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PILOT DISTANCE ESTIMATION WITH UNAIDED VISION, NIGHT-VISION GOGGLES AND INFRARED IMAGERY

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INTRODUCTION AND BACKGROUND

Advanced display technology is now available to allow rotorcraft pilots to fly with increased effectiveness under visibility conditions not possible a few years ago. Night-vision devices, such as night-vision goggles (NVGs) which intensify low-level light, and infrared (IR) sensors sensitive to infrared energy, are two examples of such systems.

Despite the claims of the overzealous, however, these sensors do not "turn night into day". There are specific important human performance issues that result from the use of these systems. These sensors suffer from poorer resolution, smaller field of view (FOV), and a spectral sensitivity different than the human visual system. These differences have been cited as potential factors leading to problems with their use in flight (see Brickner, 1989).

Accurate distance estimation is an important task for most aircraft pilots, but is critical for helicopter pilots. Rotorcraft, by their very nature, can maneuver amongst trees and other obstacles (i.e., fly nap of the earth, NOE), land in very low-clearance areas, fly at low altitudes, and maintain a hover at a fixed altitude above a certain point. All of these pilotage tasks require accurate distance estimation to implement the maneuver properly and safely. For safe operation, helicopter pilots must constantly verify that the aircraft has adequate clearance in all directions: The tail boom to the rear, the skids or wheels below, and the rotor blades above, to the sides, and in front. All must clear obstacles, sometimes by only a few feet, depending upon the operational requirements. Additionally, distance estimation for farther distances (up to a few hundred feet) is important to maintain low-level altitude, and to maintain hover in the fore/aft and lateral directions. To maintain hover, pilots are taught to pick objects in front of them and to the side, and then control the aircraft to maintain those distances.

Inaccurate distance estimation has been determined by the US Army to be a factor in some night crew-error accidents (Fuson, 1990). Night-vision goggles have been reported to yield distance overestimates (see Brickner, Wagner & Gopher, 1987 as reported in Brickner, 1989), while pilots using infrared (IR) sensors have been reported to underestimate distances (Bennett & Hart, 1987 as reported in Hart & Brickner, 1989). It is not clear what mechanism may be operating to yield distance overestimates (possibly misaccomodation, see Roscoe, 1985), but the finding of distance underestimation is predictable from the restricted FOV conditions: Research has shown that size of the viewing field can affect the perceived size of objects, thereby influencing distance estimates. Kunnapas (1955) and Walker (1989) have shown that size estimates of objects increase as the frame around the object decreases. Texture gradient has also been posited as an important distance cue (Gibson, 1950). Lower resolution in sensor systems may lead to a loss of this information producing poorer distance estimation performance. The present field-study experiment was conducted to allow the comparison of distance estimation with various sensors.

METHOD

Subjects

Four helicopter pilots were tested in three sessions of approximately two hrs each. All subjects had flight hours with daytime conditions, nighttime conditions and NVGs. Two pilots

(Subjects 1 and 4) had used the US Army infrared Pilot Night Vision System (PNVS) sensor previously.

Stimuli

Seven viewing conditions were used: Day unaided (DU), day unaided restricted (40 deg) FOV (DUR), night unaided (NU), night unaided restricted (40 deg) FOV (NUR), ANVIS 5, ANVIS 6 (two US Army NVG systems) and the PNVS sensor. The viewing conditions were chosen to assess the effect of various FOV and resolution values on distance estimation (see Table 1). Targets were two white plywood squares (2.25 and 3.0 ft per side) placed vertically facing the subject (upright and perpendicular to the line of sight). Testing was conducted at NASA Ames Research Center in a field containing uniformly scattered small (1 to 3 in) plants. Night testing was restricted to times of 3/4 moon overhead illumination (0.02 to 0.07 LUX). Day testing was conducted in the early afternoon. Subjects saw only one of the two targets on each trial. Target distances tested were the 20 equi-log distances from 20 to 200 ft inclusive, tested twice each. Order of the distances and the assignment of target size to distance were randomized in each test session.

TABLE 1. SENSOR SYSTEM CHARACTERISTICS

SYSTEM	RESOLUTION		FOV (deg)
	SENSOR SPACING (min)	VISUAL ACUITY (min)	
HUMAN EYE (DAY)		1.0 [2]	160 [5]
RESTRICTED EYE (DAY)		1.0 [2]	40
HUMAN EYE (NIGHT)		7.5 [2]	160 [5]
RESTRICTED EYE (NIGHT)		7.5 [2]	40
ANVIS 5 (NVG)	5.2 [1]	3.5 [3]	40 [1]
ANVIS 6 (NVG)	3.6 [1]	2.5 [4]	40 [1]
PNVS (IR)	5.0 [1]		40(H) x 30(V) [1]

Note: Night and NVG acuity are for quarter moon with a high contrast target (>90%, .0016 cd/m^2).

