COCKPIT WINDOW EDGE PROXIMITY EFFECTS ON JUDGEMENTS OF HORIZON VERTICAL DISPLACEMENT

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ABSTRACT

To quantify the influence of a spatially fixed edge on vertical displacement threshold, twenty-four males (12 pilots, 12 non-pilots) were presented a series of forced choice, paired comparison trials in which a 32° arc wide, thin, luminous horizontal stimulus line moved smoothly downward through five angles from a common starting position within a three second-long period. The five angles were 1.4, 1.7, 2, 2.3, and 2.6°. Each angle was presented paired with itself and the other four angles in all combinations in random order. For each pair of trials the observer had to choose which trial possessed the largest displacement. A confidence response also was made. The independent variable was the angular separation between the lower edge of a stable "window" aperture through which the stimulus was seen to move and the lowest position attained by the stimulus. Three lower edge positions were studied making a total of 15 angular separation values between 0.4° and 5.6° upon which a threshold curve could be derived. It was found that vertical displacement accuracy is inversely related to the angle separating the stimulus and the fixed window edge ($p = .05$). In addition, there is a strong tendency for pilot confidence to be lower than that of non-pilots for each of the three angular separations. These results are discussed in terms of selected cockpit features and as they relate to how pilots judge changes in aircraft pitch attitude.

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INTRODUCTION

This investigation was conducted to gain a better understanding of how the visual system uses a nearby stable frame of reference to assist in judging vertical displacement of a horizontal line. Research by Bonnet (1975), Brown (1927, 1931), Cartwright (1938), Duncker (1929), Johnson and Scobey (1982), Koffka (1935), Legge and Campbell (1981), and Tyler and Torres (1972) showed that motion is discriminated more accurately in the presence of a fixed visual reference. This work suggested that the nearer this reference was to the moving stimulus the more sensitive is the visual system to motion. This will be referred to as the "proximity effect." Portions of this literature will be reviewed in the following section labelled "background research on motion judgments." Of more practical relevance is the possibility that pilots may be influenced in their ability to judge aircraft pitch attitude and pitch attitude changes by how angularly near the (distant) horizon appears to some part of their cockpit window frame. This topic is discussed later in a section labelled "practical applications for these data."

Background Research on Motion Judgments.

The subject of how humans perceive motion has been of interest to a great many investigators over the years. The interested reader may want to consult reviews by Brown (1931), Gibson (1950), Graham (1962), LeGrand (1965), and Spigal (1965). Of particular interest here are those studies dealing with the influence of a spatially fixed frame(s) of reference or visual field detail, including inhomogeneous backgrounds immediately behind a moving stimulus. Work on the former topic has been carried out by Breitmeyer (1974), Brown (1931), Brown (1965), Cartwright (1938), Duncker (1929), Graham (1968), Johnson and Scobey (1982), Leibowitz (1955), Mates and Graham (1970), and Mattson (1976) and on the latter by Brandt et al. (1973), Brown (1931), Harvey and Michon (1974), Owen et al. (1981), and Tynan and Sekuler (1982).

Perhaps the earliest work on the proximity effect was that of Brown (1927) who reported that when a horizontally moving row of equally spaced black circles (pasted on a white background) are viewed moving behind a small rectangular aperture of a given size and another identical pattern is placed along side the first there is almost no difference in their phenomenal speed as long as their angular velocities are equal. However, when one of the two apertures and moving stimuli are spatially separated so that the comparison must be made in succession, Brown reported a striking difference of speed. The larger circles seen in the larger aperture now appeared much slower than did the smaller circles moving behind the smaller aperture. Also, the darker the surrounding room was the more conspicuous was the effect. Differential subjective motion as great as 1:7 was reported. It should be noted that Brown's method was a temporally and spatially separated, paired- comparison, forced choice requiring a judgment of which of the two stimulus fields appeared faster. An experimenter adjusted the variable stimulus' velocity until a match was achieved. Earlier research on motion sensitivity by Aubert (1886, 1887) and Bourdon (1902) had considered such field factors as extraneous.

In a subsequent paper (1931), Brown found that in an opening four times the area as another (both with identical stimuli), the physical velocity had to be 3.8 times as great in the smaller aperture if a just perceptible movement was to be perceived correctly. Unfortunately, this early work did not attempt precise quantification of this type of effect.

Koffka (1935) suggested that visual sensitivity to such differential motion may depend on the magnitude of the angle between the moving stimulus and the nearest edge of a surrounding frame. Cartwright (1938) then offered that "...objective velocities will...appear inversely proportional to the linear dimensions of these frames; and objective velocities will have to be changed in proportion to these dimensions, if equal phenomenal speeds are to be obtained." (Ibid., pg. 324)

Considered from a Gestalt viewpoint, for situations in which an observer judges stimulus motion relative to a fixed aperture, the edge (of the aperture) that is being approached should exert an increasingly strong proximity effect to produce a perception of motion while the opposite edge should exert a diminishing effect over time. If, on the other hand, such judgments are mediated by non Gestalt and/or more localized retinal capabilities one might expect no such effect.

In all of the early work the immediate background for a stimulus (within an aperture) was homogeneous. The influence of spatial detail or texture immediately behind the moving stimulus did not receive much interest until 1955 when Leibowitz considered an aspect of it by including a series of parallel, vertical grid lines behind which the equally spaced black stimuli moved horizontally. Bonnet (1975; 1977), Johnson and Scobey (1982), Legge and Campbell (1981), and Tyler and Torres (1972), also have studied the effect reference lines have on the proximity effect. More closely related to the present study is work by Johnson and Scobey (1982) who studied the influence of a vertical, fixed, luminous reference line (3.2' arc thick by 30' arc long) upon the displacement threshold for a vertically oriented moving stimulus which moved at constant velocity and which was 1' arc thick, 50' arc long, and only 11' arc away at the start of each trial. The stimulus always moved horizontally away from the reference line; both lines were viewed on the screen of a cathode ray tube measuring 10° arc high by 30° arc wide. Each of the two Os had to respond whether or not the stimulus had moved. The results showed that for all stimulus durations studied (from 10 msec to 2.5 sec), the reference line reduced displacement threshold by about five times (e.g., from about 6.5' arc to about 1.6' arc for one O and from about 5' arc to about 0.8' arc for the other for the 2.5 second stimulus duration condition. The question can be raised whether this proximity effect of a stable reference line exists for larger separation angles. While one might consider this as a reasonable possibility for foveally imaged stimuli (e.g., viewing with a separation angle of only 11' ar
mechanisms might need to be invoked if a proximity effect is found to

separation angles of (say) more than one degree. The present study was conducted to investigate this possibility.

