

Night Vision Goggles, Human Factors Aspects - A Questionnaire Survey of Helicopter Aircrew

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SUMMARY: Night vision goggles have become an essential component of military aviation. They provide superior visual capability over unaided night vision, but there are several inherent limitations associated with human factors and systems limitations. This study used a questionnaire survey of Army helicopter aircrew to investigate the incidence of human factors problems which continued after NVG use, with particular reference to visual problems and neck discomfort. It also looked at hardware interaction problems, such as cockpit lighting, and other aspects of NVG use, such as training and aircrew concerns. The issues are described and analysed, and areas of concern, which may have bearings on operational effectiveness and/or safety, have been highlighted.

Introduction

Night operations are playing an increasing role in military operations. Night vision goggles (NVGs) are widely used to enhance visual capabilities at night and as such have become an essential component of military aviation (1). Night vision goggles provide an amplified image of the ambient light, and although this is superior to unaided night vision, it is still inferior to daylight vision (2).

NVGs are a binocular assembly of two image intensifier tubes. Each of these has an objective lens, which focuses an image onto a photo-cathode and hence produces an amplified image that is viewed through an eyepiece lens (3). NVGs are a valuable aid to night flight, but there are inherent limitations on them. These limitations can be split into three groups: Visual limitations and spatial disorientation (related to field-of-view, visual contrast and acuity). Crew performance (affected by fatigue, endurance and crew co-ordination), and systems/hardware problems such as the inability to see wires and dimming of the image (by the automatic gain control) due to bright lights (4).

NVG training for helicopter pilots is split into three categories. All student pilots in the Army Air Corps are required to fly at Category One. Categories Two and Three require successively more flying and NVG experience and include tactical flying (5). Several types of NVGs are available, but the Army Air Corps mainly employed two types; ANVIS and Nite-op, at the time of the questionnaire.

Most of the literature reports about NVG associated problems concentrate on those occurring during flight, and give little or no indication of the frequency with which they occur in the user population (6,7,8). The concerns covered by these reports can be split into two groups: human factors, such as optical illusions and stress; and systems/hardware limitations, such as the limited field of view and incompatible lighting. This study was carried out using a questionnaire designed to investigate the incidence of human factor problems that occurred both during flight and those which continued after NVG use by helicopter aircrew. Copies of the questionnaire are available from the author.

Methods

A questionnaire was compiled to identify the problems experienced by helicopter aircrew, associated with the use of NVGs. This was designed to be filled in anonymously and was divided into sections: Personal details; History of flying; Vision and NVGs; Comfort and NVGs, in particular neck discomfort; and NVG training and use.

Four aircrew completed a trial questionnaire, with the interviewer present. They were encouraged to discuss the

questions with the interviewer and their suggestions were taken into consideration before the final questionnaire was assembled.

Questionnaires were personally delivered to and collected from the Officers Commanding (OCs) Army Air Corps (AAC) squadrons at the School of Army Aviation, Middle Wallop and 5 Regiment AAC, Northern Ireland. The OCs then distributed them amongst their NVG users and assumed responsibility for the collection and return of completed forms. Several other questionnaires were sent to individuals upon request and these were returned by post.

Chi-squared statistical analysis was performed on the data.

Results

Respondents

Seventy-five questionnaires were distributed and 59 returned (i.e a 70% return) by: 31 qualified helicopter instructors; 11 aircraft (pilot) commanders; 2 helicopter pilots; 7 student pilots and 8 door gunners. Their NVG experience ranged from 6 to 830 hours.

The respondents were all male with an age range from 21 to 62 years (mean=33.8 years; sd=7.9). Eighty six percent of the respondents were pilots, of which 60% held NVG category 1; 32% held NVG category 2; and 18% held NVG category 3.

Eighty-five percent used ANVIS Mk1 NVGs most often, with Nite-op making up the other 15%. All respondents flew in Lynx and/or Gazelle helicopters.

Vision and NVGs

This section dealt with the occurrence, frequency and duration of visual symptoms that had been experienced during and after an NVG sortie. A summary of the results is shown in Table 1.

NVG focusing

Thirty-five percent of respondents reported needing to refocus their NVGs and they were shown to be linked to those who suffer from tired eyes ($p<0.05$). This set was also linked to those who experience blurred vision ($p<0.05$), inferior 'daylight' vision ($p<0.01$), inferior night vision ($p<0.01$) and distance vision problems ($p<0.05$).

