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Exposures from Headset Interference Tones

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16. Abstract

This study evaluated the acoustic characteristics of interference tones as experienced by FAA Air Traffic Control Specialists (ATCS's) and pilots who wear headsets with insert type ear pieces. The Sound Pressure Levels (SPL's) of generated tones were measured through the headset at five randomly selected ATCS positions in each of seven Air Route Traffic Control Centers (ARTCC's). The SPL's were compared within and between four frequencies (.5, 1, 2, and 3 KHz) over ten discrete signal power levels. The comparisons demonstrated that SPL's of tones could not be predicted for ARTCC's or for positions within an ARTCC, and that the durations of exposure were brief, i.e. limited to the time needed to remove the headset earpiece from the ear canal.

Potential amounts of temporary threshold shifts (TTS's) also were evaluated in a laboratory by checking hearing levels following exposures to tones played with ATCS/pilot communication through the same headset. Audiometric checks of 20 volunteer subjects indicated TTS could be detected following 1 KHz/114 dB/60 and 145 seconds, 2 KHz/108 dB/60 and 145 seconds, and 3 KHz/99 dB/145 seconds exposures, when hearing checks were made within the first 15 minutes. Such extended durations are highly unlikely for pilots and ATCS's and no TTS was detectable following exposures to shorter durations or to other frequencies with equivalent durations.

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EXPOSURES FROM HEADSET INTERFERENCE TONES

INTRODUCTION

Air traffic control specialists (ATCSs) and other members of the aviation community have been made aware of both the non-auditory and the potential auditory effects of interference tones. Although the non-auditory effects of "sudden and loud" noises have been extensively investigated (1), conclusions made by Kryter (2) in 1972 still appear applicable to interference tones. Most of the potential auditory effects have been investigated by measuring the acoustic characteristics and other aspects of tone exposures, and by checking for shifts in hearing acuity (3).

Alexander et al (4) evaluated exposures of telephone operators to interference tones through headsets, equipped with insert type ear pieces. Tones were measured as sound pressure levels (SPLs) in decibels (dB re 20 micronewtons per meter squared), and by checking for temporary threshold shifts (TTSs) in hearing. After measuring 36 "acoustic disturbances" over 6 days, the author reported no tones exceeded the headset varistor protection level, reported as 114 dB SPL for Plantronics Corporation, Model MS-80 Headsets. No hearing threshold level (HTL) shifts were detected when measured in dB (re ISO-1964/ANSI-1969) and checked within "approximately 15 minutes" of the tone. These results confirmed earlier conclusions by Glorig et al (5) after investigating "clicks" and "low intensity beeps" also experienced by telephone operators.

The Plantronics Corporation, Model MS-80 Headset also is extensively used by Federal Aviation Administration (FAA) ATCSs. Each ATCS determines the size of the ear piece that comfortably occludes the ear canal as shown on the instructions provided by the manufacturer. When an ATCS experiences an interference tone, the insert type ear piece usually is removed from the ear and incoming communication is switched to a speaker. Although tone durations have been recorded between less than 1 second and more than 145 seconds, exposure durations were estimated as the time required to remove the ear piece from the ear canal. All signals, including ATCS/pilot communication and interference tones are amplified or attenuated for clarity before recording, consequently, the acoustic levels of interference tones have not been routinely measured in FAA facilities.

The maximum levels of interference tones in FAA facilities were evaluated in the past by testing the operational characteristics of headsets used during interference tone incidents. When an interference tone incident was reported, the headset was sent to the FAA Logistics Center, Engineering and Production Branch (FAA Order 3900.39, Hazardous Interference Tones in the Interphone System).

