimination at non-zero pitches & VPEL at 0° in the darkened pitchroom (V_d), and six measurements of each discrimination at 0° in the illuminated pitchroom. The order in which discriminations were obtained for each individual setting of pitch was: VPEL discrimination; PVP discrimination; VPEL discrimination; PVP discrimination. After each discrimination, subjects were asked to give a confidence rating on a

Figure 6. Cutaway drawing of the pitchroom and pitch match frame (both oriented topbackward) inside the erect room of the building. The pitchroom was illuminated by the lamp shown attached to the top of the interior wall facing the observer; a shield (not shown) prevented direct viewing of the lamp by the observer. The point of the interior wall facing the observer indicates the laser beam that was set by the observer's instruction to visually perceived eye level (VPEL). The arrows indicate the directions of change of the target during psychophysical measurement. A black cloth (not shown) was attached to the bottom shelf of the pitchroom, and draped around the shoulders of the observer. The observer's chair was positioned just at the opening of the pitchroom. The pitch match frame was positioned opposite the pitchroom, against the erect visual field of the erect exterior room.



scale from one to ten indicating how sure they were that they had discriminated the objectively correct setting. VPEL was calculated in degrees of visual angle from TEL. The angle at which the subjects set the frame for the PVP discrimination was read directly from a protractor set on the back side of the frame. The protractor was never visible to the subject.

All but two of the subjects used binocular viewing. One female (M.S.) and one male (R.D.) subject performed the experiment under monocular viewing conditions. Their results were not distinguishable from those of other subjects.

The VPEL discrimination was performed with the subject facing the far wall of the pitchroom (see Figure 6), upon which the point of laser light was projected. Subjects were instructed to make the VPEL discrimination by verbally indicating that the experimenter move a red point of laser light (from an attenuated 0.95 mW He-Ne laser mounted behind the subject, projected onto the pitched wall within the subject's midsaggital plane) up or down until she felt it was at eye level. Eye level was defined for each subject by the experimenter as the point at which a line perpendicular to gravity and projected from the eye would intersect the far wall of the pitchroom.

Subjects were told to close their eyes while the light was being moved up or down in response to their instructions. This was repeated until the subject indicated that it was positioned at eye level. Subjects indicated the direction of movement by 'up' or 'down' commands, to which the experimenter responded by moving the laser approximately 2.5° in the direction indicated, until smaller adjustments were required. Each time the subject indicated that smaller adjustments were required, the experimenter would move the laser approximately half the distance of the previous adjustment.

At the start of each VPEL discrimination, the laser light was initially positioned far above or far below the region of uncertainty. For each individual setting of the pitchroom, at which two VPEL measurements were always taken, the initial position of the laser was placed once above and once below the region of uncertainty, except in the case of several very tall or very short subjects, when the VPEL for 20° or -30° was close enough to the top or bottom (respectively) of the pitchroom to make it impossible to place the light both far above and below the region of uncertainty. In these cases, both initial positions were either high or low, depending upon the circumstance.

All but two of the subjects were positioned so that the coronal plane containing their eyes intersected a bar set just inside the bottom edge of the entrance to the pitchroom[2]. These subjects were then always positioned at some distance from 150 cm to 185.4 cm normal from the pitchroom. The remaining subjects (M.S. and R.D.) were positioned at a distance 100 cm normal from the pitchroom.

Subjects spent approximately 1-2 seconds with their eyes open looking at the wall to direct each movement of the laser light, and sat with their eyes closed at all other times. All subjects had their heads stabilized during the VPEL discrimination by a chinrest.

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[2] See Appendix for a detailed description of the geometry of the pitchroom and the calculation of VPEL

PVP Discrimination

Each VPEL discrimination in the illuminated pitchroom was followed by a PVP discrimination, with the position of the pitchroom remaining as it had been for the preceding VPEL discrimination. The PVP discrimination was performed with the subject facing sideways in the pitchroom (relative to the position shown in Figure 6). In this position, the subject was turned 90° in a clockwise direction from that shown in Figure 6, such that his left shoulder was facing the far wall of the pitchroom (the direction of the wall upon which the VPEL discrimination was made), and his right shoulder was facing the pitch match frame. This allowed the subject to look comfortably both toward the far wall of the pitchroom (over the left shoulder) and toward the pitch match frame (over the right shoulder).

Subjects sat with their chairs facing the side of the pitchroom throughout the PVP procedure, turning only their heads. They first looked at the inside of the pitchroom (at the same far wall that was used for the VPEL discrimination), knowing that they would be matching its pitch with that of the frame. They then turned to face outside of the pitchroom, toward the frame. Subjects were told to give the experimenter verbal instructions to move the top of the frame forward or backward until the pitch of the frame matched the pitch of the far wall of the pitchroom. After giving each instruction to move the frame, subjects were required to look back to the pitchroom and again at the frame before they issued their next instruction to have the frame adjusted. They were asked to close their eyes while turning to look at either the wall or the frame, as well as while the frame was being moved, and were cautioned to open their eyes only while their heads were still (as subjects were not using the chinrest during the PVP discrimination). This was repeated until the subject indicated that the pitch of the frame matched that of the far wall of the pitchroom.

For each individual PVP discrimination, the frame was initially positioned so that it was 20° – 60° from the physical pitch of the pitchroom, once above (top too far forward) and once below (top too far backward) for each setting of the pitchroom. Subjects indicated the desired direction of movement by 'toward' (top of the frame toward the subject) or 'away' (top of the frame away from the subject) commands, to which the experimenter responded by moving the frame approximately 8° – 12° in the direction indicated, until smaller adjustments were required. Each time the subject indicated that smaller adjustments were required, the experimenter would move the frame approximately half the distance of previous adjustment. Subjects spent approximately 1-2 seconds looking at both the wall and frame for each adjustment of the frame.

The horizontal distance at which subjects sat from the far wall of the pitchroom during the PVP discrimination was identical to the distance at which the subjects sat during the VPEL discrimination for all but two subjects. The positions of the remaining two subjects (M.S. and R.D.) were adjusted during the PVP discrimination so that they would have the same approximate distance to the pitchroom and the frame as the other eighteen subjects. The approximate horizontal distances from the subjects to the vertical axis of the frame (given in terms of the pitch of the pitchroom) were:

First Eighteen Subjects: 100 cm at 0°, 10°, and 20°, 125 cm at $^{-}10^{\circ}$, 130 cm at $^{-}20^{\circ}$, and 135 cm at $^{-}30^{\circ}$;

M.S. and R.D. : 85 cm at 0°, 73 cm at 10°, 60 cm at 20°, 92 cm at $^{-}10^{\circ}$, 103 cm at $^{-}20^{\circ}$, and 120 cm at $^{-}30^{\circ}$.

Section II

Participants

Eighteen of the original twenty subjects participated in the second part of the study. Only J.W. (female) and S.D. (male) did not participate.

Materials

The Gestalt Completion Test and the Snowy Pictures Test, as well as the standard form of the Embedded Figures Test, were used (see Figure 7 for an example of each).

Procedure

Subjects were tested individually, and the order of test presentation was random.

Embedded Figures Test (Witkin, Oltman, Raskin, & Karp, 1971)

The standard form of the Embedded Figures Test (EFT) was used. No modifications to the instructions or scoring were made. Each subject's EFT score was the arithmetic average of the time (in seconds) it took to find twelve geometric objects (simple figures) within a more complex geometric object (complex figures; see Figure 7). Each of the twelve items were presented individually, and subjects were never able to see both the complex and simple object at the same time, although they were able to look back at the simple object (while the complex object was covered) at any time they chose. While subjects were taking another look at the simple object, the clock was stopped. If subjects had not found the simple figure within the complex figure within 3 minutes, they were stopped and asked to continue with the next item, and given the maximum score of 180 seconds for the skipped item.

Gestalt Completion Test (Ekstrom, French, Harman, & Dermen, 1995)

Subjects were given a set of twenty picture fragments (contained on 4 sheets of paper, laid out on a desk so that no sheet was covered by another; see Figure 7), and below each picture were required to write the name of the object depicted. Synonyms were accepted. Subjects were given two minutes in which to

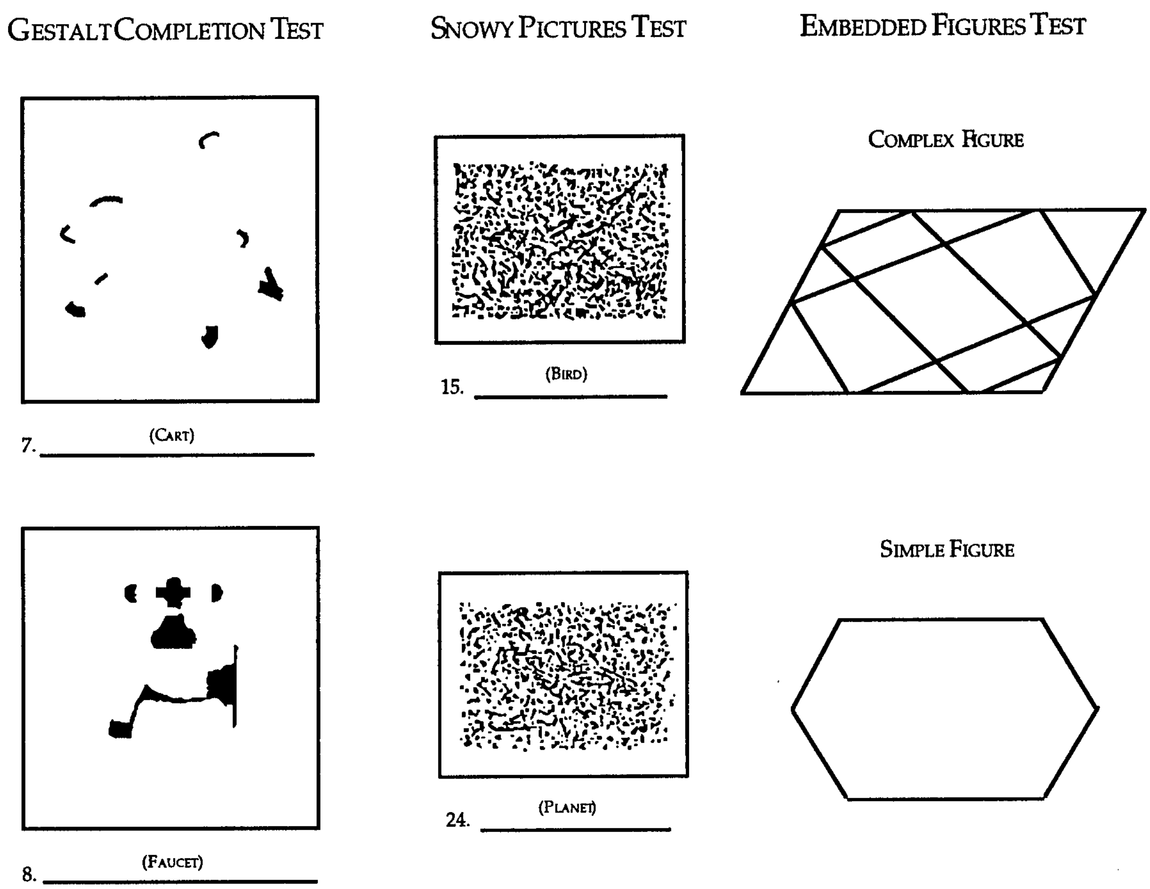

Figure 7. Examples of each type of cognitive disembedding task.

name the objects, in any order they chose, and were stopped when time was up. The number of correct, incorrect, and skipped items was recorded.

