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Performance Evaluation of Aviation Headset in Indian Army

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ABSTRACT

Passive hearing protective devices, referred also as ear defenders, work by obstructing noise propagation through the ear canal of the receiver. These gadgets are a popular choice as they offer high attenuation over a broad frequency range, though at times inadequately, especially in the low frequency region, as per International Standards of occupational exposure to noise. Upward masking of speech signal by low frequency noise also degrades the intelligibility of speech in noise that may lead to decrement in performance and hamper the safety of individuals working in noisy occupational environments. Active noise reducing hearing protective devices lend the possibility of avoiding these problems particularly where the major acoustic energy is centered at low frequencies, rendering these active contraptions a powerful tool in preventing noise induced hearing loss without hampering speech/oral communication. Accordingly, the present study was undertaken to investigate the potential of Telex Stratus 30 Headset in providing protection against noise induced hearing loss and to evaluate its efficacy in improving the speech intelligibility of our Armed forces personnel working in different noise spectral environments.

Keywords: Active Noise Reduction; Temporary Threshold Shift; Insertion Loss; Speech Intelligibility; Noise Dose

1. INTRODUCTION

Noise is one of the most common cause of hearing loss[1-3], and one of the most common occupational hazards in the military environment worldwide. The effects of noise are often underestimated because there are no externally-visible physical changes. Noise induced hearing loss (NIHL) is characterised by a gradual, progressive loss of high frequency hearing sensitivity over time, as a result of exposure to excessive noise levels[4-5]. In later stages, the hearing loss may spread to frequencies that are more critical to understanding human speech (500 Hz - 3000 Hz). The impact of noise-related hearing loss is not appreciated until one is frustrated by a permanent communication problem. Once hearing sensitivity has been lost, it is impossible to reclaim. A sorry situation that is entirely preventable.

Loss of hearing and decline in frequency selectivity hinder the detection, localisation and identification of acoustic sources in the military environment, hampering the efficiency, security and well-being of the soldier. Moreover, the impairment of speech intelligibility in noisy environments can drastically reduce the performance of complex and expensive weapon systems[6-7]. There is a growing concern regarding the effects of noise and the necessity to control it.

The available techniques to control noise and protect the hearing fall into three categories; noise can be reduced at the source, in the propagation path or on the personnel working in noisy occupational environment. The source of the acoustic energy emitted by mechanical devices may be single or multiple. Due consideration on acoustic aspects during the design stage of the mechanical equipment is the most effective way to reduce noise, as engineering modifications at later stages will not yield cost effective solutions. The next line of defense is to modify the transmission path to block or reduce the flow of sound energy before it reaches the receiver. This can be achieved by reflection, diffraction, insulation or dissipation of noise. These techniques are best suited for high frequency component of noise but may become bulky, expensive, and unfeasible solutions for low frequencies. Reduction of noise at the receiver's auditory system has proven to be the most effective and least costly of the options.

Passive hearing protective devices[8-9] such as earplugs or earmuffs, reduce noise at the entry point of the ear canal of the receiver. These passive ear defenders are very effective because of their high attenuation over a broad frequency range; however, they provide little attenuation in the low frequency region. Since low frequency noise causes upward masking of speech signal[10-11], use of passive ear defender in noisy environment is detrimental to speech/oral communication. Due to the poor efficiency of passive hearing protectors in the low frequency region, the exposure level even when 'protected' with a standard circumaural protector is still very high, which will seriously limit the training period of the soldiers in noisy environments as per the international noise exposure standards[12-14].

Exposure time limitation, reduction in speech intelligibility and increased fatigue are important factors

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that strongly impede the efficiency of the soldiers in noisy occupational environments. One possibility of avoiding these problems, where the major acoustic energy is centered at low frequencies (as experienced during the running of tanks, helicopters, propeller aircrafts etc.) is the use of active noise reducing (ANR) hearing protectors[15-18]. Properly selected passive hearing protective devices (HPDs) incorporating active noise cancellation can be a powerful tool for preventing NIHL without hampering the speech/oral communication.

2. MATERIALS AND METHODS

2.1 TELEX Stratus 30 Aviation Headset

The TELEX Stratus 30 ANR Headset as shown in Fig. 1 was evaluated for its performance efficacy and user's acceptability at Army Base workshop during testing of T-72 tank and testing and repairing of TATRA Engine.

The device is working on the principle of destructive interference. It has microcontroller based active noise cancellation circuitry. The device has the noise reduction of ≤ 30 dB and weight is 403 gm, as per datasheet of the product.

Figure 1. Telex Active Headset.

2.2 Selection of Subjects

The study was carried out on 19 audiometrically normal healthy volunteers belonging to the age group 19 – 30 years. Subjects were further divided into two groups, I and II, based on their routine exposure conditions namely, exposed to T-72 tank noise (Group I) and exposed to Tatra engine in B-Engine test house (Group II). The subjects were familiarised with experimental design, aims, objective and methodology and informed written consent taken, which was duly approved by the Institute's Ethics Committee.

2.3 Audiometry

The same subjects were exposed to noise in two different conditions namely, (i) ON Mode, while wearing Active Headset in ON condition (active mode) and (ii) OFF Mode, while wearing Active headset in OFF condition (passive mode). The baseline audiometry of the subjects was carried out in a quiet room after overnight rest and the post exposure audiometry in the two different conditions was carried out soon after the exposure to noise on successive days. Difference between pre and post audiogram indicated the temporary threshold Shift (TTS) developed at each frequency. The audiometry of the subjects was carried out with Maico, MA 53 that meets the specification IEC 645-1/EN 60 645-1 Type 2, IEC 645-2 Type A. The instrument has 1 dB resolution and provides the facility for precise assessment of hearing acuity of individuals. The instrument was calibrated prior to use. The audiometric test was carried out for both the ears in air conduction mode in frequency range of 0.125 kHz to 8 kHz.