Blurred vision

The link between those who experience blurred vision and those who refocus inflight ($p<0.05$) may imply an association with visual fatigue (see NVG focusing above).

Night vision problems

The quality of the respondents; 'naked eye' night vision was rated on a scale of 1 to 5, (one being normal, 5 being very poor), both 15 minutes and an hour after NVG use. The quality of

Table 1
Incidence of visual symptoms experienced after NVG use.

Symptom	No. of respondents	% of respondents	Frequency	Duration
Brown images	38	65	30 Always	22 <10mins
			4 often	7 10-30mins
			4 Infrequently	7 >30mins
Blurred vision	12	22	4 Often	3 <30mins
			8 Infrequently	4 1/2 -1hour
				4 >1hour
Dimmed Vision	4	7	2 Often	4 <1hour
			2 Infrequently	
Double Vision	0	0		
Tired Eyes	37	63	6 Always	4 <30mins
			9 Often	7 1/2 -1hour
			17 Infrequently	16 >1hour
Sore Eyes	13	22	5 Often	4 <30mins
			8 Infrequently	5 >1hour
Red Eyes	4	7	2 Often	4 >1hour
			2 Infrequently	
Watering Eyes	3	5	1 Often	3 <30mins
			2 Infrequently	
Subnormal night vision (1 hour after NVG)	37	63		
Subnormal 'daylight' vision (1 hour after NVG)	27	47		
Distance vision problems (within 1 hour)	12	22		1 <30mins
				3 1/2 -1hour
				5 >1hour
Close vision problems (within 1 hour)	12	22		4 1/2 -1hour
				7 >1hour
Judging distances(near)	2	3		
Judging distances (far)	1	2		

vision was generally felt to improve with time, with 33% of respondents reporting normal vision after 15 minutes but 67% doing so after an hour. However, 10% of respondents reported that the quality of their night vision deteriorated with time.

'Daylight' vision problems

The quality of respondents' 'daylight' vision was rated on a scale of 1 to 5, both 15 minutes and one hour after NVG use. The quality of vision was generally felt to improve with time, with 53% of respondents reporting normal vision after 15 minutes, but 67% doing so after an hour. However, 15% of the respondents reported that the quality of their 'daylight' vision deteriorated with time.

Distance vision problems

Of respondents 12 reported problems with their distance vision within 1 hour of an NVG sortie. A third of these did so after every NVG sortie, and 7 of them (57%) also reported problems with close vision.

Near vision problems

Of respondents 12 reported problems with near vision within 1 hour of an NVG sortie. A quarter of these did so after every NVG sortie and 7 of them (58%) also reported problems with distance vision.

Comfort and NVGs

This section dealt with the occurrence, frequency and duration of discomfort (such as headaches and neck ache) which had been experienced after an NVG sortie. There were also subsections covering neck discomfort during and after NVG sorties. A summary of the results is shown in Table 2.

Neck discomfort

The incidence and nature of neck discomfort associated with the use of NVGs, both during and after flight, was investigated. Control questions about neck discomfort during and after non-NVG sorties were included and the results (presented in Table 2) indicate a clear association between NVG use and both in-flight and post-flight neck discomforts.

More respondents reported neck discomfort beginning during flight (n=34) than after flight (n=28), whilst 26 respondents reported having experienced both. Furthermore, the symptoms of post-flight neck discomfort occurred less frequently and tended to be less severe than those of in-flight neck discomfort. Ten respondents reported having suffered a neck injury, but this was unrelated to the incidence of NVG associated neck discomfort.

In-flight neck discomfort

Neck discomfort was more common during an NVG sortie

Table 2
Comfort concerns associated with NVG use.

