CRITIQUE AND RESPONSE

Distance Estimation with Night Vision Goggles: A Little Feedback Goes a Long Way

Keith K. Niall, Defence and Civil Institute of Environmental Medicine, Toronto, Ontario, Canada, **Jack D. Reising,** Boeing Corporation, Seattle, Washington, and **Elizabeth L. Martin,** Warfighter Training Research Division, Air Force Research Laboratory, Mesa, Arizona

Immediate feedback was given to correct observers' estimates of distance in an experiment in which those estimates were made outdoors at night while observers wore night vision goggles (NVGs). Initially observers made unguided estimates of distances between marked positions in an open field. Those distances ranged from 7.6 m (25 ft) to 64 m (210 ft). Later the same observers made more estimates. After each of these they were told the measured distance between the positions. During this training, the observers' height from the ground plane was either at a standing position or at an elevated position raised 2.3 m (7 ft 7 in) from standing position. After the training – either immediately after, a week late1; or at both times – observers made unguided estimates of distance for a second time. These latter estimates of ground distance made with the NVGs were improved. Average improvement of the observers' estimates persisted for at least one week after training. This training can be applied to improve clearance estimates and estimates of hover height for pilots of rotary-wing aircraft.

INTRODUCTION

Night vision goggles (NVGs) are used in both rotary-wing and fixed-wing aircraft to enhance the ability to conduct operations under the cover of darkness. NVGs provide an intensified image of landscapes illuminated by ambient energy in the night environment. The photosensitive components of the goggles are most sensitive to the red and near-infrared portion of the electromagnetic spectrum (approx. 600-900 nm). The NVG device amplifies the energy in this portion of the spectrum. The luminance of the postobjective image can be between 2,000 to 7,000 times that of an image that enters the goggles. As a consequence of their design, most NVGs affect field of view and resolution. Depending on their make and type, they provide a limited field of view of approximately 40 degrees of visual angle. Visual acuity can be expected to be approximately 20/30 Snellen acuity at best under optimal lighting conditions. Uttal, Baruch, and Allen (1994) discuss a range of psychophysical issues associated with the enhancement of vision by NVG devices.

Because NVGs have a restricted field of view and a diminished resolving power when compared with the capability of the unaided human eye in daylight, we can anticipate that NVG users unaccustomed to these altered viewing conditions may experience misperceptions or illusions. Numerous field reports suggest that NVG viewing induces misperceptions that compromise flight safety, including difficulty in judging ground distances or the separation of objects. Inaccurate distance estimation with NVGs has been identified as a serious problem by aircrew members (Crowley, 1991; Donohue-Perry, Hettinger, & Riegler, 1992) and has been

Address conespondence to Keith Niall, Simulator Technologies Group, Defence and Civil Institute of Environmental Medicine, 1133 Sheppard Avenue West, P.O. Box 2000, Toronto, Ontario M3M 3B9, Canada. E-mail: Keith.Niall@dciem.dnd.ca. HUMAN FACTORS, Vol. 41, No. 3, September 1999, pp. 495-506.

implicated as a factor in some rotor-wing accidents (Fuson, 1990). The problem is of particular concem to helicopter crew members, who must estimate distances often during the hover and landing phases of flight (e.g., to judge that a helicopter rotor blade will not strike a fixed object or that a patch of ground is sufficiently wide to serve as a landing zone). The relevant range of distances for these tasks is within about 46 m(150 ft) with crucial distances ranging from about 12 m to 18 m (40 ft to 60 ft), which conesponds to rotor blade lengths.

These field reports have been bome out by experiment. Foyle and Kaiser (1991) reported that NVG-aided distance estimation is significantly poorer than unaided distance estimation on the ground in daylight, for distances between about 6 m and 61 m (20 ft and 200 ft) with AN/AVS-6 type NVGs (Hoffman Engineering, Stamford, CT). A similar result was obtained by Wiley, Glick, Bucha, and Park (1976), for distances between about 61 m and 610 m (200 and 2,000 ft), with generation II NVGs, type AN/PVS-5. Crowley (1990) tasked helicopter pilots to maintain a set altitude under NVG or under unaided daylight conditions. Pilots made significantly more en-ors in the former than in the latter condition. The misperception of distance with NVGs was attributed to limits on resolution rather than to limits on the field of view. By contrast DeLucia and Task (1995, page 383) find "effects of NVGs (compared to unaided vision) did not occur in the field when participants judged when to initiate a tum to maneuver a car in front of a wall without collision." In addition there may be important differences between judgments with NVGs made on the ground and those made in the air.