2.4 Measurement of Noise Levels and Frequency Spectrum

The attenuation characteristics of the device were evaluated using microphone in real ear (MIRE) technique. 1/3 octave frequency spectrum at both ears was recorded with the help of B&K data acquisition system with PULSE v 6.0 software in combination with Binaural Microphone. The frequency spectrum was recorded in three conditions:

(a) Open ear spectrum (OE): during noise exposure without any ear defender,
(b) Passive-protected-ear spectrum (PP): during active headset donned in 'OFF' mode, and
(c) Total protected spectrum (TP): during active headset in 'ON' mode.

From the 1/3 octave frequency spectrum obtained, the following insertion losses[19] (IL) were calculated. 'A' weighted equivalent continuous sound pressure level (LAeq), 'A' Weighted instantaneous peak sound pressure level (LA_{pk}) and frequency spectrum of T-72 tank noise and TATRA Engine at 505 Army Base Workshop were recorded with the help of B & K Type 2260 Type 1 Modular Precision Sound Level Analyser. The function of B & K Type 2260 conformed to IEC specifications and recommendations.

The noise dose received by the personnel during their exposure to noise was recorded while wearing the device in 'OFF' and 'ON' mode using Noise Dose Meters B & K Type 4442 and Type 4443.

2.5 Speech Intelligibility

Speech intelligibility performance was carried out in field conditions. 50 commonly used hindi words were presented with noise to speech ratio 1:1 at background noise of 90 dBA[17, 20-21]. The participants wrote down the words presented to them through speaker under two conditions namely, (i) noise and speech words with active headset in 'OFF' mode and (ii) noise and speech words with active headset in 'ON' mode.

2.6 Statistical Analysis

The data obtained for TTS evaluation and speech intelligibility was statistically analysed using paired t-test.

2.7 Subjective Impression

A questionnaire was given to each subject at the end of the experimental procedure for obtaining the subjective impression regarding the operation, comfort and effectiveness of the device.

3. RESULTS

3.1 Physical Characteristics of the Subjects

The physical characteristics of the human participants selected for the study at 505 Army Base Workshop is presented in Table 1. Both groups were homogenous with respect to age and physical status.

Table 1. Physical characteristics of human volunteers

Groups	Age (Years)	Height (cms)	Body Weight (kg)	BMI (kg/m^2)
Exposure to T-72 Tank Noise (n=9)	23.4 ± 3.5	173.2 ± 8.0	63.8 ± 9.5	21.2 ± 2.4
Exposure to Tatra Engine (n=10)	23.1 ± 3.8	172.0 ± 8.2	65.4 ± 13.2	22.3 ± 4.4

3.2 Noise Levels and Frequency Spectrum

Table 2 gives LAeq and LA_{pk} of T-72 tank and TATRA Engine running in idling condition.

LAeq at a distance of 1 m ranged from 93.2 dBA to 95.7 dBA and 94.4 dBA to 98.0 dBA for T-72 tank and TATRA Engine respectively. LA_{pk} at a distance of 1 m ranged from 107.9 dBA to 111.4 dBA and 109.2 dBA to 112.8 dBA for T-72 tank and TATRA Engine respectively. These LAeq values are almost same and well within the acceptable limit of exposure standards for exposure duration of 45 min.

Table 2. Noise parameters of T-72 Tank and TATRA Engine at a distance of 1 m

Source of Noise	LAeq (dBA)	LA_{pk} (dBA)	LAE (dBA)
T-72 Tank	93.2 – 95.7	107.9 – 111.4	111.1 – 113.6
Tatra Engine	94.4 – 98.0	109.2 – 112.8	112.2 – 116.1

A-weighted constant sound exposure level integrated over 1 s duration (LAE) at a distance of 1 m ranged from 111.1 dBA to 113.6 dBA and 112.2 dBA to 116.1 dBA for T-72 tank and TATRA Engine respectively. The values are well within the limits of exposure standards of 135 dBA for 1s duration.

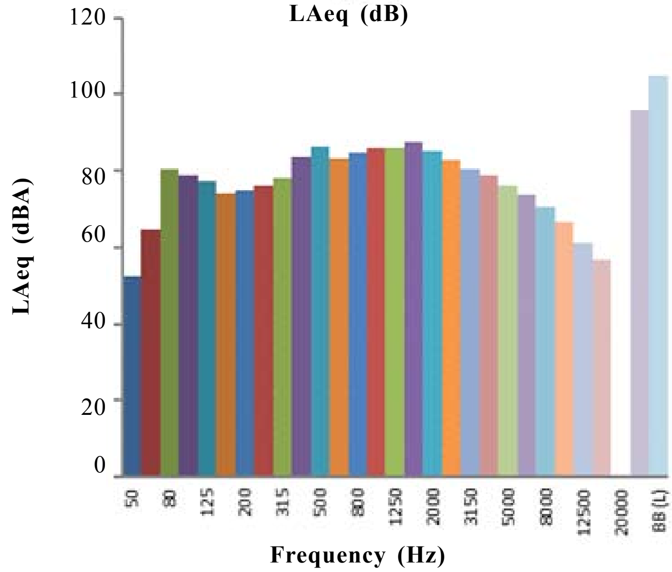
1/3 octave frequency spectrum of noise taken at a distance of 1 m from T-72 tank and TATRA Engine is presented in Figs. 2(a) and 2(b), respectively. Frequency spectrum of T-72 Tank noise (Fig. 2(a)) clearly indicates the presence of high level of low frequency component in the frequency range of 50 Hz to 250 Hz, as compared to TATRA engine (Fig. 2(b)). At all other frequencies the frequency spectrum for T-72 tank and TATRA engine is almost the same.