Snowy Pictures Test (Ekstrom, et. al., 1995)

The pictures of the SPT were very similar to those of the GCT, except that there were extra short unconnected lines added to the drawing, creating noise in the form of 'snow' around and over the picture itself (see Figure 7). The procedure was the same as for the GCT, except that there were twenty-four objects contained on two sheets of paper, and subjects were given three minutes to complete the set. The number of correct, incorrect, and skipped items was recorded.

For both the GCT and SPT, several subjects indicated before testing that they might not know the English names of some items. These subjects, as well as several others for whom English was not their native language (as indicated on the Consent Form), were given the option to write the name of the item in their native language, and then translate for the experimenter after completion of the test. None of the subjects found it necessary to adopt this strategy.

Results

Section I

All raw scores were averaged across the two repetitions of each of the two presentations of the 6 pitches. A least squares fitted regression was computed for both the VPEL and PVP discriminations, plotted against physical pitch (θ), from which slopes and intercepts were obtained. V' is the first derivative, or slope, of the best fit line for the VPEL discrimination as a function of pitch, or $VPEL(\theta)$; V_0 is the intercept of $VPEL(\theta)$. Similarly, P' is the first derivative of the best fit line for the PVP discrimination as a function of pitch, or $PVP(\theta)$; P_0 is the intercept of $PVP(\theta)$. More formally, these variables are defined as:

$$V' = \frac{d(VPEL)}{d(Pitch)} = \frac{d(V)}{d(\theta)} = VPEL'(\theta) \ ;$$

$$P' = \frac{d(PVP)}{d(Pitch)} = \frac{d(P)}{d(\theta)} = PVP'(\theta) \ ;$$

V_0 = y-intercept of the best fit least-squares regression of $VPEL(\theta)$;

V_d = mean VPEL discrimination in the darkened, erect pitchroom;

P_0 = y-intercept of the best fit least-squares regression of $PVP(\theta)$.

Visually Perceived Eye Level Discrimination

Each subject's VPEL changed as a positive linear function of the pitch of the visual field, such that topforward pitches produced VPEL settings above true eye level (TEL), and

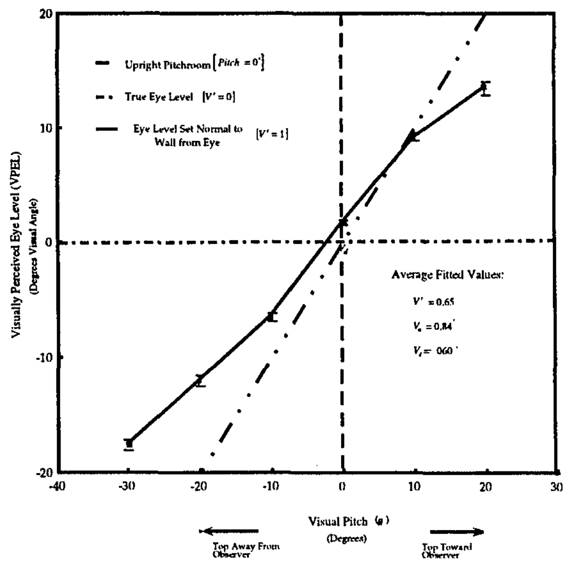

Figure 8. Average visually perceived eye level (VPEL) values as a function of pitch. The slope of the best fit line for all subjects (0.65) falls in between the line indicating veridical eye level discrimination (0.0) and that indicating settings of VPEL at the normal (N) from the pitched plane to the observer's eye (1.0).

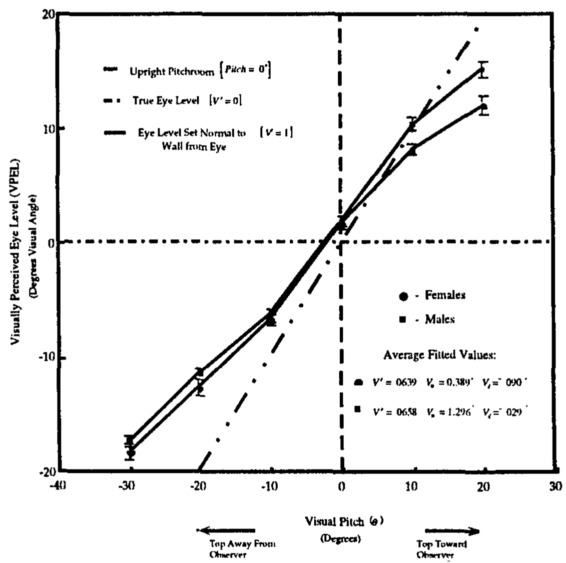

Figure 9. Average visually perceived eye level (VPEL) values by sex as a function of pitch. The slope of the best fit line for both male (0.66) and female (0.64) subjects falls in between the line indicating veridical eye level discrimination (0.0) and that indicating settings of VPEL at the normal (N) from the pitched plane to the observer's eye (1.0).

topbackward pitches produced VPEL's below TEL. V' ranged from 0.327 to 0.861 (Mdn = 0.636, Mean = 0.648), with V_0 ranging from $^-4.53^\circ$ to 5.68° (Mdn = 0.567°, Mean = 0.843°).

The V_d settings ranged from $^-6.64^\circ$ to 5.51° (Mdn = 0.483°, Mean = $^-0.597^\circ$). The plot of VPEL against pitch averaged across subjects is shown in Figure 8. As with each individual subject's data, the average data changes linearly with the visual pitch of the pitchroom. The table of mean VPEL settings and summary statistics by subject is given in Table 1.

The average V' across subjects (0.65) differed significantly from both 0 (t(19) = 23.32, p $= 1.8 \times 10^{-15}$), and 1 (t(19) = 12.66, p $= 1.0 \times 10^{-10}$). Further, there were no differences between Subjects' average V_d settings ($^-0.60^\circ$) and 0 (t(19) = $^-0.734$, p = 0.47), or between 0 and their average V_0, of 0.84° (t(19) = 1.401, p = 0.18).

Sex Differences in the VPEL Discrimination

The Female subjects' V' values ranged from 0.327 to 0.861 (Mdn = 0.623, Mean = 0.639), with V_0 ranging from $^-4.53^\circ$ to 5.07° (Mdn = 0.430°, Mean = 0.389°). The V_d

Average Visually Perceived Eye Level (VPEL) Settings and Summary Statistics

Subject*	Pitch Condition (θ)							Summary	
	-30	-20	-10	0	10	20	V_d	V'	V_0
M.S.	-19.5	-8.6	-3.7	3.1	10.0	12.2	2.29	0.64	2.26
L.S.	-21.5	-12.7	-5.4	4.5	13.5	16.7	2.40	0.80	3.16
J.W.	-10.8	-5.7	-0.9	5.1	11.7	16.9	2.52	0.56	5.07
K.N.	-14.3	-12.5	-8.1	-1.8	1.6	-1.4	-6.36	0.33	-4.53
J.S.	-14.1	-11.3	-5.2	3.3	7.2	12.1	-4.77	0.56	0.70
L.P.	-17.6	-11.5	-7.0	1.5	7.2	11.9	-0.13	0.61	0.44
C.T.	-21.0	-14.8	-8.3	2.0	9.8	15.5	-3.76	0.76	0.42
B.B.	-24.2	-19.3	-10.3	-1.4	4.7	11.1	1.19	0.74	-2.20
N.I.	-15.5	-11.4	-5.8	-0.2	6.2	10.1	3.67	0.53	0.42
H.G.	-25.4	-20.1	-11.6	0.0	9.0	14.9	-6.05	0.86	-1.84
R.D.	-20.0	-13.3	-6.7	2.2	10.6	13.8	1.33	0.72	1.43
J.H.	-14.5	-10.3	-4.7	1.6	9.7	12.5	0.22	0.58	1.88
T.F.	-17.2	-11.3	-4.9	3.0	13.0	16.4	2.94	0.71	3.27
S.T.	-13.7	-9.1	-2.3	3.9	13.2	18.0	1.16	0.66	4.33
S.D.	-14.0	-6.0	-1.2	5.7	13.5	17.3	5.51	0.63	5.68
M.R.	-17.9	-12.1	-8.5	-1.4	7.1	11.2	-4.00	0.60	-1.14
L.L.	-22.7	-12.4	-12.5	1.7	9.7	15.5	-2.61	0.78	0.09
J.P.	-20.1	-16.2	-9.6	-3.0	5.0	9.9	-6.64	0.63	-3.14
M.G.	-18.9	-15.5	-8.7	0.5	11.8	17.0	0.74	0.77	1.37
E.A.	-14.0	-11.0	-9.1	-0.1	5.1	9.6	-1.60	0.50	-0.82
Avg. Female	-18.38	-12.79	-6.63	1.60	8.08	12.02	-0.90	0.639	0.389
Avg. Male	-17.31	-11.74	-6.83	1.42	9.86	14.11	-0.29	0.658	1.296
Avg. All	-17.85	-12.26	-6.73	1.51	8.97	13.07	-0.60	0.648	0.84

* - The first ten subjects are female, the last ten are male

Table 1

ANOVA of Visually Perceived Eye Level (VPEL) Settings

	df	Sum of Sq	Mean Sq	F Ratio	Pr(F)
Pitch	5	59866.91	11973.38	427.316	$< 1.0 \times 10^{-16}$
Sex	1	97.29	97.29	0.535	0.47
Pitch x Sex	5	100.37	20.07	0.716	0.61
Pitch x Subject	90	2521.65	28.02	7.413	$< 1.0 \times 10^{-16}$
Residuals	400	1511.03	3.78		

Table 2

settings ranged from $^{-}6.36^{\circ}$ to 3.67° (Mdn = 0.528°, Mean = $^{-}0.900^{\circ}$). See the first ten entries of Table 1 for the females' mean individual VPEL settings.

ranged from $^{-}6.64^{\circ}$ to 5.51° (Mdn = 0.483°, Mean = $^{-}0.293^{\circ}$). See the second ten entries of Table 1 for the males' mean individual VPEL settings.

