Original Article

Analysis of problems with distance determination using Night Vision Googles

Baburaj VP[*], Gomez G [+]

ABSTRACT

Distance judgment and depth perception are fundamental skills required in aviation. Accurate distance estimation is an important task for most aircraft pilots and is extremely critical for helicopter pilots. This study ascertained distance judgment of the observers for egocentric (distance from the object to the subject) and exocentric (distance between two objects under consideration) setup using naked eye and Night Vision Googles. The study was conducted in two experimental set-ups viz. photopic illumination condition and degraded illumination condition. The study was conducted indoors with 30 healthy volunteers (29 male and 1 female) belonging to age group 20 to 35 years (Mean age 29.45±4.08 years). A Gen 2$^+$ helmet mounted passive binocular device was used for the study. The second set-up included the same procedure as was conducted before but with subjects wearing the NVG. The mean egocentric distance was significantly underestimated in conditions of both photopic vision and with the usage of NVG. However the extent of underestimation with the photopic vision was lesser as compared with distance estimation with NVG usage. An increasing standard deviation was also noted with the increase in distance of observation. Unlike egocentric distance estimation, the observation for exocentric estimation by NVG showed a definite and highly significant overestimation ($p<0.01$). With the use of NVG, the amplitude of overestimation of exocentric distance was found to be directly proportional to the magnitude of the distance under consideration.

IJASM 2009; 53(2): 1-9

Keywords: Egocentric, Exocentric, Night Vision Goggles.

Introduction

Beginning in the early 1970's, the proliferation of sophisticated weapon systems has necessitated changes in the way an aviator will fight in a modern combat scenario. In order to survive and succeed in combat, Air Forces world over now depend largely on the ability to fly and fight at low altitudes and at night utilizing night vision devices.

Advanced display technology is now available to allow rotorcraft pilots to fly with increased effectiveness under visibility conditions, which was not possible to fly few years ago. Night vision devices such as Night Vision Goggles (NVGs) and Forward Looking Infrared devices (FLIR) are examples of two such systems.

These devices do not provide normal photopic vision and thus compromise human performance in certain important areas. The prime shortcoming of these devices includes reduced acuity of vision, smaller Field of View (FOV) and a spectral sensitivity different from the human visual system. These differences have been cited as potential factors leading to problems with their use in flight [1].

Distance judgment and depth perception are fundamental skills required in aviation [2]. Accurate distance estimation is an important task for most aircraft pilots. This is not taught in pilot training and rules of thumb are typically passed on from instructor to student in an informal and invalidated manner. Accurate distance estimation is critical for helicopter pilots. Rotorcraft, by their very nature, can

* Classified Specialist (Av Med) Institute of Naval Medicine, INHS Asvini, Mumbai- 400 005

\+ Commandant & Principal, IAM, IAF, Bangalore

Date of submission: 11 Dec 08

Date of approval : 30 Nov 09

manoeuvre amongst trees and other obstacles and fly Nape-of-the-Earth (NOE), fly at low altitudes, land in very low clearance areas and maintain a hover at a fixed altitude above a certain point. All these piloting tasks require accurate distance estimation to implement the manoeuvre properly and safely. For safe operations, helicopter pilots must constantly verify that the aircraft has adequate clearance in all directions: The tail boom to the rear, the skids or the wheels below and the rotor blades above, to the sides and in front. Obstacles must be cleared, 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 hover, pilots are trained to pick objects in front and 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 [3].

Till date, there had been a few studies with the NVG concerning the problems with the spatial estimations. These studies had indicated a definite change in the perceptual pattern when viewing through the NVG. The distance and size judgments were reported to be generally an underestimate and the magnitudes of these deviant estimates were determined by a hoard of factors. The study conducted by Foyle and Kaiser [3] with ANVIS 6 NVGs and four helicopter pilots with extensive NVG experience as subjects resulted in all observers underestimating the distance to the target using unaided viewing with either their normal or a restricted field of view, but during NVG viewing two observers overestimated and two observers underestimated distance.