The present experiment was conducted to determine the efficacy of training NVG-aided distance estimation by a most effective feedback technique: immediate and direct feedback. This has been shown to be an effective technique in outdoor viewing without the use of NVGs, as in Gibson and Bergman, 1954, and Gibson, Bergman, and Purdy, 1955. Direct feedback training occurs when observers are required to make an explicit estimate of distance, and they are informed of the true ground distance immediately after making their judgment.

The scope of the present investigation is not as broad as hoped. A number of practical issues will remain unanswered for now – the influence of variations in illumination, and also the degree to which the results of simple and direct feedback training may transfer to a pilot's ability to estimate separation distances on landing. It could be that direct feedback training is specific to a type of terrain; pilots may have to be trained before every mission to compensate for the appearance of unfamiliar types of terrain. It might also happen that savings in the training schedule can be achieved if the training does prove effective. For example, direct feedback for distance estimation may have to be given only under conditions of low illumination (starlight or quarter-moon), given assurance that such training transfers to other judgments made under conditions of high illumination. But the present experiment addresses only two, preliminary questions:

1.) Can distance estimation be improved by direct feedback?

2.) Does such an improvement last for at least a week, given that the training is effective?

METHOD

Observers

A total of twelve observers (9 male and 3 female) volunteered for the experiment. All observers had at least 20/20 photopic visual acuity and received specific training on F4949 NVG adjustment procedures (described in Antonio & Berkley, 1993). Ages ranged from 21 to 40 years (mean, 33.6 years). None of the observers had previous experience with NVGs. All demonstrated at least 20/30 NVG-aided visual acuity after NVG adjustment as measured with a Hoffman Engineering ANV-20/20 NVD Infinity Focus System (Hoffman Engineering, Stamford, CT).

Apparatus and Stimuli

The experiment was conducted in a large open field. A few trees were visible about 275 m (300 yd) beyond the test area. Note that all distance measurements were taken in feet and inches. Some cultural lights – that is, artificial lights from houses and businesses -were visible in the far distance; none were located within 4.8 km (3 mi) of the direction of gaze of the test area, and most were more than 24 km (15 mi) away. The area was divided into an approximately 53 m x 53 m (175 x 175 ft) square grid, marked off in approximately 7.6 m (25 ft) increments. The markings that defined these increments were not visible through NVGs, but they were retained for the purpose of arranging the stimuli. At any one time, 8 targets were randomly positioned in eight of 64 distinct locations defined by the increments of the grid (Figure 1). The targets consisted of white cylinders that were approximately 0.6 m (2 ft) high and 0.3 m (1 ft) in diameter. Each cylinder was raised on a pole approximately 0.6 m (2 ft) high. Observers viewed the targets approximately 7.6 m (25 ft) away from the midpoint of one edge of the square. They viewed the targets from standing and from elevated vantage points. This was to distinguish between the effects of visual angle and those of ground distance on judgments of distance. Observers viewed the targets from both the ground level and elevated on a platform that could be reached by stairs. (The platform was a standard B- 1 stand used for aircraft maintenance.) The stand raised the observers 2.3 m (7 ft 7 in.) off the ground, from the base of the wheels to the floor of the platform. All testing was conducted under clear starlight conditions, though the presence of cultural lights increased ambient illumination. NVIS radiance, as defined in *M ilitary Specification MIL-L-85762A, Lighting, Aircraft , Interior, Night Vision Imaging System (NVIS) Compatible,* measured from the targets was 3.62 x 10^9 NRA, which is approximately equivalent to a quarter moon. *(NR,* or NVIS radiance, is standardized by the amount of energy within the spechal response range of the NVGs that would be reflected by a defoliated tree under a cloudless starlit sky.) The radiance was measured wit h a Hoffman Engineering NVG-103 Inspection Scope (Hoffman Engineering, Stamford, CT). The particular model and brand of the NVG is called a Class A ITT F4949D.

