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Original Article

Visual acuity through Night Vision Goggles (NVGs): A comparative assessment between Gen 2^{++} and Gen 3 NVGs under different illumination conditions

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ABSTRACT

Introduction: During night flying operations, Night Vision Goggles (NVGs) help the aircrew to visualize by intensifying lights reflected from an object. Night sky illumination and image intensification mechanism are the two important factors that affect visual acuity (VA) through NVG. Hence, assessment of visual acuity through Gen 2^{++} and Gen 3 NVG under different illumination conditions and comparative analysis between the two NVGs was the desired objective of the study.

Material and Methods: In a prospective repetitive measure design, a total of 60 volunteered subjects were examined for their VA through Gen 2^{++} and Gen 3 NVGs using USAF Tri-Bar Chart in the eye lane room of the NVG Lab. The VA was measured under four different illumination conditions; full moon (FM), half moon (HF)quarter moon (QM), and starlight (SL) conditions. The measured VA was converted to logMAR values and analyzed.

Results: VA deteriorated significantly with decreasing illuminations through both Gen 2^{++} ($\chi^2 = 149.9$, $P < 0.001$) and Gen 3 NVGs ($\chi^2 = 156.5$, $P < 0.001$). For Gen 2^{++} NVG, the difference in VA was statistically significant in all conditions other than between FM and HM. Whereas, it was almost significant for all illumination conditions for Gen 3 NVG. The VA through Gen 2^{++} was better than Gen 3 in all conditions and the difference in VA widened with decreasing illuminations.

Conclusion: VA declined with decreasing illuminations for Gen 2^{++} as well as Gen 3 NVG, even though, the difference was not significant between FM and HM for Gen 2^{++} NVG. VA was observed to be consistently better through Gen 2^{++} NVG compared to Gen 3 across all four illumination conditions. However, keeping in view the dynamic changes in night sky illuminations during flying operations, the findings of the study need to be validated in operational conditions.

Keywords: Visual acuity, USAF 1951 Tri-Bar Chart, Illumination, Gen 2^{++} NVG, Gen 3 NVG

INTRODUCTION

Vision is the primary sense used to gather information about the surrounding environment. Visual target acquisition remains the key to successful operational flying task.[1] However, in many situations, our eyes are unable to capture desired information from the environment due to limitations of the human visual system. Poor illumination such as flying at night severely affects primary flight information through vision. Modern military warfare, however, requires pilots to operate at night.[2,3] Operation at poor illumination conditions at night results in decrement in visual acuity, distance and depth perception, and poor color perception. This is because humans have developed exceptional photopic or day vision but have a somewhat less sensitive scotopic or night vision system.[4,5] To overcome these limitations, vision technology has been developed that enhances vision in low light circumstances.[6] This is achieved by Image Intensification Systems or Night Vision Devices (NVDs). The Night Vision Goggles (NVGs) are a specialized class of device which enhance VA at low illumination levels.[7]

The history of NVDs goes back to just before World War II. Germany developed primitive infrared devices, and the Allies followed suit, it included the cascade image tube and the infrared illuminator.[7,8] The operating principle is light intensification wherein very low light levels are multiplied to provide a high degree of night vision.[7] I^2 devices capture the light reflected from the objects in night illumination conditions both in visual and near-infrared spectrum and use light-amplifying technology to enable us to visualize an object more clearly than without NVG.[7,9,10] The quality of image through the NVG thus depends on the night sky illumination conditions and the quality of image intensification mechanisms in-built in the NVGs.[8-10]

The Gen 2^{++} NVG (Israeli) has been in use in the military aviation since long time, and multiple studies have been undertaken to see the effects of illumination, contrast, vibration, and other factors on VA. Of late, Gen 3 NVG (Russian) has been introduced in the advanced Air Forces and is being used extensively. However, literature showing assessment of visual performance of Gen 3 NVGs is scant. Since, night flying involves dynamically changing illumination conditions, the effect of these conditions on VA through NVGs is considered essential. With this on the background, the present study was undertaken to examine the changes in VA through the two different types of NVGs under various levels of illuminations.

MATERIAL AND METHODS

Subjects

A total of 60 healthy volunteers, 52 were male and 08 were female, consented to participate in the study. The mean age of the participants was 30.67 ± 5.37 with a range of 23–44 years. The inclusion criteria were (a) corrected visual acuity (VA) of 6/6, checked by Snellen chart, (b) no visual abnormalities (b) without any medications, (c) no alcohol for the past 24 h and smoking for the past 6 h, and (d) adequate sleep the previous night.

