Thresholds for Shifting Visually Perceived Eye Level Due to Incremental Pitches

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Abstract

Visually perceived eye level (VPEL) was judged by subjects as they viewed a luminous grid pattern that was pitched by 2 or 5 deg increments between -20 deg and +20 deg. Subjects were dark adapted for 20 min and indicated VPEL by directing the beam of a laser pointer to the rear wall of a 1.25 m cubic pitch box that rotated about a horizontal axis midpoint on the rear wall. Data were analyzed by ANOVA and the Tukey HSD procedure. Results showed a 10.0 deg threshold for pitches \( P_i \) above the reference pitch \( P_0 \), and a -10.3 deg threshold for pitches \( P_i \) below the reference pitch \( P_0 \). Threshold data for pitches \( P_i < P_0 \) suggest an asymmetric threshold for VPEL below and above physical eye level.
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Judgments of direction in space carry obvious significance for efficiency and safety in aviation and space flight. Incorrect assessments of direction have been reported as important contributors to spatial disorientation and accidents (NAMRL: Spatial Awareness in Naval Aviation, 1999; Scott, 1989). In laboratory studies of perceived direction, judgments may be assessed by asking subjects to indicate where they localize a line that extends outward from the eye tangent to the earth's surface. This task yields measurements of Visually Perceived Eye Level (VPEL).

Physiological, physical and anatomical factors

Several physical conditions of the subject determine the judgment of VPEL, including the relationship between positions of the eyes, the head, and the neck relative to each other and to the gravity vector. Stopper, A. & Cohen, M. (1986) referred to the Target/Gravity System as the source of information about head position relative to gravity, visual sight line relative to the head and target position relative to the sightline. They also noted another source, the Target/Surface system that supplies optical information from the visible surfaces of the target and environment. In a later paper (Stopper A. & Cohen, M., 1989) their theoretical focus on target-related information was reformulated in empirical terms as 3 types of "eye level", including Head Referenced Eye Level (HREL), surface referenced eye level (SREL) and gravity referenced eye level (GREL). These definitions of eye level suggest ways to assess components of perception by use of behavioral measures. Stopper and Cohen analyzed within-subject variability to conclude that Ss use both the eye/head/gravity system and the optical pattern system to
determine VPEL when the surrounding visual pattern is pitched. Data from a subsequent study of VPEL during parabolic flights and human centrifugation (Cohen M., 1992) illustrate how gravitoinertial forces can act on GREL to influence VPEL and account for such changes in apparent target location as the Elevator Illusion. DiZio, P., Li, W., Lackner, J. and Matin, L. (1997) offered two alternative theoretical formulations to account for the means by which gravitoinertial force combines with visual information to determine VPEL. Their data did not allow a decision between a weighted averaging model or an approach based on vector sums. DiZio, et al. used 1.0 g and 1.5 g gravitational conditions.

Matin, L. and Li, W. (1992a) partially immobilized the extraocular muscles and showed that VPEL deviated systematically due to eye position within the head. They also developed a set of geometric propositions labeled The Great Circle Model (GCM), to account for the behavior of VPEL due to retinal information. Using an ISCAN camera to record eye position, Cohen, M., Ebenholtz, S. & Linder, B. (1995) determined that Ss are unaware of a visually induced change in eye position (i.e., the "optostatic response") when a target is manipulated. However, gaze elevation and judgments of target elevation are systematically affected by the shift in eye position.

Perceptual factors

VPEL experiments usually produce an outcome in which the judgments of eye level (in deg visual angle) are linearly related to the pitch (in deg) of the visual stimulus. Much theoretical work has been done to suggest how nervous system combines information that determines HREL, GREL and SREL. Matin, L. & Fox, C. (1989) proposed a simple weighted linear model that adds influences from visual and body sources. Shortly
thereafter, Matin, L & Li, W. (1992a) proposed the GCM based on the geometry of images projected onto the concave surface of a sphere that is taken as an idealized representation of the human eye.

Subsequent testing of the GCM with 2-line stimulus pairs and single line stimuli (Matin, L. & Li, W., 1992b, 1994a) yielded results that supported the GCM and led them to use the slope of the VPEL-vs.-pitch function as a useful dependent measure of the shifting perception of eye level when target, physiological and physical conditions were manipulated. Experiments with pilocarpine (Matin, L. & Li, W., 1992a) eliminated pupil size as a possible contributor to VPEL. However, VPEL is strongly dependent on the total vertical length of stimulus lines, whether coextensive or separated in the visual field (Matin, L. & Li, W., 1994b). Other properties of the spherical geometry cause identical images to appear on the retina from vertical lines that are pitched or from tilted (rolled) lines on an erect, frontoparallel surface (Li, W. & Matin, L., 1995, 1996). VPEL is similarly affected by either stimulus, but Visually Perceived Straight Ahead (VPSA) does not respond to horizontal lines that are slanted from frontal, i.e., yawed about a vertical axis (Li, W. & Matin, L., 1995).