Symptom	No. of respondents	% of respondents	Frequency	Duration
Neck ache (during NVG sortie)	34	59	5 Always 16 Often 13 Infrequently	27 <1 day 6 1-2 days 1 3-7 days
Neck ache (after NVG sortie)	28	48	1 Always 6 Often 7 Infrequently	8 <1 day 4 1-2 days 1 3-7 days 1 <1 month
Headache - at the front	15	26	5 Often 7 Infrequently	9 <1 hour 3 >1 hour
Headache - between temples	10	17	4 Often 5 Infrequently	5 <1 hour 4 >1 hour
Headache - at the back	10	17	2 Often 4 Infrequently	5 <1 hour 2 >1 hour
Nausea	4	7	4 Infrequent	3 1/2-3 hrs
Dizziness	1	2		

than during a non-NVG sortie, with 59% of respondents (n=34) reporting symptoms after NVG sorties compared to 14% (n=8) otherwise. There was no significant difference between the frequency of neck discomfort experienced with and without NVGs, and the severity of the symptoms was less with NVGs than without.

Post-flight neck discomfort

More respondents had experienced neck discomfort after an NVG sortie than after a non-NVG sortie. Forty-eight percent of respondents (n=28) reported having symptoms after an NVG sortie compared to 12% (n=7) otherwise. There was little difference between the frequency of symptoms and the degree of restriction of movement experienced by individuals, between these two groups. The severity of the symptoms was less after NVG sorties than otherwise.

Headaches

Of the 25 respondents who reported having suffered from headaches of any type after NVG sorties, no control questions about headaches after non-NVG sorties were asked, and so the significance of these results cannot be assessed.

The types of headaches were reported singly or in various combination, but it was noted that individuals were more likely to report headaches both of the front and between the temples than in any of the other combinations.

Duration of the headaches was normally less than one hour and was often linked to the length of the sortie, and the amount of concentration required during the sortie.

Headaches - frontal, or between the temples

These were shown to be associated with visual difficulties, such as problems with near (p<0.01) and distance vision (p<0.01) and sore eyes (p<0.01). They were also linked to muscular symptoms, with the group of respondents experiencing these headaches being significantly related to the group experiencing in-flight neck discomfort (p<0.01).

Headaches - at the back of the head

The only significant link appeared to be with in-flight neck discomfort associated with the use of NVGs (p<0.01), probably due to muscular symptoms in the neck and the weight distribution on the helmet causing muscular fatigue.

NVG training and use

This section dealt with training and specific hardware usage on interaction problems or worries. Many of the questions in this section were open ended to allow identification and description of problem areas.

Training

Of respondents 22 felt that the ground-based NVG training before their first NVG sortie was insufficient.

Pre-flight adjustment and focusing

All of the respondents reported focusing their NVGs out of doors (on the airfield) or inside the aircraft, except for two pilots who use printed material in their offices. Most respondents reported to adjust and focus their NVGs as per training, although for some this was reported to be 'set the dioptre at 0 and then focus the objective'. More alarming comments, such as 'fiddle with the adjustments for a bit until a clear image is formed' were made, and this is likely to provide less than perfect visual acuity, and consequently lead to decreased aircrew performance.

Thirty-five percent of respondents (n=20) reported that they normally refocus their NVGs during and NVG sortie.

Of respondents 20 indicated that they normally readjust their NVGs during an NVG sortie.

About 10% of respondents do not find NVGs straightforward to focus and adjust. There was some feeling that ANVIS are harder to adjust than Nite-op, which is probably because the former requires more focusing adjustments to be made.

Difficulties experienced when using NVGs

Forty-four percent of respondents (n=26) reported difficulties with NVG flying. Respondents were asked to specify the nature of the difficulty, and in 70% of cases (n=18) it was due to lighting problems, both inside and outside of the cockpit. This figure represents over 30% of the total number of respondents and is extremely high considering the open-ended nature of the question.

Seventeen percent of respondents wear spectacles (n=10), but there was only one report of any problems related to their use, this described reflection when using a (eye protection) visor with spectacles. Other difficulties experienced include shifting focus between inside and outside of the cockpit, and the

monitoring of instruments underneath the NVGs. This may be caused by fatigued eye muscles being slow to change focus from the outside to the inside of the aircraft, or it may be associated with night myopia.

General feelings and concerns about NVGs

Of respondents, 14 felt concern about some aspect of NVG use. When asked to express any general worries, 8 of the respondents (14%) indicated concern about the long-term effects on eyesight. The incidence of spectacle wearers is the same in both NVG user (10%) and total aircrew populations (12%).

Other worries concerned the consequences of the extra weight of the helmet plus goggles on accident survival rates. There seems to be a general feeling that more up to date and easily available information would be welcomed.

