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Communications Effectiveness When Using the Communications Earplug or Expandable-Foam Earplug With the HGU-56/P Aviator Helmet

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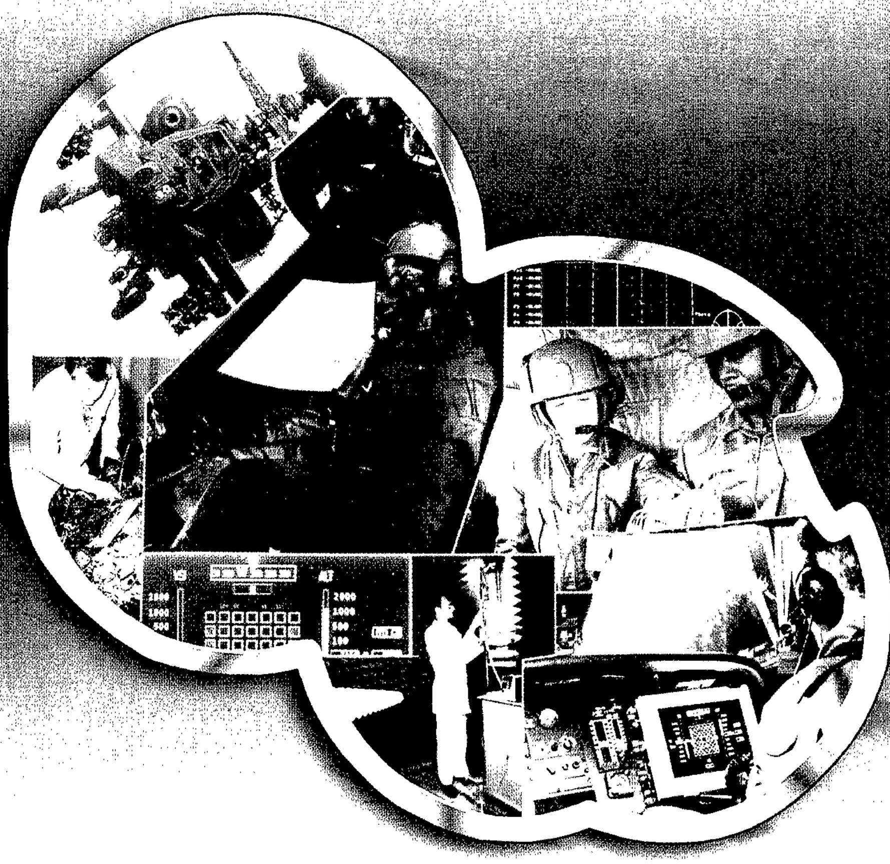

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The ability of rotary-wing aircrew to utilize cockpit communications to successfully coordinate missions is impaired by the high noise inherent in the aviation environment and by hearing protection strategies designed to protect the aviators from noise-induced hearing loss. The use of the communications earplug in place of an expandable-foam earplug when using double-protection (sound-attenuating helmet and earplugs) significantly reduces the number of events classified by the CIRCLE measurement technique in the sub-code associated with pilots requesting that a communication be repeated. The sub-codes associated with missed transmissions (i.e., repeated verbalizations caused by an assumed missed transmission) and improper responses (where the response was inappropriate to the message received) did not show statistical significance. However, the relatively low frequency of occurrence of these sub-codes may limit the application of these two sub-coded behaviors.

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Introduction

Communication in the high-noise rotary-wing aircraft environment is unusually difficult. High noise levels and consequent low signal-to-noise ratios in the communications systems frequently are responsible for degraded communications among aviators and between aviators and ground personnel. Stress and tensions associated with high work loads further compound problems facing the aviator attempting to coordinate complex missions with fellow crewmembers and support personnel.