Several research reports have dealt with up-down and left-right symmetry of VPEL judgments. In the work of Stoper, A. & Cohen, M. (1986), Ss were placed in a 3.1 m X 3.1 m X 2.6 m chamber and asked to adjust the (up-down) height of their chair until they arrived at eye level with respect to a target. In dark conditions, chair heights averaged 0.90 deg above physical eye level when approached from below, but mean chair height was 2.18 deg above the target when approached with a downward motion. Chair height was not significant in the light condition. However, when Stoper, A. & Cohen, M.
(1989) used a 72 cm X 72 cm X 115 cm pitch box, chair height was 1.3 deg higher when the target referenced eye level was approached from above than when it was approached from below.

Other up-down asymmetries were reported by Cohen, M., Ebenholtz, S. & Linder, B. (1995) for eye elevation when a 1.22 m X 2.79 m X 1.68 M room was pitched around a subject who sat at the pitch axis located at the center of the side walls of the room. Ss in the "horizontal instruction" condition were instructed to direct their gaze "horizontally, or parallel to the earth and perpendicular to gravity." Mean data for these Ss show 0 deg elevation at 0 deg room pitch, but a +20 deg pitch only elicited an elevated gaze of about +4 deg (estimated from figure 2) while a pitch of -20 deg depressed the gaze to -10 deg. In the "relaxed instruction" condition were told to direct their gaze so the eyes were in a "comfortable and relaxed position". Here, the gaze was at true eye level (0 deg) at +20 deg room pitch, -5 deg at 0 deg room pitch, and -11 deg at -20 deg room pitch. Similar VPEL results were reported by Post, R. & Welch, R. (1996) when Ss viewed 2 displays composed of parallel vertical lines. The larger display was 3 times the size of the smaller in all dimensions. Both displays were viewed at either 1 m or 33.3 cm. Mean VPEL varied asymmetrically around 0 when the pitch of the display was changed from +20 to -20 deg. VPEL ranged from +2 to -9 deg.

Right-left symmetry was described by Howard (1982) in his discussion of the Dietzel-Roelofs effect, whereby Ss shift their judgment of "straight ahead" toward the center of an asymmetric visual display. Up-down symmetry on VPEL resulted from comparisons of stimuli presented on the left vs. right by Matin, L., & Li, W. (1999). They employed vertical lines that could be independently pitched, and/or rolled lines presented
on a frontoparallel plane. In the case of either the pitched or rolled lines retinal images were identical because the pitched or rolled lines fell on the nodal plane. Symmetry arose when subjects viewed the left and right sides that were simultaneously pitched or rolled in opposite directions and the resulting VPEL closely agreed with results that would be expected from a 2-line stimulus with pitch equal to the average of the two discordant lines. Thus, the available evidence shows that VPEL moves symmetrically when target patterns vary in the right-left direction, but asymmetric shifts of VPEL occur when targets vary in the up-down direction.

The experiment reported in the present paper sought to measure the sensitivity of VPEL to small changes in pitch of a complex, structured visual display. In this context, pitch "threshold" is taken to be the minimal change sufficient to prompt VPEL judgments that are just statistically different from those resulting from adjacent pitches. Thus, for any given pitch, \( P_0 \), pitches \( P_i \) that are positive to \( P_0 \) were analyzed to assess threshold for increasing pitch. Pitches \( P_i \) that are negative to \( P_0 \) were analyzed to assess threshold for decreasing pitch.

METHOD

Apparatus

The visual display consisted of a grid pattern constructed with strips of 2.54 cm wide luminous tape fixed to three inside walls and ceiling of a 1.25 m X 1.25 m X 1.25 m pitchbox. The walls and framework of the box were painted flat black. Tape strips were located on 20.3 cm centers. Therefore, a vertical stripe on the rear wall would subtend a visual angle of 49.6 deg (.86 rad) in the eye of a subject located at a distance of 1.3 m. White poster board 81 cm X 102 cm was mounted horizontally at the center of the rear
Thresholds for Shifting

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wall of the box to provide a target area free of reference cues. Subjects directed the laser pointer to this portion of the rear wall to indicate their judgments of VPEL.

A harness and pulley system suspended the front of the pitchbox from the ceiling of the room. The rear of the box was attached at the midpoint to a horizontal axis located at 1.22 m above the floor. Thus, pitched displays rotated about the axis in a topforward or topbackward direction with respect to the viewer and did not also translate to a new vertical position in space. A digital carpenter's level was fixed permanently to the pitch box and used to calibrate the topforward ("positive") and topbackward ("negative") pitch in degrees. Maximum pitch used in this experiment was 20 deg (0.35 rad) positive and negative.