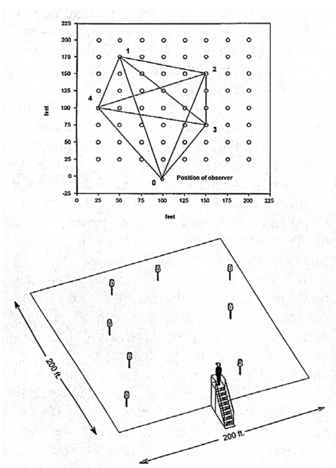

Figure 1. The positions of the four targets ('1; '2; '3; and '4'), plus the position of the observer (marked 'O'), define teri distances among locations. A less schematic overview is included as well, to clarify the relation of the observer to the ground plane.

PR

OCEDURE A pretest assessed the accuracy of ob- servers' distance estimates in the absence of formal haining. The data from this portion of the experiment serve as a baseline for assessing the impact of the training procedure. First,

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focus system. Then they were either positioned on the ground immediately under the stand or elevated on top of the stand. Of the eight targets, four were used for distance judgments at one time. All the white targets were readily distinguished under NVG viewing conditions by labels on which large black numbers were printed.

Observers were required to judge all of the distances (see the upper diagram of Figure 1) between four targets (six distances), as well as the ground distances of each of the four targets to their own position (four distances). Those four distances that extend between the observer and a target may be called *egocentric* distances; the six distances that extend between pairs of targets that do not lie on a line with the ground position of the observer may be called *exocentric* distances. (The distinction between egocentric lengths and exocentric lengths is a theoretical one.) The targets were configured in the field in a predefined random arrangement among 64 possible positions. The observer made 10 judgments of the distances of these targets from one another – that is, a group of four targets of the eight present in the field. The observer also made judgments of the distances of each of these targets from her or his · own position. For example, if the targets are (1, 2, 3, 4), and the observer's position is (0), then the pairs that define the distances to be judged are as follows: (1, 2), (1, 3), (1, 4), (1, 0), (2, 3), (2, 4), (2, 0), (3, 4), (3, 0), and (4, 0). The observer made these judgments from one of two positions: either standing at the edge of the field or elevated on a platform; so the eye-height of the observer was raised (by 7 ft 7 in). The starting position of the observers was counterbalanced. The order in which these distances were judged was randomized and dictated by the expedmenter. After judging these 10 distances, observers were repositioned – to the ground or elevated on the platfo lm, depending on their starting location – and asked to judge another 10 distances on the second four targets. Observers' verbal estimates of distance were recorded by the expedmenter. Observers were not given a specific time limit in which to make their estimates.

After the pretest, observers were given training. Half of them were trained only on the ground and the other half were trained only on the elevating stand. Two target sets were used for the training. The first target set was the same eight targets used during the pretest. Observers were asked to estimate 20 distances, and the experimenter provided the actual distance through verbal feedback immediately after each estimate was made. After the first target set (20 distances) was estimated and corrected, the target positions were reconfigured, and 20 more distances were estimated and corrected. This training lasted approximately 15 to 20 minutes.

After training, a posttest was administered. A new target set was used, and the posttest procedure was the same as that used for the pretest: no feedback was administered. Each observer was assigned to one of three groups, and each group included four observers. The groups differed in the posttest onditions; Posttests occurred either immediately after the second training pedod or one week after training. One group received only the immediate posttest; another group received only the posttest after one week; and a third group received both the immediate and one-week posttest.

RESULTS

The results of the expedment can be stated simply: Rudimentary training improves performance under NVG viewing conditions, and improvement persists for at least one week. Observers learn to estimate distances quickly with NVG devices under the illumination conditions of the expedment. Though their verbal estimates of distance have an initial bias toward underestimation, observers soon learn to estimate distance accurately when given direct feedback. As a reflection of that accuracy, the geometdc consistency of observers' estimates also increases with feedback. These improvements in consistency and accuracy transfer to unguided performance, both immediately after training and after a delay of one week. Observers' estimates of distance parallel actual distance and not visual angle or its tangent function. In terms of feet estimated, there is a small but robust error in estimation that may be attdbuted to the difference between egocentric and exocentdc distance. Such effects may best be explained by the influence of foreshortening rather than by the product of some psychological mechanism for the estimation of distance. Foreshortening is not a cue for estimation of distance; it is the aggregate effect of perspective that impedes estimation of distance.

