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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.

Thresholds for Shifting Visually Perceived Eye

Level Due to Incremental Pitches

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. Stoper, 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

(Stoper 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. Stoper 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 right-left 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

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 presents

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),[i] 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)[ii] 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_0 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_0. 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_0. Q values in boldface identify the smallest pitch difference $P_0 - P_i$ that meets the Q_{CV} for $a = .05$. For example, consider pitch P_0 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_0 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 $P_0 = +6$ 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 ($P_0 - P_i$) for each pitch value P_0. 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 (ΔP) for each pitch P_0 when the comparison pitch P_i is positive to P_0. The lower

curve describes threshold values (ΔP) 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.

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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 ($\Box P = P_0 - P_1$) for each pitch value P_0. Threshold is defined as the smallest value of ΔP 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_1 is positive to P_0; the lower curve presents threshold values for comparison pitches $P_{1\ negative}$ to P_0.
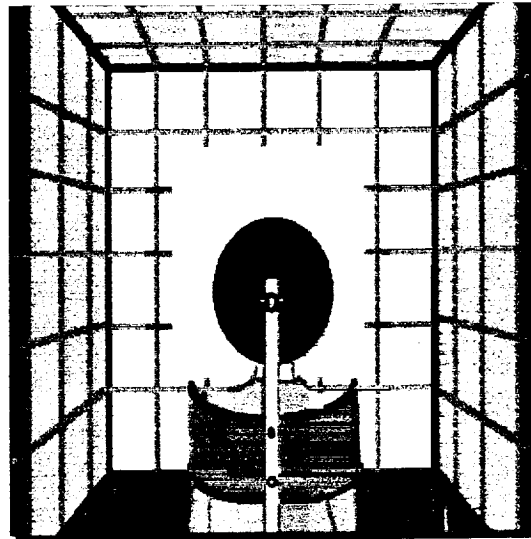
Figure 1

Table 1

Table 1
Average VPEL Judgments in Deg. for All Subjects at All Pitches

Subject	-20	-15	-10	-8	-6	-4	-2	0	2	4	6	8	10	15	20
CMK	-	-	-2.23	-4.73	-3.06	-2.36	-4.50	1.18	-2.84	-0.82	-0.12	-3.35	-0.75	-	-
CRH	-6.41	-6.04	-2.68	-5.88	-1.91	0.53	0.97	0.14	3.52	6.47	7.20	7.06	7.14	8.54	12.46
DMB	-	-	-4.53	-3.10	-5.01	-2.21	-0.20	0.78	0.30	2.25	2.15	2.19	3.01	-	-
DMS	-5.01	0.09	-	1.46	-0.42	-3.65	-2.22	2.20	2.88	2.73	2.59	3.87	0.92	4.22	4.99
HJB	-10.65	4.35	-6.28	-5.71	-1.29	-3.30	-4.17	-2.00	-1.77	0.26	2.08	-1.53	3.34	11.42	10.45
JAS	-4.41	0.61	-3.95	-4.72	2.71	-3.76	-6.01	0.58	-2.22	-0.23	0.39	0.35	3.35	3.22	6.46
JRS	-12.10	-12.77	-10.79	-8.28	-4.57	-8.40	-2.69	1.77	-1.68	-0.64	-1.99	-0.65	3.25	0.96	13.48
KEL	-6.98	-8.29	-6.76	-8.28	-6.50	-5.04	-3.95	-5.97	-4.94	0.61	2.16	3.50	2.45	6.08	7.24
KJM	-	-5.61	-2.52	-1.75	-2.67	-2.08	-3.95	-	-0.20	-	-	-	4.39	4.77	6.01
KNM	-9.81	-7.65	7.02	-4.15	-0.58	-3.08	-1.46	4.86	5.61	4.80	6.51	7.03	7.74	10.89	14.34
LKH	-9.26	-10.79	-8.31	-4.78	-6.27	-4.60	-2.40	-1.74	1.51	2.36	5.74	3.80	5.84	10.31	11.89
LL	-10.75	-6.04	-6.38	-3.99	-1.92	-0.74	0.88	-1.51	3.50	3.62	1.97	5.49	5.78	7.50	5.61
MEM	-7.94	-9.31	-7.62	-5.21	-6.63	-5.34	-7.25	-5.00	-4.04	-0.62	0.80	-2.28	-0.14	0.97	0.70
MMB	-9.66	-7.14	-0.01	0.01	2.34	1.74	3.26	4.21	4.98	3.63	7.85	6.18	7.85	9.83	10.84
NEJ	-6.14	-5.01	-6.96	-5.13	-4.89	-2.14	-1.60	0.19	1.50	-0.62	2.18	5.99	3.77	7.34	7.61
SEK	-11.87	-	-7.16	-2.63	-3.92	-3.62	0.40	1.82	-0.64	3.33	0.85	0.29	2.48	-	-
SML	-12.29	-10.72	-9.78	-7.04	-6.18	-4.89	-6.72	-2.18	-1.26	-2.14	-0.41	-0.36	1.55	1.49	3.25
VGS	-4.61	-5.82	-4.66	-1.00	-2.61	-1.89	4.16	2.78	5.61	6.39	8.63	8.95	7.77	11.47	14.09
YGD	-7.50	-9.90	-6.93	-4.55	-0.70	-3.02	0.65	1.50	7.00	0.33	0.59	3.56	6.30	2.91	17.06