Discussion

Visual fatigue and NVG focusing

Although visual fatigue is a common experience, it does not have an accurate scientific description. The main contributing factors may be: physical (e.g. neck muscle strain); psychological (e.g. linked to stress); and physiological (as discussed below) (6).

Incorrect focusing of NVGs (especially of the dioptre lens) results in eye muscle fatigue (3). If the diopter focus ring is turned too far, the eye muscles will initially accommodate for the over adjustment, but over time they will become fatigued (9). Another cause of eye fatigue is the use of NVGs with incorrectly set interpupillary distances (IPD). If the NVG tubes are not properly adjusted for IPD, the user will have to add either convergent or divergent fusion effort (10). Vergence is linked to accommodation and so errors in vergence lead to degraded accommodation and hence degraded resolution. This results in the user having fatigued eye muscles and a compromised visual capability.

Correctly focused NVGs should not need to be adjusted in-flight and so any requirement to do so indicated that the NVGs were incorrectly focused. Use of incorrectly focused and adjusted NVGs leads to eye muscle fatigue (3).

Use of standardised NVG focusing routine before each NVG sortie may help to reduce the incidence of visual problems associated with the use of NVGs. Such a pre-flight routine has been tested and shown to result in a better visual capability (11), which implies better NVG focusing.

Brown images

This condition is well documented (1,5,7,12) and all NVG users should have been made aware of it during training. It is a physiological effect of looking for prolonged periods at a green image (the NVG display) and is thought to be due to fatigue of the green photoreceptors (12). This effect is not thought to cause any long-term physiological problems (13) and these results show its transience.

Night vision problems

Ten percent of respondents reported that the quality of their night vision deteriorated with time. Reasons for this are unclear, but may be linked to tiring of the eye muscles with time and hence increasing severity of the symptoms of visual fatigue (such as blurred vision). Misunderstanding of the scale rating the visual quality is also a possible reason for the result.

Blurred vision ($p<0.01$), distance vision problems ($p<0.05$) and in-flight refocusing ($p<0.05$) are linked with reports of inferior night vision problems and these may all be linked with visual fatigue.

'Daylight' vision problems

Fifteen per cent of the respondents reported that the quality of their 'daylight' vision deteriorated with time. Reasons for this are unclear, but may be linked to tiring of the eyes and so increasing awareness of the symptoms of eyestrain (such as blurred vision). Misunderstanding of the scale for rating the visual quality is also a possible reason for the result.

Blurred vision ($p<0.01$), distance vision problems ($p<0.05$) and in-flight refocusing ($p<0.01$) are linked with reports of 'daylight' vision problems and these may all be associated with visual fatigue. Inferior 'daylight' vision is also linked to problems with close vision.

Distance vision problems

Problems with distance vision were related to tired eyes ($p<0.01$). The need to refocus NVGs in-flight was also associated with distance vision problems ($p<0.05$) and this inferred that visual fatigue may have been the problem (see NVG focusing). The group of subjects with high amounts of total and NVG experience (above 3000 hours and 100 hours respectively) were shown to be related to the group of who experienced distance vision problems ($p<0.05$ for both). Therefore, this may indicate a problem that develops with flying experience and age, rather than NVG use.

The group who reported problems with near vision was related to the group who experienced tired eyes ($p<0.01$) and blurred vision ($p<0.01$), both of which were associated with visual fatigue. Subjects with high amounts of total and NVG experience (above 3000 hours and 100 hours respectively) were shown to be related to those with near vision problems ($p<0.01$ for both). Therefore, this again may indicate a problem that develops with flying experience and age, rather than purely NVG use.

Tired eyes

The group of respondents who reported experiencing tired eyes was related to that of respondents with more than 100 hours of NVG experience ($p<0.05$). However, there is no association with total flying experience and so there may be a cumulative relationship between NVG experience and tired eyes.

Sore eyes

A link between those who experienced sore eyes and those who reported headaches (occurring either at the front of the head or between the temples) ($p<0.01$) was shown. One cause of frontal headaches (at the front or between the temples) is excessive contraction of the ciliary muscles, as occurs when an individual is having difficulty focusing (14). This was shown in the association of sore eyes and headaches. There was an association between the groups reporting sore eyes and near vision problems within 1 hour of an NVG sortie ($p<0.05$).