3.3 Temporary Threshold Shift Evaluation

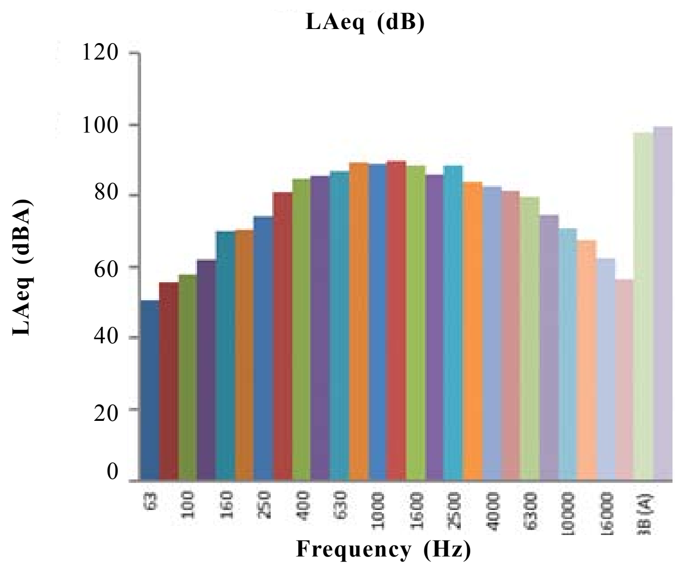
The mean hearing threshold levels (dB) of both groups of subjects before and after the exposure to noise for 45 minutes were recorded in air conduction mode just after the exposure to noise in two different conditions on successive days.

The mean temporary threshold shift (TTS) in right and left ears of the subjects after 45 minutes exposure to T-72 tank noise (Group I) in idling condition and TATRA engine running at 1100 rpm (Group II) in two conditions is presented in Figs. 3(a)-3(b) and Figs. 4(a)-4(b) respectively.

In passive (OFF) mode, exposure to T-72 tank noise resulted in the development of TTS ranging from 2.4 dB to 8.4 dB and 2.0 dB to 9.6 dB in the right and left ears respectively (Figs. 3 (a) and 3(b)). With exposure to TATRA engine noise the TTS ranged from 1.4 dB to 6.8 dB and 1.6 dB to 6.2 dB in the right and left ears respectively as shown in Fig. 4(a) and 4(b).



(a)



(b)

Figure 2. 1/3 Octave Frequency Spectrum of (a) T-72 Tank noise (b) TATRA Engine noise.

In active (ON) condition, the TTS was significantly reduced in both groups of subjects. The mean TTS in group I ranged from 0.4 dB to 4.2 dB and 0.7 dB to 3.8 dB in the right and left ears respectively as shown in Fig. 3 (a) and 3(b). Whereas in group-II it ranged from 0.6 dB to 3.6 dB and 1.0 dB to 3.8 dB in the right and left ears respectively as shown in Fig. 4(a) -4(b).

The development of TTS was significantly less when the subjects were wearing active headset in ON mode as compared to OFF mode due to attenuation of lower frequency component of noise in addition to the higher frequencies.

Further, as seen from Figs. 3(a)-3(b) vis-a-vis Figs. 4(a)-

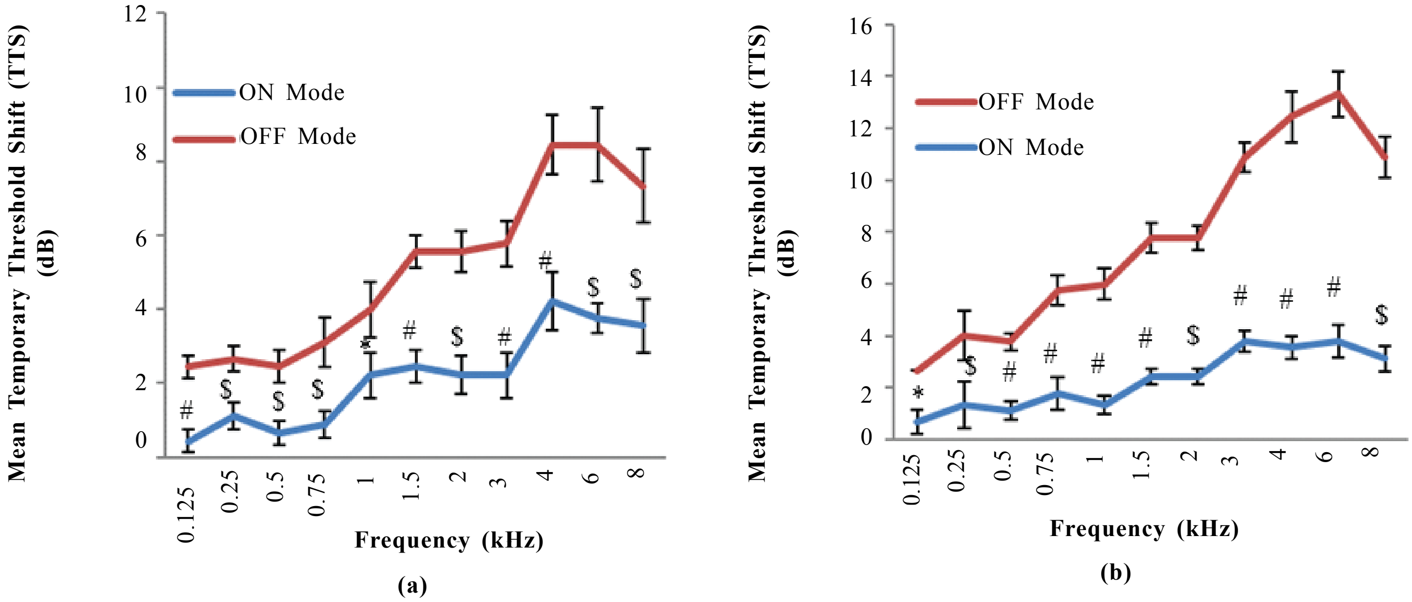


Figure 3. Mean temporary threshold shift of (a) Right ear and (b) Left ear on exposure to T-72 Tank noise.