Perception of Visual Pitch Discrimination

Each subject's PVP changed as a positive linear function of the pitch of the visual field, with linear fits ranging from $r^2 = 0.84$ to $r^2 = 0.99$. P' values ranged from 0.578 to 1.344 (Mdn = 0.951, Mean = 0.946), with P_0 ranging from $^{-}6.44^{\circ}$ to 0.609° (Mdn = $^{-}3.68^{\circ}$, Mean = $^{-}3.00^{\circ}$). The table of mean $PVP(\theta)$ settings and summary statistics by subject are given in Table 3.

The plot of $PVP(\theta)$ averaged across subjects is shown in Figure 10. As with each individual subject's data, the average data changes linearly with the visual pitch of the pitchroom.

The average P' across subjects (0.95) differed significantly from 0 (t(19) = 18.90, p $= 8.9 \times 10^{-14}$), but did not differ significantly from 1 (t(19) = 1.08, p = 0.29). Further, subjects had a significantly negative average P_0 of $^{-}3.0^{\circ}$ (t(19) = $^{-}6.24$, p = 5.4×10^{-6}).

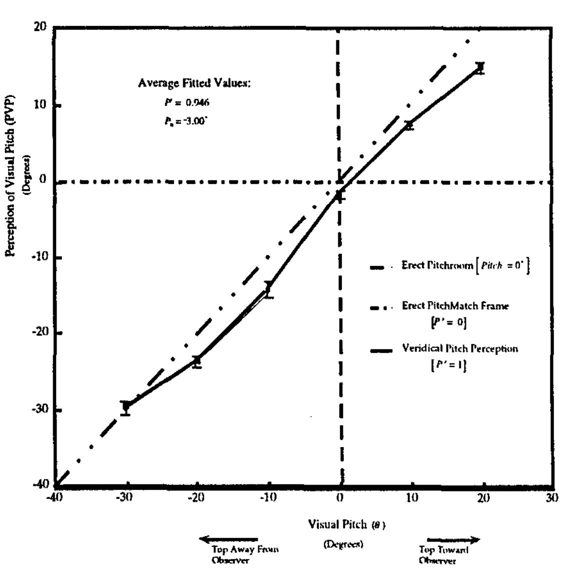

Figure 10. Average perception of visual pitch (PVP) values as a function of pitch. The slope of the best fit line for all subjects (0.95) is indistinguishable from that indicating veridical pitch perception.

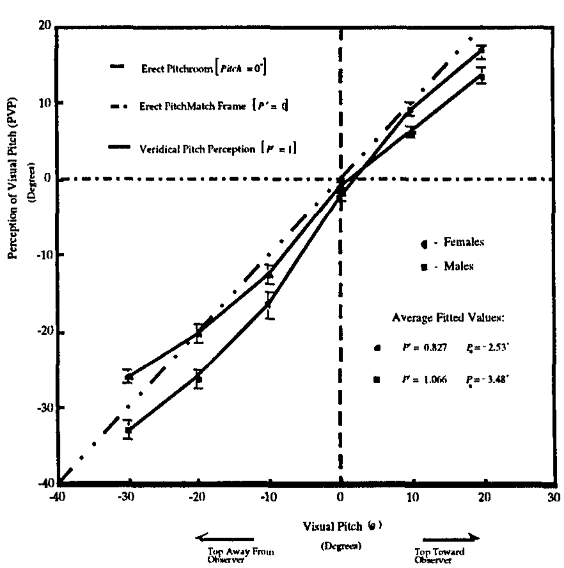

Figure 11. Average perception of visual pitch (PVP) values by sex as a function of pitch. The slope of the best fit line for male subjects (1.07) is indistinguishable from that indicating veridical pitch perception, while that of female subjects (0.83) is significantly different from veridical.

Average Perception of Visual Pitch (PVP)
Settings and Summary Statistics

Subject*	Pitch Condition(θ)						Summary	
	-30	-20	-10	0	10	20	P′	P_0
M.S.	-27.7	-25.6	-18.5	7.3	1.3	4.2	0.76	-4.64
L.S.	-32.8	-25.8	-14.3	-5.2	7.5	14.5	0.98	-4.45
J.W.	-20.0	-15.5	-12.9	-0.5	2.3	7.0	0.58	-3.47
K.N.	-32.5	-25.8	-17.8	-4.5	6.0	18.8	1.04	-4.12
J.S.	-24.0	-18.1	-15.5	-1.6	10.4	21.4	0.93	-0.05
L.P.	-26.5	-20.4	-11.6	0.2	7.5	13.9	0.85	-1.74
C.T.	-27.0	-24.5	-20.0	-6.0	2.8	11.3	0.82	-6.44
B.B.	-19.3	-10.0	-4.0	-0.3	7.3	12.3	0.61	0.61
N.I.	-30.0	-20.9	-16.3	-1.8	12.3	17.4	1.00	-1.54
H.G.	-20.6	-17.6	1.5	-0.3	6.6	13.4	0.69	0.54
R.D.	-27.8	-22.8	-17.0	-2.7	3.9	9.5	0.81	-5.23
J.H.	-33.5	-31.0	-6.9	0.3	3.3	11.0	0.96	-4.30
T.F.	-33.8	-28.8	-17.0	-4.5	5.3	17.9	1.07	-4.80
S.T.	-21.1	-16.5	-7.8	-1.7	6.1	13.3	0.70	-1.15
S.D.	-42.5	-27.3	-23.1	-3.5	13.3	20.5	1.30	-3.89
M.R.	-31.5	-24.6	-14.0	-5.0	8.3	13.3	0.95	-4.27
L.L.	-38.3	-21.9	-19.9	-1.0	12.0	26.6	1.27	-0.73
J.P.	-37.6	-33.0	-24.3	0.0	18.0	20.8	1.34	-2.43
M.G.	-35.3	-38.1	-26.3	0.0	11.5	12.8	1.19	-6.08
E.A.	-33.6	-26.3	-9.3	-0.7	6.0	19.9	1.07	-1.88
Avg. Female	-26.04	-20.41	-12.93	-1.26	6.39	13.39	0.827	-2.531
Avg. Male	-33.49	-27.01	-16.54	-1.87	8.75	16.54	1.066	-3.475
Avg. All	-29.76	-23.71	-14.73	-1.56	7.57	14.97	0.946	-3.003

* - The first ten subjects are female, the last ten are male

Table 3

Sex Differences in the PVP Discrimination

The Female subjects' P' values ranged from 0.578 to 1.042 (Mdn = 0.837, Mean = 0.827), with P_0 ranging from $-6.44°$ to $0.61°$ (Mdn = $-2.60°$, Mean = $-2.53°$). See the first ten entries of Table 2 for the females' mean individual PVP settings.

The Male subjects' P' values ranged from 0.702 to 1.344 (Mdn = 1.066, Mean = 1.066), with P_0 ranging from $-6.08°$ to $-0.73°$ (Mdn = $-4.08°$, Mean = $-3.48°$). See the second ten entries of Table 2 for the males' mean individual PVP settings.

A 6 (Pitch) x 2 (Sex) x 20 (Subject) ANOVA was calculated for PVP settings (see Table 4), using pitch as a repeated measure. The a priori predictions of a significant main effect of pitch, as well as of the pitch x subject interaction (based upon the expectation of individual differences in the linear fit of the *PVP(θ)* function) were supported. Further, a significant pitch x sex interaction, indicating different average slopes for male and female subjects, was found.

ANOVA of Perception of Visual Pitch (PVP) Settings

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Pitch	5	127475.6	25495.11	244.28	$< 1.0 \times 10^{-16}$
Sex	1	516.9	516.90	3.36	0.08
Pitch x Sex	5	2082.4	416.48	3.99	2.58×10^{-3}
Pitch x Subject	90	9393.7	104.37	5.07	$< 1.0 \times 10^{-16}$
Residuals	400	8229.9	20.57		

Table 4

The interaction of pitch x sex was confirmed in a t-test of the fitted P' values by sex, which differed on average by 0.24 (t(18) = 2.78, p = 0.012), indicating smaller average fitted slopes for females. Further analysis revealed that the average of the P' values of female subjects was significantly less than 1 (t(9) = 3.308, p = 0.0091), while the average of the P' values of male subjects was not significantly different from 1 (t(9) = 0.959, p = 0.36). There were no significant sex differences in P_0 (t(9) = $^-$0.98, p = 0.3403), supporting the lack of any main effect of sex in the ANOVA. The interaction of pitch $\times$ sex is shown in Figure 11.

Comparison of VPEL and PVP Discriminations

The VPEL settings at each separate pitch setting were strongly positively correlated with the corresponding PVP settings (r(258) = 0.869, p < 1.0×10^{-20}). The correlation of the P' and V' scores was, however, not significantly different from zero (r(18) = $^-$0.104, p = 0.66).

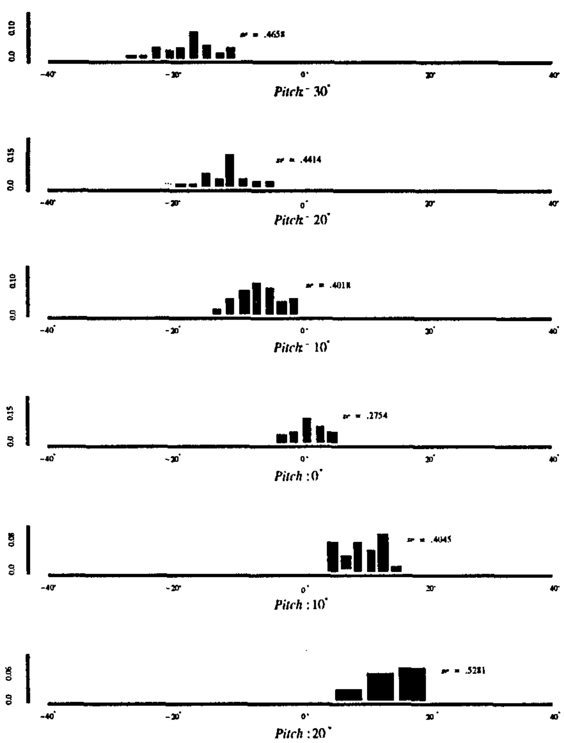

Figure 12a. Probability density histograms of visually perceived eye level (VPEL) settings by pitch condition. VPEL settings are given on the abscissa, and probability on the ordinate. Standard errors of the mean (se) are given for each pitch condition. Bin width was autoscaled in S-plus.