Concerning the matter of proximity effects produced by the edge of the stimulus' display area, Brown (1931) tried to make the edges of his aperture more conspicuous by including a high contrast "wall paper pattern" of squares so that a relatively thin rim of black cardboard remained around each aperture. He reported that this type of pattern lead to higher phenomenal velocities of the horizontally moving stimulus than when the entire apparatus up to the edge of the aperture was covered with the patterned wall paper. He stated, "It may be concluded that the physical velocity of the stimulus alone conditions the phenomenal velocity only when all of the properties of the visual field are kept constant." (pg. 228-9) Or put another way, there is no single perceptual criterion which can be applied to predict the magnitude of a particular phenomenal velocity or whether one velocity is more correct than another in a given matching task.

Brown (1931) suggested that phenomenal velocities were determined in a *"...dynamical field, the essential nature of which can not be described as a sum of independent local events. They correspond to dependent events in the functional whole. Therefore the whole functional structure of the excited field, not the excitation present at any given point within the field, must be considered in order that one understand the physiology of the visual perception of velocity." (Ibid., pp. 229-30; italics mine).* Of course, one implication of such a view is that the concept of an absolute threshold for movement is virtually meaningless, particularly when all of the relevant independent variables are not known, not controllable, and/or not even reported as is the case in actual airplane flight and its simulation.

Thus, for useful insights to be gained from laboratory motion perception studies it is necessary to hold virtually everything constant except the variable of interest. This was attempted here. Because of the confounding influences produced by the many visual variables that are present during actual and simulated flight (see Owen et al., 1981; Warren and Owen, 1982), the present study was designed to vary only one of the six degrees of freedom of motion (pitch) while holding the other five constant.

In this study the major objective was to obtain vertical displacement threshold measurements when the angular separation between the stimulus line and a nearby stable reference (window edge) was varied systematically over a relatively large range of angles. As will be noted, the basic temporal and spatial parameters approximated the apparent movement of the horizon as viewed from a turbojet type commercial airplane cockpit during a nose up pitch (flare) maneuver just prior to touchdown.

METHOD

Procedure.

The test procedure can best be described in the following sections: instructions, eye tests, practice, and data collection.

Instructions. The test instructions were read by each observer (O) and a brief black board demonstration was given to emphasize the required visual fixation location, displacement judgement, which response toggles to use, and the importance of maintaining a stable eye position (hereafter called the *Reference Eye Position; REP).*

A *Bausch & Lomb* Orthorater (far series) battery of vision tests was given to insure that all Os possessed at least 20:20 distance acuity, normal horizontal and vertical phoria balance. This required about 20 minutes.

Practice. The practice session consisted of 16 paired comparison trials having vertical displacements different from but similar to those used during data collection. All stimulus movement was downward starting from the center of the optical display. Presentation order of all trials was randomized. O had an opportunity to ask questions and try different response toggles. A typical response interval lasted about eight seconds.

O was carefully positioned in an adjustable seat through the use of a low light level TV system; his eyes were positioned at the REP of the display unit. An experimenter (E) visually monitored eye location continuously during data collection to insure that no deviations greater than +/- 0.1 inch occurred in any direction.

Data Collection. O remained in the semi-darkness of the laboratory for at least 20 minutes. Temporal intervals were identical for each of the two trials in a pair, viz., the horizontal stimulus was stationary for two seconds in its initial position at the center of the display which was at the same level as O's eyes; it descended through one of the five displacement angles over a three second period (ramp displacement); it remained stationary in its final position for two more seconds; it disappeared for 0.2 seconds between the two trials. It disappeared after the second trial indicating the start of the response period. The instructions were to choose whether the first or second stimulus trial had moved (down) the farthest.

Because each trial was initiated by O it was not possible to control total test time or total trial time. An average trial lasted about 20 seconds; 25 trials required about nine minutes.

Prior to data collection and unknown to O, an E positioned the diffuse black lower window surface (hereafter called the *edge*) into one of the three positions of interest. The following steps were followed to insure that O would not be influenced in his displacement judgments because of prior knowledge of a positional change in the window's lower edge. First, the moveable edge was carefully located so that it was -3°, -4°, or -7° below and parallel to the stimulus' starting position (as measured from a level line of sight). O was never permitted to watch this operation but was led to believe that another variable was being tested. Second, O was told that his head and eyes had to be checked for position and that (subsequently) he would be shown the horizon (stimulus) and that he should adjust his seat up or down appropriately so that it appeared to lie exactly on top of the window's edge. Third, the stimulus was then located in such a position that it's displacement equalled the pre-set vertical edge position. Since O did not have to adjust his seat (but only sit a little taller or shorter), he was led to believe that nothing had changed from earlier testing conditions. When asked after testing was completed whether anything had been varied during testing no O was consciously aware of the deliberate repositioning of the edge. Finally, the stimulus was turned off and the data collection period began.

Since the stimulus moved downward through five angles and the lower window edge was located in each of three positions, there were a total of fifteen angular separations presented to each O upon which a mean threshold curve could be based. These angles are shown on the abscissa of Figure 5; they ranged from 0.4° to 5.6° arc from the stimulus' final (displaced) position.

Apparatus.

The apparatus consisted of three basic elements: digital computer to calculate stimulus equations of motion, stimulus derivation/display computer, and display collimating optics. A DEC PDP 11/60 digital computer was used to solve rate and amplitude equations for the stimulus which was displayed at apparent optical infinity as will be described. The stimulus line was programmed to lie 50,000 feet away with a vertical "eye height" of 50 feet to the imaginary ground plane which is a nominal airplane altitude at initiation of the flare maneuver.

An Evans and Sutherland Picture System II was used to generate the mathematical coordinates and display the stimulus on a calligraphic (stroke) CRT display. This 21 inch Zytron (model A21R-7C) monitor was collimated (-0.01 diopter) by means of a mirror/beam splitter imaging system of 25 inch (63.5 cm) focal length.

The stimulus subtended 0.033° (0.58 mrad) in width and 34.5° (0.602 rad) in length. Its intensity was adjusted by E prior to testing while being viewed by O through a 2.0 log ND Wratten filter (after prolonged adaptation to ambient illuminance) to be just visible over its full length. Of course, all stimulus viewing during data collection was without this filter. The stimulus appeared white against a very evenly dark background.

As is shown in Figure 1, a large, flat, rigid plastic aperture surface was located between the eyes and the collimating optics. O's side of this aperture surface was flat black with a reflectance of approximately six percent. This surface was illuminated by two 25 watt frosted, tungsten incandescent filament lamps operated at 40 volts and aimed so as to produce even illumination of approximately 0.54 lx (0.05 ft-c). The contrast (C) between the dimly illuminated aperture surface and the darker background of the moving stimulus was 6 where:

$$C = Lt - Lb/Lb$$

and Lt = aperture surface illuminance and Lb = background illuminance.