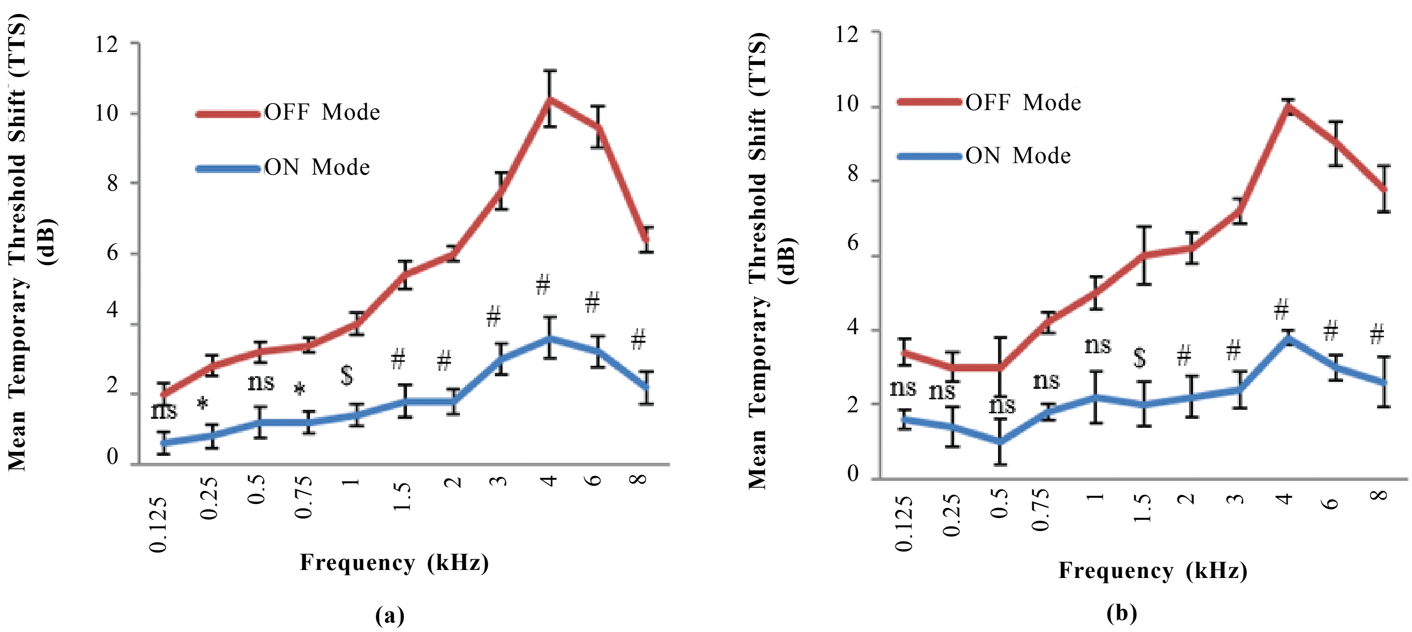


Figure 4. Mean temporary threshold shift of (a) Right ear and (b) Left ear on exposure of TATRA engine noise.

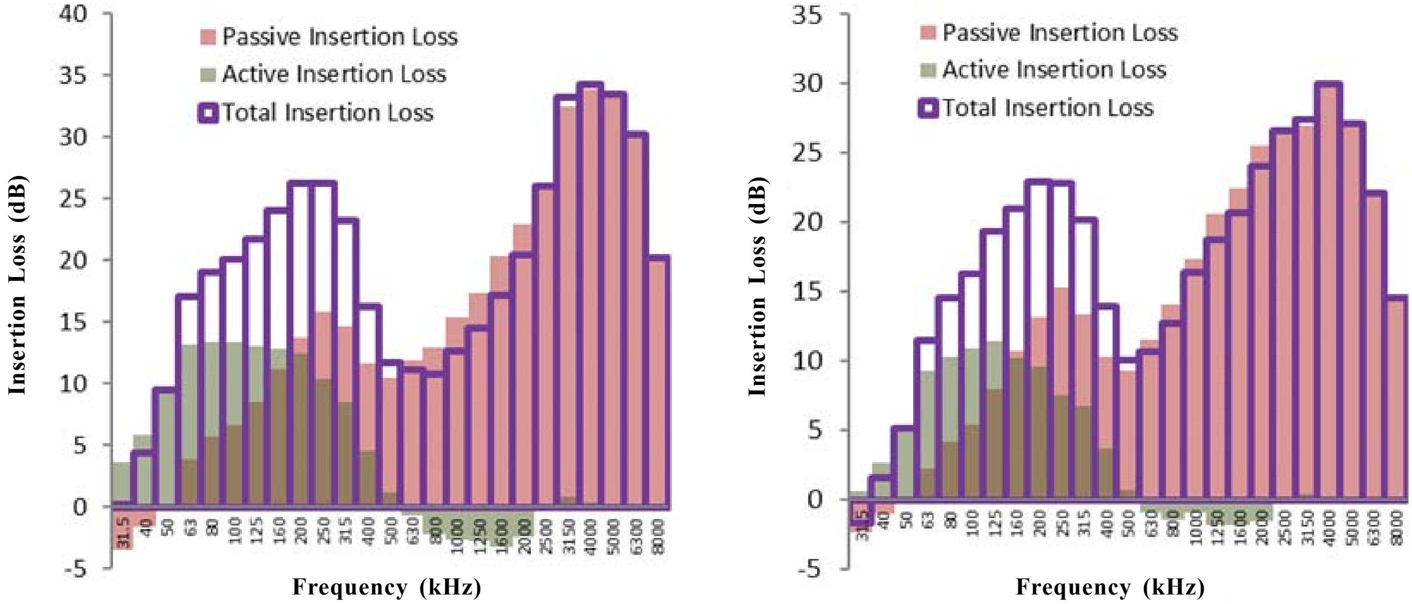
4(b) development of TTS in OFF mode is more when the subjects were exposed to T-72 tank noise as compared to when the subjects were exposed to TATRA engine noise due to poor performance of the active headset in OFF mode against low frequency component of noise.