Judging distances

The ability to judge distances is a subjective assessment of depth perception. It has been shown that use of NVGs with incorrect setting of the interpupillary distance (IPD) may lead to a reduction in depth perception of the user (10). This is because if the NVG tubes are not directly in front of the eyes, the user has to add either convergent or divergent effort. This leads to a degradation of accommodative accuracy and gives rise to a loss of depth perception.

In-flight neck discomfort

The discomfort described, associated with NVGs, was mostly minimal or moderate pain at the extremes of movement. The

head position associated with the pain varied, but appeared to be slightly more common when looking to the side. This may be related to the scanning movements required during NVG sorties. The duration of neck discomfort was mostly less than 3 days and the only effect on subsequent sorties was a cumulative increase in pain with each sortie. Medical treatment for NVG associated neck discomfort was not sought by any of the respondents.

Questions about the type of NVG and whether or not a counterbalance was used, when neck discomfort was experienced, would have been valuable. Furthermore, opinions regarding the use of the counterbalance may have proved interesting.

Post-flight neck discomfort

The discomfort described associated with NVG sorties was mostly minimal pain at the extremes of movement (i.e. less severe than in-flight neck discomfort). The head position associated with the pain varied between individuals, but there appeared to be an increased incidence of pain when looking behind. This movement is an extreme of the 'to the side' position (when in-flight neck discomfort was experienced), and may also be caused by the scanning movement required during NVG sorties. The duration of neck discomfort was mostly less than 3 days, and the only effect on subsequent sorties was a cumulative increase in pain with each sortie. Medical treatment was sought by one of the respondents for NVG associated neck discomfort, compared with two who did so for non-NVG associated discomfort.

Nausea

Nausea after an NVG sortie may be associated with changes in dark focus, similar to that observed during simulator sickness and further work in this area has been recommended (15).

NVG training

Suggestions for improvements included more hands on training in the adjustment and focusing methods, and the possible provision of focusing aids. A demonstration of the best possible image achievable was also suggested.

None of the door gunners had had any formal NVG training. Provision for the training of door gunners is extremely important in order to ensure a high level of operational effectiveness.

Pre-flight adjustment and focusing

Correctly focused NVGs should not need to be refocused in flight, and so any need to do so indicates that they were not correctly focused initially. Reasons for refocusing ranged from 'fine tuning the focus' to 'having a bad set of goggles'.

The provision of a standardised pre-flight routine for NVG alignment and focusing, using a Snellen chart or a focusing aid, would ensure that all aircrew could achieve the best possible visual capability (11). This should decrease the incidence of visual problems and headaches currently being reported by NVG users.

The main reason for readjusting the goggles was that the flying helmet had moved, but some comments about discomfort were also expressed, particularly with reference to Nite-op use. One respondent also indicated that the readjustment was needed to allow monitoring of the instruments. This adjustment should not be necessary and may lead to decreased visual capability if the NVGs are not repositioned correctly.

Difficulties experienced when using NVGs

Exterior lighting was the main concern, being both due to city

lights and navigation lights. High light levels cause the NVGs to reduce the gain and hence produce a picture that is less detailed. This decrease in visual quality makes flying harder and more dangerous. It also produces glare on the NVG display, which is uncomfortable for the user. Navigation lights were reported to cause problems during certain manoeuvres. For example, the reflection of navigation lights off the under side of the rotor whilst banking lead to dimming of the NVG image. Interior lighting problems were also mentioned, with various items of equipment (e.g stand-by compass and NVG torch) being hard or distracting to use with NVGs, and cockpit reflections causing distractions.

Concerns about the longer term effects on eyesight

Fourteen percent of respondents indicated concern about the long-term effects on eyesight. The relationship between those with extensive NVG experience (greater than 100 NVG hours) and those who need to wear spectacles was investigated and found not to be significant, but there was a link with age.

Critique of Questionnaire

The requirement to ask as many control questions as necessary to validate the results would have produced a huge questionnaire, which had to be avoided to ensure that sufficient numbers were completed fully and returned. With hindsight more control questions could have been asked.

That being said, the results have highlighted areas which justify more research, such as visual fatigue and neck discomfort. They have also identified a need for door gunner training.

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