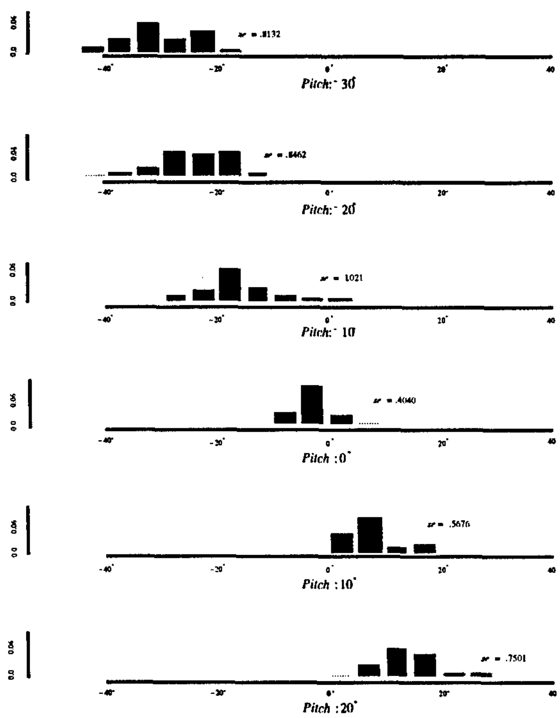

Figure 12b. Probability density histograms of perception of visual pitch (PVP) settings by pitch condition. PVP settings are given on the abscissa, and probability on the ordinate. Standard errors of the mean (se) are given for each pitch condition. Bin width was autoscaled in S-plus.

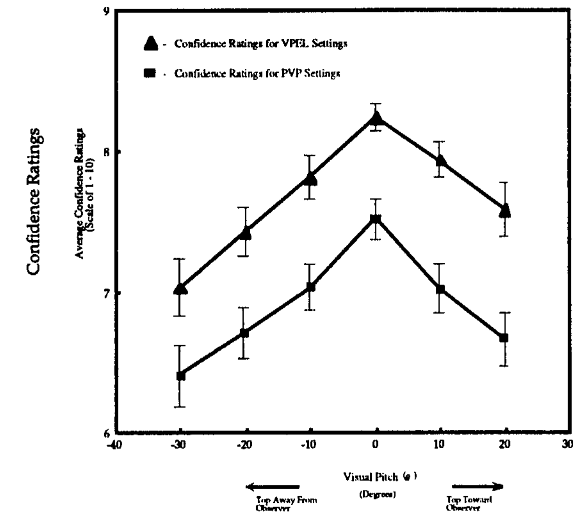

Figure 13. Average confidence ratings for the VPEL and PVP discriminations.

The probability density distribution functions of *VPEL(θ)* and *PVP(θ)* are shown in Figures 12a and 12b.

Sex Differences in the Comparison of the PVP and VPEL discrimination

The individual VPEL and PVP settings (across pitch conditions) were very strongly correlated to one another for both females and males ($r(128) = 0.839$, $p < 1.0 \times 10^{-20}$, and ($r(128) = 0.917$, $p < 1.0 \times 10^{-20}$, respectively). The correlations of the P' and V' values were, however, not significantly different from zero for either males or females ($r(8) = 0.152$, $p = 0.68$, and $r(8) = -0.440$, $p = 0.20$, respectively).

Confidence Ratings for VPEL and PVP Discriminations

As is clear from Figure 13, the confidence ratings of both the VPEL and PVP discriminations changed linearly with the absolute value of pitch. The confidence ratings for VPEL and PVP correlated significantly with the absolute value of the pitch of the room ($r(258) = -0.278$, $p = 2.7 \times 10^{-6}$, and $r(258) = -0.233$, $p = 1.0 \times 10^{-4}$, respectively), and the confidence ratings of the VPEL discrimination correlated significantly (but weakly) with the absolute value of the actual VPEL settings ($r(258) = -0.156$, $p = 0.012$), but the confidence ratings for the PVP discrimination were not significantly correlated with the difference between PVP settings and physical pitch ($r(258) = 0.023$, $p = 0.713$). Further, the average within-pitch confidence ratings of the VPEL and PVP discriminations were highly negatively correlated (-0.747 and -0.588, respectively) with the standard errors of the VPEL and PVP discriminations for the corresponding pitches ($df = 4$, $p = 0.09$, and $df = 4$, $p = 0.22$, respectively). The ANOVA's for the confidence ratings of the VPEL and PVP discriminations are given in Tables 5 and 6 (respectively).

ANOVA of Visually Perceived Eye Level (VPEL)
Confidence Ratings

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
|Pitch|	3	77.566	25.855	17.679	4.0×10^{-8}
Sex	1	25.432	25.433	0.645	0.43
|Pitch| x Sex	3	7.885	2.628	1.797	0.16
|Pitch| x Subject	54	78.972	1.462	2.538	1.1×10^{-7}
Residuals	440	253.5	0.576		

Table 5

ANOVA of Perception of Visual Pitch (PVP)
Confidence Ratings

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
|Pitch|	3	74.264	24.755	11.490	6.2×10^{-6}
Sex	1	136.069	136.069	3.062	0.10
|Pitch| x Sex	3	7.572	2.524	1.172	0.33
|Pitch| x Subject	54	116.342	2.155	2.451	3.3×10^{7}
Residuals	440	386.823	0.879		

Table 6

Section II

Embedded Figures Test

The average time required for subjects to complete all twelve items was 392.1 sec, or an average of 32.7 seconds per item. The scores of the total times ranged from 162 sec to 1171 sec, with a median score of 255.5 sec. Of the 18 subjects, seven ran out of time at least once (by the 'three minute rule') and proceeded to the next item without finding the simple figure within the complex figure. Of these subjects, only two had this happen more than once (one had two, the other had 5). All but four of the subjects used the rule which allowed them to take another look at the simple figure. The number of relooks ranged from 0 to 16, with a median of 2.5. The individual means for the three EFT measures are given in Table 7.

Gestalt Completion Test and Snowy Pictures Test

Subjects finished the GCT and SPT within the two or three allotted minutes (respectively) without any trouble. Still, all subjects skipped at least one item, except subject L.S., who gave a response for every item on the SPT. The greatest number of items skipped was 14 for the SPT and 12 for the GCT, with the median number of items skipped being 6 for the GCT and 7 for the SPT. The median number correct responses was 12 for the GCT and 13.5 for the SPT. The median number oferrors was 2 for the GCT and 3.5 for the SPT. All subjects responded correctly on at least half of the items for which they made a response. The individual means for the three GCT and SPT measures are given in Tables 8 & 9, respectively.

Relations among the Cognitive Tests and the VPEL Discrimination

All of the cognitive tests were highly correlated with one another for similar measures. The correlation of the EFT times to the number correct for the GCT was, $r(16) = -0.733$ ($p = 0.0005$). The correlation of the EFT to the number correct on the SPT was, $r(16) = -0.476$ ($p = 0.0461$). The correlation of the number correct on the GCT and SPT was, $r(16) = 0.707$

Embedded Figures Test (EFT)

Subject	Total Time for All Items (sec.)	Per-Item Time (sec.)	# of Items Skipped	# of Relooks Taken
M.S.	457	38.1	1	0
L.S.	184	15.3	0	1
K.N.	177	14.8	0	0
J.S.	240	20.0	0	2
L.P.	352	29.3	1	2
C.T.	162	13.5	0	6
B.B.	728	60.7	1	16
N.I.	389.5	32.5	0	4
H.G.	232	19.3	0	0
R.D.	169	14.1	0	2
J.H.	535	44.6	0	4
T.F.	271	22.6	1	0
S.T.	166	13.8	0	1
M.R.	1171	97.6	5	13
L.L.	536	44.7	1	6
J.P.	217	18.1	0	3
M.G.	860	71.7	2	12
E.A.	212	17.7	0	11
Average: Female	324.6	27.1	0.3	3.4
Average: Male	459.7	38.3	1.0	5.8
Average: All	392.1	32.7	0.7	4.6

* - The first ten subjects are female, the last ten are male

Table 7

Gestalt Completion Test (GCT)

Subject*	# of Items Correct	# of Errors	# of Items Skipped
M.S.	12	5	3
L.S.	14	5	1
K.N.	13	1	6
J.S.	15	1	4
L.P.	13	2	5
C.T.	15	2	3
B.B.	9	0	11
N.I.	11	0	9
H.G.	13	1	6
R.D.	14	3	3
J.H.	12	0	8
T.F.	11	4	5
S.T.	11	3	6
M.R.	7	2	11
L.L.	6	2	12
J.P.	11	0	9
M.G.	10	2	8
E.A.	13	0	7
Average: Female	12.8	1.9	5.3
Average: Male	10.6	1.8	7.7
Average: All	11.7	1.8	6.5

* - The first ten subjects are female, the last ten are male

Table 8

Snowy Pictures Test (SPT)

Subject *	# of Items Correct	# of Errors	# of Items Skipped
M.S.	15	2	7
L.S.	17	7	0
K.N.	11	6	7
J.S.	19	2	3
L.P.	15	2	7
C.T.	13	3	8
B.B.	14	4	6
N.I.	13	2	9
H.G.	13	4	7
R.D.	14	3	7
J.H.	14	2	8
T.F.	16	5	3
S.T.	9	5	10
M.R.	7	7	10
L.L.	5	5	14
J.P.	16	1	7
M.G.	10	5	9
E.A.	12	1	11
Average: Female	14.4	3.6	6.0
Average: Male	11.4	3.8	8.8
Average: All	12.9	3.7	7.4

* - The first ten subjects are female, the last ten are male

Table 9

(p = 0.0010). Further, the correlation of errors on the SPT and GCT was r(16) = 0.707 (p = 0.0677), and the correlation of the number of skipped items on the SPT and the GCT was r(16) = 0.641 (p = 0.0042). There were no other correlations within the cognitive tests that reached significance.

There were no significant correlations between any of the cognitive measures and the VPEL discrimination for the 18 subjects taken as a group. The correlation between the EFT and V' was r(16) = 0.086 (p = 0.735), between the number of correct responses on the GCT and V' was r(16) = -0.132 (p = 0.602), between the number of errors on the GCT and V' was r(16) = 0.377 (p = 0.123), between the number of items skipped on the GCT and V' was r(16) = 0.377 (p = 0.123), between the number of correct responses on the SPT and V' was r(16) = -0.023 (p = 0.928), between the number of errors on the SPT and V' was r(16) = 0.233 (p = 0.353), and between the number of items skipped on the GCT and V' was r(16) = -0.116 (p = 0.646). There were still no correlations between EFT scores and V' values, even when female and male subjects were analyzed separately. Females' V' and EFT scores had a correlation of r(7) = 0.09 (p = 0.8), and Males' V' and EFT scores had a correlation of r(7) = 0.09 (p = 0.8), or when field dependent (based upon EFT performance) subjects were separated from field independent subjects (r(7) = 0.14 (p = 0.72), r(7) = -0.02 (p = 0.96), respectively).