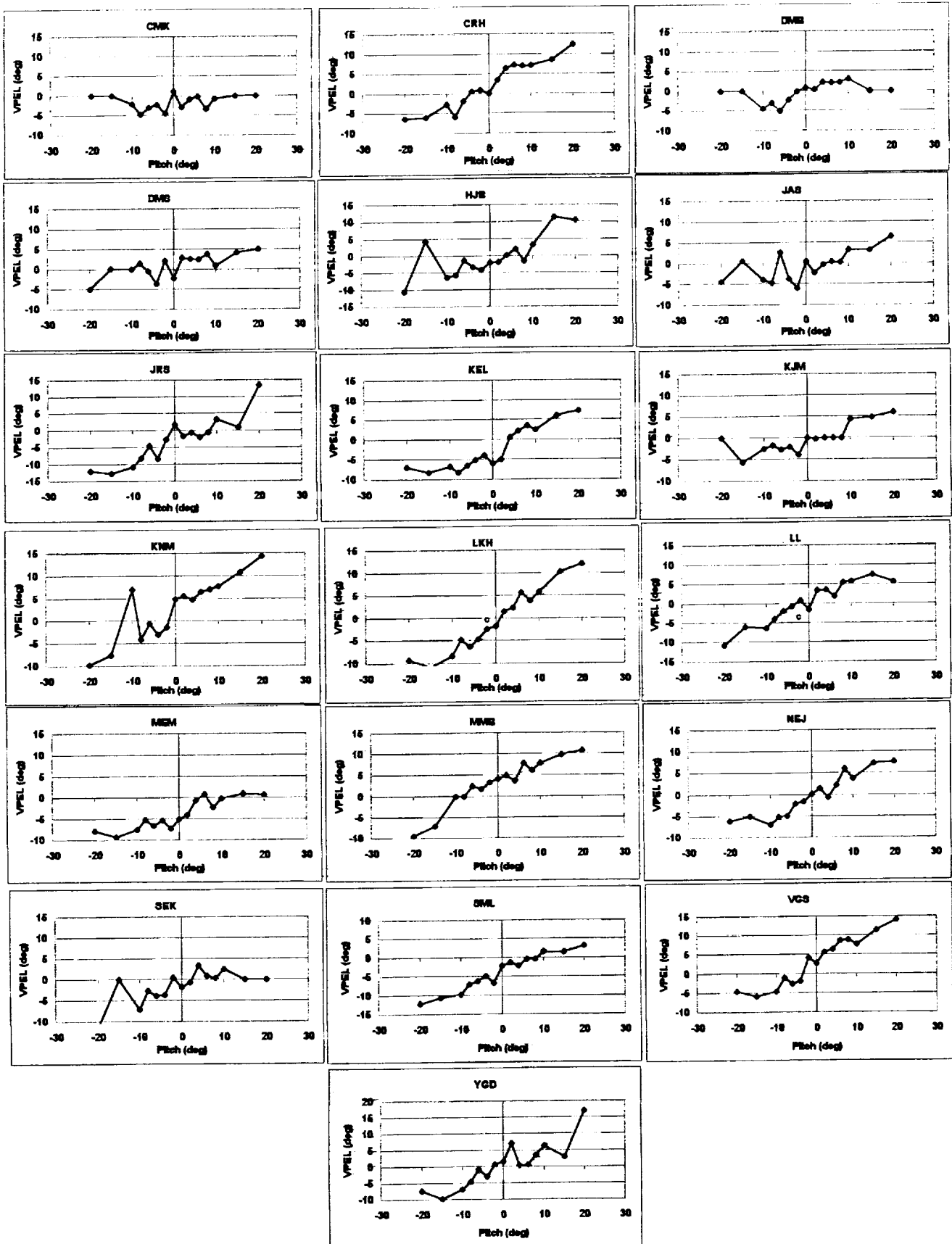Note: Each value represents mean of 20 judgments by a subject at a pitch.