Noise levels found in military helicopters exceed noise exposure limits established by the Department of the Army Pamphlet (DA Pam) 40-501, "Hearing Conservation" (Department of the Army, 1991) criteria. Noise levels in cargo helicopters such as the CH-47 and CH-53 often exceed the aviator's helmet's sound protective capabilities. Double protection (i.e., earplugs worn along with the aviator's helmet) is a technique commonly used to provide additional hearing protection in high-noise aircraft. Double protection is mandated under many common conditions in the UH-60 Black Hawk helicopter (CAE-LINK, TM 55-6930-217-10, 1989). Studies show that the SPH-4 or HGU-56/P aviator helmets in combination with an expandable-foam earplug is adequate hearing protection in all but the top one percent of noise conditions (Mozo and Murphy, 1997a). Unfortunately, the addition of earplugs under the helmet earcups decreases the aviator's ability to communicate since it attenuates the speech signal from the earphones located in the earcups, in addition to the noise from outside the earcups.

The U.S. Army Aeromedical Research Laboratory (USAARL) has been investigating various techniques to reduce noise exposure for rotary-wing aircrew and to improve communication, even under the noisiest conditions. The Communications Earplug (CEP) was developed especially for these conditions. The CEP couples an expandable-foam earplug to miniature sound transducers to reduce the noise entering the ear canal from outside the helmet but to allow communication signals to enter the canal without the additional attenuation. It is worn in combination with the aviator's helmet, thereby providing hearing protection that is similar to that provided by the combination of the helmet and expandable-foam plugs.

The CEP consists of a miniature receiver encapsulated in a plastic housing, which includes a threaded adapter used for attaching the replaceable earplug. The earplug tip has an internally-threaded insert channel that extends through the center from the base to tip, and mates with the threaded adapter on the transducer housing. The speech signal is delivered directly from the receiver into the occluded portion of the ear canal. The small wires used to connect the CEP to the communications system are highly flexible for comfort and small enough to minimize the potential for leakage when the wire is routed between the ear cup seal and the aviator's head. This approach provides sound attenuation and speech intelligibility that is as good as any technique observed to date (Mozo and Murphy, 1997a).

A number of operational tests of the CEP have been performed. It has received almost universal enthusiastic acceptance and endorsement by aircrew in a variety of U.S. Army rotary-wing aircraft including the UH-1 Huey (Mozo, Murphy, and Ribera, 1995), the CH-47 Chinook

(Ribera, Mozo, and Murphy, 1996), and the OH-58D Kiowa Warrior (Murphy and Mozo, 1999). The CEP was also evaluated by aircrew of U.S. Navy rotary-wing aircraft (H-53A/E Sea Stallion and CH-46A/E Sea King) and users reported reduced noise levels and increased speech clarity and quality when compared to the Navy aviator's helmet alone (Mozo and Murphy, 1997b). In both operational (Mozo and Murphy, 1997a) and laboratory (Staton, Mozo and Murphy, 1997) comparisons of CEP and active noise reduction (ANR) devices, the CEP compared favorably with ANR devices in noise attenuation and speech intelligibility. In addition, when ancillary devices such as spectacles or chemical and biological protective masks were worn, the sound attenuation and speech intelligibility using the CEP were significantly greater than that measured in subjects using the ANR devices. Aircrew indicated a preference for CEP over the ANR devices.

The results of a number of operational tests involving CEP-user questionnaires and laboratory studies of sound attenuation and speech intelligibility demonstrate that the CEP is a viable and useful addition for a rotary-wing aircrew. While speech intelligibility is improved significantly by the use of the CEP, there have been no investigations to determine how this improvement effects the coordination among aircrew members.

In the past, the "goodness" of voice communications between individuals had been measured using standardized speech intelligibility tests. These techniques typically employed phonetically balanced words that were presented to the listener through the system being evaluated. Usually, this type of measurement was conducted in a simulation of the end user's noise environment. While this approach was standardized, face validity was compromised because of the artificial nature of the measurement. In addition, many stress-related characteristics of the actual workplace were not present in the simulation. Speech in context with on-going tasks also was a factor that was not considered in the standardized speech materials that were used in speech intelligibility assessments.

The Coordination Index Rating for Crew Linguistic Events (CIRCLE) is a sequential analysis system employed at USAARL for quantifying cockpit communications as coded pairs of events (Katz, Fraser, & Wagner, 1998a). Each verbalization is labeled as one of eight verbalization types and operates as a response to the previous utterance and a stimulus for ensuing verbalizations. CIRCLE is a system that codes all verbalizations as well as a lack of expected verbalizations between pilot and copilot. The codes that CIRCLE employs are Command, Question, Observation, Self-report, Acknowledgement, Reply, Zero response, and Dysfluency. Subcodes within each of these major codes are possible.