Materials

The test articles were two different generations of NVGs – Gen 2^{++} (Israeli) and Gen 3 (Russian). The weight of Gen 2^{++} NVG was 540 g and that of Gen 3 NVG was 550 g. The experiment was conducted in the eye lane room of the NVG Lab at IAM. USAF 1951 Tri-Bar Chart was used to record the VA through NVG. Modified Goose Neck Lamp with Rheostat was used to simulate moon light conditions with varying illumination and Yokogawa Make Lux Meter was used to assess desired illumination level at Tri-Bar Chart.

Experimental protocol

This research was approved by the Institute Ethics Committee. A written informed consent was obtained from all study participants. The experimentation was undertaken in the standard laboratory conditions in the eye lane room of the NVG Lab. The subjects were well indoctrinated on the adjustment and focusing procedures for both the NVGs. On the day of experimentation, the subjects undertook adjustment procedures as applicable for each NVG. Following this, focusing was undertaken and VA was measured for each subject through Gen 2^{++} NVG using USAF 1951 Tri-Bar Chart at full moon (FM) light condition. The desired illumination was simulated by Modified Goose Neck Lamp and was confirmed by Lux Meter at the level of chart. The subjects were instructed not to readjust during the entire experiment procedure. VA was measured under four different illumination conditions; FM, half-moon (HF), quarter moon (QM), and conditions akin to starlight (SL) condition as measured by Lux Meter at the level of USAF 1951 Tri-Bar Chart.

Data analysis

Data were compiled and analyzed using Microsoft® Excel 2019 Professional Edition and IBM SPSS v26 for statistical analysis. Friedman test was performed to find the differences between groups. *Post hoc* pairwise analysis was performed to ascertain the statistical significance in between the different illumination conditions. Results with $P < 0.05$ were considered as statistically significant.

RESULTS

Gen 2^{++} NVG

The VA in logMAR values for Gen 2^{++} NVG under FM, HM, QM, and SL conditions is depicted in Table 1 and Box-and-Whisker plot in Figure 1. In each box, the middle horizontal line represents the median of VA of Gen 2^{++}, the upper and lower bounds of the box represent the 75^{th} and the 25^{th} centile of Gen 2^{++}, respectively. It was observed that the VA showed a statistically significant (Friedman test: $\chi^2 = 149.9$, $P \leq 0.001$)

Table 1: VA through Gen 2^{++} NVG (*n*=60).

Illumination condition	VA Gen 2^{++} (logMAR values)			Friedman test	
	Mean (SD)	Median (IQR)	Range	χ^2	*P*-value
Full moon	0.22 (0.05)	0.21 (0.05)	0.11–0.31	149.9	<0.001
Half-moon	0.24 (0.05)	0.26 (0.05)	0.11–0.31		
Quarter moon	0.27 (0.06)	0.26 (0.10)	0.16–0.41		
Starlight	0.48 (0.10)	0.48 (0.11)	0.26–0.71		

decrement in VA with decreasing illumination. *Post hoc* analysis [Table 2] revealed that the difference in VA was statistically significant between all illumination levels other than FM and HF. Furthermore, the difference was marginally significant between HF and QM conditions.

Post hoc pairwise tests performed using Nemenyi test method for *P* value correction. Blue background denotes statistically significant difference.

Table 2: Difference in VA between different illumination conditions: GEN 2^{++}.

Illumination condition	FM	HM	QM	SL
FM	-	0.468	<0.001	<0.001
HM	0.468	-	0.050	<0.001
QM	<0.001	0.050	-	<0.001
SL	<0.001	<0.001	<0.001	-

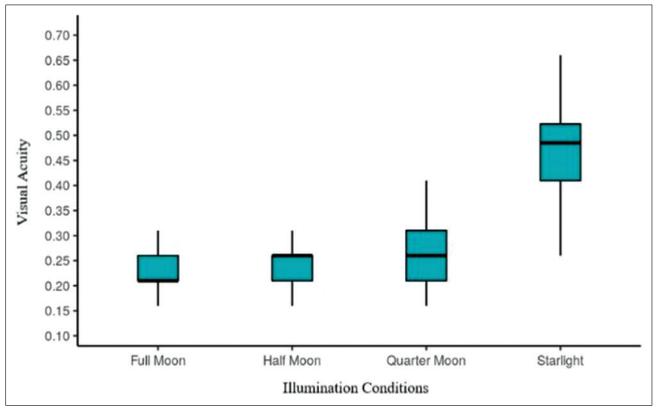

Figure 1: Box-and-Whisker plot (VA Gen 2^{++} NVG).

Gen 3 NVG

The VA in logMAR values through Gen 3 NVG under FM, HM, QM, and SL condition is depicted in Table 3 and Box-and-Whisker plot in Figure 2. In each box, the upper and lower bounds of the box represent the 75th and the 25th centile, for Gen 3, respectively [Figure 2]. As was observed with Gen 2^{++} NVG, there was a significant decrement in VA with decreasing illumination conditions (Friedman test: $\chi^2 = 156.5$, $P \leq 0.001$) while viewing through Gen 3 NVG. *Post hoc* analysis revealed that the difference in VA was statistically significant between all illumination levels and marginally between HF and QM conditions [Table 4].