3.4 Attenuation Characteristics

Figures 5 and 6 give the Passive insertion loss (IL_P), active insertion loss (IL_A) and total insertion loss (IL_T) in one-third octave spectrum against background noise of T-72 tank running in idle condition and TATRA engine running at 1100 rpm in the field conditions.

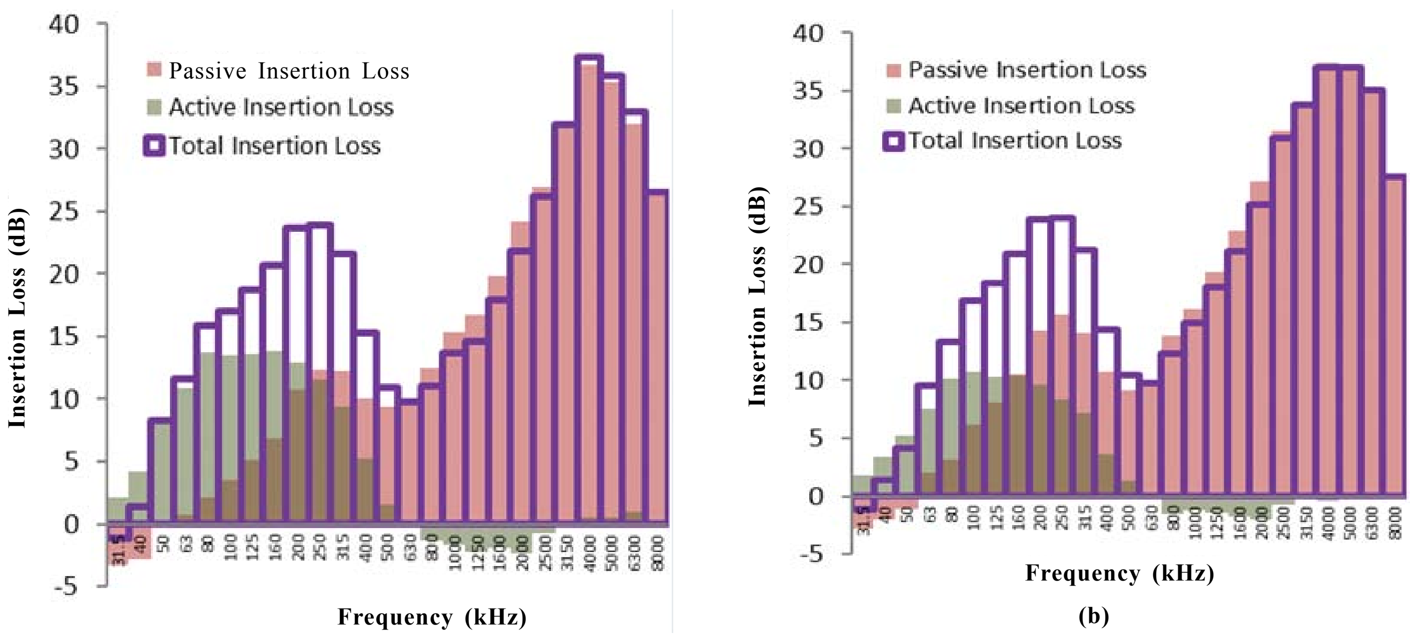
As seen from the Figs. 5 and 6, the high frequency component of the noise is attenuated by the passive insertion loss of the headsets. Active insertion loss (IL_A) is more dominant in the lower frequency range below 250 Hz, as compared to passive insertion loss (IL_P). Passive protection provides more than 20 dB reduction in the frequency range of 1250 Hz- 6300 Hz, whereas active noise cancellation provides maximum attenuation in the range of 80 Hz to 160 Hz. Thus broadband noise attenuation (IL_T) both in low and high frequency band is obtained.

The broadband sound pressure level of T-72 tank noise at the right ear was reduced by 6.6 dB and 12.0 dB with active headset in OFF and ON mode respectively, and at the left ear the reduction in the level was 8.9 dB and 14.3 dB with active headset in OFF and ON mode respectively as shown in Fig.7(a). In similar mode of operation of the headset, TATRA engine noise at the right ear was decreased by 10.4 dB and 11.5 dB respectively, while at the left ear the noise level was reduced by



(a) (b)

Figure 5. Insertion loss of T-72 tank noise at (a) Left ear and (b) Right ear.



(a) (b)

Figure 6. Insertion loss of TATRA engine noise at (a) Left ear and (b) Right ear.

10.0 dB and 12.0 dB respectively as shown in Fig. 7(b).

Further, as can be seen from the Fig. 7(a) vis-a-vis Fig. 7(b), the headset in active (ON) mode provided better attenuation against T-72 tank noise in comparison to TATRA engine noise on account of the presence of high level of low frequency component in T-72 tank noise.

3.5 Speech Intelligibility Performance of Active Headset

Speech Intelligibility performance of active headset was evaluated in OFF and ON mode in background noise of TATRA engine. Figure 8 represents the speech intelligibility score in OFF and ON mode. In the OFF mode the score obtained was 36.9 per cent ± 3.1 per cent, which significantly improved in the ON mode with the score of 51.1 per cent ± 2.7 per cent.