Verbalizations are paired and converted into indicators of eight crew coordination basic qualities (U.S. Army Aviation Center, 1992). These basic qualities include Team Relationships, Decision-Making Techniques, Prioritize Actions and Distribute Workload, Statements and Directives Clear and Concise, Situational Awareness, Decisions and Actions Communicated, Supporting Information Sought, and Supporting Information Offered. The Coordination Index Rating (CIR) of each basic quality demonstrated in each minute of each session as a fraction of the total verbal pairings for that minute is calculated. The per-minute data are used to establish a mean for each basic quality for the particular epoch of interest (e.g., flight phases, 10-minute segments, etc.).

Coordination index ratings yield useful information regarding how well crewmembers communicate with each other at various times during a flight. A study using CIRCLE was conducted to differentiate crews who handle a single-engine emergency procedure correctly from those who misdiagnose the problem and "crash" the rotary-wing simulator (Katz, Fraser, & Wagner, 1998b). The results of the study showed that the crews following procedures had correctly distributed their use of crew coordination basic qualities more evenly across the flight prior to the emergency. The crews that had lulls in communication at low-workload phases and bursts of coordinated behaviors at high-workload epochs failed their missions. CIRCLE has been used to establish a normative template of crew coordination across workload levels (Katz, Fraser, & Wagner, 1998a) and to assess an aviation unit's crew coordination by comparing it to that baseline.

It was the purpose of this investigation to examine crew coordination in a realistic aircraft scenario and to perform a comparison of crew coordination with crews using the CEP with the aviator's helmet and crews using double protection afforded by the aviator's helmet and an expandable-foam earplug. The CIRCLE technique was used to measure crew coordination.

Methods and instrumentation

Human subjects

Twenty U.S. Army volunteer rated aviators qualified in the UH-60 Black Hawk helicopter participated in this study. Subjects were paired randomly, with one subject in each pair being designated pilot in command. All subjects were briefed on the objectives of the study and the simulated flight profiles. All elements of informed consent were present and subjects could withdraw from the study at any time without any penalty or loss of benefit. No subjects withdrew from the study.

Devices and test conditions

The independent variable used in this investigation was the type of earplug used in conjunction with the HGU-56/P aviator's helmet: the standard expandable-foam earplug or the CEP. Technicians trained in fitting hearing protective devices refreshed the subjects on the proper fitting procedures for the expandable-foam earplug and trained the subjects on the use and fitting procedures for the CEP.

The communication conditions were performed using a repeated-measures design and were counterbalanced to reduce learning effects. Each subject was allowed to adjust the volume settings for the simulator intercommunications system (ICS). The subjects were asked to annotate that change in position relative to a calibrated reference scale if the ICS level was changed. The ICS volume adjustment knob was monitored by a video camera in the event that a subject failed to annotate the change.

The USAARL NUH-60/FS Black Hawk full-motion research flight simulator was used for this study. The cockpit of this simulator is shown in Figure 1. A single flight scenario with two sequence arrangements was used to determine the effectiveness of: (a) speech communication between the two crewmembers; and (b) speech communication received from outside the simulator. The flight profile is shown in Table 1. During one session, the profile was flown as illustrated in the table, and in the second session, the profile was reversed. The directions of the scenarios were counterbalanced across the groups. Each flight scenario was approximately 1 hour in duration and covered standard procedures encountered during rotary-wing operations. A 15-minute rest period separated the two flight scenarios.