Means of Cognitive Tests by Sex

Test	Sex	Mean
EFT	F	27 seconds
	M	38 seconds
GCT [1]	F	12.8 items
	M	10.6 items
GCT_{SKIP}	F	5.3 items
	M	7.7 items
GCT_{ERROR}	F	1.9 items
	M	1.8 items
SPT [2]	F	14.4 items
	M	11.4 items
SPT_{SKIP} [3]	F	6.0 items
	M	8.8 items
SPT_{ERROR}	F	3.6 items
	M	3.8 items

Significant Sex Differences :

1 - t(16) = 2.06, p=0.056

2 - t(16) = 1.95, p=0.069

3 - t(16) = -2.00, p=0.062

Table 10

Sex Differences in the Cognitive Tests

There were no significant differences between the scores of the female and male subjects on the EFT. There were, however, several scores from the other tests which had significant sex differences. In particular, there were sex differences in the number of items identified correctly on both the GCT and SPT, as well as in the number of skipped items on the SPT. The full set of mean scores is given in Table 10.

Discussion

Section I

VPEL Discrimination

The VPEL results indicate that, as expected, subjects' VPEL discriminations are linearly related to the visual pitch of the pitchroom, with an average V' of 0.65, and V_d and V_0 values near zero. This is a strong indication that the small deviations from previous procedures used in the pitchroom (Matin and Fox, 1989; Matin and Li, 1992a, 1994a) had no significant influence on the VPEL results of the present study. Of particular concern was the greater viewing distance used in the present experiment which reduced the retinal size of the visual field, although the sum of visual angles of the vertical line lengths was well above the saturation levels suggested by Matin & Li (1992a). It is clear, however, from the results that the change in median viewing distance from 1 meter to 1.85 meters, and the variations in viewing distance by pitch did not produce a significant drop in effectiveness of the pitchroom upon VPEL. Further, it has been shown previously (Stoper and Cohen, 1989; Matin and Li, 1992b) that binocular as opposed to monocular viewing produces no effect on the VPEL discrimination.

The probability density histograms of the VPEL settings (Figure 12a) for the twenty subjects at each tested pitch condition show the uniform changes in position of the VPEL settings with the changing pitch of the visual field, as well as the range of settings at each pitch. The distribution for the $+20^{\circ}$ topforward pitch condition seems to be somewhat skewed. This is most likely due to the physical size limitations of the pitchroom. Several subjects' VPEL settings for the $+20^{\circ}$ pitch condition were near the highest setting possible given the height of the room. Still, this did not seem to cause the average results of the $VPEL(\theta)$ function to deviate significantly from linearity ($r^2 = 0.993$). Further, the normal probability plot of all VPEL settings (expressed as within-pitch deviations from the mean) gives no indication of significant deviations from normality (see Figure 14).

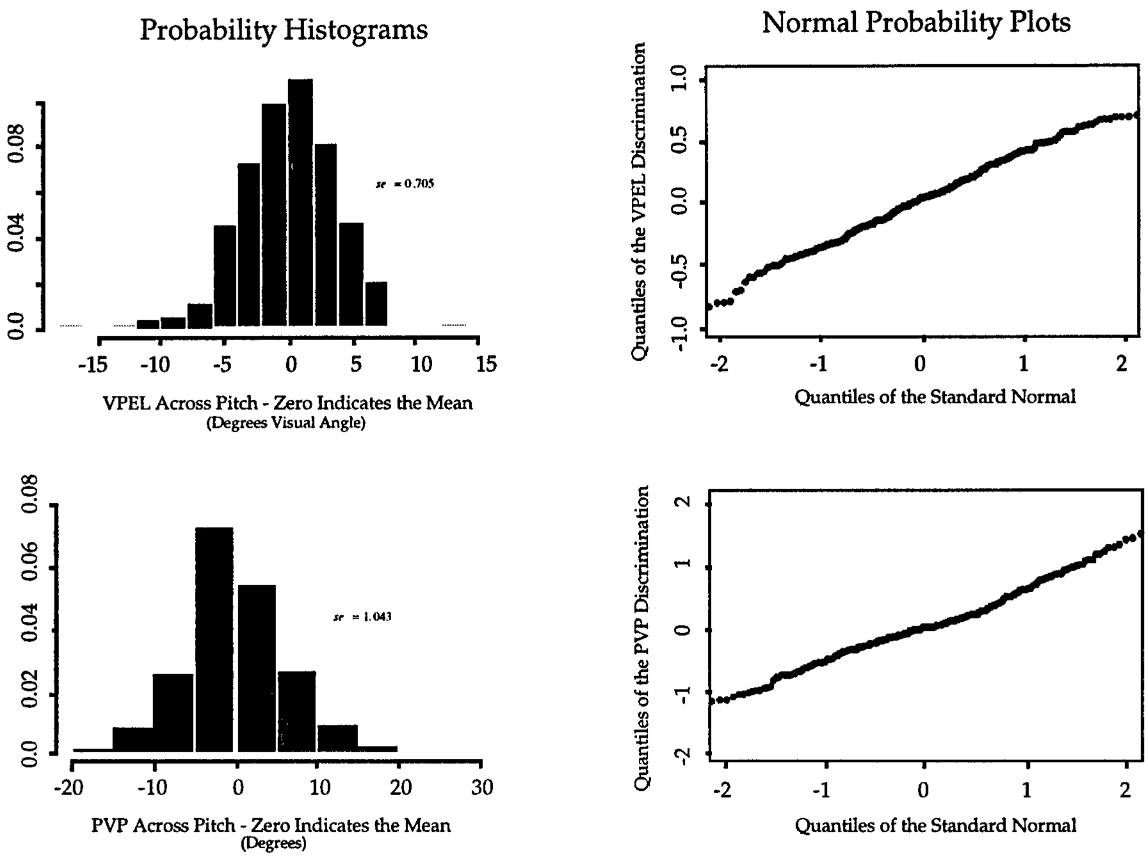

Figure 14. (a) Probability histograms of VPEL and PVP settings for 20 subjects and 6 pitch conditions, normalized so that the mean setting for each pitch condition was set to 0. The standard error of the mean (se) is given for each. Bin widths were autoscaled in S-plus.

(b) Normal probability plots for the VPEL and PVP discriminations. Suggest a roughly normal distribution of settings around the mean.

Sex Differences in the VPEL Discrimination

There were no significant sex differences in the VPEL discrimination, as indicated by both the ANOVA (see Table 3) and the t-tests of the fitted V', V_0, and V_d values. The lack of a main effect of sex indicates that slight across-pitch downward shift of female subjects' settings relative to male subjects' settings (see Figure 9) is insignificant. Further, the lack of an interaction of sex by pitch (see Table 3), indicates that the difference between the average slope of the male as opposed to the female subjects is also insignificant, as can be seen in Figure 9. The best fit line of both the male and female subjects show no significant deviations from linearity ($r^2 = 0.990$, and $r^2 = 0.992$, respectively).

Perception of Visual Pitch Discrimination

The results of the PVP discrimination conform to the general pattern expected from past experiments, but differ in several important respects. PVP was found to be positively linearly related to visual pitch, as has been found in previous studies (Clark, Smith, & Rabe, 1955; Epstein & Mountford, 1963; Flock 1964a; Freeman, 1965a, 1965b, 1966a, 1966b; Smith, 1956, 1959, 1964). One interesting difference obtained here is that the average P' across subjects (0.946) indicates veridical pitch matching, while previous average P' values were rarely above 0.7 (Flock, 1965). One notable exception to this was Freeman (e.g., 1965a), who found essentially veridical pitch matching for outline rectangles. It is possible that the many previous studies which found significantly non-veridical pitch matching used restricted viewing conditions where only a portion of the pitched surface was visible, and even the full surface (when used) was only a fraction of the size of our pitchroom (e.g., retinal heights ranging from about 0.42° to 16.5°; Freeman, 1966a). Both Stavrianos (1945) and Freeman (1965a; 1966a; 1966b) suggest that the size of the visual field (or pitched object) could influence the accuracy of pitch matching. Of course, there are a wide variety of cues which could have been responsible for the greater veridicality of these results, such as binocular disparity, linear perspective, or retinal gradient information. Although a full investigation of the influences of these cues is beyond the scope of this paper, the outcome of such an investigation would be of little relevance to the goals of the present paper; we must assume that any influence upon PVP will have a symmetric influence upon VPEL, or we beg the question of the independence of the two processing systems.

The probability density distributions of the PVP discrimination (Figure 12b) for the twenty subjects at each tested pitch condition show the range of settings at each pitch, as well as the expected uniform changes in the position of the PVP settings as the pitch of the visual field changes. There are several pitch conditions which give some indication of possible non-normalities in the PVP distribution. These possible non- normalities do not seem to cause the combined results of $PVP(\theta)$ to deviate significantly from linearity ($r^2 = 0.991$). Further, the normal probability plot of all PVP settings (expressed as within-pitch deviations from the mean) gives no indication of significant deviations from normality (see Figure 14).

Sex Differences in the PVP Discrimination

There were two significant sex differences in the PVP discrimination, the main effect of sex, and the sex by pitch interaction (see Table 4). The main effect indicates an overall shift in the data for the male and female subjects. This overall shift is, however, quite mild compared with the changes in PVP settings which accompany changes in pitch. The sex by pitch interaction indicates a difference in the amount by which females and males change their PVP settings with changing pitch. This difference is substantial, and is supported by the significant t-test of the male and female fitted $PVP(\theta)$ slopes. By separating P' scores by sex, we see that the male subjects' P' values are indistinguishable from 1, indicating essentially veridical pitch matching, while the average female P' value is significantly different from 1, indicating a general tendency to underestimate in their PVP settings. Still, the data for both female and male subjects show no deviations from linearity ($r^2 = 0.993$, and $r^2 = 0.989$, respectively).