3.6 Measurement of Noise Dose

Table 3 gives the noise dose received by the personnel while wearing active headset in OFF and ON mode during 45 minute exposure to noise of T-72 tank. As can be seen from the table, the noise dose received by the personnel during exposure to T-72 tank noise in OFF mode was 4.7 per cent, which reduced to 0.7 per cent in ON mode. However, 8 h projected noise dose was reduced to 7.4 per cent in ON mode as compared to 51.3 per cent in OFF mode.

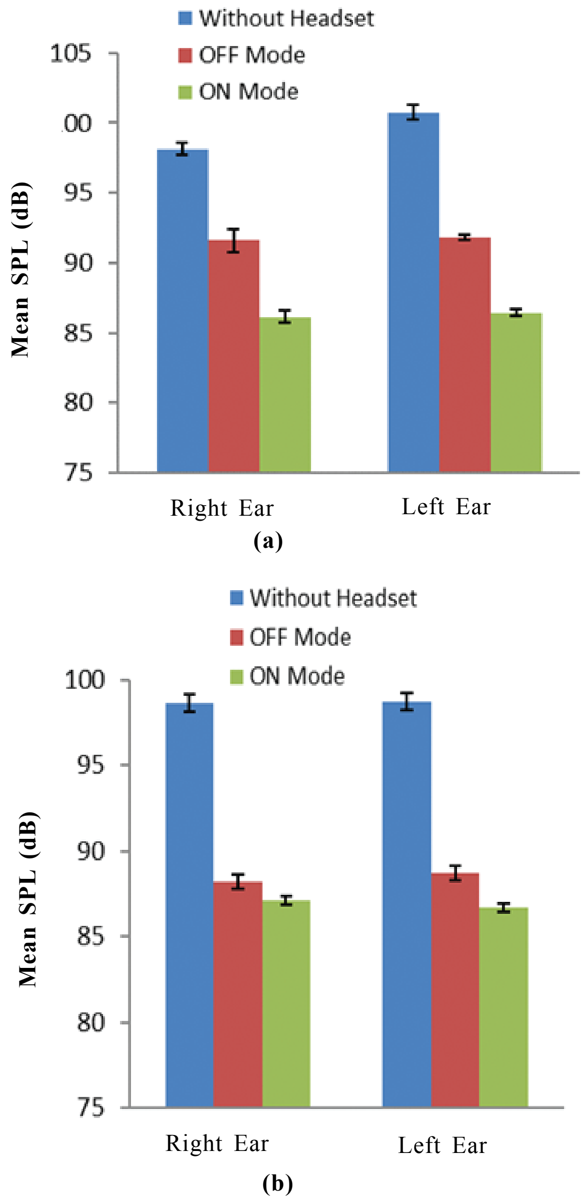


Figure 7. Mean Sound Pressure Level (a) T-72 Tank noise (b) TATRA engine noise in three conditions.

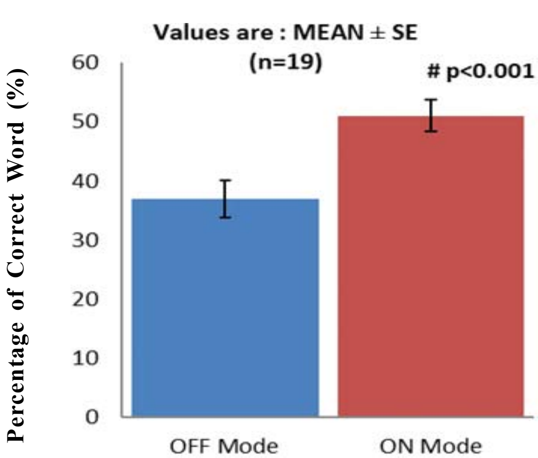


Figure 8. Speech Intelligibility Score.

Table 3. Noise dose received by personnel at 505 Army Base Workshop

	Duration of exposure (min.)	Actual measured dose (%)	8 h projected dose (%)
Without headset	**45.0**	**69.5**	**758.6**
OFF mode	**45.0**	**4.7**	**51.3**
ON mode	**45.0**	**0.7**	**7.4**

Criterion level = 90 dBA: Exchange rate Q = 3

3.7 Subjective Evaluation on the Useability and Effectiveness of Active Headset

The following Table 4 and Table 5 give the subjective impression of the individuals on the comfort and operation of the active headset.

As indicated in the Tables 4 and 5 the majority of the subjects found the device comfortable and well fitting. None of the subjects experienced any difficulty on wearing the device.

Table 4. Subjective Impression of Personnel exposed to T-72 Tank noise

Parameters	Excellent (%)	Very Good (%)	Good (%)	Can't Say (%)
Comfort	66.7	33.3	0.0	0.0
Fitness	66.7	33.3	0.0	0.0
Noise Attenuation	33.3	44.4	22.3	0.0
Oral Communication	0.0	88.9	11.1	0.0
Overall	33.3	66.7	0.0	0.0

Values are in %, n=9

Table 5. Subjective Impression of Personnel exposed to TATRA Engine noise

Parameters	Excellent (%)	Very Good (%)	Good (%)	Can't Say (%)
Comfort	40.0	50.0	10.0	0.0
Fitness	40.0	50.0	10.0	0.0
Noise Attenuation	0.0	50.0	50.0	0.0
Oral Communication	0.0	70.0	30.0	0.0
Overall	0.0	80.0	20.0	0.0

Values are in %, n=10

Further, the individuals expressed their satisfaction on the effectiveness of the headset in reducing the noise levels and in understanding of speech/oral communication.