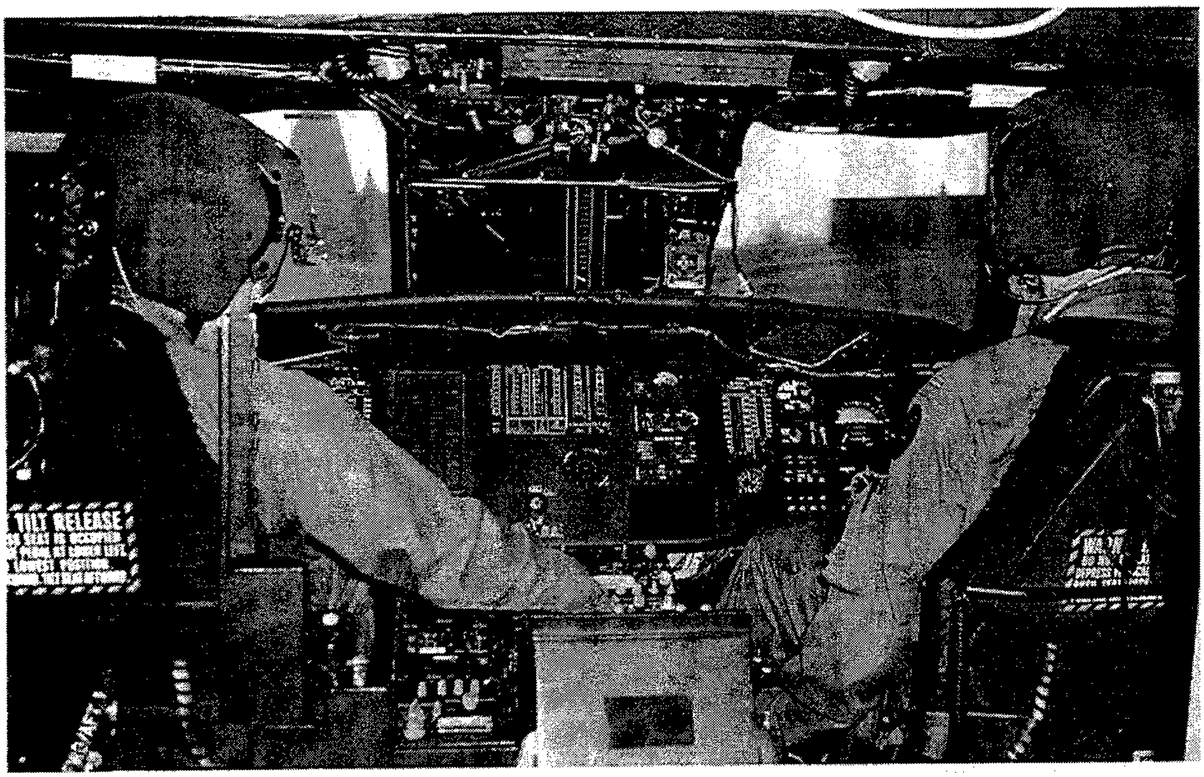

Figure 1. Cockpit of the USAARL NUH-60/FS Black Hawk flight simulator.

Noise levels in the USAARL NUH-60/FS Black Hawk simulator were measured at five noise level settings and are reported in Gordon and Ahroon (2000). To simulate a UH-60 aircraft cruising at 120 knots, simulator Noise Level 9 was used in the present study. The octave-band spectra of the simulator at Noise Level 9 and an actual UH-60A at 120 knot cruise (Mace et al., 1981) are depicted in Figure 2. The calculated noise exposure level while wearing the HGU-56/P with CEP is 79.9 dBA and in combination with the standard expandable-foam earplug

Table 1.
Flight scenario flown in the present experiment. One-half of the subjects flew the tabulated scenario while the other half flew the scenario in reverse.

Task Number	Task Description	TIME (sec)	HDG (deg)	ALT (FEET)	Airspeed (kias)
1	HVR	60	090	10' AGL	0
2	HVRT (LEFT)	60	090>090	10' AGL	0
3	LL CP 11>12	240	086	700' MSL	120
4	CLIMB (500 fpm)	60	100	700>1200' MSL	120
5	RSRT	60	100>280	1200' MSL	120
6	S/L	60	280	1200' MSL	120
7	RSRT/DESCENT	60	280>100	1200>700' MSL	120
8	NOE CP14>15	180	344	25' AGL	120
9	CONT CP 15>16	180	031	80' AGL	120
10	LND FARP 1	120	015	N/A	N/A
11	NOE CP16>17	240	338	25' AGL	120
12	CONT CP 17>18	120	296	80' AGL	120
13	LND FARP 36	120	255	N/A	N/A
14	CONT CP 18>19	240	319	80' AGL	120
15	CONT CP 19>20	120	250	80' AGL	120
16	CLIMB (500 fpm)	60	200	1000>1500' MSL	120
17	LSRT	60	200>020	1500' MSL	120
18	S/L	60	020	1500' MSL	120
19	LSRT/DESCENT	60	020>200	1500>1000' MSL	120
20	CONT CP 21>22	180	173	80' AGL	120
21	LND CLA #3	120	215	N/A	N/A
22	CONT CP 22>23	240	066	80' AGL	120
23	CONT CP 23>24	120	076	80' AGL	120
24	CONT CP 24>25	120	181	80' AGL	120
25	CONT CP 25>26	240	214	80' AGL	120
26	LND MLA #3	120	180	N/A	N/A
27	NOE CP 26>11	240	249	25' AGL	120