The subject chair was fitted with a batter's helmet for the purpose of holding the subject's head in a fixed and known position. The helmet was attached to a brace and was adjustable in a vertical direction to give a comfortable fit. The chair height was adjusted so that the subject's eye was 1.22 m above the floor, corresponding to the height of the pitch axis. Subjects were positioned 1.32 m from the rear wall.

Subjects held an ordinary laser pointer in their lap and directed it to the rear wall to indicate VPEL. The vertical location of the subject's VPEL was measured by overlaying the spot of light from the subject's laser pointer with light from another laser pointer controlled by the experimenter. The experimenter's laser pointer was fixed to a digital level that was mounted on a tripod. Thus, with the pitchbox, subject and the experimenter's laser pointer in known positions, sufficient geometric parameters were available to allow the experimenter to record the degrees elevation or depression of the
tripod mounted laser pointer and then calculate VPEL in degrees visual angle for the subject. A diagram of the pitchbox is shown in Figure 1.

**Participants**

Nineteen subjects participated in this experiment including 16 undergraduate females, one undergraduate male, and one male age 60. All subjects received orientation to the purposes of the study and sufficient information about the procedures to be followed so they could knowledgeably give informed consent to participate. All subjects signed consent forms.

**Procedure**

All experimental sessions were conducted in a dark room following 20 min dark adaptation by the subjects. Room lights were extinguished and subjects donned a blindfold at the beginning of the session. After 20 min, the luminous tape had decayed in illuminance to a relatively stable state. Each judgment of VPEL was made following an experimenter's verbal cue for the subject to raise the blindfold and look straight ahead toward the rear wall of the pitchbox. The subject held a laser pointer in his or her lap and directed it to the rear wall to indicate a judgment of VPEL.

Each subject gave 20 judgments of VPEL while viewing each of 15 pitch conditions. The entire pitch set was: [values expressed as degrees (radians)]: -20 (-.35), -15 (-.26), -10 (-.17), -8 (-.14), -6 (-.10), -4 (-.07), -2 (-.03), 0 (0), 2 (.03), 4 (.07), 6 (.10), 8 (.14), 10 (.17), 15 (.26) and 20 (.35). A randomization procedure was followed individually for each subject to program 60 pitch presentations. The 60 presentations together with the 20 min dark adaptation resulted in an experimental session of length about 60 min. From the initial set of 15 pitches, 3 were randomly chosen for the first
session. The sequence of pitches to be used for that session was assembled as a random ordering of the 20 presentations of each pitch selected for that session. For the next session, 3 pitches were randomly selected from the remaining 12 and another random sequence of 60 was formed from 20 presentations of each pitch. This process continued for subsequent sessions, thus requiring each subject to participate in 5 sessions on different days. In this way, 19 subjects rendered 20 judgments of VPEL while exposed to each of 15 pitches. Note that pitches in the middle range (-10 deg to +10 deg) occurred in increments of 2 deg (.03 rad); outside the middle range, increments were 5 deg (.09 rad).

RESULTS

Data from judgments of VPEL were recorded as deg elevation or depression of the experimenter's laser pointer when the laser light spot overlaid the spot from the subject's laser pointer. Each measurement was converted to deg visual angle, and statistical procedures were applied to the resulting values. Table 1 and Figure 2 present mean VPEL judgments for each subject. Data are incomplete for 5 subjects due to equipment and procedural difficulties during the experiment. Figure 3 shows mean VPEL judgments with error bars (SEM) calculated across subjects. The general pattern for individuals and for the group means shows a linearly increasing relationship between VPEL and pitch of the grid display, consistent with reports by Matin & Li (1992). A regression line fitted to the data has a slope of +.44, somewhat below the values of +.61 reported by Matin & Li in 1992 for a "fully structured visual field" (i.e., a grid display). They obtained a VPEL-vs-pitch slope of +.52 from experiments with a pair of vertical lines 139.7 cm in length, subtending a visual angle of 63.1 deg (1.10 rad) and pitched
from +25 deg topforward to -40 deg topbackward. A later report (Matin & Li, 1994) described an experiment using a single line of length 64 deg that gave an average VPEL-vs-pitch slope of +.53.