Comparison of VPEL and PVP Discriminations

There is a strong positive correlation of the individual VPEL and PVP settings (shown in Figure 15), indicating that the VPEL and PVP settings vary in direct proportion to one another; in other words, the two discriminations are both positive linear functions of pitch. This correlation suggests that the cues used to make both the VPEL and the PVP

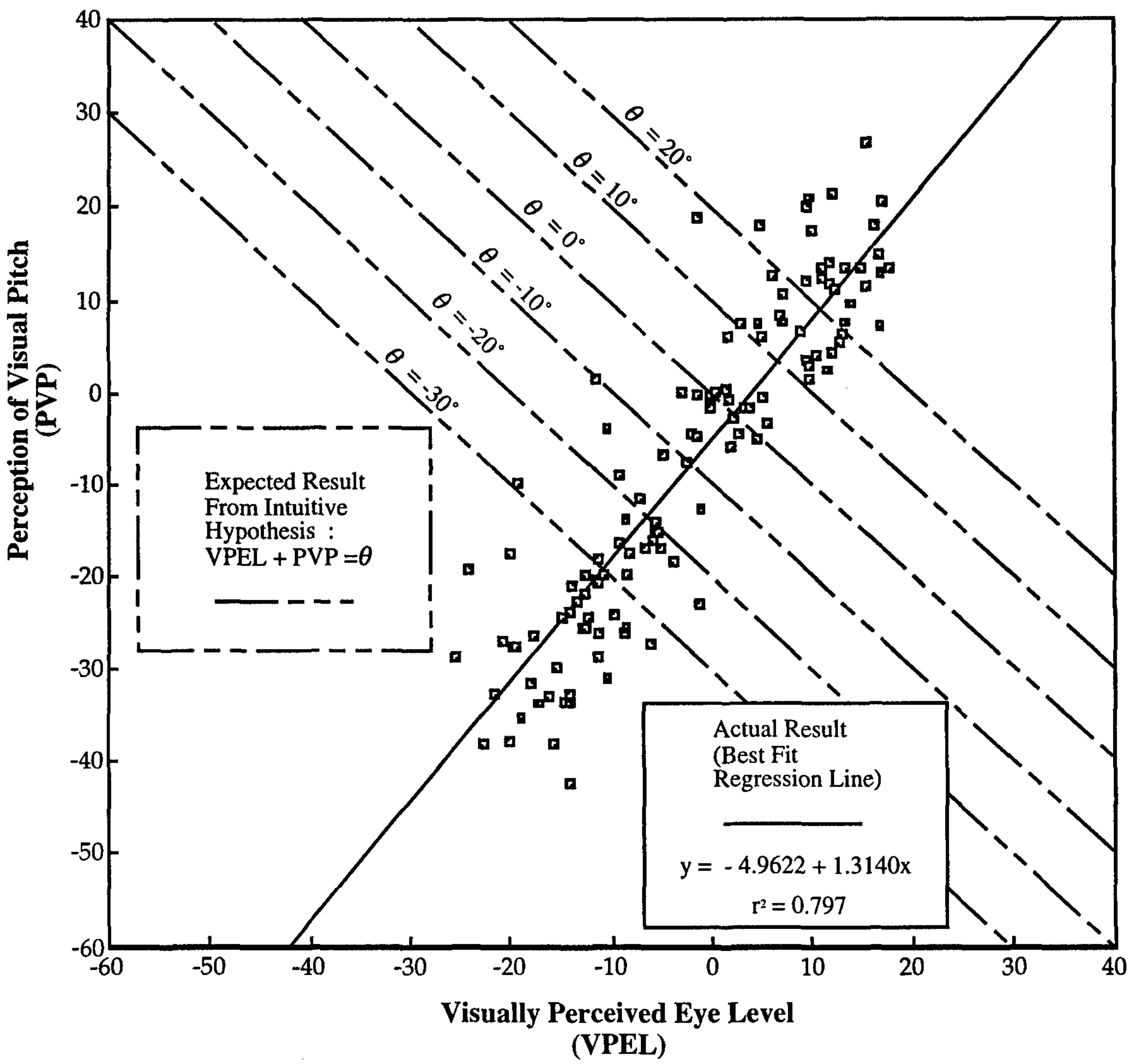

Figure 15. Average perception of visual pitch (PVP) settings plotted against average visually perceived eye level (VPEL) settings. The intuitive hypothesis requires that these settings fall along the dashed theoretical (negatively sloped) lines indicated for each pitch condition, clustering relatively close to the regression line. For the pitched visual field, there is no indication of points falling along the theoretical lines; the points corresponding to the erect visual field give some indication of conforming to theory.

discriminations are embedded within the visual field of the pitchroom. This particular correlation does not, however, provide any information as to whether or not the two discriminations are related to *one another*. To accomplish this, we test equation (5), as well as the relationship of higher order variables, such as the derivatives of $VPEL(\theta)$ and $PVP(\theta)$.

Equation (5), which we derived in the introduction, describes the expected relationship between individual subjects' VPEL and PVP settings; we call this relationship the intuitive hypothesis. The theoretical and empirical values associated with the intuitive hypothesis are shown in Figure 15. It is clear from Figure 15 that the intuitive hypothesis does not describe the data. For each particular pitch of the visual field, we expect a linear function with a negative slope of one and an intercept equal to θ to describe the relationship between the VPEL and PVP discriminations. In order to perform t-tests of equation (5), we change it to the form:

$$\{\theta - (VPEL(\theta) + PVP(\theta))\} = 0,$$

the t-test of which is significantly different from zero ($t(119) = {}^{-}11.20$, $p < 0.001$). Therefore we must reject equation (5) as a description of the across-pitch relationship between VPEL and PVP settings. Further, the t-tests of the intuitive hypothesis for each individual (nonzero) value of the pitch of the visual field are significant as well (${}^{-}30^{\circ}$:$t(19) = {}^{-}47.00$, $p < 0.001$; ${}^{-}20^{\circ}$: $t(19) = {}^{-}34.19$, $p < 0.001$; ${}^{-}10^{\circ}$: $t(19) = {}^{-}19.15$, $p < 0.001$; 0°: $t(19) = {}^{-}0.06$, $p = .95$; 10°: $t(19) = {}^{-}5.97$, $p < 0.001$; 20°: $t(19) = {}^{-}5.74$, $p < .001$), indicating that equation (5) does not describe the data for any pitch of the visual field except 0°.

The intuitive hypothesis described by equation (5) is highly restrictive in that it is sensitive to changes in the intercepts of $VPEL(\theta)$ and $PVP(\theta)$. It is conceivable that what is of more importance is the relationship between the change in VPEL and PVP associated with changes in pitch. It is possible then, that while a strict interpretation of the intuitive hypothesis fails, the changes in VPEL and PVP settings associated with changes in pitch will sum to the change in pitch. This alternative relationship between VPEL and PVP is given by the first derivative of equation (5):

$$VPEL'(\theta) + PVP'(\theta) = 1$$

which is the same as:

$$V' + P' = 1,$$

and is shown in Figure 16. Notice that this argument requires that negative fitted slopes for VPEL result from fitted PVP slopes greater than 1. As we have never observed a negative fitted slope for VPEL, we should expect that we observe no consistent overestimations of PVP,

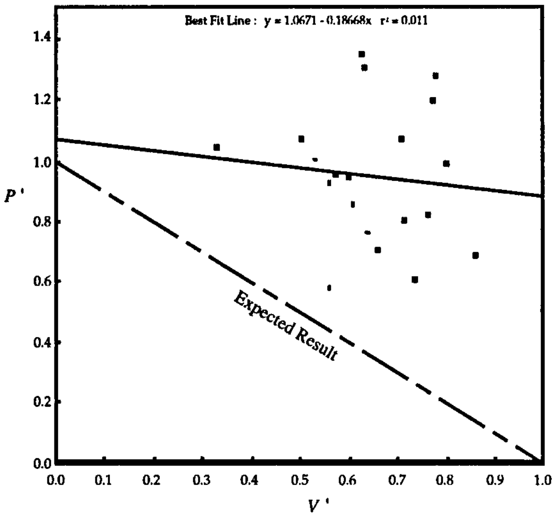

Figure 16. Plot of the first derivatives of the VPEL and PVP functions. The result expected from the intuitive hypothesis is given by the dashed line. The solid line shows the best fit line through the data, which is rather poor, as can be seen from the r2 value (0.11).

or no fitted PVP slopes greater than one. The results show that eight of twenty, or almost half, of the subjects have P' values above one. By re-arranging the above equation into the form :

$$\{1-(V'+P')\}=0$$

we can perform a t-test for deviation from zero. The intuitive hypothesis requires that there be no significant deviation. The test shows, however, highly significant deviation ($t(19) = {}^{-}10.867, p = 1.4 \times 10^{-9}$).

In an attempt to generalize the previous two results, we looked at the correlations analogous to the t-tests above. For the first of these, we looked at the correlations of VPEL and PVP settings within each pitch ($^{-}30^{\circ}$: $r(18) = {}^{-}0.076, p = 0.75$; $^{-}20^{\circ}$: $r(18) = {}^{-}0.051$, $p = 0.83$; $^{-}10^{\circ}$: $r(18) = {}^{-}0.107, p = 0.65$; 0°: $r(18) = {}^{-}0.029, p = 0.90$; 10°: $r(18) = {}^{-}0.187$, $p = 0.43$; 20°: $r(18) = {}^{-}0.192, p = 0.42$). The intuitive hypothesis would require that there be significant negative correlations. The obtained correlations are insignificant, necessitating the rejection of the intuitive hypothesis for all pitches, including the case of the erect pitchroom. In the second, we generalize the case where the derivatives sum to one, to the case where they sum to any constant; the case where there is some linear relationship between P' and V'. Any significant correlation of P' and V' would indicate such a relationship. The correlation is insignificant ($r(18) = {}^{-}0.104$, $p = 0.66$), confirming the no-relationship result obtained with the t-test of the specific case, and generalizing to a linear approximation of it.

Sex Differences in the Comparison of the PVP and VPEL discrimination

The test of the intuitive hypothesis that $\{1-(P'+V')\}=0$ was significantly different from zero for both female and male subjects ($t(9) = {}^{-}8.602, p = 1.2 \times 10^{-5}$, and $t(9) = {}^{-}9.328$, $p = 6.4 \times 10^{-6}$, respectively). Further, the correlation of the fitted VPEL and PVP slopes did not reach significance for either females or males ($r(8) = {}^{-}0.44$, $p = 0.20$, and $r(8) = 0.15$, $p = 0.68$, respectively).

Confidence Ratings for VPEL and PVP Discriminations

Subjects were told to report on how close they felt their settings of VPEL and PVP came to being objectively correct. If subjects were able to report on their own accuracy, we would expect to see the confidence ratings for the VPEL discrimination to be linearly related to the absolute value of pitch, and the confidence ratings for the PVP discrimination to be uncorrelated with the absolute value of pitch. In addition, we would expect that the confidence ratings for the VPEL and PVP discriminations would both be highly negatively correlated with the deviations of each discrimination from its objectively correct value; the absolute value of VPEL settings for the case of the VPEL discrimination, and the difference between PVP settings and physical pitch ($PVP - \theta$) for the case of the PVP discrimination. We would further expect that the confidence ratings for the PVP discrimination would be on average greater than those of the VPEL discrimination, corresponding to the lower mean absolute value of $PVP - \theta$ (5.5) than of the mean absolute value of VPEL settings (9.7). The fact that the average confidence ratings for the VPEL settings vary linearly with the absolute value of pitch may at first appear to give an indication that subjects are in some sense 'aware' of their misperceptions of VPEL. This interpretation, however, is inconsistent with the remainder of the results. The most obvious of these inconsistencies are: (a) the reversal of the expected overall mean confidence ratings, with confidence ratings for the VPEL discrimination considerably higher than those for the PVP discrimination, and (b) the clear linear relationship of the confidence ratings of the PVP discrimination to the absolute value of pitch. This line of reasoning suffers further from the fact that the confidence ratings for the PVP discriminations are uncorrelated to the absolute values of $PVP - \theta$, and the confidence ratings for the VPEL discrimination are only weakly correlated with the absolute values of the VPEL settings. The fact that the confidence ratings for VPEL and PVP and the corresponding (absolute values of) VPEL and $PVP - \theta$ are not correlated when the two are combined ($r(518) = 0.023$, $p = 0.61$) seems to indicate that subjects are not able to report on their own accuracy.