Testing was performed by ensuring all electronic components were functional and measuring the acoustic output of a 1 KHz tone generated at -10, -5, 0, 5, and 10 dBm (decibels as referenced to 10 pico-Watts) as it was passed through the headset. The acoustic output of the headset was recorded in dB SPL as indicated by a Bruel and Kjaer (B&K), Type 2204 Sound Level Meter connected to a B&K, Type 4152 Artificial Ear. The dB SPL measurements were interpreted as the maximum levels that could be obtained within the limits of the functional headset electronic components or the "varistor protection limit." Higher acoustic levels would be observed with failure of the headset varistor since the acoustic output of the headset would be limited only by the maximum amount of diaphragm displacement.

Testing was conducted in this manner between 1975 and 1981 on 5,047 headsets, 16 of which had been physically damaged and were not operational. Although the maximum level, varistor protection limit, was 114 dB SPL for telephone operators using the same brand and model of headset, all acoustic levels were recorded between 120 and 122 dB SPL for functional Plantronics Corporation, Model MS-80, Series B Headsets issued to FAA ATCSs. Headsets used during interference tone incidents since 1981 are sent to the headset distributor for testing (FAA Order 3900.39B, a revision of Order 3900.19 listed above).

Testing headsets in this manner also could lead to the assumption that levels of 1 KHz tones are equivalent or higher than tones of other frequencies in FAA facilities. A 1 KHz tone tested with a minimum signal power level of 5 dBm also should not be indicative of the acoustic levels in ARTCCs operating at -17 dBm. Variability in the acoustic levels experienced by an air traffic control specialist in an ARTCC would include any amplification or attenuation of the signal as it passed through the ARTCC before entering the headset. If the headset test levels, 120 to 122 dB SPL for Plantronics Model MS-80 and 127 dB SPL for the Plantronics Model MS-50 for a 1 KHz tone, and maximum measured durations, up to 145 seconds, were assumed as potential exposures, hearing acuity could be adversely affected.

METHOD

This study was divided into a field study to determine if information on generated interference tone levels indicated variability within and between FAA ARTCC communication systems, and a laboratory study to evaluate the potential of the averaged maximum generated tone levels producing TTSs in hearing when using an insert type headset. The field study was conducted to determine if levels of generated interference tones could be predicted for ARTCCs. The laboratory study was conducted to check for TTSs when HTLs were checked within 15 minutes following the exposures. The levels of the stimuli for the laboratory study were selected by averaging the highest dB SPL measured as each of four tones were generated at -17 dBm.

Field Study

The field study was conducted at 7 of the 21 FAA ARTCCs. These were the Seattle, Oakland, Los Angeles, Anchorage, Fort Worth, Houston, and Salt Lake City ARTCCs. The same Plantronics Corporation, Model MS-80, Series B Headset with a Number 5 insert type ear piece was used at 5 randomly selected, unoccupied positions in each ARTCC. The gain at each ATCS position was set at maximum for all measurements.

The headset was connected to the jack normally used by the ATCS and the Number 5 earpiece was connected to a calibrated B&K, Type 4152 Artificial Ear with an uncovered 1 inch B&K, Type 4144 Condenser Microphone, and a B&K, Type 2209 Sound Level Meter, with a B&K Type 2619 Preamplifier. The sound level meter calibration was checked with a B&K, Type 4200 Piston Phone and a B&K, Type 4230 Level Calibrator before and after obtaining measurements at each position. Continuous pure tone signals were generated at 5 dBm signal power level increments between -35 and 10 dBm and at 0.5, 1, 2, and 3 KHz frequencies with a Northwest Electronics, Oscillator and Power Meter. The sound level meter was set on slow and linear, and measurements were obtained by recording the indicated SPL.

Three null hypotheses were proposed for testing the 0.05 level of significance for the field study. These were:

> There are no mean SPL differences between tone frequencies and between positions within an ARTCC;
>
> There are no mean SPL differences between positions within each frequency; and
>
> There are no mean SPL differences between ARTCCs and between positions within each frequency, when the 3 highest power levels were used.