4. DISCUSSIONS

Noise is an integral part of the life of a soldier as he is exposed to it repeatedly during routine exercise and training. Noise encountered by the soldiers may be impulsive, continuous or combination of both. The auditory system is most vulnerable to noise and impairment in its functioning may affect the efficiency and well-being of the soldiers. Therefore, every effort should be made to protect the hearing to enhance the performance and efficiency of our armed forces personnel. The most commonly used hearing protective devices include the earplugs and earmuffs that are passive methods of protection. However due to their limitations in attenuating noise in the lower frequencies, active noise cancellation technique is being incorporated in these passive devices to enhance their range of attenuation and enable good oral communication. The two techniques passive and active are complimentary to each other.

Currently, there are several manufacturers of ANR headsets. Most of the circumaural type headsets, where the pinna is completely covered by the muff, are primarily used in the aviation sector. One such device (TELEX Stratus 30 Active Headset) available in market has been evaluated in the occupational environment of our armed forces. The performance of active headset was evaluated in field conditions of the three wings of the armed forces for its noise attenuation, protection against NIHL, speech intelligibility and noise dose characteristics, to enable us to determine the efficacy of the device and to develop active noise cancellation device suitable to our environment.

Testing of the TELEX Stratus 30 Active headset by Microphone In Real Ear (MIRE) method, which gives the performance of the device at each 1/3 octave frequency band. Passive protection alone attenuates the noise above 1250 Hz by ≥ 17 dB. In the active mode, additional attenuation in the lower frequencies of approximately 10 dB from 80 Hz to 250 Hz was obtained. Hence the device offered total protection by attenuating noise in the entire frequency range. A properly fitting earmuff offers least leakage of sound thereby enhancing its efficacy in attenuating noise. The headset exhibited nominal negative attenuation between 800 Hz - 2000 Hz due to the sound leakage and resonance as shown in Figs. 5 and 6. The results are in close agreement with studies on different headsets conducted in controlled laboratory conditions by other researchers[22-23].

Evaluation of the active headset by Temporary Threshold Shift Reduction (TTSR) method gives the extent of protection offered by the device in preventing development of TTS, which is an indicator of the extent of noise induced hearing loss[18, 24-27]. Exposure to noise induces a temporary shift in the hearing threshold referred as TTS[28-29].

The results revealed significantly lower development of TTS at all frequencies in active mode as compared to passive defense against noise as shown in Figs. 3 and 4. This may be due to the broadband attenuation offered by the device at all frequencies in active mode thus reducing the overall noise levels at the entrance of ear canal.

Further, TTS development was less in the lower frequencies between 125 Hz -750 Hz as shown in Figs. 3 and 4 since the human ear at low frequencies is least affected by noise due to the auditory system being less sensitive in this region.

In military operations intelligibility of speech is of paramount importance for successful completion of the mission. HPD's not only protect the ear against the ill effects of noise, but they may also help in improving the intelligibility of speech when the background noise level is high (>90 dBA). Hence the speech intelligibility performance of the device was evaluated in field conditions with speech to noise ratio of 1:1. The speech intelligibility score is significantly improved in ON mode as compared to OFF mode as shown in Fig. 8. The poor attenuation of noise at lower frequencies causes a masking effect on the speech signal, which significantly reduces the speech intelligibility in passive mode. Several researchers have reported similar findings in which the sound level of the communication signal had to be increased to hazardous levels by the user to overcome this low frequency masking effect[30,31] while using the passive communication headset. Similar findings were reported earlier using different methods for evaluating the speech intelligibility performance of active headset[32-35].

The performance of the headset was further ascertained by the protection it offered against noise dose, indicative of whether the exposure to noise is hazardous to our auditory system or within the acceptable limits. The device in passive mode was able to bring the noise dose to within acceptable limits of exposures, which was further significantly reduced in active mode with highly desirable noise dose as shown in Table 3.

5. CONCLUSIONS

Higher protection was attained with the device in active as compared to passive mode on the basis of the performance of the device against development of TTS in noisy environment. Thus the device is found to be useful to in providing protection from NIHL.

The device led to significant improvement in speech intelligibility in ON mode as compared to OFF mode in industrial environment of army. Improvement in speech intelligibility permits effective oral communication, enhancing the success rate of mission or task.

The noise dose received by the personnel during their exposure to noise was significantly reduced in ON mode, enabling the personnel to work in the noisy occupational environment without affecting their hearing and in consonance with International Standards of occupational noise exposure.

REFERENCES

1. Salmivalli, A. Acoustic trauma in regular army personnel. Clinical audiologic study. *Acta Otolaryngol* (Stockh), 1967, Suppl. 222, 1-85.
2. Chaturvedi, R.C.; Rai, R.M. & Sharma, R.K. Safety Criteria of Noise Exposure. *Ind. J. Med. Res*., 1982, **76**, 758-65.
3. Kryter, K.D. The effects of noise on man. Edn. 2nd, 1985, Academic Press, New York, 688.
4. Dancer, A.; Buck, K.; Hamery, P. & Parmentier, G. Hearing protection in the military environment. *Noise Health*, 1999, **2**(5), 1-15.
5. James, S.; Hancock, M.; Hazel, A. & Rood, G.M. Primary contributors to hearing damage risk in the military aircraft cockpit. *In* International Military Noise Conference, 2001, Baltimore, MD.