In the study conducted in a laboratory, Hadani [5] had reported that observers underestimated the distance to an object and according to him, the forwardly displaced location of the nodal point of the objective lens of NVGs compared with the nodal point of the eye was the cause for the altered perception. In another study, DeLucia and Task [6] compared judgments in the laboratory and in a field experiment. In the laboratory, they found that while wearing NVGs, observers underestimated distance compared with normal photopic viewing. In contrast, they found no significant differences between NVG and unaided viewing in the field experiment.

Reising and Martin [7] had observed in their study that while making estimates of absolute depth between themselves and triangular targets, and making depth judgments between pairs of targets under starlight in field conditions, 14 out of 20 observers underestimated the absolute distance to targets and two observers overestimated distances. They also observed that there was a significant improvement in distance estimates when observers had been given feedbacks of their estimates and the experiment repeated again with a different setting. Niall, Reising and Martin [7, 8] confirmed the value of direct verbal feedback for distance estimation when viewing through NVGs. They also showed that observers typically underestimated the true physical distance only if they had limited experience using NVGs and had no feedback on their performance.

It has been established by Gibson that similar visual cues are involved in judging both size and distance so that any degradation in viewing conditions is likely to affect both size and distance judgments [9]. Because the NVGs have a restricted field of view and a diminished resolving power when compared with the capability of the unaided human eye in daylight, it can be anticipated that NVG users unaccustomed to these altered viewing conditions may experience misperception. Many field reports indicate [10, 11, 12] that NVG viewing induces misperceptions that compromise flight safety, including difficulty in judging ground distances (egocentric distance estimation) or the separation of objects (exocentric distance estimation). Inaccurate distance judgment have been implicated as a serious problem by aircrew members [12] to be a factor in many rotary wing aircraft accidents. The problem is of particular importance to helicopter crew members, who must estimate distances often during the hover and landing phases of flight (e.g. to judge that the helicopter rotor blade will not strike a fixed object or that a patch of ground is sufficiently wide enough to serve as a landing zone). The relevant range of distances for these tasks is about 46 m (150 ft) with crucial distances ranging from about 12 m to 18 m (40 ft to 60 ft), which corresponds to rotor blade lengths [6,8].

In absence of a formal training, the aviator repeatedly and somewhat systematically pairs visual precepts with valid distance data to form an internal perceptual calibration that will be relied upon in the circumstances when the pilot cannot crosscheck on instruments while in flight. This internal perceptual yardstick breaks down when there is substantial changes in the visual environment particularly when the visual array is impoverished or ambiguous. It is in these environment where NVGs are used for their advantages and yet their associated disadvantages may cause unfortunate problems.

NVGs are electro-optical devices that enhance visibility in low light. Vision with NVGs differs in many ways from unaided human vision. This study explores the altered distance estimation with NVG usage.

Materials and Methods

The study was conducted indoors in the NVG Training Laboratory at the Institute of Aerospace Medicine, Bangalore. The subjects for the study were 30 healthy volunteers (29 male and 01 female) belonging to the age group of 20 to 35 years (Mean age 29.45±4.08). The subjects were randomly selected from the normal population and a written informed consent was taken prior to the study. The distant vision status, near vision status and colour vision of the volunteers was ascertained. Only emetropic volunteers with colour vision having cut-off limit maintained above CP-II by Ishihara book test for colour vision were selected for the study. The subjects acted as their own controls as the same subjects were used for both the conditions of the study i.e. photopic illumination condition and NVG conditions in both size determination and distance determination.