Sources: [1] Brickner (1989), [2] Olzak and Thomas (1986), [3] Wiley (1989), [4] Wilkinson and Bradley (1990), [5] Arditi (1986).

TABLE 2. DISTANCE DATA LINEAR REGRESSION:

$$\log(D_{estimated}) = m \log(D_{actual}) + b$$

SENSOR SYSTEM	VALUE	SUBJECTS S1	S2	S3	S4
DU	m	0.823	1.042	0.854	1.161
	b	0.276	-0.104	0.054	-0.327
	R^2	0.985	0.956	0.977	0.974
DUR	m	0.820	0.996	0.806	1.148
	b	0.268	-0.076	0.163	-0.306
	R^2	0.993	0.905	0.943	0.962
NU	m	0.717	1.183	0.848	1.272
	b	0.417	-0.212	0.137	-0.590
	R^2	0.979	0.954	0.965	0.941
NUR	m	0.765	0.969	0.748	1.304
	b	0.384	0.070	0.207	-0.567
	R^2	0.978	0.964	0.944	0.945
ANVIS 5	m	0.730	1.150	0.741	1.177
	b	0.388	-0.271	0.239	-0.350
	R^2	0.976	0.955	0.971	0.950
ANVIS 6	m	0.735	1.387	0.852	1.243
	b	0.382	-0.629	0.144	-0.395
	R^2	0.978	0.978	0.969	0.966
PNVS	m	0.729	1.211	0.957	1.129
	b	0.405	-0.323	-0.157	-0.190
	R^2	0.952	0.933	0.970	0.948

Note: DU/NU = Day/Night Unaided

DUR/NUR = Day/Night Unaided Restricted (40^{o}) FOV

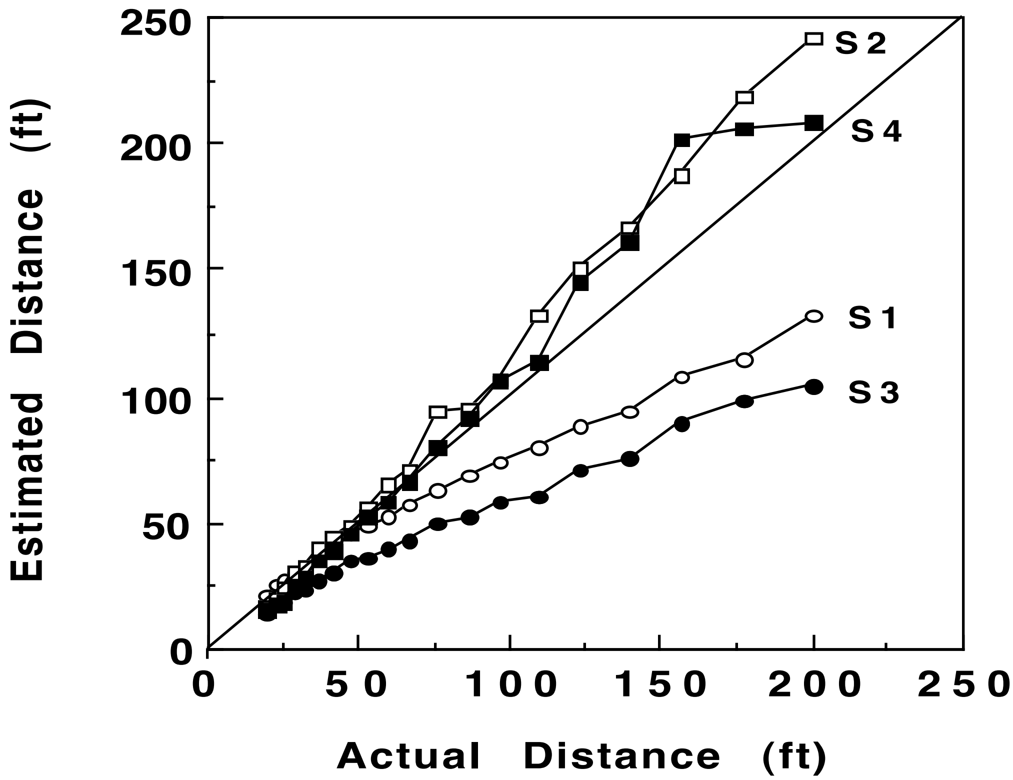

Figure 1. Average estimated distance for the four subjects (S1 - S4) as a function of actual distance averaged over viewing conditions.