6. Casto, K.L. & Casali, J.G. Effects of headset, flight workload, hearing ability, and communications message quality on pilot performance. *Human Factors*, 2013, **55**(3), 486 – 498. doi: 10.1177/0018720812461013.
7. Prella, C.G.L. & Clavierb, O.H. Effects of noise on speech recognition: Challenges for communication by service members. *Hearing Research*, 2017, **349**, 76-89. doi: 10.1016/j.heares.2016.10.004
8. Gerges, S.N.Y. & Casali, J.G. Hearing protectors. *In* Handbook of noise and vibration control. *Edited by* Crocker, M.J. New Jersey: John Wiley & Sons, 2007, 364–76. doi: 10.1002/9780470209707.ch31
9. Dancer, A.L.; Franke, R.; Parmentier, G. & Buck, K. Hearing protector performance and NIHL in extreme environments: Actual performance of hearing protectors in impulse noise/nonlinear behavior. *In* Scientific basis of noise-induced hearing loss. *edited by* Axlesson, A.; Borchgrevink, H.; Hamernik, R.P.; Hellstrom, P.; Henderson, D. & Salvi, R. J., Thieme Medical Pub., New York, 1996, 321-38.
10. Pickett, J.M. Low frequency noise and methods for calculating speech intelligibility. *J. Acoust. Soc. Am.*, 1959, **31**(9), 1259-1263. doi:10.1121/1.1907855
11. Loeb, M. Noise and human efficiency. Wiley, New York, 1986.
12. Criteria for a recommended standard: Occupational noise exposure. NIOSH, 1998, Cincinnati, OH, 98-126. (http://www.cdc.gov/niosh/98-126.html).
13. Permissible exposure limit for general industry. Occupational Safety and Health Administration, 1992, 29 CFR 1910.95.
14. Hearing Conservation Program, 2004, US Military, DoD Instruction 6055.12
15. Crocker, M. (ed.) Handbook of Noise and Vibration Control, 2007, John Wiley.
16. Horie, S. Improvement of occupational noise–induced temporary threshold shift by active noise control earmuff and bone conduction microphone. *J. Occup. Health*, 2002, **44**, 414-420.
17. Ribera, J.E.; Mozo, B.T. & Murphy, B.A. Speech intelligibility with helicopter noise: Tests of three helmet-mounted communication systems. *Aviation Space Environmental Med.*, 2004, **75**, 132–137.
18. Ong, M.; Choo, J.T.L. & Low, E. A self controlled trial to evaluate the use of active ear defender in the engine rooms of operational naval vessels. *Singapore Med. J.*, 2004, **45**(2), 75-78.
19. Cuia, J.; Behar A.; Wong, W. & Kunov, H. Insertion loss testing of active noise reduction headsets using acoustic fixture. *Applied Acoustics*, 2003, **64**(10), 1011–1031. doi: 10.1016/S0003-682X(03)00067-7
20. Chaturvedi, R.C.; Sharma, R.K.; Arora, K.B. & Srivastava, K.K. To identify suitable ear defenders for the personnel of artillery and armoured corps with special reference to auditory perception. Report No. DIPAS/13/94, 1994
21. Mozo, B.T. & Murphy, B.A. The assessment of sound attenuation and speech intelligibility of selected active noise reduction devices and the communications earplug when used with the HGU- 56/P aviator helmet. USAARL Report No. 97-08, 1997.
22. Brammer, A.J.; Peterson, D.R.; Cherniack, M.G. & Gullapalli, S. Improving the effectiveness of communication headsets with active noise reduction: influence of control structure. *In* RTO-MP-HFM-123 New Directions for Improving Audio Effectiveness, 2005, Neuilly-Sur-Seine, France: North Atlantic Treaty Organisation.
23. Berger, E.H. Methods of measuring the attenuation of hearing protection devices. *J. Acoust. Soc. Am.*, 1986, **79**(6), 1655-87. doi: 10.1121/1.393228
24. Melnick, W. Human temporary threshold shift (TTS) and damage risk. *J. Acoust. Soc. Am.*, 1991, **90**, 147-154. doi: 10.1121/1.401308
25. Kryter, K.D.; Ward, W.D.; Miller, J.D. & Eldredge, D.H. Hazardous exposure to intermittent and steady-state noise. *J. Acoust. Soc. Am.*, 1966, **39**(3), 451-64. doi: 10.1121/1.1909912
26. Nixon, J.C. & Glorig, A. Noise –induced permanent threshold shift at 2000cps and 4000cps. *J. Acoust. Soc. Am.*, 1961, **33**(7), 904-908. doi: 10.1121/1.1908841
27. Kapoor, N.; Mani, K.V.; Shyam, R.; Sharma, R.K.; Singh, A.P. & Selvamurthy, W. Effect of vitamin E supplementation on carbogen-induced amelioration of noise induced hearing loss in man. *Noise Health*, 2011, **13**(55), 452-58. doi: 10.4103/1463-1741.90327
28. Kvaerner, K.J.; Engdahl, B.; Arnesen, A.R. & Mair, I.W. Temporary threshold shift and otoacoustic emissions after industrial noise exposure. *Scand. Audiol.*, 1995, **24**, 137-141.
29. Hetu, R. & Parrot, J. A field evaluation of noise- induced temporary threshold shift. *Am. Ind. Hyg. Assoc. J.*, 1978, **39**(4), 301-311. doi:10.1080/0002889778507762
30. Backteman, O.; Köhler, J. & Sjöberg, L. Infrasound-tutorial and review: Part 2. J. Low Freq. *Noise Vibration*, 1983, **2**(4), 176–210.
31. Beranek, L.L. Acoustics. 4th ed., 1993, American Institute of Physics, New York.
32. Rogers, I.E.C. An assessment of the benefits active noise reduction systems provide to speech intelligibility in aircraft noise environments. Southbank University, London, United Kingdom, 1997, MSc Thesis.
33. Wheeler, P.D. & Halliday, S.G. An active noise reduction system for aircrew helmets. *In* Proceedings of NATO AGARD Aural Communication in Aviation Conference proceedings 311, 1981, 22-1-22-8.
34. Chan, J.W. & Simpson, C.A. Comparison of speech intelligibility in cockpit noise using SPH-4 flight helmet withand without active noise reduction. NASA Contractor Report 177564, 1990.

35. Brammer, A.J.; Bernstein, E.R. & Yu, G. Strategies for improving speech intelligibility and warning signal detection in communication headsets/hearing protectors. *J. Acoust. Soc. Am.*, 2013, **134** (5), 4189 doi: 10.1121/1.4831362.

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