The NVG equipment used was a self-contained Gen 2+ helmet mounted passive binocular device. White cut outs were used as objects for distance determination. These were identical in size and shape, two in number and comprised of white chart paper of size 1m x 1m in an hourglass shape. The upper end of the cut-out had an extension, which was used to get it affixed on the clip available behind the arm of the black stand. The black stands were two in number and had an adjustable vertical arm at the end of which there was affixed a clip to hold the cut-out. The stands were painted black so as to give a contrast to the white colored cut-out.

The NVG focusing procedure was instructed to every subject prior to commencement of the NVG aspect of distance estimation study. The study proceeded further only after it was ensured that the subject had learnt the complete focusing procedure and was getting the maximum possible resolution with the NVG. The subjects were encouraged to spend as much time as required to adjust and focus the goggles prior to commencement of the study. The subject was made to view

Sildermann's 3x3 NVG resolution chart from 6 m with full moonlight illumination on the chart for the purpose of focusing.

The subjects were then taken to a corridor of length 144 ft which was perfectly darkened. The illumination measured when darkened was 0.052 Lux. There was provision of artificial lighting inside the corridor which was utilized for assessing the photopic distance estimates by the subjects. The entire corridor was measured and the measured distances were marked in meters and small labels were affixed on the floor blind to the subjects. The subjects were shown distance of 1 m, 4 m and 10 m with positive feedback correction as a practice session by keeping the object at the respective distances and asking the subject to make a mental picture of the same. The objects at photopic illumination in the NVG corridor were placed at predetermined distances which were blind to the subject and the estimated distance was noted down. Four estimations were made in a single setting.

For egocentric estimation, the distances were arbitrarily chosen as 13 m, 22 m, 28 m and 37 m. First measurement of egocentric distance estimation at photopic illumination was carried out followed by egocentric distance estimation using the NVG. The objects were randomly assigned to these distances under both photopic and NVG settings.

This was followed by four exocentric distance estimation of predetermined distance combination blind to the subject. The distances chosen were again arbitrary. Two of these distance were closer one and two; more apart. The distances were 3 m, 5 m, 11 m and 16 m. Similar readings as for egocentric were then taken firstly in photopic condition and then using the NVG with randomized combination of the same distances as in normal illuminations.

Single sample t-test was used to test the significance of departure of distance judgment from actual distances under photopic and NVG conditions. Paired t-test was done to estimate the differences between distance determination under photopic condition and with the usage of NVG.

Results

The distance estimation was done in two setups: Egocentric and Exocentric.

The mean estimated egocentric distance and error scores both with the photopic vision and with the usage of NVG with their corresponding standard deviation is shown in Table 1.

Single sample t-test was used to test the significance of departure of egocentric distance judgments from the actual egocentric distance under photopic and NVG conditions. The t values and corresponding significance levels are placed at Table 2.

Table 1: Mean (±SD) and error scores of egocentric distance estimates under photopic and NVG viewing conditions (n=30)

Egocentric	Estimated Distance (m)				
Distance (m)	Photopic ±SD	Error Scores	NVG ±SD	Error Scores	t -value
13	12.3 ± 0.53	-0.7	10.7 ±1.15	-2.3	6.352**
22	20.6 ± 0.81	-1.4	18.53 ± 2.70	-3.47	4.623**
28	25.53 ± 2.03	-2.47	21.77 ±3.55	-3.76	6.031**
37	34.23 ±2.61	-2.77	30.83 ±5.08	-3.4	4.418**

** $p < 0.01$ (Highly significant)

Table 2: Test result of significance in comparison of egocentric distance estimates with actual distance in two viewing conditions (n=30)

Distance (m)	Condition	Mean ±SD distance estimation (m)	Calculated t value
13	Photopic	12.3 ± 0.53	-7.17**
13	NVG	10.7 ± 1.15	-10.96**
22	Photopic	20.6 ± 0.81	-9.42**
22	NVG	18.53 ± 2.70	-7.03**
28	Photopic	25.53 ± 2.03	-6.66**
28	NVG	21.77 ± 3.55	-9.62**
37	Photopic	34.23 ± 2.61	-5.81**
37	NVG	30.83 ± 5.08	-6.65**