The average confidence ratings are, however, highly correlated with the standard errors of the within-pitch discriminations for both VPEL and PVP. The se's of the VPEL and PVP discriminations are also linearly related to the absolute value of the pitch of the visual field. Further, the overall se of VPEL discriminations is lower than the overall se of the PVP discriminations. This suggests that subjects may be sensitive not to their absolute accuracy, but rather to the variability of their discriminations. This interpretation is further supported by the fact that the combined confidence ratings for the VPEL and PVP discriminations and the combined se's for the VPEL and PVP discriminations are highly negatively correlated ($r(10) = -0.795$, $p = 0.002$). The hypothesis that the confidence ratings correspond to the variability of the discriminations rather than the veridicality of the discriminations seems to account for all aspects of the confidence rating data.

Section II

Comparison of the Embedded Figures Test, Gestalt Completion Test, and Snowy Pictures Test

For each of the three components of the GCT and SPT (number of correctly identified items, number of incorrectly identified items, and number of skipped items), subjects' scores are correlated. That is, subjects' rank orderings within each of the components of the tests are approximately equal for both the GCT and SPT. Further, the EFT scores are highly (negatively) correlated with the number correct on both the GCT and SPT. The correlations of these tests support the view that the disembedding tasks required for the completion of all three tests are equivalent, and that there is a single underlying mechanism responsible for performance on all three tasks.

Comparison of VPEL and Cognitive Disembedding Tasks

Individual differences in subjects' fitted VPEL slopes are not correlated with any of the components of the GCT and SPT, nor are they correlated with performance on the EFT. This is clearly contrary to the expected result, given the assumption of a single underlying mechanism governing performance on all disembedding tasks. There are several inferences which can be drawn from this result. First, it is clear that there cannot be one global mechanism which governs performance on both the VPEL task and on the EFT, GCT, and SPT. This suggests that the mechanism which is believed to underlie the significant correlation between EFT, GCT, SPT, RFT, and other established disembedding tasks cannot account for individual differences in V', and that whatever the basis for individual differences in V', they cannot be described in terms of disembedding of the type used to describe individual differences in the RFT and EFT. In particular, these results do not support the analysis of the VPEL discrimination in terms of perceived pitch. The interpretation of these results is not changed if we consider only the results of the male (or field independent) subjects, as may be warranted given the overall lower corrleations for female subjects in the original studies relating EFT performance to the RFT performance.

V' as a Measure to be Compared with Performance on EFT, GCT, and SPT

The validity of the comparison of the slope of the VPEL function (V') with performance on the EFT requires some explanation. In previous comparisons with perceptual measures, such as the Rod and Frame Test (RFT), the EFT was correlated with performance at one particular setting of the visual field, not with a function describing performance over a range of settings. It is clear, however, that if we were to compare EFT scores to VPEL performance on a restricted set of pitches rather than on the full range of pitches, then there would have to be some reason for preferring the chosen subset of pitches. As there is no such reason, any choice of one pitch for VPEL to be used to compare to EFT performance would have to be made completely arbitrarily. It is clear, then, that the V' value is an appropriate measure of overall performance on the VPEL task, and an appropriate comparison with EFT scores. Still, it is possible to compare EFT scores with the VPEL settings at particular pitches. Not unexpectedly, all correlations of EFT scores to average VPEL settings at individual pitches are not significantly different from zero ($^-30°$: $r(16) = {}^-0.14$, $p = 0.58$; $^-20°$: $r(16) = {}^-0.10$, $p = 0.68$; $^-10°$: $r(16) = {}^-0.24$, $p = 0.33$; $0°$: $r(16) = {}^-0.33$, $p = 0.18$; $10°$: $r(16) = {}^-0.06$, $p = 0.82$; $20°$: $r(16) = 0.05$, $p = 0.84$).

Learning, Age and Sex Differences in the EFT

In a study by Goldstein & Chance (1965), subjects displayed learning effects on the EFT such that within one test session of greater than standard length (68 rather than 12 items), all subjects showed a decrease in their time to find the embedded figure, and the sex differences disappeared. Further, Witkin, Goodenough & Karp (1967) found that subjects improved their EFT scores with age until about age 15, and found a decline (increasing field dependence) in subjects past about 25 years of age (Schwartz & Karp, 1967). Although EFT scores changed with age, people did seem to show relative stability, such that they kept the same rank order within the generationally defined groups in which the testing was conducted. In other words, while EFT scores would change with age, people kept the same relative ranking within their cohort. The sex difference found traditionally on the EFT (see Witkin, et. al., 1954 for review), in which adult women are more field dependent than adult men, was not found here. Given the possibility that the sex distribution of EFT scores could have changed across generations due to differences in the average learning histories of men and women, and that these sex differences appear only after adolescence, it is not surprising that no significant sex differences were found here.

General Discussion

It is clear from the Section I data that while individual VPEL and PVP settings are correlated across pitches, there is no evidence of a relationship between the two discriminations resembling the intuitive hypothesis. This requires rejecting both: (a) that the VPEL and PVP discriminations require pitch or eye level information, respectively, and (b) that the VPEL discrimination shares a processing system with the PVP discrimination (see Figure 17).

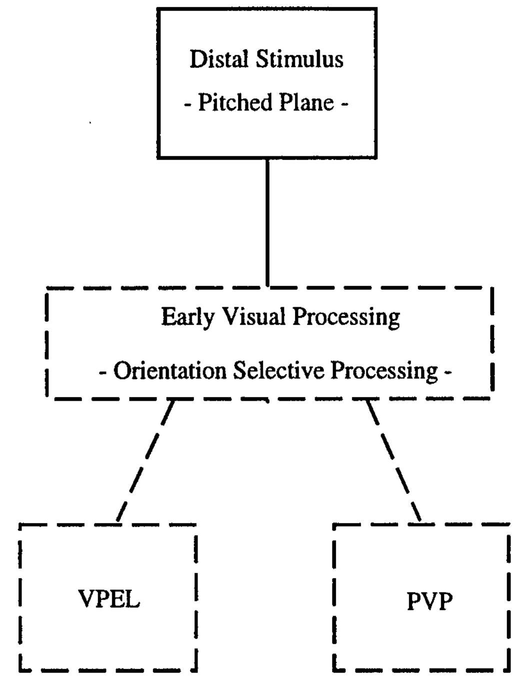

Figure 17. Representation of the likely relation between processing of VPEL and PVP.

The results of Section II further suggest: (a) that individual differences in the VPEL task and in the EFT are not produced by a single mechanism, and (b) that, insofar as the analysis of the VPV in terms of disembedding tilt information is valid, the analysis of the VPEL task in terms of disembedding pitch information is not valid. Thus, we have converging evidence that the VPEL discrimination and the PVP discrimination do not share a common mechanism.

Several other studies support our results. In the first, a study by Li & Matin (1997), three subjects were presented with a visual field consisting of two tilted from vertical lines within the erect frontoparallel plane. As predicted by the Great Circle Model of egocentric space perception (Matin & Li, 1992b; 1994a), tilted-from-vertical lines produced changes in VPEL corresponding to the changes a pitched-from-vertical field would produce. When asked to (manually) set a pitchable frame to match the pitch of the (unpitched) tilted visual field, subjects correctly set the frame very close to its erect position for all magnitudes of tilt. Further suggestion of a dissociation between VPEL and PVP comes from the neuropsychological patient DF. DF has a profound visual form agnosia, with damage to the ventral visual processing stream (due to anoxia), but no noticeable damage to her dorsal stream, or to primary visual cortex. In a study by Servos, Matin, and Goodale (1995), DF performed the VPEL task normally in the presence of a pitched visual field, but her matches to the pitch of the visual field were uncorrelated with the physical pitch, unlike the age and sex matched control, whose matched pitch settings correlated 0.99 to the physical pitch of the visual field, suggesting a neurological basis for the dissociation.

The counterintuitive nature of the finding that there exists no simple relationship between VPEL and PVP cannot be overstated. Virtually every subject (learned or otherwise) upon first introduction to the dramatic shifts in eye level accompanying changes in the pitch of the visual field suggests some form of the intuitive hypothesis in explanation. One of the most often suggested of these is the ecologically motivated hypothesis that we are simply *used* to looking at erect walls, the only situation in which VPEL and N (see Figure 5b) coincide. The suggestion here is that in a pitched environment, we differentiate between N and eye level insufficiently due to incorrect estimations of the pitch of the visual field. Obviously, if this were the case, our mislocalizations of eye level would be based upon a failure to utilize pitch information correctly, which is exactly what was shown not to be the case. Another suggestion, dealt with explicitly in Li & Matin (1997), is that some mental representation of the pitched surface is used for the VPEL discrimination. These results support their conclusion that no such 'Implicit Surface Model' is used. Of course, the above intuitions have run in both directions. It has often been assumed in the pitch perception literature that subjects have access to veridical eye level information, which is used as a natural point from which to calculate density gradients or other ratios. It is from these gradients or ratios that subjects have been assumed to make pitch discriminations. If this were the case, then we would expect to observe errors in perceived pitch corresponding to errors in perceived eye level. Again, this has been shown not to be the case. So, while the determinants of PVP remain unclear, it seems that the mechanisms subserving PVP and VPEL diverge at an early stage of processing and do not interact.

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Appendix

The derivation of VPEL has been shown previously in Matin and Fox (1989), but needs some elaboration for the present experiment. VPEL can be computed by the following formula:

$$VPEL = \tan^{-1}\left(\left\{\frac{D}{h-TEL}\right\} - \tan(\theta)\right)^{-1}$$

where D is the horizontal distance from the observer's eye to the pitched wall, and h is the vertical linear height of the laser point for the VPEL setting. TEL and θ are, as before, true eye level and the pitch of the room, respectively. Previous procedures all utilized the relation between the distance, D, and the distance from the eye normal to the plane of the pitched wall of the pitchroom (N), where:

$$D = \frac{N}{\sin(\theta)}.$$

The distance N has always been kept constant through the appropriate positioning of the subject, making D a trivial aspect of the VPEL calculation. This same procedure was used here on two subjects, but D takes on a more complex role for the remainder of the subjects, as N changes with each pitch of the pitchroom. The two measures which are held constant are TEL measurements, by the use of a chinrest, and the distance (BL in Figures A2a and A2b) represented in the schematic diagram of Figure A1 by the diameter of the small solid circle, interposed between the erect plane of the subject's eye and the pitched far wall of the room. This circle corresponds to the semicircular axis of rotation of the pitchroom, as shown in Figure 3. The subject's chair was always positioned such that the erect plane of her eye intersected the end of the diameter of the circle, where the other end of the diameter line was at the point tangent to the far wall of the pitchroom. This distance was 185.4 cm., which of course always corresponded to the value of D in both the dark and lit 0° pitch conditions. TEL was a measured value that varied by subject.

