Assessment of Simulator Visual Cueing Effectiveness by Psychophysical Techniques

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ABSTRACT

Growing emphasis on simulation of low altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. However, such studies can be costly and time consuming, and often they provide equivocal results. The present study investigated the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cues provided by five visual system displays.

Thirty Air Force pilots made estimates of the altitude above ground level (AGL) shown in slides of visual system displays varying in object density and object detail. Slides showed a 90° field-of-view scene taken in the F-16 cockpit of the Advanced Simulator for Pilot Training. Eight altitudes (range 50-400 ft AGL) were presented for each visual scene condition. A random sequence of 40 slides (8 altitudes X 5 scenes) was presented three times. Power functions relating perceived to actual altitude were determined. Reliable differences were found between the displays which accorded well with differences found in a simulator flying study using the same display environments. Results are discussed in terms of display features and the measurement methodology.

INTRODUCTION

As a result of the current trend in flight simulation toward tactical flight and combat scenarios, a need exists for methodologies to evaluate the effectiveness of visual system displays in providing out-of-the-cockpit flight cues. The simulator visual system presents the pilot with a variety of cues he needs to perform his task. These range from airspeed, altitude, and navigation cues to cues relating to the presence, range, and behavior of threats and targets. Simulator flying studies have been performed to determine the effectiveness of texture (Edwards et al, 1981), color (Kellogg et al, 1981), and three-dimensional objects (Rinalducci et al, 1981) in providing low-altitude flight cues. While such studies provide the ultimate measure of the effectiveness of a visual system display in providing cues needed to perform simulated flight tasks, they can have severe methodological limitations. The requirements of such studies for simulator time, subject time, and development time are great. Simply to study the effectiveness of one type of visual cue can require as much as 50 hours of simulator time, even if only a small number of subjects is run. Therefore, only a limited number of visual environment displays may be investigated. In order to perform the parametric studies required for the design of effective simulator visual environments, techniques are required for assessing the cueing effectiveness of visual displays quickly and at low cost. Such techniques might be used to screen candidate displays so that only the most effective need be examined in more comprehensive simulator flight studies.The purpose of the present research was two-fold. The primary purpose was to determine th effectiveness of a methodology for assessing the quality of simulator visual displays quickly and at low cost. The technique investigated involved having pilots estimate the altitude above ground level (AGL) in static (slide) presentations of a simulator visual system display. This technique permits "mass production" evaluation of visual displays but does not permit examination or evaluation of the capability of visual scenes to provide altitude cues based on scene dynamics. Because of this limitation in the quality of altitude cues available, it was necessary to compare the results of the static estimation technique with those of a dynamic, simulator flying approach.

A second purpose of the research was to examine the aspects of scene content, object density, and object detail in order to determine their effects on the perception of altitude. Two aspects of visual scene content were investigated. These were the density of 3-dimensional objects in the environment and the level of detail of the objects.

METHOD

Materials

Stimulus materials were 35 mm color slides taken with a 90° field-of-view lens in the F-16 cockpit of the Advanced Simulator for Pilot Training (ASPT) at Williams AFB. The out-of-the-cockpit scene consisted of flat terrain with 200 ft aiming towers at eight-mile separation. Altitude cues of varying quality were provided by inverted pyramids. Condition 1 and condition 2 were high detail conditions in which the sides of the pyramids were black and the base (top) was white. Condition 3 and condition 4 were medium detail conditions in which the pyramids were all black. Two conditions (conditions 1 and 3) were high object density conditions, with the mean distance between pyramids equal to 1500 ft. In the low density conditions (condititons 2 and 4), separation between pyramids was 4500 ft. In all four conditions the pyramids were 50 ft tall. A fifth condition was intended to have lowest detail. In this condition, the pyramids were displayed so that only the base was visible above the ground. Thus, the pyramid had the appearance of a triangle laying flat on the ground.

Unfortunately, the level of detail was so low that the triangles appeared only as scintillations in the dynamic scene as the objects moved across the raster lines of the CRT display and were nearly invisible in the static display. As a result, only the 200 ft aiming towers, separated by eight miles, provide any real altitude cue. In all conditions, eight altitudes, ranging from 50 to 400 ft in 50 ft increments, were presented. A single set of 40 slides was used in which each of the 40 altitude-visual environment conditions was presented once in random sequence.

Subjects

Thirty pilots in A-10 combat crew training served as subjects. Their flying experience ranged from approximately 400 hr to 3000 hr. None had had any previous experience in ASPT.

Procedure

Subjects were run in groups of ten in a squadron meeting room having projection facilities. Subjects were seated from 15 to 25 feet from the screen image, which was 7-1/2 ft wide. At the start of the session, the experimenter explained the purpose of the research. The experimenter then explained that a sequence of 40 color slides showing straight and level flight would be presented. Subjects were told that the slides would show five different simulator visual environments. Since none of the subjects had ASPT experience, they were told that the range of altitudes would be 50 to 400 ft. Subjects were not informed of the size of the inverted pyramids since no attempt was made to equate the size of the static display with that of the display in the simulator cockpit. Subjects were then given response sheets and told that when the first slide appeared, they were to estimate the altitude (AGL) shown. Estimates for subsequent slides were to be made relative to the first. Thus, if the estimated altitude for the first slide was 100 ft AGL and the second slide appeared at twice as high an altitude, the estimate would be 200 ft AGL. Subjects viewed the sequence of 40 slides three times without feedback. Each slide was presented for eight seconds with the interval between slides being only the cycle time of the carrousel projector.