The plumb bob indicates the REP, a curved, padded head rest is seen to its left, and a response panel with white top and a row of spring-loaded toggle switches also is visible. The bottom edge of the aperture was adjustable as described above. Except for its lower edge, this aperture possessed the same frontal area and occupied the same position relative to O's eyes as the forward window in a B-727 type airplane on the captain's side. It subtended approximately 63° arc width across its upper edge with 18° vertically above the center of the stimulus (at its initial position) to the upper edge. There was no glass within the aperture, however. Figure 2 illustrates the shape and angular dimensions of this aperture as viewed from the REP.

Figure 1.

Photograph of Observer's Seat, Window Aperture, and Other Apparatus.

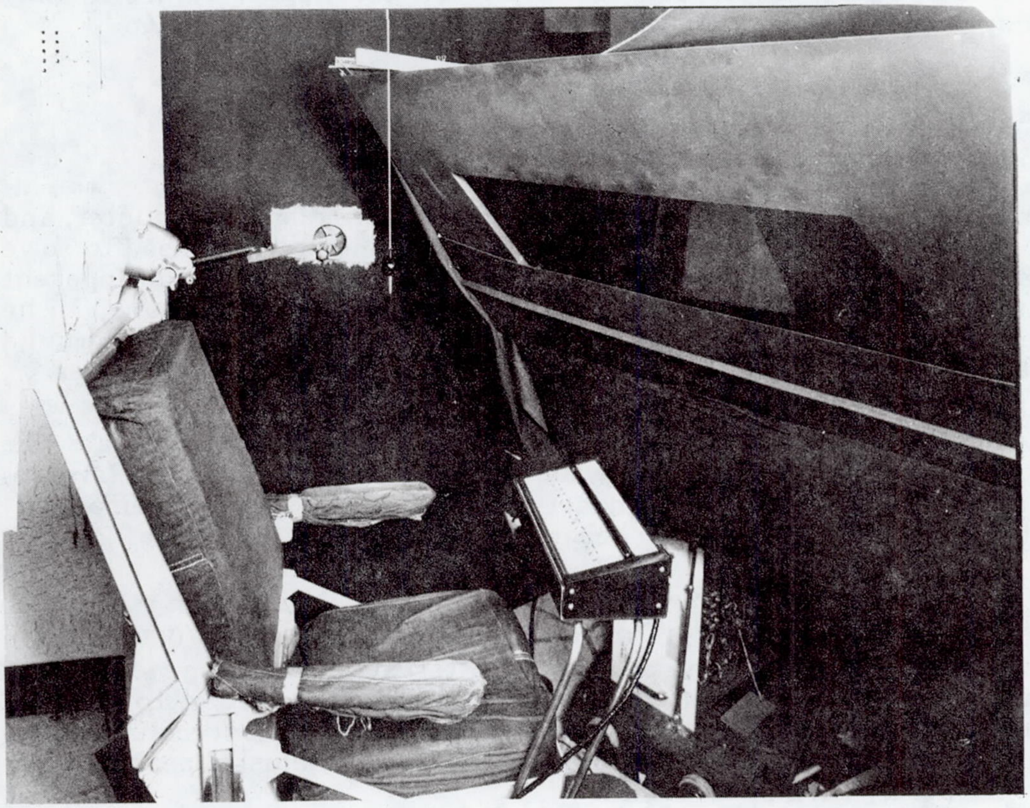
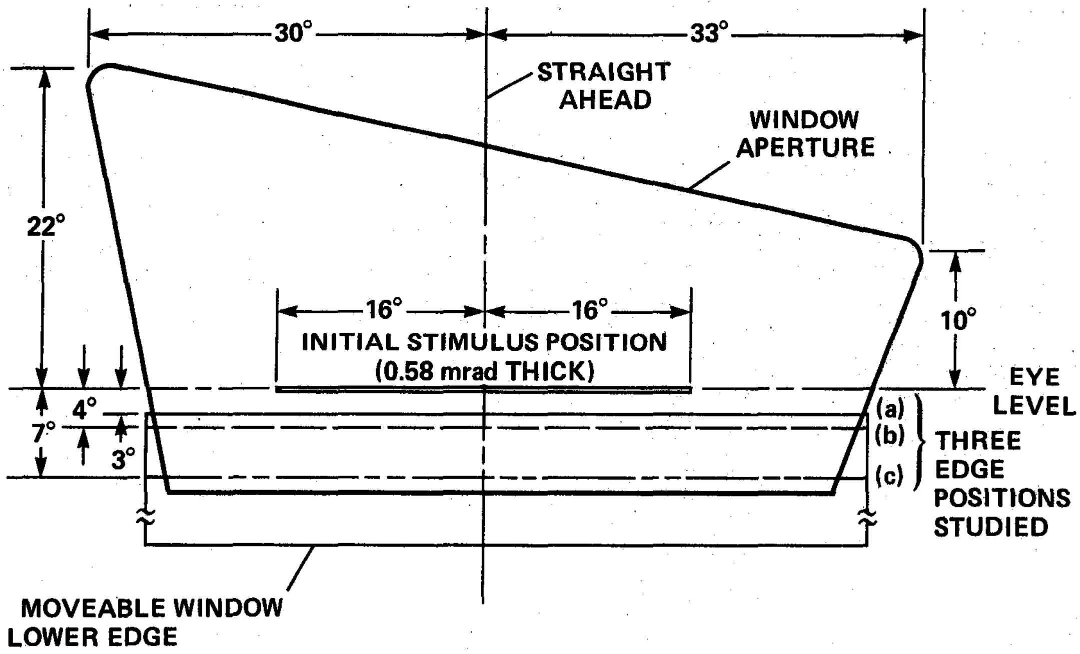


Figure 2.

Diagram of Aperture with Dimensions



Experimental Design.

The experimental design may be characterized as an observer by treatment design with the five stimulus displacement angles nested within each treatment. The three edge positions and five stimulus displacement angles were presented in random order.

Observers.

Twenty four males took part as paid Os. They were obtained through a NASA contractor. Twelve were non pilots (mean age = 27.9; SD = 8.8 yrs) and twelve were pilots (mean age = 26; SD = 10.7 yrs). Except for one non pilot all Os possessed 20:20 or better uncorrected distance acuity. The single O wore glasses which corrected his acuity to 20:20. The total flight time of the pilot group ranged from 70 to 14,000 hours (mean = 1,727). Table 1 presents selected O information.

Table 1.