Post hoc pairwise tests performed using Nemenyi test method for *P* value correction. Blue background denotes statistically significant difference.

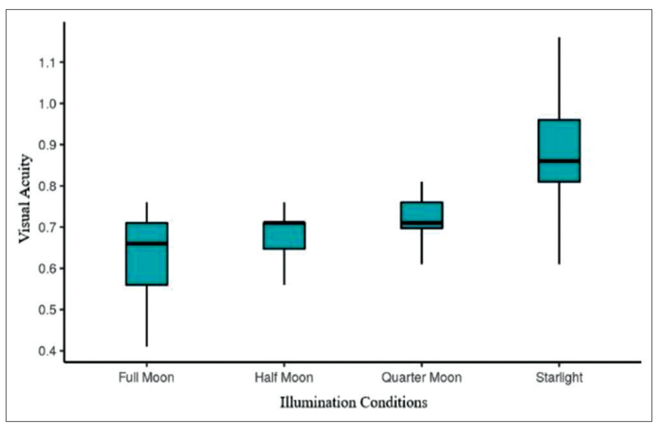

Figure 2: Box-and-Whisker plot table (Gen 3 NVG).

Comparison between Gen 2^{++} and Gen 3 NVG

Comparison of VA through both the NVGs, using the generalized estimating equations method, across various illumination conditions is depicted in Table 5. It was observed that the VA obtained through Gen 2^{++} NVG was significantly better than Gen 3 NVG in all illumination conditions (FM, HM, QM, and SL). This is depicted in the line diagram at Figure 3.

DISCUSSION

In a prospective repetitive measure design, a total of 60 healthy volunteers with 6/6 vision, aided or unaided, were examined for their VA through two different NVGs vis Gen 2^{++} and Gen 3 in the standard lab conditions of the eye lane room of the NVG Lab. The changes in VA were compared under four different illumination conditions; FM, HF, QM, and SL condition and between the two NVGs.

The results of the study brought out that the VA through Gen 2^{++} NVG decreased significantly with decrease in illumination ($\chi^2 = 149.9$, $P \leq 0.001$). Similar finding was also observed for Gen 3 NVG, where a statistically significant decrement in VA occurred with reduction in ambient illumination

Table 3: VA through Gen 3 NVG (*n*=60).

Illumination condition	VA Gen 3 (logMAR values)			Friedman test	
	Mean (SD)	Median (IQR)	Range	χ^2	*P*-value
Full moon	0.62 (0.08)	0.66 (0.15)	0.41–0.76	156.5	<0.001
Half-moon	0.67 (0.08)	0.71 (0.06)	0.41–0.81		
Quarter moon	0.71 (0.08)	0.71 (0.06)	0.46–0.91		
Starlight	0.89 (0.11)	0.86 (0.15)	0.61–1.16		

Table 4: Difference in VA between different illumination conditions: GEN 3.

Illumination condition	FM	HM	QM	SL
FM	-	0.027	<0.001	<0.001
HM	0.027	-	0.033	<0.001
QM	<0.001	0.033	-	<0.001
SL	<0.001	<0.001	<0.001	-

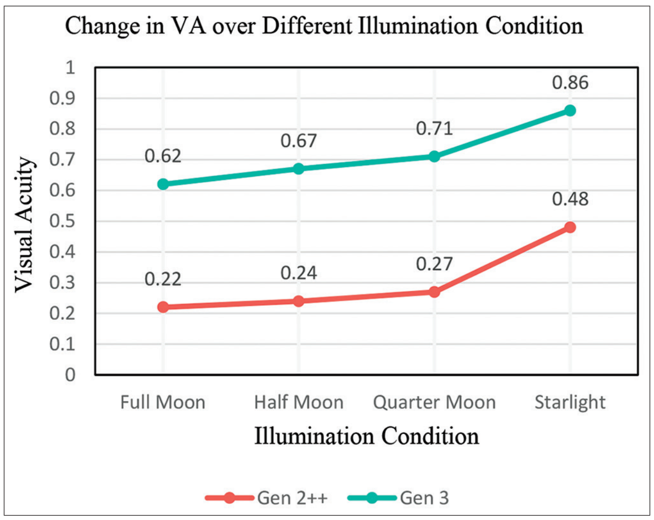

Figure 3: Line diagram depicting the change in VA (logMAR values) between Gen 2++ and Gen 3 NVG.