** $p < 0.01$ (Highly significant)

Table 3: Egocentric distance estimation by (%) subjects under photopic illumination (n=30)

Estimations	Distance (m)			
	13 m	22 m	28 m	37 m
Overestimation (%)	0%	0%	0%	3.33%
Correct (%)	3.33%	20%	23.33%	13.33%
Underestimation (%)	66.67%	80%	76.67%	83.33%

Table 4: Egocentric distance estimation by (%) subjects under NVG usage (n=30)

Estimations	Distance (m)			
	13 m	22 m	28 m	37 m
Overestimation (%)	0%	6.67%	10%	13.33%
Correct (%)	3.33%	0%	0%	0%
Underestimation (%)	96.67%	93.33%	90%	86.67%

Table 3 and 4 depict the individual break down of egocentric distance estimation by 30 subjects as the percentage function of overestimation, correct estimation and underestimation of egocentric distance in either condition.

The mean estimated exocentric distance and error scores both with the photopic vision and with the usage of NVG with their corresponding standard deviation is also shown in Table 3.

Single sample t-test was used to test the significance of departure of exocentric distance estimates from the actual exocentric distance of consideration. The t values and corresponding significance levels are shown in Table 4.

The following two tables give the individual break up of exocentric distance estimation by 30 subjects as the percentage function of overestimation, correct estimation and underestimation of exocentric distance in either condition:

Discussion

The altered NVG image as compared with normal unaided vision under photopic conditions is the major cause for the limitations when viewing through the NVG. What is less certain, however, is how aspects of higher order visual performance such as form, motion, and space perception are affected by NVG imagery, and in turn, the effect of these factors on operational flying tasks that rely on complex visual and cognitive input. Although the precise role of contributing factors remains uncertain, there is sufficient operational and anecdotal evidence to conclude that NVGs are associated with errors in the estimation of depth, altitude, distance and size [4].

This study revealed that the mean egocentric distance is underestimated in conditions of both photopic vision and with the usage of NVG. With the photopic vision to some extent and with the NVG to the greater extent, degradation in estimation and increasing standard deviation is seen with the increase in the distance of observation. It is pertinent to mention that the deviation from the actual, in case of photopic vision, is marginal as compared to that using NVG. This is evident from the error scores as tabulated in Table 1. The level of significance in difference of estimation was determined for each distance under consideration for the photopic viewing condition and the usage of NVG (Table 2 refers). It was thus determined that the egocentric underestimation with NVG was highly significant ($p< 0.01$) for all the four egocentric distances. The studies done by Atsuki Higashiyama and Koichi Shimono [13], where they had studied distance determination over distances of 40 cm to 15.3 km, Witmer and Kline [14] on distance determination in Virtual Environment, Hadani [5] with NVG, Delucia and Task [6] with NVG and Reising and Martin [7] with NVG, are in agreement with the result obtained in the present study. Only the result of the study done by Foyle and Kaiser [3] was contrary to the results of the present study. They found out that that error does not appear to be uniformly overestimation or underestimation, but was subject idiosyncratic. Out of only four pilots that they used as subjects, two overestimated and two underestimated the distance.

Contrary to the observations of the egocentric distance estimation, the observations tabulated in Table 5-8 for exocentric estimation by NVG points towards a definite and highly significant tilt towards the overestimation element ($p< 0.01$). The results of the exocentric estimation of photopic illuminations are however varied. It is non significant to very low significance in estimation of distance from the actual distance in smaller distance of consideration whereas in the larger distance of consideration there is obvious tilt towards overestimation. In the latter aspect, the results are presumably more influenced by the reasons aligned with the egocentric estimations.