is 74.4 dBA. Both these exposure levels were well below the 85 dBA limit specified by DA Pam 40-501. It is possible that the lower simulator noise levels in the upper frequencies of the speech range (when compared with the actual UH-60 noise levels) may compromise the generalization of the data obtained in this study to operational environments. However, the noise levels in the simulator were the same for both double hearing protection schemes and thus should have no effect on any conclusions regarding crew coordination in noisy environments.

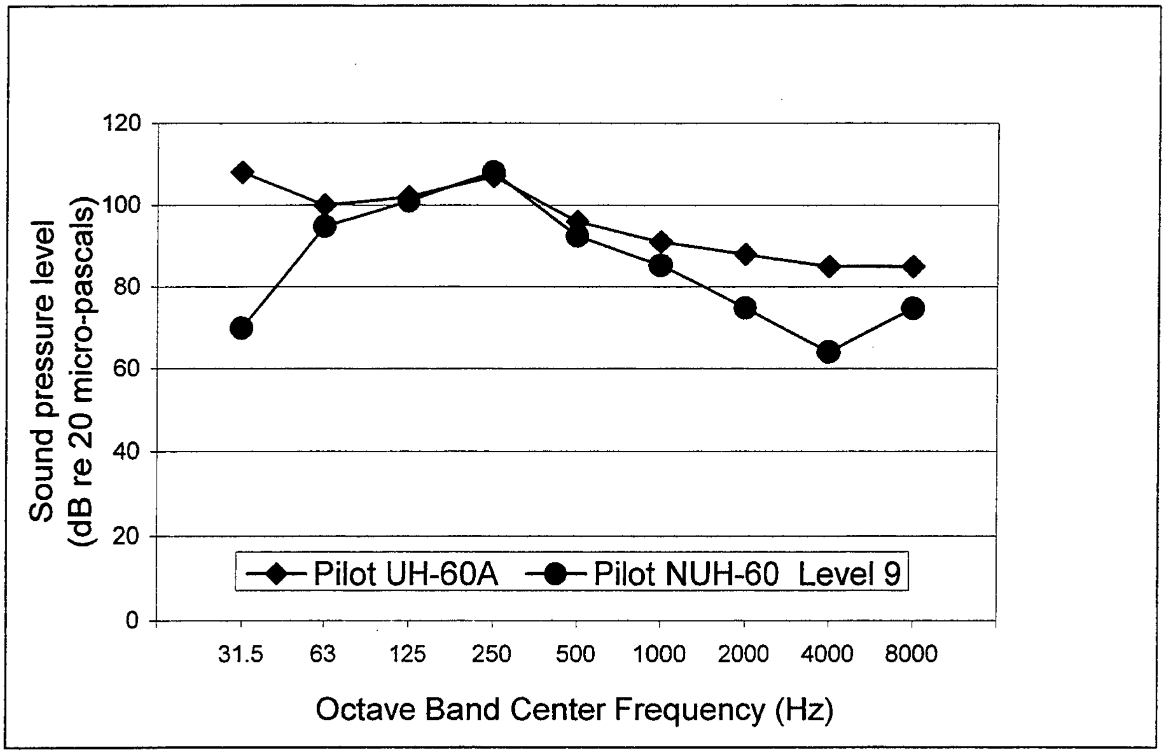

Figure 2. Sound pressure levels in the USAARL NUH-60/FS Black Hawk flight simulator at Noise Level 9, at the pilot location, during flat-pitch operation with main rotor speed 100 percent, collective full down, and cockpit doors closed, and a UH-60A helicopter at pilot location during 120-knot cruise with doors closed (Gordon and Ahroon, 2000).