Laboratory Study

Twenty-seven volunteer subjects were selected for the laboratory study. Each had no prior history of physical findings suggestive of significant previous disease of the auditory system or ototoxic medication, and HTLs were no greater than 10 dB relative to the ISO-1964/ANSI-1969 Audiometric Zero. Subjects were also selected if they could participate in one orientation and twelve test sessions. The average age of the twenty non-ATCS subjects who completed the twelve test sessions was 36.3 years with a standard deviation of 7.4 years as shown in Table I.

Table I. List of Subjects

Subject Number	Age	Years of Education	Occupation	Test Ear
1	43	16	Quality Assurance	L
2	52	14	Quality Assurance	R
3	37	16	Flight Test Pilot	R
4	31	14	Pilot	L
5	27	16	Aircraft Records Specialist	R
6	29	14	Electronics Technician	L
7	30	14	Electronics Technician	L
8	28	14	Electronics Technician	L
9	24	16	Electronics Technician	L
10	43	12	Warehouse Worker	L
11	39	14	Flight Test Pilot	R
12	44	16	Production Controller	R
13	31	16	Electronics Technician	L
14	29	14	Pilot	R
15	40	16	Flight Test Pilot	R
16	41	12	Aircraft Mechanic	R
17	45	14	Electronics Technician	R
18	34	16	Electronics Technician	R
19	37	14	Electronics Technician	L
20	41	16	Electronics Technician	L
Mean	36.3	±7.4 Years		

Electromechanical equipment was assembled for sound generation, exposure monitoring and HTL checks. Four replicate tapes were prepared on a NAGRA, Model SJ Tape Recorder as two 1 minute recordings of the two calibration signals used to check the sound level meter calibration, a 1 minute blank recording, and 10 minutes of reversed ATCS/pilot communication recorded at an average equivalent-continuous level of 88 dBA (decibels as measured on an A weighting network of a sound level meter). The reversed communication was interrupted on each tape with a 145 seconds recording of one of the four tone stimuli. The tones were 0.5 KHz at 109 dB SPL, 1 KHz at 114 dB SPL, 2 KHz at 108 dB SPL, and 3 KHz at 99 dB SPL.

All exposures and HTL checks were made in an Industrial Acoustics Company Audiometric Test Chamber. Ambient noise levels required for audiometric testing were measured in the closed chamber before each test session and conformed with standards for audiometric testing (6). White noise was delivered as background noise in the test chamber through an 8 inch speaker, located .75 meter in front and above the subjects heads as the reversed communication and tone stimuli were delivered through the headset. The SPL measurements of ambient and background noise are listed in dB in Table II. The ambient noise levels were checked before each test session and levels of the background noise were monitored with a B&K, Type 2204 Sound Level Meter and with the microphone located within 3 centimeters of each subject's ear.

One of the four tape recordings was used for three of the twelve test sessions by playing each of the recorded tones for 5, 60 or 145 seconds. The twelve test sessions were randomly selected for each subject. The levels of the calibration signals were used to adjust the amplification of the stimuli played by the NAGRA, Model SJ Tape Recorder into duplicate headsets. The reversed ATCS/pilot communication and tones were detected inside the chamber by the subject and through a duplicate Plantronics Corporation, Model MS-80, Series B Headset. The same size of insert type earpiece was connected to the B&K Artificial Ear and the B&K Sound Level Meter used in the FAA ARTCCs. The sound level meter was connected to B&K, Type 2305 Level Recorder located outside the chamber.

During the orientation session, each subject was provided instructions, was asked to sign a consent form, provided a pre-experiment audiogram and was examined by a physician before selection. Each subject agreed to be reexamined before and after participation in each test session by the same physician. If a TTS was indicated after a test session, each subject agreed to remain under the physician's care until no TTS was indicated. Test sessions were scheduled for each subject at least 24 hours apart.