Observer Information

	Age	Acuity	Pilot Flight Hours (heaviest airplane flown)
Pilots			
A	19	20:20	650 Hrs. Multi-engine rating
B	23	20:17	110 Hrs. (2,300 lbs.)
C	34	20:17	135 Hrs. Cessna 182
D	21	20:17	120 Hrs. Cessna 172
E	27	20:20	70 Hrs. Archer 2
F	33	20:20	1,200 Hrs. Cessna 420
G	35	20:17	534 Hrs. Cessna 206
H	45	20:18	14,000 Hrs. B-747
I	31	20:17	4,100 Hrs. B-727
J	25	20:20	500 Hrs. Piper-Turbo Lance
K	23	20:18	275 Hrs. Piper-Apache
L	22	20:20	100 Hrs. Cessna 206
Non Pilots			
M	29	20:20	
N	39	20:17	
O	30	20:20	
P	33	20:17	
Q	16	20:20	
R	29	20:18	
S	31	20:17	
T	45	20:20 (corrected)	
U	20	20:20	
V	25	20:17	
W	16	20:18	
X	31	20:17	

RESULTS

Two separate responses were required on each pair of trials (I. vetical displacement comparison; II. confidence). Each type of response is presented and discussed separately.

I. Vertical Displacement Comparison Results:

Analysis of Variance Results. An analysis of variance was performed on the mean proportion data (Univ. of Calif., 197 ; BMD-08V). The Os were considered as a random factor and the three edge positions as a fixed factor. The five displacement angles were nested within each edge position. The only significant factor found was the edge position main effect (F = 3.04; df = 2/44; p = 0.05). It is of value to consider this significant edge position effect more closely.

Proportion Data. The data were analyzed following procedures set forth in detail elsewhere (Guilford, 1954). The proportion of total responses on which these Os responded that the first trial in a pair possessed the larger displacement is referred to as P. The bivariate normal transform of P also was determined and is referred to as Z. Tables of P and Z values for all 25 cell conditions, averaged across the 24 Os, are given in Appendix 1 through 3.

The mean data from Appendix 1 - 3 were plotted with the percent of responses correct on the ordinate and the angular magnitude of the difference between the two trials of a given pair on the abscissa. For instance, a difference of 0.6° is obtained from three pairs of angles presented (-1.4° vs. -2°; -1.7° vs. -2.3°; and -2° vs. -2.6°). Figures 3 through 5 present these threshold curves for the -3°, -4°, and -7° edge position conditions, respectively. Dots represent trials in which the larger angle was presented second in a pair while crosses represent the opposite. Each curve is fit by eye.

Figure 3.

Mean Displacement Threshold Curve for the -3° Edge Position Condition.

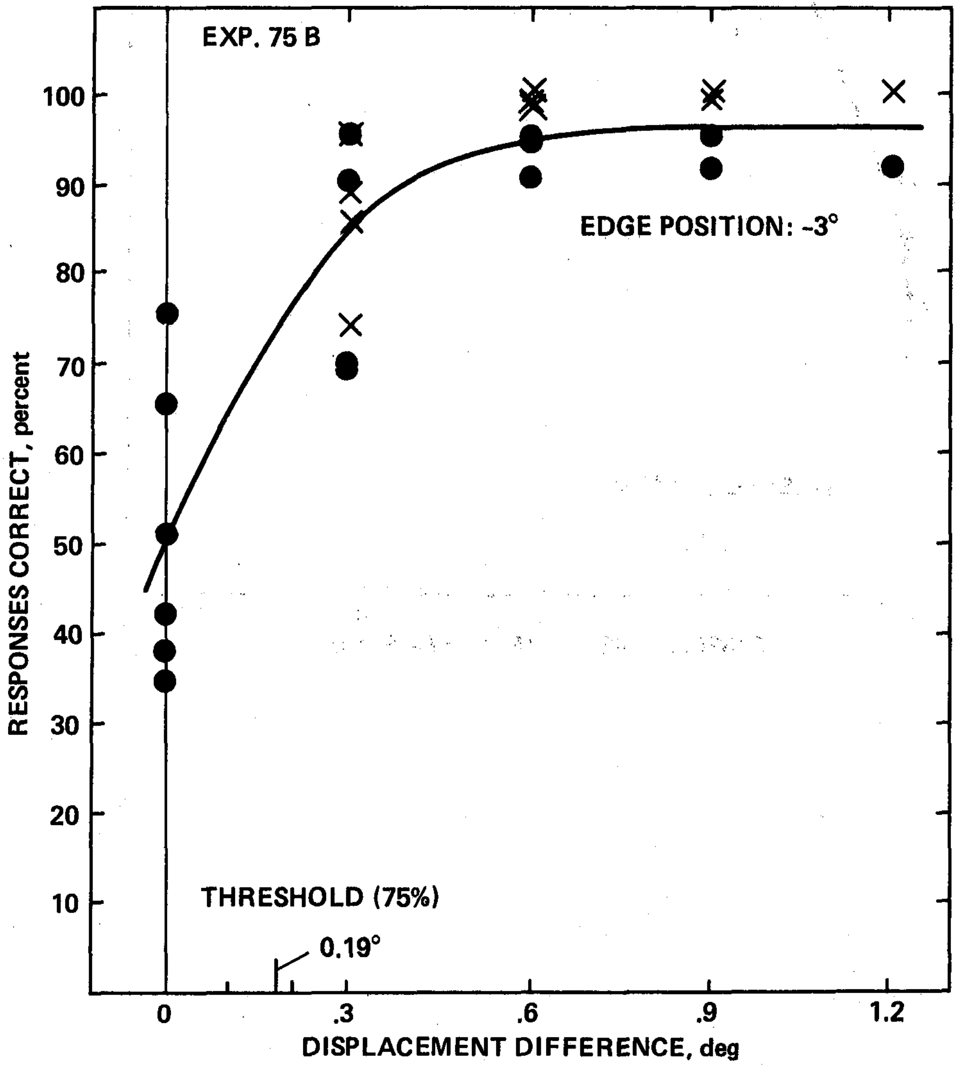


Figure 4.

Mean Displacement Threshold Curve for the -4° Edge Position Condition.