As we can see by the three dashed lines in Figure A1, there are two triangles which can be extracted from the experimental setup, one extending above the head of the subject ($Pitch = 20^{\circ}$ in the diagram), and one extending below the floor of the room ($Pitch = {}^{-}30^{\circ}$ in the diagram), which will allow the calculation of topforward and topbackward pitches, respectively. These triangles correspond to the diagrams of Figure A2a and A2b, respectively. In both Figure A2a and A2b, θ represents the pitch of the pitchroom, and α represents its complement.

Topforward Pitches

Figures A1 and A2a describe all topforward pitches.

The horizontal length from the eye to the far wall of the pitchroom (D) can be derived for topforward pitches, where θ_1 is any nonzero positive pitch, as follows:

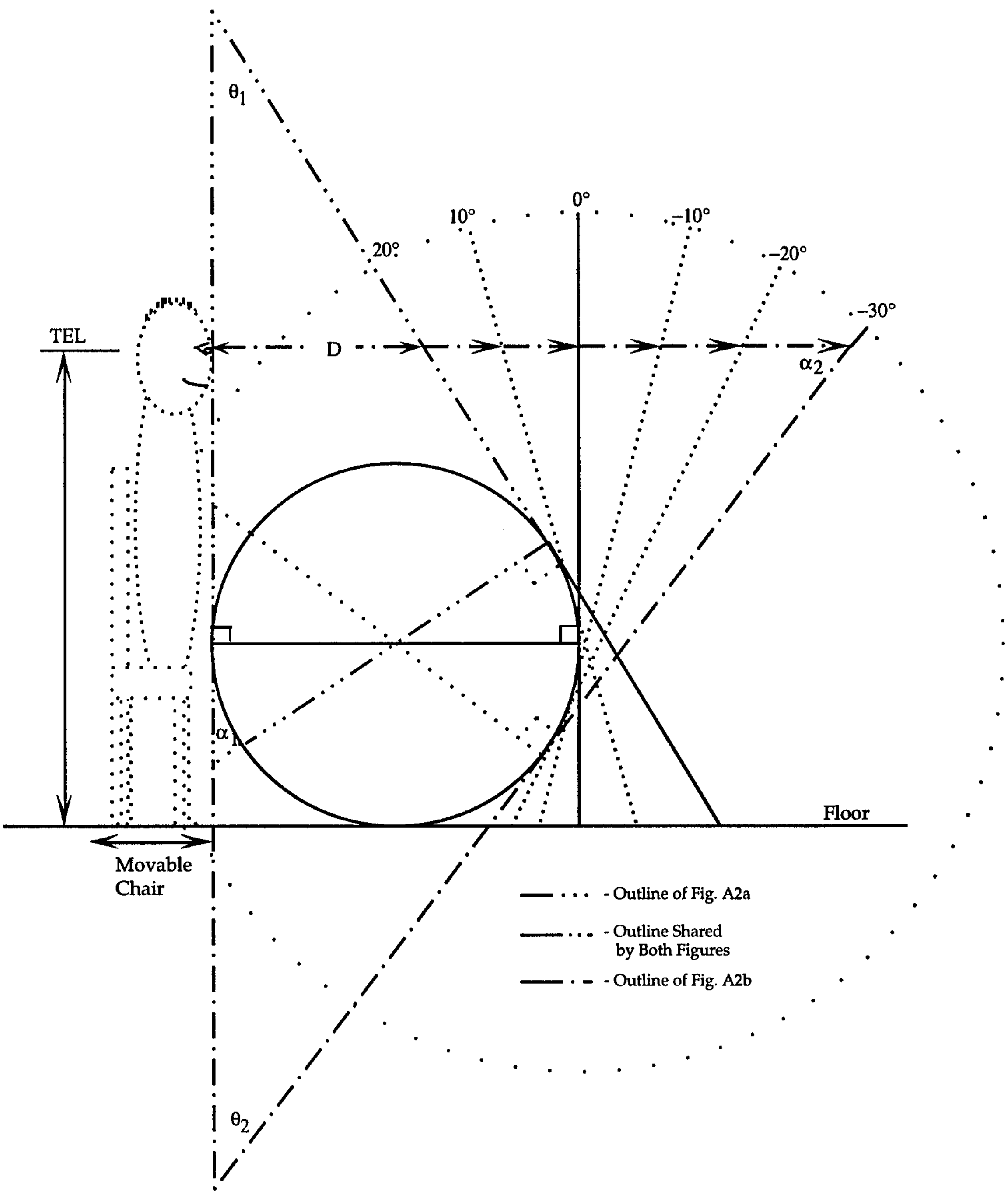


Figure A1. Schematic of the relationship between the observer's true eye level (TEL) and pitched room. The chair was arranged such that it positioned the observer's eye along the vertical tangent line to the solid circle, the diameter of which is the length of the pitchroom. The details of the geometry of the topforward (A2a) pitched and topbackward (A2b) pitched room are given in figure A2.

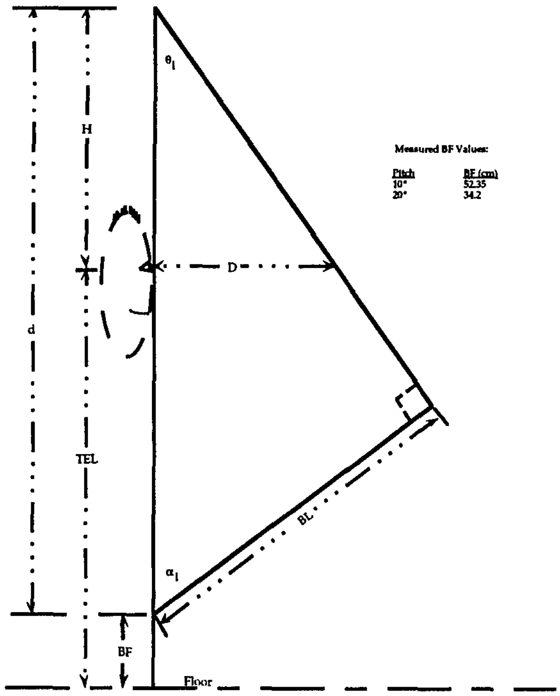


Figure A2a. Schematic of the geometry of an example of the topforward pitched pitchroom. θ_1 is the topforward pitch, and α_1 its compliment. The calculation of VPEL is based upon the distance of the observer from the pitched plane, D, which is in turn a function of the observer's true eye level (TEL), and the dimensions of the pitchroom.

$$Sin\theta_1 = \frac{BL}{d}$$

$$d = \frac{BL}{Sin\theta_1}$$

Where BL, as stated earlier, is the 185.4 cm distance normal from the far wall of the pitchroom to the subject along the top of the pitchroom's semicircular axis of rotation. The point at which BL intersects the erect plane of the subject's eye defines the height from the floor, BF. This point also defines the lower extreme of the distance, d, to the top of the large triangle of Figure 2a.

Because the height, BF, is a function only of the pitch of the room and the radius of the axis of rotation, it was simply measured for the desired pitches. The values of BF are shown along with the diagram in Figure A2a.

Given d, we can determine H, which forms one of the sides of the small right triangle, the other leg of which is defined by the horizontal distance, D , to the wall of the pitchroom, and the hypotenuse of which is defined by the extension of the wall from the point of its intersection with D is its intersection with the erect plane of the subject's eye. H then becomes:

$$H = d - (TEL - BF)$$

$$= \left(\frac{BL}{Sin\theta_1}\right) - (TEL - BF)$$

Once H has been determined, this small upper triangle can be used to derive D from a simple tangent relation:

$$Tan\theta_1 = \frac{D}{H}$$

$$D = H(Tan\theta_1)$$

$$= \left[\left(\frac{BL}{Sin\theta_1}\right) - (TEL - BF)\right](Tan\theta_1)$$

Topbackward Pitches

Figures A1 and A2b describe all topbackward pitches.

The horizontal length from the eye to the far wall of the pitchroom (D) can be derived for topbackward pitches, where θ_2 is any negative pitch, as follows:

$$Sin\theta_2 = \frac{BL}{d}$$

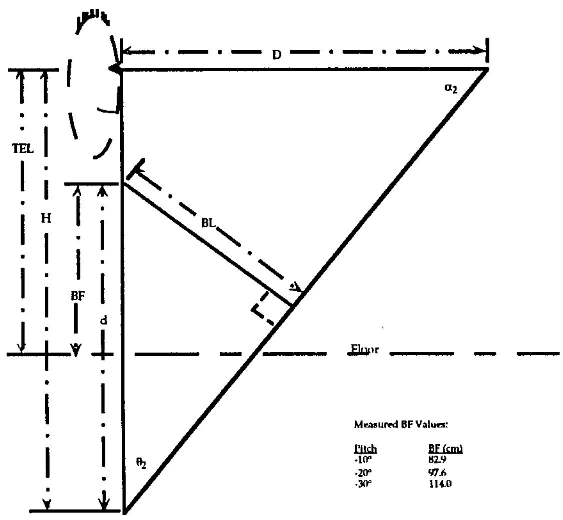
$$d = \frac{BL}{Sin\theta_2}$$

Where BL is defined exactly as for positive pitches. Given d and BF (also defined as before), we can determine H, which is defined here as the distance along the vertical plane of the subject's eye to its intersection with the extended plane of the wall of the pitchroom. H then becomes:

$$H = d + (TEL - BF)$$

$$= \left(\frac{BL}{Sin\theta_2}\right) + (TEL - BF)$$

H and D then form the two legs of the large right triangle, with the negatively pitched wall of the pitchroom, extended to intersect both D & H, as its hypotenuse. D can then be derived from the same tangent relation as for θ_1, which, when expanded, resembles quite closely the analogous equation for topforward pitches.



$$Tan\theta_2 = \frac{D}{H}$$

$$D = H(Tan\theta_2)$$

$$= \left[\left(\frac{BL}{Sin\theta_2}\right) + (TEL - BF)\right](Tan\theta_2)$$

Figure A2b. Schematic of the geometry of an example of the topbackward pitched pitchroom. θ_2 is the topbackward pitch, and α_2 its compliment. The calculation of VPEL is based upon the distance of the observer from the pitched plane, D, which is in turn a function of the observer's true eye level (TEL), and the dimensions of the pitchroom.