A Tukey HSD procedure was used to assess pairs of pitches that differ significantly. For this purpose, the $df_w$ and $MS_w$ must be calculated. An Analysis of Variance was performed on the data of Table 1, yielding the ANOVA results presented in Table 2. The results of the HSD calculation are presented as Table 3. The pitch designation $P_o$ denotes a pitch to which another, $P_i$, may be statistically compared using the $Q$ statistic. $P_i$ may be greater or smaller than $P_o$. The critical values $Q_{CV}$ for $df_w = 253$ and $k=15$ groups are given as 4.80 for $p = .05$ and 5.45 for $p = .01$. $Q$ values in the body of Table 3 compare all pitches $P_i$ against each pitch $P_o$. $Q$ values in boldface identify the smallest pitch difference $P_o - P_i$ that meets the $Q_{CV}$ for $\alpha = .05$. For example, consider pitch $P_o$ of -2 deg. Mean VPEL for pitch $P_i$ of -15 deg may be considered significantly lower than those for a pitch of -2 deg because the $Q$ value of 5.64 exceeds the $Q_{CV} = 4.80$. Similarly, pitch $P_i = +6$ deg also carries a $Q (= 5.50)$ that exceeds the $Q_{CV}$. Therefore, for $P_o$ of -2 deg, a "threshold" for detecting changes in pitch of the display to another value $P_i$ would be $-15 - (-2) = -13$ deg on the negative side and $6 - (-2) = +8$ deg on the positive side. The boxed value of $Q$ for $P_o = +6$ and $P_i = +15$ does not quite achieve the magnitude of $Q_{CV}$, but has $p < .10$.

Figure 4 presents the "threshold" values for detecting changes in pitch ($P_o - P_i$) for each pitch value $P_o$. The mean "threshold" on the positive side is 10.0 deg, and the mean threshold on the negative side is -10.3 deg. The upper curve describes the threshold values ($\Delta P$) for each pitch $P_o$ when the comparison pitch $P_i$ is positive to $P_o$. The lower
curve describes threshold values ($\Delta P$) for each pitch $P_0$ when the comparison pitch $P_i$ is negative to $P_0$. The data point at $P_0 = +6$ deg is represented by a star to indicate that it does not achieve the same level of statistical significance as the other data points. Values of the upper curve ($P_i > P_0$) hover around a $\Delta P = +10$, thereby describing a fairly constant threshold of 10 deg for subjects who initially view pitches from -20 deg to +15 deg. A regression line fitted to these data exhibits slope of 0.01 ($t = 0.169$, $p < .87$, N.S) and intercept of 10.0. Values of the lower curve are fitted by a regression line of slope 0.13 ($t=1.35$, $p<0.21$, N.S)and intercept -10.8.
References


Figure Captions

Figure 1. Diagram of pitchbox with 1.25 m sides, with pattern composed of squares with 20.3 cm between centers. White poster board 81 cm X 102 cm was centered on the rear wall. The rear wall was attached to horizontal axis at midpoint of vertical dimension to allow pitch of the rear wall when entire box was rotated about the axis.

Figure 2. Mean VPEL judgments (in deg visual angle) for 19 subjects plotted against pitch of box in deg.

Figure 3. Mean VPEL judgments (in deg visual angle) and error bars to represent standard errors of the mean plotted against pitch of box in deg. Data points and SEM represent data from all 19 subjects.

Figure 4. "Threshold" values for detecting changes in pitch ($\Delta P = P_0 - P_i$) for each pitch value $P_0$. Threshold is defined as the smallest value of $\Delta P$ that achieved statistical significance using the Tukey HSD post hoc analysis. The upper curve describes threshold values for each pitch $P_0$ when the comparison pitch $P_i$ is positive to $P_0$; the lower curve presents threshold values for comparison pitches $P_i$ negative to $P_0$. 
Figure 2
### Table 2
Analysis of Variance for Pitches

<table>
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<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>5556.52</td>
<td>14</td>
<td>396.89</td>
<td>36.18</td>
<td>2.45E-52</td>
<td>1.73</td>
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<tr>
<td>Within Groups</td>
<td>2775.58</td>
<td>253</td>
<td>10.97</td>
<td>36.18</td>
<td>2.45E-52</td>
<td>1.73</td>
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<tr>
<td>Total</td>
<td>8332.10</td>
<td>267</td>
<td></td>
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</table>
Mean VPEL VS Pitch
VPEL = 0.44 \times \text{pitch} - 0.27
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<tr>
<th>Base P</th>
<th>0.05</th>
<th>0.01</th>
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<tbody>
<tr>
<td>2.78</td>
<td>2.36</td>
<td>2.01</td>
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<tr>
<td>2.58</td>
<td>2.15</td>
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<td>2.19</td>
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<td>2.14</td>
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<td>2.01</td>
<td>1.55</td>
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</tr>
</tbody>
</table>

*Type of error indicates the number of groups compared.*

Tukey HSD Results for Comparison of Pitches Differences P - P' Table 3
"Threshold" for Detection of Changed Pitch

Pitch $P_b$ of Display (deg)

$P_1 - P_0$ "Threshold" (deg)