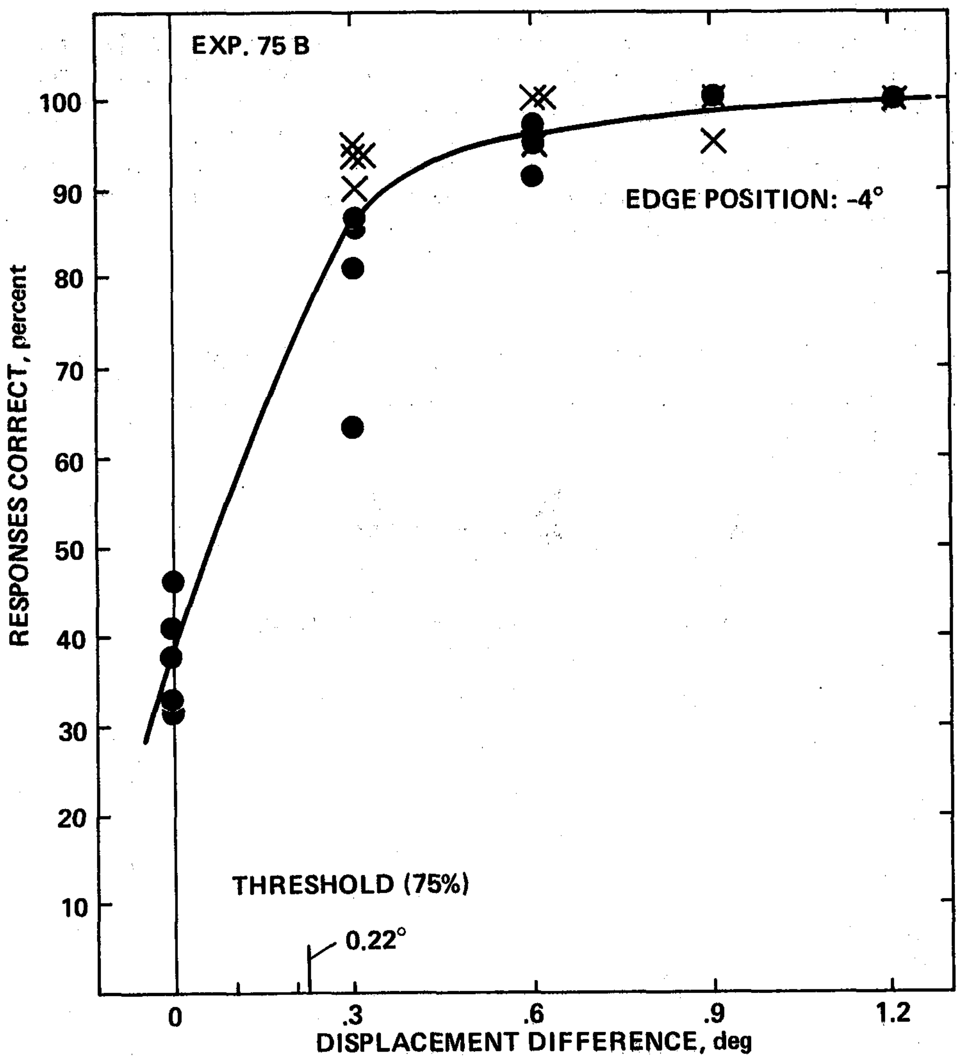
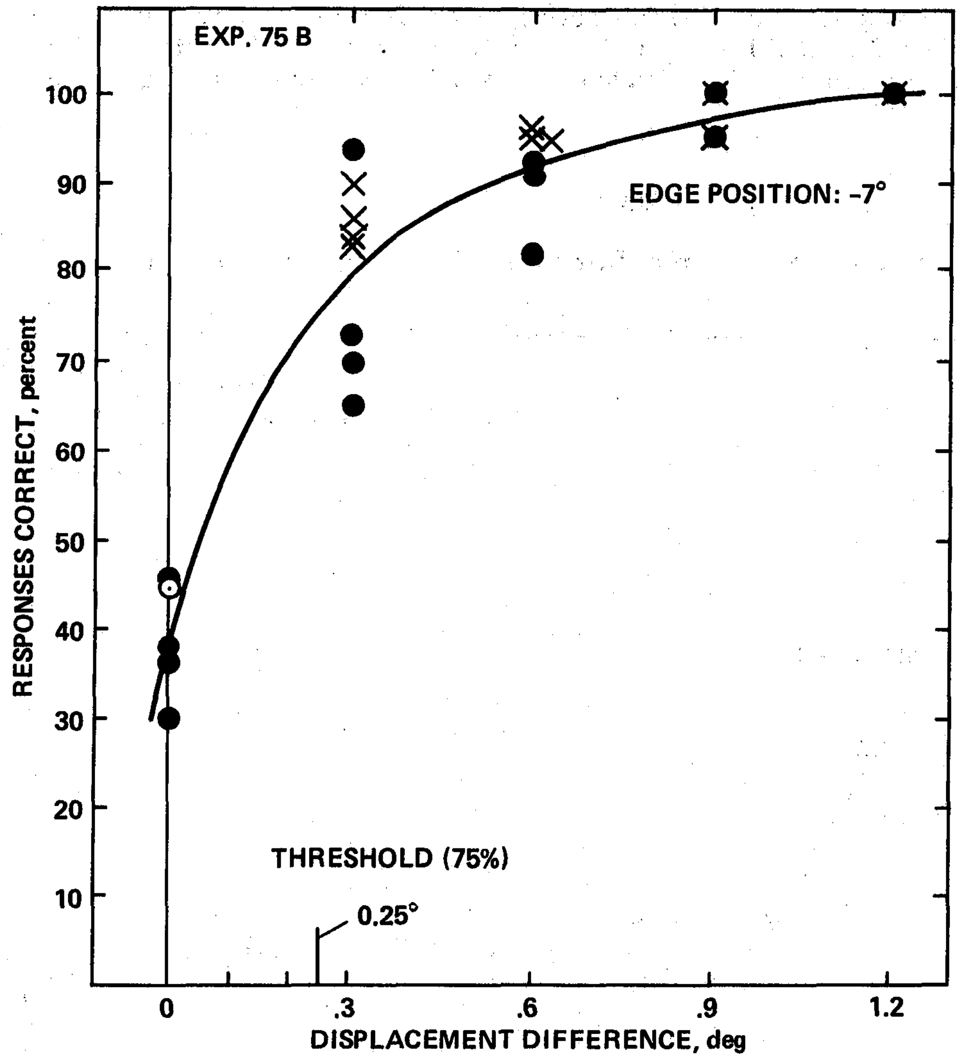


Figure 5.

Mean Displacement Threshold Curve for the -7° Edge Position Condition.