Communication scenarios

The communications scenarios used in the present investigation consisted of several segments of communications input from outside of the cockpit which simulated signals received through a radio-telephone link. The communication signals were transmitted at six different levels in 5-decibel increments to determine the threshold at which the signals were detected and understood by the volunteer. The actual sound pressure level at the aviator's ear depended on the subject's setting of the ICS volume level and the test condition. The communication segments consisted of a call sign followed by a three-character alphanumeric string. An equal number of communications segments at an equal number of levels were selected randomly and used in each of the test conditions.

Crew coordination measure: CIRCLE

The effectiveness of speech communication was determined using the CIRCLE measurement technique described above. The CIRCLE measurement was performed for each of the experimental conditions. Each flight was videotaped and reviewed by research personnel who were trained in the CIRCLE technique. A 90% inter-rater reliability standard was required of all personnel reviewing data videotapes for the CIRCLE analysis. The 1-minute interval index values determined by the CIRCLE technique were used to describe the effectiveness of the verbal exchanges between the aviators during the flight scenarios. The dependent variables included the eight crew coordination qualities measured and the three subcode-indicators of hearing difficulties. Higher values of the CIR associated with a subcode are indicative of increased hearing difficulty.

In addition to the standard CIRCLE codes, a subset of three subcodes indicating hearing difficulty was used: Impaired hearing (IH), Improper response (IR), and Repeated verbalizations (RV). A trained observer evaluated the reaction of the aircrew to a received message and determined if the response was appropriate. The IH subcode was assigned to the verbalization pair whenever a crewmember indicated an inability to hear the other crewmember clearly with such verbalizations as "huh?," "what?," "repeat," or "Did you say ...?." The IR subcode was used if the analysis of the interaction indicated that the message was not received correctly. The RV subcode was applied when a crewmember repeated a previous verbalization made by that same crewmember, whether or not the other member had specifically indicated impaired hearing. CIR values for each variable were calculated for all verbal pairings in the minute reflecting that variable. For the purposes of this investigation, only these three subcodes were analyzed. CIR was analyzed for each 5-minute interval of each hour-long flight scenario.

Results and discussion

The mean CIRs for the three dependent-variable subcodes and earplug type are presented in Table 2. The data were analyzed using a mixed model analysis of variance with repeated

Table 2.
Means and standard deviations of the Coordination Index Rating (CIR) for subjects wearing expandable-foam earplugs and the CEP.

	IH	IR	RV
Expandable-foam plug			
Mean	8.2	0.8	1.9
Standard deviation	1.8	1.0	1.6
Communications earplug			
Mean	1.2	0.2	0.7
Standard deviation	1.2	1.8	1.0

measures on one variable (earplug type). The main effects of earplug type and type of hearing difficulty were statistically significant [Earplug: $F(1,9) = 37.6, p < .01$; Type: $F(2,18) = 35.7, p < .01$). Since the interaction of earplug type and type of hearing difficulty was statistically significant [$F(2/18) = 19.4, p < .01$), Tukey HSD post-hoc tests were performed. The post-hoc tests revealed that there were no differences resulting from the independent variables of earplug type for either the IR or the RV dependent variables. There was, however, a statistically significant difference in CIR between the expandable-foam earplug and CEP in the IH dependent variable ($p < .01$). The usefulness of the CIRCLE measurement technique with these flight scenarios may be limited because of the relatively low number of occurrences of these events.

Conclusion

The ability of rotary-wing aircrew to utilize cockpit communications to successfully coordinate missions is impaired by the high noise inherent in this aviation environment and by hearing protection strategies designed to protect the aviators from noise-induced hearing loss. The use of the CEP in place of an expandable-foam earplug when using double-protection (sound-attenuating helmet and earplugs) significantly reduces the number of events classified by the CIRCLE measurement technique in the subcode associated with pilots requesting that a communication be repeated. The subcodes associated with missed transmissions (i.e., repeated verbalizations caused by an assumed missed transmission) and improper responses (where the response was inappropriate to the message received) did not show statistical significance. However, the relatively low frequency of occurrence of these subcodes may limit the application of these two subcoded behaviors.

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