RESULTS

The first slide presentation sequence was treated as practice and the altitude estimates from the second and third runs only were analyzed. The data were analyzed by first transforming the actual and estimated altitudes to logarithms. Estimated altitudes were then adjusted for each subject's overall bias. A least-squares linear function was determined relating log estimated altitude to log actual altitude for each of the five visual scenes. The slope of the log-log linear function is the power of the function relating estimated altitude to actual altitude. A power (slope) of 1.0 indicates perfectly accurate estimate of altitude. A power of greater than 1.0 indicates expansion or overestimation of changes in altitude, and a power of less than 1.0 indicates compression or underestimation of changes in altitude (Kling and Riggs, 1971).

In addition to giving the relationship between actual and estimated changes in altitude, the technique gives a zero intercept. This zero intercept can be considered an estimate of what it would look like "sitting on the deck" under the display conditions used in the study, although it may not be an accurate estimate of the perceived zero in the simulator. However, in a relative sense, the zero measures one aspect of the quality of altitude cues provided by the different visual scenes.

Altitude estimates from all five visual scenes showed marked compression (see Table 1). In addition, intercepts for all scenes were inflated. The inflation of the intercept tended to be most pronounced when compression was most marked. The lowest detail scene (condition 5) showed the greatest compression with a log-log slope (B) of .197. The intercept (A) was also greatest for this condition (a = 1.85). Thus, for this condition, the estimated altitude was 85 ft at 50 ft actual and 122 ft at 400 ft actual. Clearly the altitude cues provided by this scene are very poor.

TABLE 1

Condition	Object Density	Object Detail	B	A
1	High	High	.82	.31
2	Low	High	.51	1.1
3	High	Med	.70	.51
4	Low	Med	.50	1.1
5	Low	Low	.20	1.85

Slopes (B) and Intercepts (A) of the Altitude Estimation Functions for the Five Visual Display Environment Conditions

The best altitude cues were provided by the high detail, high density scene (condition 1). The power, B, was .821 and A was .314. Thus, estimated altitude was 25 ft at 50 ft actual and 257 ft at 400 ft actual. Assessment of the differiential altitude cueing effectiveness of the five environments was accomplished by an analysis of variance on the slopes of the altitude estimation functions (see Table 2). The effect of object density on altitude estimation was determined by post-hoc comparision of

TABLE 2

SOURCE	MEAN SQUARE	D. F.	F-RATIO	P
TOTAL	.113	149	-	-
DISPLAY CONDITIONS	1.684	4	39.6	.001
ERROR	.043	116	-	-

Results of Repeated Measures ANOVA on Slopes of the Altitude Estimation Functions for Five Visual Display Conditions

conditions 1 and 3 with conditions 2 and 4. A Scheffe' test showed the high object density conditions to provide significantly better altitude cueing than the low object density environments ($F(4,116) = 45.5$, $p < .01$). The effect of object detail was determined by comparison of conditions 1 and 2 with conditions 3 and 4. This difference was significant ($F(4,116) = 10.8$, $p < .01$) with the high detail environments providing superior altitude cueing. There was a suggestion of an interaction between object density and object detail. The effect of object detail on the slope of the altitude estimation function was greater in the high object density condition than in the low object density condition. Unfortunately the detail-density interaction failed to reach significance ($F(4,116) < 2.4$, $.10 > p > .05$).

Condition 5 was ommited from the post-hoc analysis because it was unclear how this condition should be classified. Many of the subjects reported that they had difficulty in distinguishing the triangles from flaws in the picture. Therefore condition 5 could be considered either a low density, low detail condition or an empty field condition, with only a horizon line and the distant aiming towers. In any event the altitude cueing effectiveness of condition 5 was very poor indeed and was substantially poorer than that of any of the environments containing 3-dimensional objects.

DISCUSSION

The differences obtained in subjects' ability to estimate altitude in the different visual environments have pointed up the sensitivity of the magnitude estimation technique. Substantial differences in altitude cueing effectiveness were found as a function of both object density and object detail. There was also a suggestion of an interaction between object density and object detail, although this interaction was non-significant.

Unfortunately the present data give no indication of the validity of the approach for making judgements about the effect of visual scene content on simulator flying performance.To determine the validity of the technique, it is neccessary to compare the results of the magnitude estimation technique with those of a simulator flying study. Rinalducci et al (1981) performed a simulator flying study on the Advanced Simulator for Pilot Training using three of the environments used in the present study (conditions 1,3 and 5). He monitored performance at maintaining a constant altitude of 200 ft AGL while flying through each environment. Although the variability in performance was high, significant differences were obtained between condition 1 performance and condition 5 performance, with both average altitude and RMS altitude performance being superior in condition 1. Performance in condition 3 was slightly worse than that in condition 1 but was not significantly different from either condition 1 or condition 5. The qualitative similarity between the present data and those of Rinalducci et al suggests that the magnitude estimation technique is sensitive to the effect of altitude cues needed for simulator flight. In fact the present technique may be more sensitive to the effects of visual display factors on perception than is simulator flying performance.

CONCLUSIONS

1. The magnitude estimation approach has been shown to be a usable technique for assessing the altitude cueing effectiveness of visual displays. The technique is very sensitive to differences in the cueing effectiveness of diferent visual environments. Results obtained with the magnitude estimation technique are comparable to those obtained in simulated flight studies, but the magnitude estimation technique provides equal or greater sensitivity at lower cost.

2. The density of objects in the visual environment was found to be a potent, determining factor in the cueing effectiveness of visual displays.

3. Object detail was found to be an important altitude cue. There was a suggestion of an interaction between object density and object detail in perception of altitude.

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