(χ^2 = 156.5, $P \leq 0.001$). These findings are in consonance with the results of other studies.[11-13] *Post hoc* analysis revealed that there was no significant difference in VA between FM and HM conditions in Gen 2++ [Table 2], but a significant difference in Gen 3 [Table 4]. This was also considered an important finding in the present study. This indicates that for operational usage in the field, half-moon could be the best viewing condition for NVG flying.[14] This is because FM conditions may cause blooming and glare. Brightly lit areas may saturate NVGs increasing brightness momentarily, and the user may effectively be blinded.[7,9,15] Furthermore, it is important to consider the azimuth or the moon angle with the horizontal as flying in the direction of the moon with low azimuth has a degrading effect on NVG performance.[16] With decreasing illumination, the signal-to-noise ratio decreases and this leads to scintillation of image and hence a decrement in VA.[16,17] This finding has operational implications in NVG flying, where a particular level of ambient illumination would be required to get best visual performance through NVG. A similar study keeping the contrast in view was conducted in this institute and revealed that even contrast sensitivity was better with Gen 2++ compared to Gen 3 under decreasing illumination conditions.[18]

The resolving power of the NVGs decreases with light level because the noise in the intensified image increases. The low light level resolution is not limited but continues to decrease with decreasing illumination levels. In addition to ambient illumination, VA is also a function of microchannel plate (MCP) and system focus.[10] The MCP affects VA in two ways; first, the spacing of elements within the MCP affects VA. The smaller the distance between elements, the better the VA. Second, the MCP affects VA through scintillation. Scintillation is a faint, random sparkling effect throughout the visual image produced which affects VA and image definition.[19] It is a normal characteristic of all MCP and is more pronounced under low light conditions.

Another important finding in this study was that VA was consistently better while viewing through Gen2++ NVG as compared to Gen 3 NVG contrary to our expectation. The Gen 3 has a gallium arsenide (GaAs) photocathode, but addition of the ion barrier reduces the electrons passing through to amplify the image.[20] This barrier is not present in GEN 2++. Due to the barrier, not every incoming photon is transferred into an electron; the quantum efficiency of a photocathode is in the range of 10–30%. A photon which is not transferred into an electron does not contribute to the image, thus increases the noisiness above its theoretical minimum value.[20] The MCP adds to the noisiness of the image by trapping photoelectrons which are not amplified. Especially the MCP film in GEN 3 tubes needed to protect the GaAs photocathode, is a photoelectron killer.[21,22] More than 50% of the emitted electrons get trapped by the MCP film. A photoelectron formed at the cathode, but lost at the film, could as well not be formed. This process is a substantial reduction of the effective cathode sensitivity of Gen 3 NVG.[20] It has been suggested that Gen 3 tubes are about 2 times better than for Gen 2 tubes. However, such a conclusion is typically not true due to two main reasons. First, radiant sensitivity of modern Gen 2++ tubes is much better than Gen 3 photocathodes.

Table 5: Comparison of VA with change in illumination conditions.

Illumination levels	2++		3		Wilcoxon-Mann–Whitney U-test (*P*-value)
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
Full moon	0.22 (0.05)	0.21 (0.05)	0.62 (0.08)	0.66 (0.15)	<0.001
Half-moon	0.24 (0.05)	0.26 (0.05)	0.67 (0.08)	0.71 (0.06)	<0.001
Quarter moon	0.27 (0.06)	0.26 (0.10)	0.71 (0.08)	0.71 (0.06)	<0.001
Starlight	0.48 (0.10)	0.48 (0.11)	0.89 (0.11)	0.86 (0.15)	<0.001
Overall *P*-value	0.011				Generalized estimating equations method

[22] Gen 3 photocathodes can be quickly degraded by positive ion poisoning that can reduce photocathode sensitivity up to about 2 times within a period of about 100 h. All these technical issues could possibly result in a reduced VA through the Gen 3 NVG experimented in our study.

In the present study, the effect of change in the angle of elevation of the simulated moonlight conditions could not be studied. Similarly, the effect of contrast on visual performance under varying illumination conditions was not within the scope of our study. Further, the NVGs studied were in operational usage, hence, the hours of use and its effects on the results could have been the confounding factors. These factors are also important variables in NVG performance and hence are considered the limitations of our study.

CONCLUSION

VA declined with decreasing illuminations for Gen 2^{++} as well as Gen 3 NVG, even though, the difference was not significant between FM and HM for Gen 2^{++} NVG. VA was observed to be consistently better through Gen 2^{++} NVG compared to Gen 3 across all four illumination conditions. However, keeping in view the dynamic changes in night sky illuminations during flying operations, the findings of the study need to be validated in operational conditions. The factors which need to be considered are angle of elevation as well as rapid changes in night sky illuminations.

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Declaration of patient consent

The authors certify that they have obtained all appropriate consent from the participants.

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Conflicts of interest

Dr. NK Tripathy is the Executive Editor and Dr. V Raghunandan is the technical editor of this journal. They do not have any conflicts of interest.

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