Observers underestimated distances by about 6 m (20 feet) on average before training, whereas performance did not differ significantly from perfect performance of 0 m of error (in mean value with some variability) during either training or posttests. This initial bias of underestimation is in accord with Gilinsky's

TABLE 1: Accuracy Over Trials, as Assessed by Three Dependent Measures

Trial	Dependent measure (ft)	s.e.	*n*
	estimated - actual		
■	-19	3	240
2	-2	2	239
3	-1	2	240
4	-1	2	160
5	-1	2	160
	estimated / actual		
1	0.79	0.02	240
2	1.00	0.02	239
3	1.00	0.02	240
4	1.01	0.02	160
5	1.02	0.03	160
	abs (estimated - actual)		
1	39	2	240
2	,21	1	239
3	18	1	240
4	23	1	160
5	26	2	160

Mean accuracy across trials is tabled in terms of the signed difference of estimated distance min us actual distance, the ratio of estimated distance to actual distance, and the absolute value of the difference between estimated distance versus actual distance.

(1951) classic result. She found that untrained observers tended to underestimate distances extended along a runway in daylight conditions, yet the present observers estimated distances accurately in the first feedback trial. (*Estimate* will be used to designate a single response, and *Trial* will be used to designate a group of responses by an observer in one portion of the experiment. The trials are counted as follows: unguided pretest; first feedback trial; second feedback trial; immediate posttest; and delayed posttest.)

There are several ways to measure this performance (Table 1). One method is to take the signed difference of the verbal estimate from the actual distance. The signed difference of distance estimates from ground distance (estimated-actual of distance) is plotted in Figure 2, as well as the ratio of distance estimates to ground distance (estimated/actual of distance), which is plotted separately. Another method is to take the ratio of the verbal estimate to the actual distance. In Figure 2, a ratio of one between estimated distance and actual distance represents accurate performance, just as a difference of zero between estimated distance and actual distance represents accurate performance. Means for the first three trials (pretest, first training trial, second training trial) are based on 240 observations, while means for the latter two trials (posttests) are based on 160 observations. Both measures follow the same pattern across trials. The absolute value of the difference between estimated distance and actual distance does not show the trend as clearly, because variations about zero have the same effect on this measure as a consistent bias (a consistent overestimate or underestimate).

An analysis of variance (ANOVA) can be applied to the results, ignoring one condition, to determine if performance changed from the pretest condition to the first posttest condition. (One group of subjects received two posttest conditions; we set aside their second posttest for the purposes of this single analysis:) There are a couple of ways to apply this statistical technique, corresponding to different dependent measures – for instance, the log ratio of

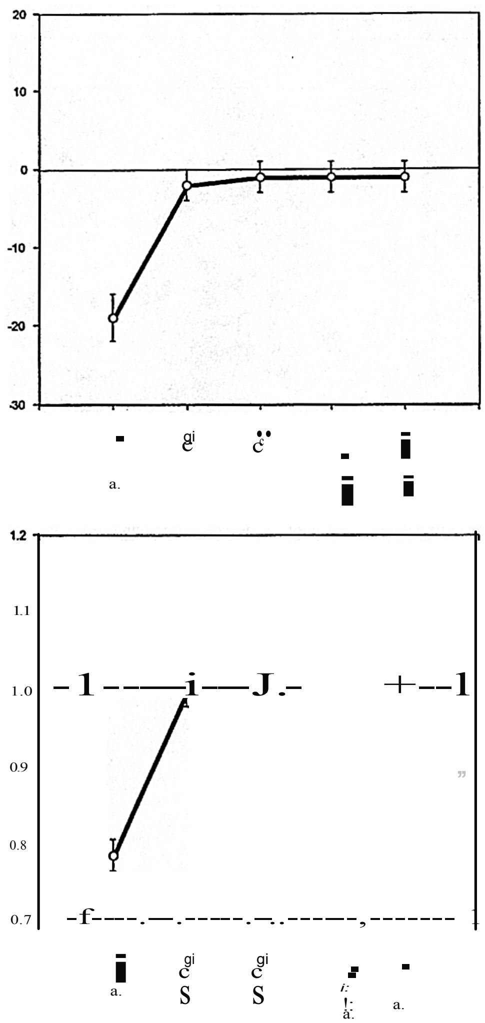

Figure 2. Mean errors are plotted by successive trials in the experiment (ie., pretest, first training trial, second training trial, immediate posttest, and postest at one week) . Standard error bars are shown. Observers' errors do not depart significantly from zero, beginning with the first training trial.