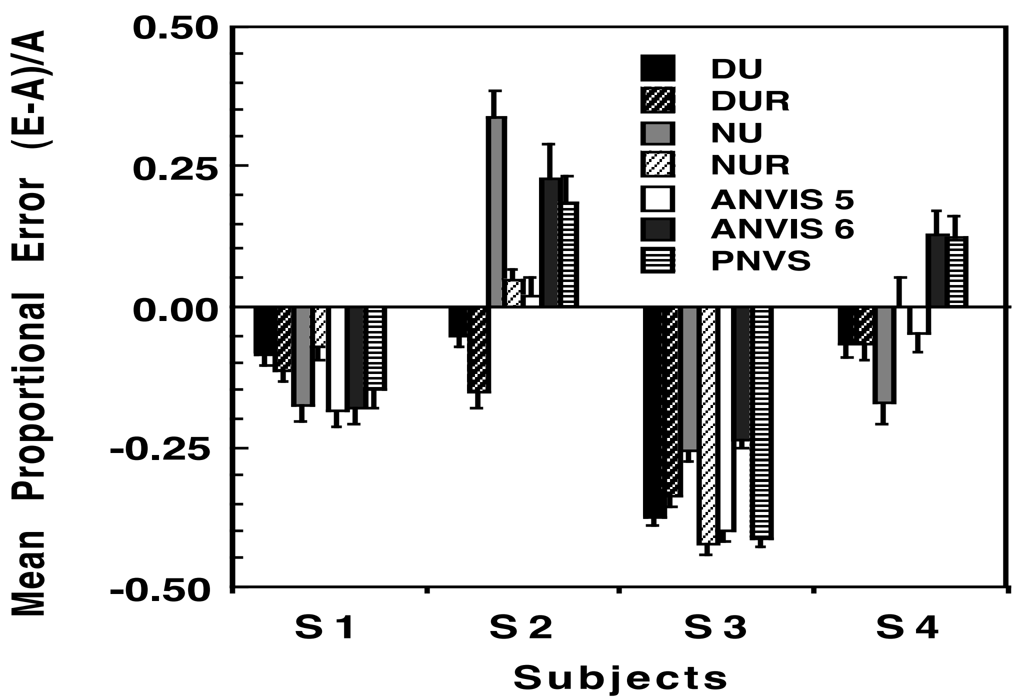

Figure 2. Mean proportional error [(Estimated Distance - Actual Distance) / Actual Distance] as a function of viewing condition and subject. Error bars represent the standard error.

Procedure

Subjects were not informed of the testing conditions: They did not know the range of distances, the size of the targets, nor were they given any feedback about their estimates.

This allowed for the investigation of two separate aspects of distance estimation: The ability to scale target distances (for example, estimating a target that is 2.0 times farther as only 1.8 times farther) and estimation accuracy (absolute distance estimation).

RESULTS AND DISCUSSION

For each viewing condition by subject, the distance data were fit with a regression line on a log-log scale. These functions were extremely linear, with mean R^2 value of 0.961 (see Table 2). This indicates that subjects were extremely sensitive to the changes of distance.

One general trend in the data is indicated in Figure 1. On average, two subjects tended to overestimate distance and two subjects underestimated. This individual difference effect was confirmed by an analysis of variance (ANOVA) with subjects as a factor ($F(3,3) = 28.70$, $p < .01$). This is also shown in Figure 2, where the distance estimates have been replotted as proportional error by condition. The two underestimating subjects (S1 and S3) underestimated distances for all viewing conditions. Subject 2 overestimated for all viewing conditions except day viewing, and Subject 4 tended to be fairly accurate, showing both over- and underestimates depending on condition. These data, however, do not support the previous reports that there is systematic bias in distance estimation (either absolute or relative to the daylight conditions) with either the ANVIS 5 or ANVIS 6 NVGs or the PNVS sensor.

There are two components to the distance estimation functions shown in Table 2, the slope (m) and the intercept (b). The intercept indicates the size of the units used to estimate the distance. For example, at a given distance, a foot may be estimated to be only 10 inches. The slope indicates a scaling factor associated with the sensitivity to changes in distance. A slope of 1.0 indicates an accurate scaling of relative distance. That is, for slopes of 1.0, a distance that is twice as large as another is estimated as such (note that the actual units that are used may be in error). Since there were no known reference points available to the subjects in the study, one might conclude that the distance functions did not have an "anchor point", and that subjects would have been more accurate if they could have mapped a perceived distance to a given actual distance. One would expect the intercept of the distance estimation function to be adjusted to match the given single known distance. In this study, the slopes are more informative in that they are indicative of the estimation of distance changes.

As Table 2 shows, Subjects 1 and 3 had distance estimation functions which were compressive: All slopes were less than 1.0. These subjects showed compressive functions indicating, for example, that a doubling in the actual distance was estimated as a factor increase of less than 2. This yielded data that showed increasing proportional error as the distances increased. This can be seen in Figure 1 in which the largest distances yielded proportionally larger errors estimates than the smaller distances.