Table 5: Mean (±SD) and error scores of exocentric distance estimates under photopic and NVG viewing conditions (n=30)

Actual Distance (m)	Estimated Distance (m)				
	Photopic	Error scores	NVG	Error scores	t-value
3	3.57 ± 1.14	0.57	5.3 ± 1.78	2.3	-5.233**
5	5.1 ± 1.32	0.1	6.83 ± 1.97	1.83	-5.017**
11	9.93 ± 1.55	-1.07	11.83 ± 2.10	0.83	-5.794**
16	14.73 ± 2.94	-1.27	19.83 ± 3.60	3.83	-9.317**

** $p < 0.01$ (Highly significant)

Table 6: Test result of significance in comparison of exocentric distance estimates with actual distance in two viewing conditions (n=30)

Distance (m)	Condition	Mean distance estimation (m) (SD)	Calculated t value
3	Photopic	3.57(1.14)	2.73*
3	NVG	5.3(1.78)	7.06**
5	Photopic	5.1(1.32)	0.41^{NS}
5	NVG	6.83(1.97)	5.11**
11	Photopic	9.93(1.55)	-3.76**
11	NVG	11.83(2.10)	2.17*
16	Photopic	14.73(2.94)	-2.36*
16	NVG	19.83(3.60)	5.82**

* $p < 0.05$ (significant) ** $p < 0.01$ (Highly Significant) ^{NS} Non significant

Table 7: Exocentric distance estimation by (%) subjects under photopic illumination (n=30)

Estimations	Distance (m)			
	3 m	5 m	11 m	16 m
Overestimation (%)	46.67%	20%	13.33%	23.33%
Correct (%)	36.67%	56.67%	0%	0%
Underestimation (%)	16.67%	23.33%	86.67%	76.67%

Table 8: Exocentric distance estimation by (%) subjects with NVG usage (n=30)

Estimations	Distance (m)			
	3 m	5 m	11 m	16 m
Overestimation (%)	83.33%	63.33%	56.67%	83.33%
Correct (%)	16.67%	33.33%	0%	3.33%
Underestimation (%)	0%	3.33%	43.33%	13.33%

In both the above experiments for distance estimation, emphasis was given for the fronto-parallel plane as the field of distance determination. This was done due to the limitations imposed by the NVG corridor. This can be justified by taking into consideration the restricted field of view of the NVG.

From this experiment and considering the other research works it is evident that estimates of distance are also adversely affected by NVG viewing. There are two likely reasons for this. First, the perception of object size is a cue for distance, and if this is affected, then the perception of distance is also likely to be affected (Size distance invariance hypothesis) [15, 16, 17]. In an experiment of size estimation using NVG by Zalevski, Meehan and Huges [18], it was concluded that the size of the objects when viewed by the NVG appeared smaller (the study was conducted till an effective distance of 6 m). This may then suggest that they are seemingly located farther than they actually are or in other words the distance will be overestimated; however, it is seen that the typical error made in distance judgment with NVGs is underestimation. This was both seen in photopic situation to a marginal extent and with NVG to a highly significant extent. By applying the size-distance invariance hypothesis, the egocentric distance estimation to a distance of 6 m can be inferred to be overestimation. Another factor which is to be considered is that the cues which influence perception of size are the same as those that influence the perception of distance. Hence, distance estimation may be more directly affected by the degradation in depth cues with NVGs, and in this case it may appear more difficult to predict whether distances will be over-estimated or under-estimated. However it is evident that the effect of NVG in the backdrop of reduced visual acuity is further amplification of the effect of underestimation by the photopic vision.

Larger distances appear to be underestimated as is evident from the egocentric distance estimation experiment. However, it can be noted that underestimation of distance in the egocentric setup cannot be translated into overestimation of size since this was not a comparison experiment keeping the visual angle same and size of the object was constant and known to the observer. This has obvious implications in both fighter flying and helicopter flying. In fighter flying, this will be important for target selection and distance estimation of the same. It will also be of tremendous value while doing low level sortie at night. Formation flying is another arena, which will have great implication due to altered spatial perceptive properties of the NVG. In helicopter flying, the distance determination is of greater signifiance since it is required during hover and NOE flight.