the estimated and the actual distances. This measure is not susceptible to the effects of skew in observations (see Ratcliff, 1993, for similar considerations of the skew of response time data) as is the signed difference of the estimated and actual distances, or the absolute value of that difference. One observer failed to make one judgment: A mean value for the condition was substituted for this missing datum: A three-way repeated-measures ANOVA was performed on the data (i.e., the log ratios) for all 12 observers to answer three main questions:

1.) Is there a difference between pretest and first posttest conditions on the dependent measure?

2.) Is there a difference between estimates taken at a standing position and estimates taken at an elevated position?

3.) Is there a difference between distances from the observer to a taiget and distances between two targets, that is, between egocenttic and exocentric distances?

The factors that conespond to these questions are called *Test, Position,* and *Distance Type,* respectively. The interactions between these factors are also evaluated in this ANOVA. The statistics associated with two of the main effects are significant in this analysis: the effect of *Test*, $F(l, 11) = 10.21, p$:=; .01, and the effect of *Distance Type*, $F(l, 11) = 55.35, p$:=; .01. None of the other effects is significant. This indicates that scores changed between pretest and posttest, and that scores for egocentric distances were different than those for exocentric distances. What this leaves unanswered is whether or not these changes are improvements. An improvement occurs when the observer's estimate and the actual distance become similar, that is, when the difference between the estimated and the actual distances approaches zero. Do the difference scores in these conditions depart from zero rather than simply being different from one another? (The difference of mean error scores from zero enor can be evaluated by application of a t-statistic.) Table 2 makes these comparisons explicit. Whereas pretest scores are different from zero, both in terms of the signed difference of distances and their log ratio, posttest scores are not significantly different from zero according to either measure. Error scores for egocentric distances are further from zero than are enor scores for exocentric distances overall.

Individual differences do persist. In terms of the difference between estimated distance and actual distance, there was either consistent overestimation or underestimation of distances by several observers. That is, observers differ in their ability to judge distance, despite training. Reising and Martin (1995) found that "subjects still vary as much as 6 ft on the critical distances (40-60 ft) after training." With regard to the present experiment, individual differences between mean pretest scores and mean posttest scores are listed in Table 3. The source of these individual differences has not been explored. Such differences have been attributed to differences of lens accommodation and convergence of the eyes (e.g., Bourdy, Cottin, & Monot, 1991), but that kind of speculation goes well beyond the evidence of our experiment.

Observers became more consistent in their judgments of distance as they became more accurate. Each trial consisted of many judgments of distance. Some of these distances were connected in triangles. Two groups of 10 triangles could be formed from the distances presented in each of the five trials. For each of these triangles, it can be asked if the observers' judgments were consistent. The three judgments that represent the three sides of the triangle are inconsistent if the two shorter of the three estimates do not add up to more than the third estimate. The number of times that the two shorter estimates do add up to more than the third can be taken as a measure of consistency of observers' judgments. (The measure is tallied in Table 4).

The distances formed connected figures, so an observer might judge the distance between points 1 and 2, later the distance between points 2 and 3, and that between points 3 and 1. Triads of judgments on the sides of a triangle like this will obey the triangle inequality, if those judgments are consistent. Say that the first distance, between points 1 and 2, is the longer side of this triangle. Then the observer's three judgments of sides 12, 23, and 31 are consistent if the estimated length of 12 is less than the sum of the estimated lengths of 23 and 31. (The labels may be permuted, should the subject judge side 23 to be the longer side of the triangle.) If the three distances are consistent, then a tally is added to the count of the consistency measure.