Similarly, Table 2 shows that Subjects 2 and 4 had expansive distance estimation functions: All slopes were near or greater than 1.0. Expansive distance functions indicate that these subjects estimated a doubling in actual distance as an increase of more than a doubling. As for the other two subjects, this gave distance estimates that yielded proportionally larger error for the larger distances than for the smaller distances.

An analysis of the slopes for the various viewing conditions was conducted. Because half of the subjects had compressive functions and half had expansive functions, the slopes for Subjects 1 and 3 were adjusted by $1/m$. In a sense, this adjusted slope value represents the "absolute value" of the error in the distance function scaling relative to accurate scaling (slope = 1.0). These adjusted slopes plotted in Figure 3 show that the day viewing (DU and DUR) conditions were the most accurate (nearest 1.0). These two conditions also gave the smallest proportional error (see Figure 2).

Specific comparisons to assess the effects of resolution (see Table 1) on distance estimation were conducted: The DU and DUR means were compared to the two night conditions, NU and NUR, and were found to be statistically more accurate (i.e., slopes closer to 1.0), ($F(1,3) = 17.23$, $p < .025$.). This may indicate that the increase in resolution (from 7.5 to 1.0 min) gives more accurate distance estimation functions. (These conclusions, of course, must be tempered by noting that there are other factors that differ between these conditions.) Other supporting evidence is that DUR viewing was better than ANVIS 5 ($F(1,3) = 14.22$, $p < .05$.). Although not significant, DUR viewing was more accurate than ANVIS 6 for three of the four subjects. The ANVIS 6s were not more accurate than the ANVIS 5s despite their increased resolution: One subject was better (adjusted slope nearer 1.0), one equal, and two subjects were worse with ANVIS 6s. Possibly, the increase in resolution from ANVIS 5s to 6s is not large enough to improve distance estimation. Distance estimation with ANVIS 6s may be better than with ANVIS 5s under lower light levels than were used here.

To assess the effect of field of view (FOV) on distance estimation, the adjusted slopes for DU and NU were contrasted with DUR and NUR. This contrast was not statistically significant ($F < 1$). This may indicate that for a constant resolution, FOV does not affect the distance estimation function. This is in contrast to the studies discussed above.

SUMMARY

Distance estimation with night-vision devices is an important flight skill. Deficiencies have been cited by the US Army as being a factor in some crew-error flight accidents. The present data indicate larger distance estimation errors with night-vision devices than with daytime viewing (but not necessarily more than unaided nighttime viewing). Contrary to the reports of previous studies, however, that error does not appear to be uniformly overestimation or underestimation, but is subject idiosyncratic. Additionally, increased resolution may be a more important determinant for accurate static distance estimation than increased field of view.

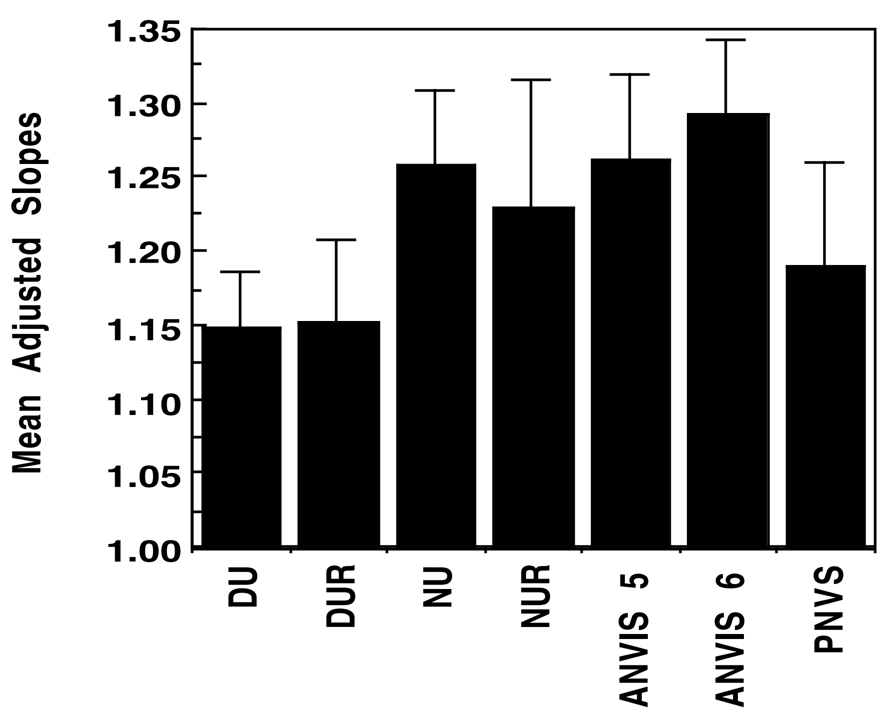

Figure 3. Mean slope values for the seven viewing conditions (from Table 1) with values adjusted for Subjects 1 and 3 by 1/slope. Error bars represent the standard error.

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