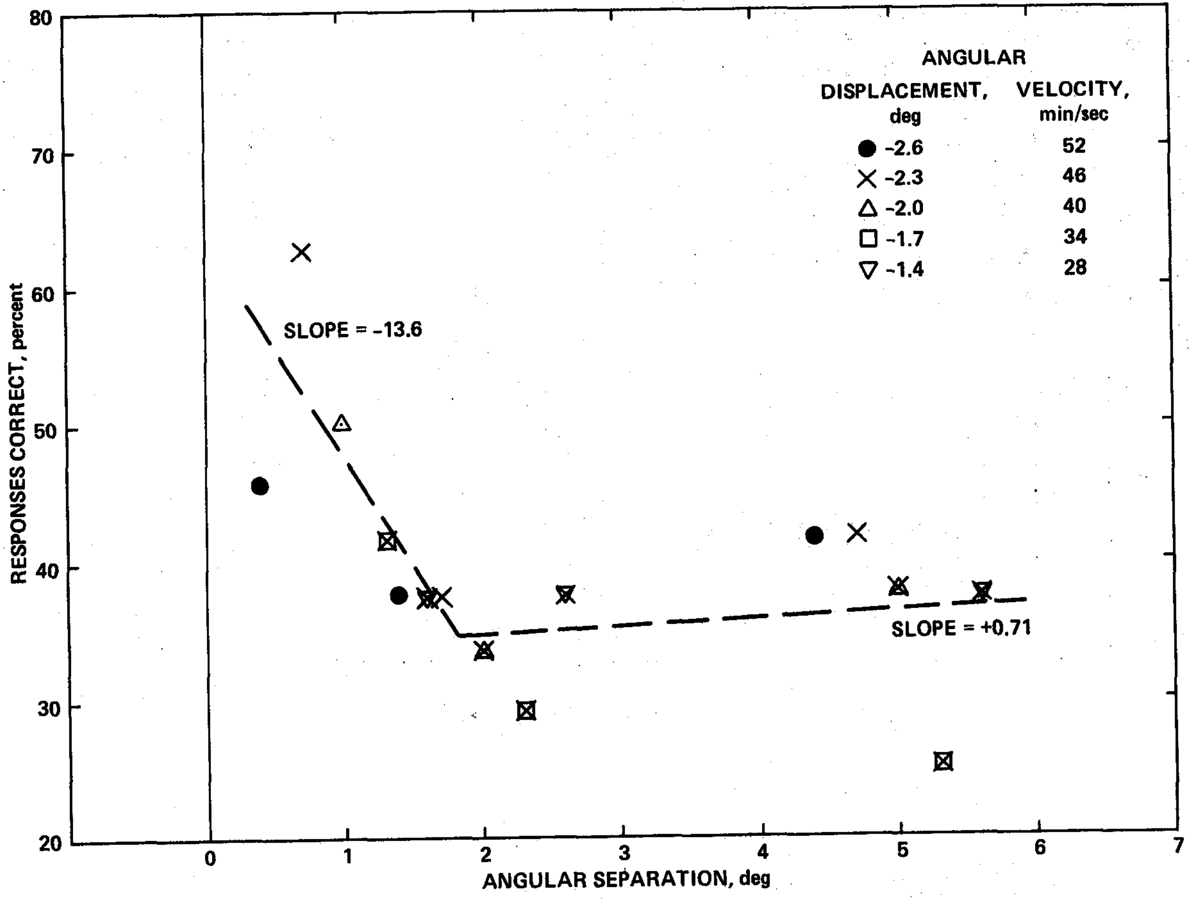


Using a threshold criterion of 75 percent correct yields mean displacement thresholds of 0.19°, 0.22°, and 0.25° for the above three edge positions, respectively (see vertical tick on abscissa).

All of the mean data from Figures 3 through 5 were combined in Figure 6 to show percent correct as a function of the angular separation between the stimulus' final position and the edge regardless of which of the three edge positions was presented. Each data point is the mean of 24 responses. Two linear, least square fit curves are shown intersecting at an angular separation of 1.7° which is the angle which divides the data used for each curve. The data points have been coded to permit identification of which displacement angle each represents.

Figure 6.

Percent Correct as a Function of Stimulus - Edge Angular Separation.



Referring to Figure 6 it can be seen that it is only within about 1.7° arc of the window's edge that the percent of responses that are correct is influenced to any marked degree.

Normal Bivariate (Z) Transform Results. Guilford (Ibid.) provides both the mathematical derivation for and suggested approaches to interpretation of paired comparison, forced choice data. He points out that for data which meets certain requirements, Z transformed data provide useful insights about the underlying data upon which they are based. For example, (a) the slope of a least squares linear fit curve of Z data is inversely proportional to the standard deviation of that data, (b) the degree of linearity of a Z curve is positively related to the normalicy of the distribution of data underlying the data, (c) given sufficient data, each curve should cross the level Z = 0 at a value corresponding to the standard or mid-stimulus value for that data set, and (d) the degree to which all curves are non- overlapping and ordered in the same order as the original stimulus dimension gives useful insights as to whether the perceptual mechanism(s) involved in the discrimination also is mediating regular, ordered discriminations.

The mean proportion data of Figures 3 through 5 are replotted as Z in Figures 7 through 9. Referring to Figure 7 for the -3° edge position condition it is seen that the five curves are not only spaced relatively evenly but possess decreasing slope (increasing standard deviation) with an increase in the magnitude of the stimulus displacement. Thus, the farther the stimulus is from the window's lower edge the greater is response variability. The (presumed) "edge effect" seems to have diminished by the time the stimulus is 7° from the edge, i.e., while the five curves are still ordered correctly their slopes do not change regularly. A similar effect has been found in earlier unpublished research from this laboratory in which the same five stimulus displacement angles were presented but in the center of a much larger field of view where, presumably, the display edges would not be expected to exert any effect on the judgment.

Figure 7.

Mean Z Deviate as a Function of Stimulus Displacement for the -3° Edge Position Condition.