Figure 2

Table 2

Table 2
Analysis of Variance for Pitches

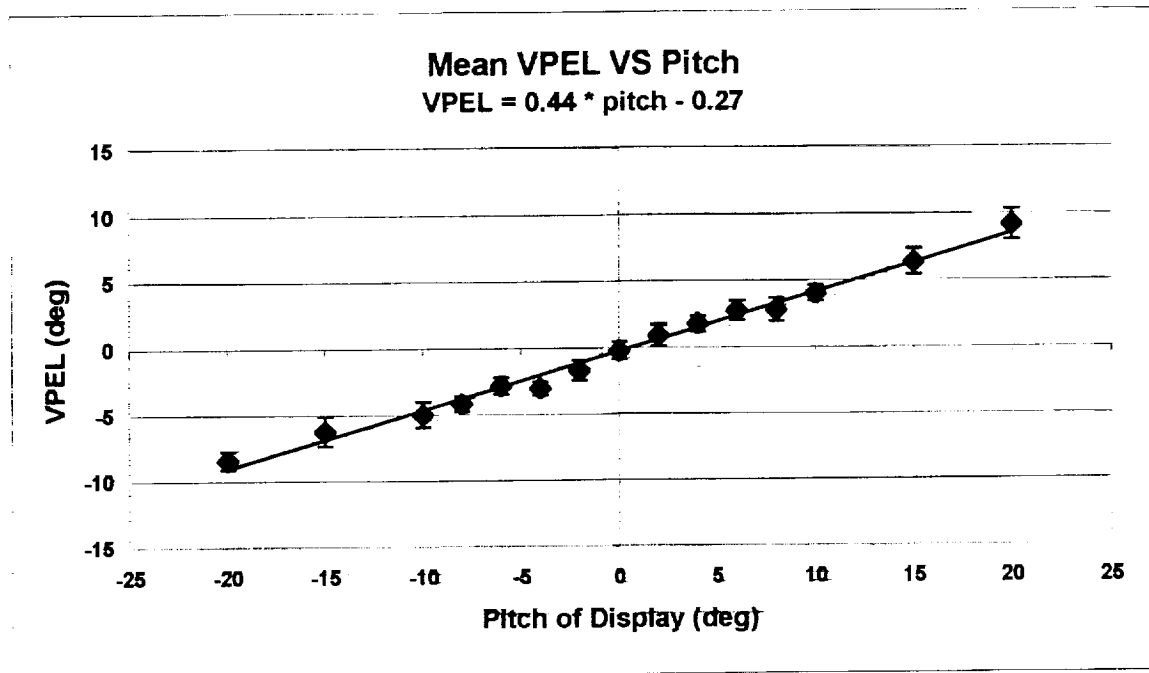| Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5556.52	14	396.89	36.18	2.45E-52	1.73
Within Groups	2775.58	253	10.97			
Total	8332.10	267				

Figure 3

Mean VPEL VS Pitch

VPEL = 0.44 * pitch - 0.27

Table 3

Table 3
Tukey HSD Results for Comparison of Pitche Differences $P_0 - P_1$
Q statistic (Studentized Range)

Comparison Pitch P_1	Base P_0 → -20	-16	-10	-8	-6	-4	-2	0	2	4	6	8	10	16	20
-20		2.79	4.35	5.43*	7.13**	6.87**	8.58**	10.43**	11.87**	12.99**	14.23**	14.30**	15.84**	18.86**	22.41**
-16	2.79		1.56	2.64	4.34	4.09	5.79*	7.6**	9.09**	10.20**	11.44**	11.51**	13.06**	16.07**	19.63**
-10	4.35	1.56		1.08	2.78	2.53	3.15	4.23	6.09**	7.53**	8.64**	9.88**	9.95**	14.51**	18.07**
-8	5.43*	2.64	1.08		1.70	1.45	1.45	3.31	4.75	5.01*	6.45**	7.56**	8.80**	11.73**	15.29**
-6	7.13**	4.34	2.78	1.70		0.25	1.45	3.56	4.75	6.12**	7.10**	8.72**	8.97**	11.98**	15.54**
-4	6.87**	4.09	2.53	1.45	0.25		1.71	3.56	3.79	5.00*	6.12**	7.10**	7.43**	10.28**	13.83**
-2	8.58**	5.79*	3.15	1.45	1.45	1.71		1.86	3.30	5.00*	5.65**	7.35**	7.43**	10.28**	13.83**
0	10.43**	7.6**	4.23	3.31	3.56	3.56	1.86		1.44	2.56	3.79	5.65**	5.41*	8.42**	11.98**
2	11.87**	9.09**	6.09**	4.75	4.75	3.79	3.30	1.44		1.12	2.35	5.65**	5.72**	6.88**	10.54**
4	12.99**	10.20**	7.53**	5.00*	6.12**	5.00*	5.00*	2.56	1.12		1.24	4.63	5.87**	5.87**	9.42**
6	14.23**	11.44**	8.64**	6.45**	7.10**	6.12**	5.65**	3.79	2.35	1.24		0.07	1.62	6.98**	10.54**
8	14.30**	11.51**	9.88**	7.56**	7.35**	7.10**	7.35**	5.65**	2.42	0.07		1.55	4.56	4.56	8.11**
10	15.84**	13.06**	9.95**	8.87**	8.97**	7.43**	5.41*	3.87	3.87	1.62	1.55		3.01	3.01	6.57**
16	18.86**	16.07**	14.51**	11.73**	11.98**	10.28**	8.42**	5.87**	4.63	5.87**	6.98**	4.56	3.01		3.55
20	22.41**	19.63**	18.07**	15.29**	15.54**	13.83**	11.98**	9.42**	2.73	2.73	9.42**	8.11**	6.57**	3.55	

Note. Underlined values indicate the smallest pitch difference $P_1 - P_0$ that is statistically significant.

* $p < .05$ ** $p < .01$

Figure 4

"Threshold" for Detection
of Changed Pitch