In the experiment, distances among four targets and the distances of those targets to the observer define 10 distances. Because all the targets are joined by distances, the four targets also define 10 triangles. If the targets are (1, 2, 3, 4), and the observer's position is (0), then the triads of distances dene 10 triangles: (1, 2, 3), (1, 2, 4), (1, 2, 0), (1, 3, 4), (1, 3, 0), (1, 4, 0), (2, 3, 4), (2, 3, 0), (2, 4, 0), (3, 4, 0). During the pretest observers' estimates were not consistent (only 55% *o(* triads qualified), but their consistency improved with feedback (79% of triads qualified). Computation of this measure is a way of tallying the geometric consistency of responses. The existence of changes in the measure does *not* imply that observers

Table 2: Differences of Mean Error Scores from Zero

	Mean	*SD*	*n*	t-statistic	*p*
(Dependent measure: estimated distance - actual distance)					
Pretest	-19.30	46.43	240	-6.44	≤ 0.001
Posttest	0.01	29.94	240	0.00	nonsignificant
(Dependent measure: estimated distance - actual distance)					
Egocentric	-22.91	39.75	192	-7.98	≤ 0.001
Exocentric	-0.80	38.09	288	-0.35	nonsignificant
(Dependent measure: Ln estimated distance/actual distance)					
Pretest	-0.33	0.45	240	-11.48	≤ 0.001
Posttest	-0.01	0.29	240	-0.84	nonsignificant
(Dependent measure: Ln estimated distance/actual distance)					
Egocentric	-0.31	0.39	192	-11.10	≤ 0.001
Exocentric	0.08	0.40	288	-3.50	≤ 0.001

These four ways of examining mean differences are not independent of one another.

Table 3: Individual differences of mean error scores

Observer	Pretest	Immediate	One week
	-50.6	*	-4.2
2	-58.1	-13.2	*
3	-19.4	30.9	33.6
4	42.3	*	27.0
5	-23.4	2.3	*
6	11.7	-0.4	-3.7
7	-6.7	*	-5.5
8	-45.3	19.8	*
9	-18.3	24.3	-28.1
10	-48.4	*	-7.9
11	32.7	-0.3	*
12	-48.0	-23.9	-26.2

*Marks conditions in which data were not collected

Mean differences in estimate (in feet) are tabled for the pretest condition (before feedback), for immediate testing after feedback, and for testing a week after feedback. One tabled score is the mean of twenty scores, each. the difference between an estimated distance and an actual distance.

used any particular method to improve the consistency of their judgments, such as learning to triangulate distances. One might suppose that observers used a known distance to calibrate their other responses, but this is unlikely, because the positions of the targets were changed during trials.

Regression analyses (simple linear regressions) were performed for each of the conditions of the experiment, both for actual distance versus estimate of distance, and tangent of visual angle versus estimate of distance. Regression scatterplots can be drawn for 12 conditions: the combinations of two conditions or types of distances (egocentric and exocentric), two viewing heights (standing low or elevated high), and three test conditions (pretest, trial 1; feedback, tiials 2 & 3; and posttest, trials 4 & 5). The number of observations involved depends on the conditions of egocentric and exocentric distances, as well as on the trials. The lowest number of observations on which these comparisons are based is 48 pairs. The answers to two simple yes-or-no questions summarize these results. First, is the slope of each regTession line cliffer-ent from zero? The question is whether or not

Table 4: Consistency of distance judgments, in terms of triangle inequalities

Trial	Count	Proportion	Total	n
	24	.55	133	240
2	23	.69	159	230
3	24	.79	190	240
4	16	.77	124	160
5	16	.76	122	160

Consistency measure based on number of violations of the triangle inequality.

Table 5: Summary of regression analyses

The significance of regression analyses is tabled for a number of conditions of the experiment. Estimates of distance are correlated with ctual distance, or else with visual angle (expressed as the tangent of angle).