All HTL checks were made with subject controlled responses to a calibrated GenRad, Model 1703, Recording Audiometer. The audiometer test tones were pulsed, 200 milliseconds on and off, pure-tone air-conduction signals and were delivered at 0.5, 1, 2, 3, and 4 KHz frequencies and through TDH 30 Ear Phones with MX-41 Cushions. The HTLs of each subject were checked and recorded for both ears on the pre-experiment and pre-test audiograms. The HTLs on the pre-experiment audiogram and each of the twelve pre-test audiograms were compared and HTL differences greater than 5 dB were used by the physician to determine subject participation in each test session. All post-stimuli HTL checks were made only in the randomly-selected, and consistently-used test ear.

A safety inspection was conducted, all equipment was checked, and biological monitoring was performed before subjects arrived for each test session. The levels of the two 1 minute calibration tones were adjusted and recorded while each subject was checked by a physician. The tape was stopped at the beginning of the 1 minute blank recording before the subject was seated in the test chamber. After the subject was seated in the test chamber, the sound level meter microphone was positioned adjacent to the non-test ear and the same set of instructions were read.

Table II. Octave Analysis in Test Chamber

KHz Frequency	.0315	.063	.125	.250	50	1.0	2.0	4.0	8.0	16.0
Ambient	54	42	32	19	10	*	*	*	*	*
Background	57	56	64	61	64	68	73	60	44	26

*** Ambient noise SPLs above 0.5 KHz were below limits of detection**

The subject donned the audiometer headset and a pre-test audiogram was obtained at the beginning of each session. The physician compared the pre-experiment and pre-test audiograms while the subject removed the audiometer headset and donned the same Plantronics Corporation, Model MS-80, Series B Headset used during this part of the study. Since greater TTS have been shown to occur with active mental states (7), all subjects were given one set of math problems for each test session. Each subject was encouraged to solve all problems during administration of the stimuli.

Power was simultaneously turned on to the tape recorder, the level recorder and the speaker. As the reversed ATCS/pilot communication began, the subject was signaled to begin solving the math problems. The duration of each tone stimulus was timed with a stop watch and by observing the level recorder tracings. Power to all noise sources was turned off at the end of 5, 60, or 145 seconds and the subject was signaled to remove the Plantronics headset earpiece and headset. Subjects then donned the audiometer headset and HTL checks were begun 20 seconds after cessation of the stimuli. The audiometer determined timed intervals for HTL checks are shown in Table III for the five post-stimuli audiograms. The 0.5 KHz audiometer test tone was begun 20 seconds after the stimuli for the first audiogram and 180 seconds post-stimuli for the second audiogram. This provided 20 seconds for changing headsets before beginning hearing checks, and 11 seconds to change the charts and reset the audiometer between audiograms.

It should be noted that TTS were not accurately measured until after 120 seconds, or until HTL checks were first made with the 3 KHz audiometer test tone. Each subject remained in the test chamber until HTLs on the last post-stimuli audiograms could be compared with those on the pre-test audiogram and no residual TTS was indicated. No TTS were detectable when checked in this manner and within 15 minutes following each tone stimulus.

All audiograms were coded and randomized, and an audiologist interpreted all subject responses at the nearest 5 dB for the study. Since some subject responses were recorded as -10 dB, relative to audiometric zero, 10 dB were added to all audiologist interpreted HTLs to avoid negative HTL values. If no TTS were detectable, approximately equal amounts of negative and positive HTL differences were expected. A TTS was produced when more positive HTL differences were obtained upon comparison of the initial post-stimuli audiogram and pre-test audiogram values.

Since a TTS should be indicated by significant differences between the HTLs recorded on pre-test and post-stimuli audiograms, and greater amounts of TTS should be indicated after longer durations of each tone, two null hypotheses were proposed for testing at the 0.05 level of significance for the laboratory study. These were:

> There are no mean HTL differences between pre-test and post-stimuli audiograms at a given audiometer test tone frequency within each treatment.
>
> There are no mean HTL differences between durations within each frequency/level stimuli when checked with the same audiometer test tone.