In case of exocentric distance estimation the results indicate a definite trend of overestimation of the distances when viewed by the NVG. In the photopic estimation of exocentric distance, near distances showed marginal overestimation and the far distances were underestimated. The exocentric distance estimation is of importance while flying the aircraft between two obstacles. It is also of a value during formation flying, though to a lesser extent.

Conclusion

The result of this study clearly demonstrates the problem in distance determination using an NVG. The present experiment set up had taken into consideration the distances of 13 m, 22 m, 28 m and 37 m for egocentric estimation and 3 m, 5 m, 11m and 16 m for exocentric estimation. The following conclusions can be drawn for the distance estimation of the two set-ups involved.

(a) *Egocentric estimation*: The underestimation of the distances was found to be highly significant with NVG usage.

(b) *Exocentric estimation*: In exocentric estimation there was overestimation of the distances. The extent was in terms of larger amplitude when distances of greater magnitudes were taken into consideration.

Conflict of interest: None

References

1. Brickner MS. Helicopter flights with night-vision goggles — Human factors aspects. NASA Technical Memorandum 101039, Moffett Field, CA. National Aeronautics and Space Administration. 1989.

2. DeHart RL. In: Fundamentals of Aerospace Medicine. 3rd Ed. Philadelphia: Lippincott Williams & Wilkins; 2002.

3. Foyle DC, Kaiser MK. Pilot distance estimation with unaided vision, night-vision goggles and infrared imagery. SID International Symposium Digest of Technical Papers. 1991:*22;* 314-7.

4. Fuson J. Crew error in night rotary wing accidents. Flightfax. 1990. 19; 1-5.

5. Hadani I. Corneal lens goggles and visual space

perception. Applied Optics. 1991:30;4136-47.

6. DeLucia PR, Task HL. Depth and collision judgment using night vision goggles. Int J Av Psychol. 1995; 5, 371-86.

7. Reising JD, Martin EL. Distance estimation training with night vision goggles under low illumination (AL/HR-TR-1994-0138). Mesa AZ: Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division: 1995.

8. Niall KK, Reising JD and Martin EL. Distance estimation with night vision goggles: A little feedback goes a long way. Human Factors. 1999:41; 495-506.

9. Gibson JJ. The perception of the visual world. Riverside Press: Cambridge; 1950.

10. Stephen C Hatley. NVGs Don't fly at night without them. Flying Saf; Sep 2001:4-8.

11. Nate Kelsey. The NVG Factor. Flying Saf; June 2002: 16-7.

12. Crowley JS. Human factors of night vision devices: Anecdotes from the field concerning visual illusions and other effects; 1991: USAARL Report No. 91-15. Fort Rucker, AL : US Army Aeromedical Research Laboratory.

13. Higashiyama A Shimono K. How accurate is size and distance perception for very far terrestrial objects? Function and causality. Percept Psychophysics; 1994: 55 (4), 429-42

14. Witmer BG. Kline P B. Judging perceived and traversed distance in virtual environmenyts. Presence: Teleoperators and virtual Environments; 1998: 7(2), 144-67.

15. Epstein W. Attitude of judgment and the size-distance invariance hypothesis. J Exp Psychol, 1963; 66, 78-83

16. Kilpatrick FP & Ittelson WH . The size-distance invariance hypothesis Psychol Rev; 1953: 60, 223-31.

17. Sedgwike HA. Space perception. In: KR Buff, L Kaufman,& JP Thomas (Eds), Handbook of perception and human performance; 1986: Vol. 1 Sensory processes and perception 21 .1- 21 .57) New York

18. Anna Zalevski, James W. Meehan, and Philip K. Hughes. Size estimation with NVG. Air Opreation Division report; DSTO-RR-0201; 2001: 1-20.