Independent var.	Condition	Height	Trial	Slope	Estimate
actual	ego	low	1	./	./
actual	ego	low	2,3	./	./
actual	ego	low	4,5	./	./
actual	ego	high		./	./
actual	ego	high	2,3	./	./
actual	ego	high	4,5	./	./
actual	exo	low	1	./	./
actual	exo	low	2,3	./	./
actual	exo	low	4,5	./	./
actual	exo	high		./	./
actual	exo	high	2,3	./	./
actual	exo	high	4, 5	./	./
tan theta	ego	low	1	./	x
tan theta	ego	low	2,3	./	x
tan theta	ego	low	4, 5	./	x
ta n theta	ego	high	1	./	x
ta n theta	ego	high	2,3	./	x
ta n theta	ego	high	4, 5	./	x
tan theta	exo	low	1	x	
tan theta	exo	low	2,3	x	
tan theta	exo	low	4, 5	x	
ta n theta	exo	high		x	
tan theta	exo	high	2,3	x	
tan theta	exo	high	4, 5	x	

the regression coefficient is significant. Second, *if* it is significant, could the statistical estimate of the regression coefficient include one? This question is whether or not the confidence interval of the estimate of slope includes one. The second question is contingent on a positive answer to the first: One must ask whether there is a significant relationship between the variables before one asks if that relationship is significantly less than perfect. A regression coefficient of one indicates a perfect correspondence between the variables.

In Table 5, a number of conditions are listed: egocentric versus exocentric distances, elevated versus standing positions of the observe1 and conditions of training (i.e., trial number). For each analysis it is asked if the slope of the regression line is greater than zero, that is, if there is a significant correlation between the variables. For the analyses in which a significant slope is found, it is asked further if the estimate of the slope of the regression line includes one, that is, if the correlation between the variables does not differ significantly from perfect correspondence.

A simple pattern emerges from this mass of results. All of the scatterplots that relate estimated distance to actual distance had a slope significantly different from zero. (The nominal a level for these comparisons is .05). All of those scatterplots had another property: the estimate of slope was not significantly different from one. In conditions that involved

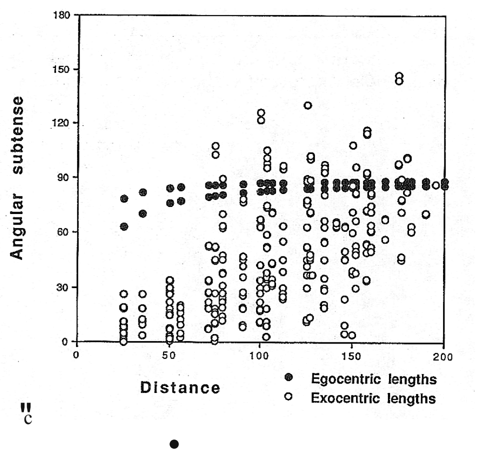

Figure 3. The angular subtense (in degrees) of each of the lengths used in the experiment is plotted against its ground distance (in feet). Exocentric lengths are marked by unfilled circles in the scatterplot; egocentric lengths are marked by filled dots. A change in elevation of the observers' height leads to the appearance of two distinct curves formed by changes in egocentric distance within this scatterplot.

exocentric distances, none of the scatterplots that relate estimated distance to the tangent of visual angle had a slope significantly different from zero. In conditions that involved egocentric conditions, all the scatterplots that relate estimated distance to the tangent of visual angle had a slope significantly different from zero. In the latter conditions all the estimates of slope of the regression line were significantly different from one, as well. In other words estimated distance could (possibly) be predicted perfectly by actual distance for both egocentric and exocentric distances.

At the same time, estimated distance could not be predicted perfectly by the tangent of visual angle, which does not produce any significant prediction of estimated distance in the case of exocentiic distances. (The pattern of these results is not altered when visual angle is considered rather than the tangent of visual angle.) The relation between ground distance and visual angle is illustrated by Figure 3. Egocentric lengths extend between an observer and a target; exocentric lengths extend between two targets which do not lie on a line with the ground position of the observer. The distinction between egocentric lengths and exocentric lengths is a theoretical one, which may or may not correspond to a qualitative difference for human perception,