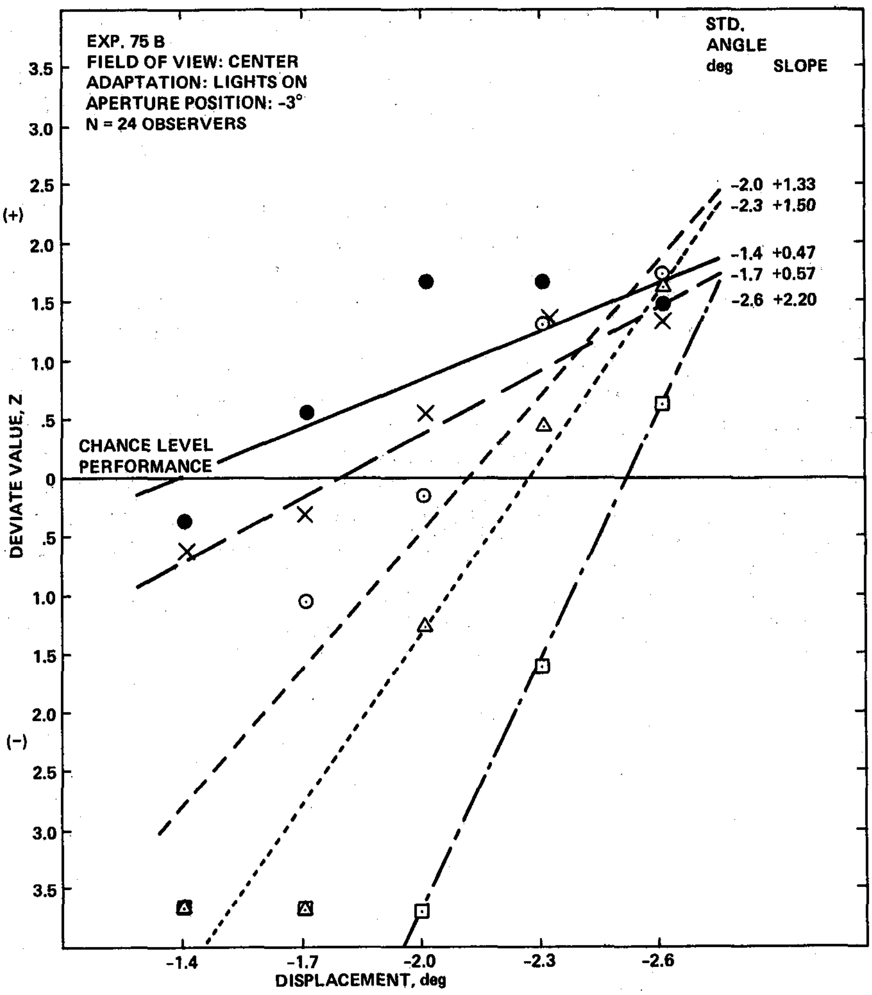


Figure 8.

Mean Z Deviate as a Function of Stimulus Displacement for the -4° Edge Position Condition.

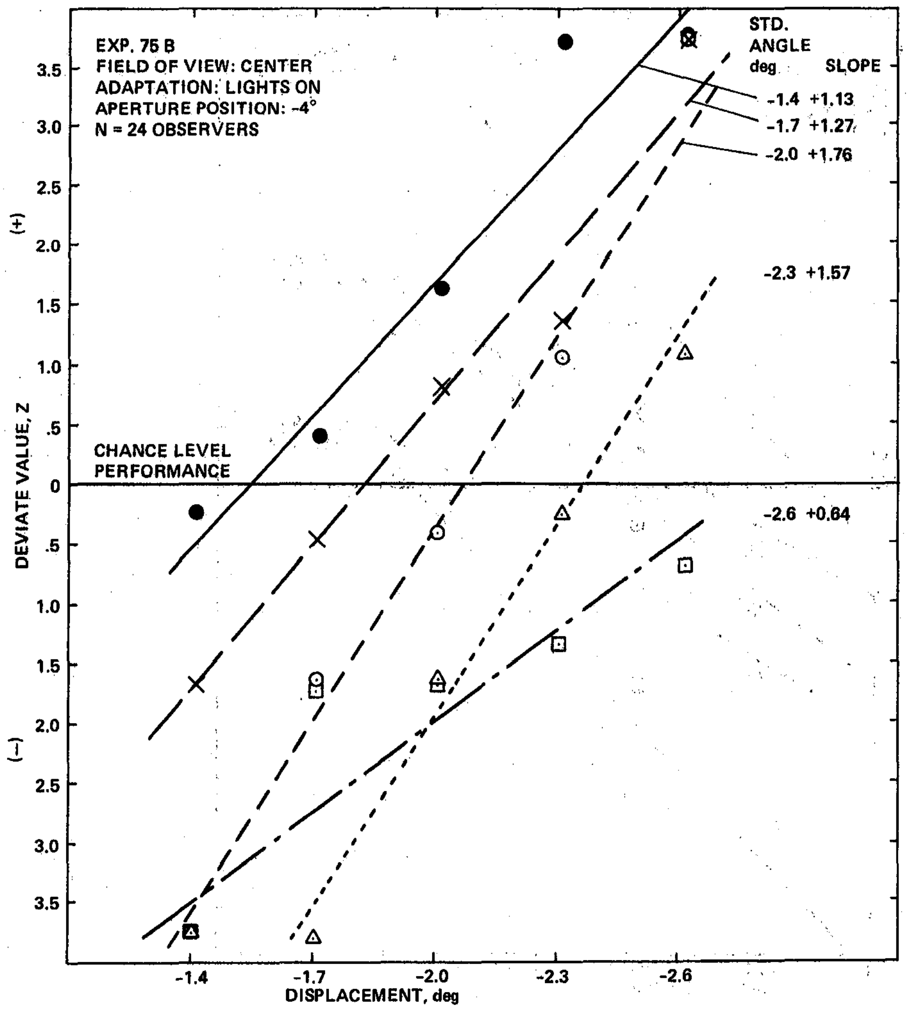
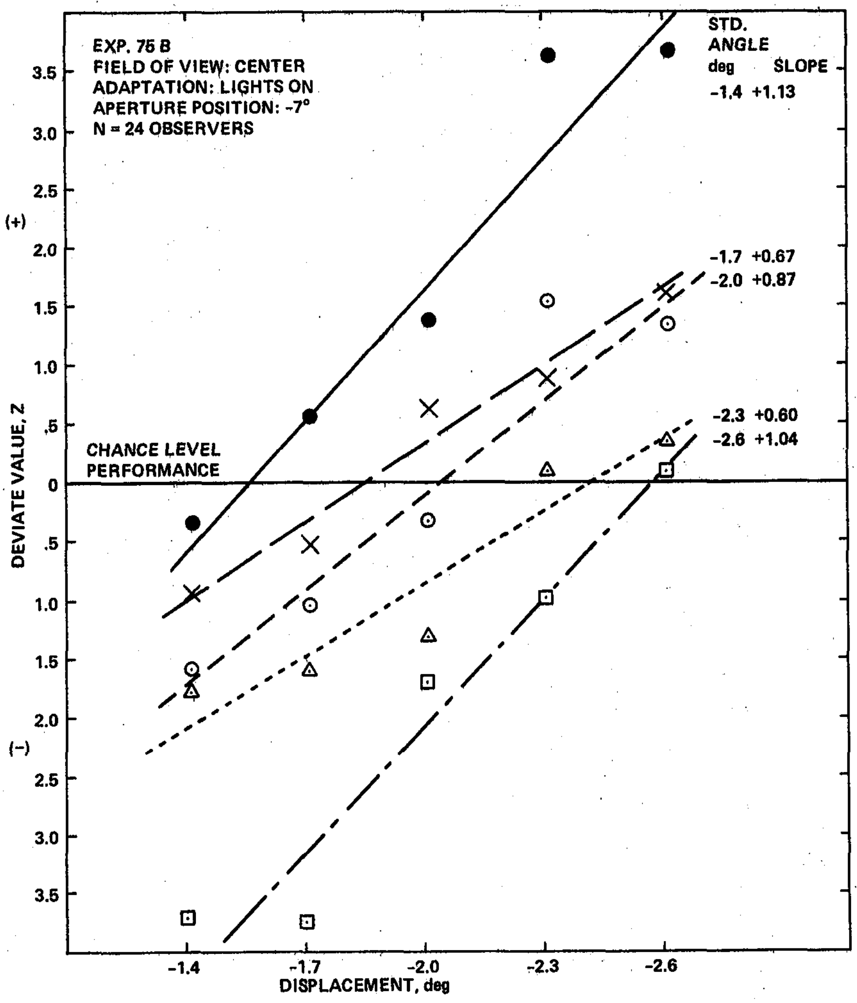


Figure 9.