The angular subtense of an egocentric length is found in Figure 3 as well. It is roughly the angle between the line formed by the observer's feet and eyes and the line formed by the observer's eyes and a target. The angular subtense of an exocentric length is found as the angle formed by the line between one posted target and the observer's eyes, and the observer's eyes and a second target. The angular subtense of egocentric lengths is compressed in range with respect to the angles subtended by exocentdc lengths. In other words egocentric lengths are just those closest to being "endwise to the eye": they are lengths that are most severely fore- shortened. Large changes in egocentric distance correspond to small changes in angular sub- tense (a target on the horizon would subtend 90° of angle, which is close to the angle sub- tended by most other egocentric distances in the experiment, for a standing observer). It is suggested that the difference between ego- centdc distance and exocentdc distance is a geometrical difference, i.e., a difference in com- pression or degree of foreshortening, rather than being a psychological difference first of all. Egocentric distances differ from exocentric distances primarily in their geometry: Ego- centric distances are most subject to foreshort- ening, that is, the compression of distances due to linear perspective. When egocentric and exo- centric distances are considered in the same experiment, distance is no longer confounded with visual angle, as it is for experiments in which an observer judges egocentric distances alone, from one eye height. (In that much, the present experiment departs from most previous work on distance estimation, including Gilinsky, 1951.) It seems unlikely that judgments of dis- tance are formed by apprehending visual angles, from which less reliable estimates of distance are formed. More likely, observers estimate dis- tance when asked to estimate distance.

DISCUSSION

Distance need not be underestimated by eye. An elementary regimen of training can be used to correct estimates on average. Estimates of distances also depend on the optical conditions under which those distances are judged – for example, whether they are presented to the eye lengthwise or endwise, and whether they are seen in a clear or a foggy atmosphere. Performance may not transfer adequately from one set of optical conditions to another, but this is not in itself a psychological matter (see Ferris, 1972 & 1973). Many psychological effects on the untrained estimation of distance have been claimed . Higashiyama (1996), for instance, claims that distance estimation changes when observers are standing, lying on their sides, or lying on their bellies. Howeve ŗ such differences may be malleable perfonnance effects rather than a reflection of the observers' competence. In the study of competence, we catch participants at their best. In the evaluation of distance, "best" simply means accurate performance (cf. Lappin and Fuqua, 1983).

The question may adse whether the correction of estimates that is contingent on feedback is due to a change in aspect, as in a compelling and immediate change in perception, or a change in report, as in a sharpened ability to tell distances without any change in aspect. A change in repmi is what has been demonstrated; such a change is necessary whether there is an accompanying change in aspect or not. The overdding consideration for practical purposes is that observers be able to use whatever means their eyes afford them to estimate distances more accurately. Whatever objections there may be in psychology to the accurate estimation of distance by eye, the results of our experiment are that such estimates are accurate (in the sense of being precise in average) when observers are given simple feedback on their perfo1mance, even under NVG viewing conditions (given the limits of the experiment in terms of range of distances, and other factors).

CONCLUSION

Vallier,jouant Cesar: On ne la voit pas.
Simon,jouant Sebastien: Tu ne peux pas le voh; Auguste, bien que tu aies des yeux de lynx.
Vallier,jouant Cesar: Et pourquoi ?
Simon, jouant Sebastien: Paree qu'il faut d'autres yeux, mmes d'une autre vertu.

(Bouchard , 1988, page 93)

Observers improved their ability to estimate distance, and this improvement persisted for at least one week. It did not make a significant difference whether they were tested at eye level or slightly elevated on a B-1 stand. Distances between the observer and an object were Jess well-estimated than distances between two objects, presumably because of the severe foreshortening resulting from the perspective on ground distances viewed from eye height or nearby. Previously, estimates of distance have fallen short of actual distances under both daylight conditions, and nighttime conditions with NVGs . Such underestimation of distance can have important operational consequences: The distances examined in this study have the most relevance to the "close-in" judgments made in helicopter operations. There is an easy way to conect estimates of distance by observers who use NVGs: simply *tell* them what distances they see, several times in succession.

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Keith K. Niall is a Defence Scientist at the Defence and Civil Institute of Environmental Medicine, a laboratory of the Canadian Department of National Defence. He is currently on exchange to the Air Force Research Laboratory in Mesa, Arizona. He received his Ph.D. in psychology from McGill University (Montreal, Quebec) in 1988.

Jack D. Reising is a human factors specialist with Boeing Defense and Missile Systems in Seattle, Washington. He was employed by the Training Operations Division of Hughes Training, Inc.. He received his M.A. in Human Factors Psychology from the University of Dayton (Ohio) in 1993.

Elizabeth L. Martin is the Associate Technical Director of the Warfighter Training Research Division of the Air Force Research Laboratory. She received her Ph.D. in psychology from the University of Arizona (Tucson, Arizona) in 1975.

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