Mean Z Deviate as a Function of Stimulus Displacement for the -7° Edge Position Condition.



II. Confidence Response Results:

An analysis of variance was conducted on the mean confidence data (cf. Appendix 4 - 6) using the same program as was used earlier. No significant main effects or interactions were found. A prominant trend was noted, however, in that the twelve pilots tended to give lower confidence responses than the twelve non pilots at each of the three edge positions (F = 3.73; df = 1/22; p = .06). Within the confidence scale from 2 to 9, the pilots' mean confidence ranged from 3.4 to 3.6 while the non pilot's mean confidence ranged from 4.3 to 4.9 across the five stimulus displacement angles studied. While it is interesting to speculate on the possible reason for this finding, it is probably just the result of the usual conservative attitudes that pilots tend to bring into a laboratory situation.

DISCUSSION

This study has shown that vertical displacement accuracy is inversely related to the angular separation between a horizontal stimulus line and a nearby fixed window edge. The effect appears to exist (for the present test conditions) within only one or two degrees arc of the edge. An "edge proximity effect" on phenomenal velocity was suggested earlier by Koffka (1935) and Cartwright (1938); both suggested that the edge that is being approached will exert an increasingly strong influence on the perception of phenomenal movement. The edge from which the stimulus is receding will exert a progressively decreasing influence. Unfortunately, the nature of this proposed "influence" has yet to be discovered.

Correlated and Uncorrelated Motion-inducing Parameters.

CMIPs in the present study include those visual cues that do not influence the stimulus displacement judgment, i.e., they are highly correlated with the perception of displacement and do not offer a source of "differential" information. It is suggested that the primary CMIPs include:

1) field of view
2) stimulus collimation angle and magnification
3) stimulus intensity and contrast with the background
4) stimulus temporal characteristics
5) retinal image position of stimulus
6) head position

It is suggested that the primary UMIPs include:

1) line of sight
2) stimulus angular velocity

According to the above view, these two UMIPs act not only to make the stimulus' displacement perceptible but also to isolate stimulus displacement and/or angular velocity as the sole contributor(s) to the judgment. Let us consider the line of sight parameter. As O visually fixates the stimulus during its downward displacement its retinal image remains approximately centered on the fovea (+/- approx. 0.1°; Yarbus, 1967). To the extent that the edges of the window are visible, however, the retinal image of the top and bottom edges will be displaced downward over the peripheral retina. It is possible that the displacement is perceived because of this image translation.

The second possible displacement cue is that of the differential angular velocity possessed by each of the five displacement angles studied. Each displacement occurred over a three second-long period. Consequently, each displacement is associated with a different angular rate; the possibility exists that the discrimination is based (partially or entirely) on a rate discrimination rather than displacement despite the fact that the criterion that was supposed to be used was, by instruction, a displacement criterion. The angular rates corresponding to each displacement angle are:

-1.4° = 28'/sec
-1.7° = 34'/sec
-2.0° = 40'/sec
-2.3° = 46'/sec
-2.6° = 52'/sec

The shape-coded data points in Figure 6 permit an assessment of this possibility. It is noted that within and across the three edge position conditions, there is no particular spatial ordering of the mean proportion data on the basis of angular velocity. A follow-on study is underway to investigate this issue further.

Practical Application of These Data.

Consider a pilot who is about to land a modern, swept-wing, turbo-jet airplane of the B-727 type in weather and illumination conditions which permit a good view of the horizon. Let us assume that he has stabilized his approach, i.e., that he is on the ILS localizer and glideslope, is at the correct approach and vertical speed, and is not deviating from the correct flight path. Until the moment of flare initiation, he will try to maintain a constant pitch attitude along with the other parameters just mentioned. This pitch attitude will cause the distant horizon to be seen imaged within the front window at some fixed angular separation above his glare shield top surface or window lower edge (whichever cuts off his LOS over the airplane's nose). The present data provides an idea about how small an amount he can pitch his airplane up and still detect it correctly. This angle is about 0.2° for a 75 per cent criterion. As Figures 3 - 5 show, this value increases at higher criterion values with an asymptote at about 0.6° threshold for a criterion of 96 per cent (for the -3° edge position condition). Slightly different values are found for the other two edge position conditions. This study also found that the larger the angular separation between the horizon and the lower edge of the window (during displacement comparison judgments), the larger must the displacement be in order to be perceived correctly.

Returning to the (above) cockpit illustration, the typical pilot alternates his line of sight (LOS) many times during an approach between cockpit display information and outside scene information (Haines, Fischer & Price, 1980). During these intra-cockpit information scans he will check his attitude direction indicator (ADI) for his basic pitch attitude, his air speed indicator (ASI), and his instantaneous vertical rate indicator (IVSI). It is important to point out that most ADIs provide pitch attitude in reduced visual angle such that one degree of actual airplane pitch is displayed as about a 0.2° index line displacement. Interestingly, this is very nearly the same vertical displacement amplitude that can be discriminated by the present observers. Once the pilot looks up through his window at the runway he typically fixates the touchdown zone and tries to notice changes in his airplane's pitch attitude by displacement of the horizon (and other ground detail).

It is suggested that the major reason why pilots cross-check flight instruments other than their ADI for pitch attitude is that they simply cannot obtain sufficient pitch attitude resolution from it. While they are able to correctly discriminate a vertical displacement of a *simulated* horizon as small as about 0.2°, they cannot discriminate pitch attitude changes equivalent to one degree of airplane pitch from this flight instrument.

CONCLUSIONS

In this investigation the horizontal (line) stimulus was located 18° arc below the top of the window's edge and either 3°, 4°, or 7° arc above its lower edge at the start of each displacement trial. After its displacement downward it was from 0.4° to 5.6° above the window's lower edge due to the fact that five different displacement angles were presented. Evidence was found to support the view that displacement sensitivity improves when the horizontal stimulus is within from one to two degrees arc of the lower edge but not more than this. It also appears that angular velocity was not a prominant cue to account for this displacement sensitivity among the five conditions tested which ranged from 28 to 52 minutes of arc per second.

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