Table III. Time Intervals In Seconds For HTL Checks

	HTL Test Tone KHz				
Post-Stimuli Audiogram	0.5	1.0	2.0	3.0	4.0
1.	20-49 Seconds	50- 79	80-109	110-139	140-169
2.	180-209	210-239	240-269	270-299	300-329
3.	240-369	370-399	400-429	430-459	460-489
4.	500-529	530-559	560-589	590-619	620-649
5.	660-689	690-719	720-749	750-779	780-809

RESULTS AND DISCUSSION

Field Study

The objective of the field study was to determine if generated interference tones could be characterized by mean acoustic levels. Although higher acoustic levels should occur with increasing power levels, potential levels of interference tones could be described with one curve, if no significant mean dB SPL differences existed between the 4 tone frequencies at each power level and between the 5 positions within each ARTCC. If one curve could not be developed for each ARTCC, four curves, one for each frequency, could be developed to describe interference tones if no significant mean dB SPL differences were measured between positions within each ARTCC.

A maximum acoustic level for the 7 ARTCCs should be measurable for each tone frequency. These maximum acoustic levels also should better indicate maximum interference tone levels than were obtained by testing the headsets. Maximum acoustic levels could be determined, if no significant mean db SPL differences existed between the 7 ARTCCs and between the positions within each frequency when SPLs were measured at the three highest signal power levels.

Higher acoustic levels were measured with increasing signal power levels; however, most graphs were not linear with increasing power levels when SPLs were plotted on linear, log/linear and log/log graphs. Most SPL measurements were about the same at the highest signal power levels, but some levels both increased and decreased for the same tone frequency at higher power levels. Although some of the SPL measurements were the same for different frequencies of tones at the same power level, the initially higher levels of one tone did not drop below the levels of the different tone.

The SPL measurements for the 3 KHz were consistently lower at each power level and for each ARTCC. Except for the Seattle ARTCC, the SPL measurements for the 0.5 KHz frequency tones were the next lowest for each ARTCC. The SPL measurements were higher for the 2 KHz tones than for the 1 KHz tones at 4 of the ARTCCs. The SPL measurements were averaged for the 5 positions at each ARTCC and then rounded to the nearest whole number as listed in Table IV.

When the 200 acoustic level measurements were averaged for each ARTCC, the mean SPLs were;

99.8 ± 10.0 dB for the Seattle ARTCC (ZSE),
101.1 ± 10.0 dB for the Oakland ARTCC (ZOA),
99.9 ± 10.1 dB for the Los Angeles ARTCC (ZLA),
103.6 ± 10.0 dB for the Anchorage ARTCC (ZAN),
99.3 ± 10.0 dB for the Fort Worth ARTCC (ZFW),
100.2 ± 9.9 dB for the Houston ARTCC (ZHU), and
97.4 ± 10.0 dB for the Salt Lake City ARTCC (ZSL).

The lowest SPL, 70 dB, was measured in the Oakland, Los Angles, and Salt Lake City ARTCCs for the 3 KHz tone at the -35 dBm signal power level. The highest SPL, 122 dB, was measured at the Oakland ARTCC at the 5 and 10 dBm signal power levels with the 1 KHz tone. At the Anchorage ARTCC, a 121 dB SPL measurement was obtained with the 1 KHz tone at -20 through 10 dBm signal power levels.

Table IV. Mean/Rounded dB SPL For ARTCCs

Seattle ARTCC (ZSE)

Power Levels dBm

Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	75	80	85	88	91	95	97	98	95	98
1 KHz	87	91	95	98	99	101	103	104	105	104
.5 KHz	91	95	98	101	102	105	104	103	104	104
2 KHz	97	102	105	107	108	110	109	110	109	109

Table IV. Mean/Rounded dB SPL For ARTCCs (Continued)

Oakland ARTCC (ZOA)

Power Levels dBm

Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	79	84	87	91	94	97	98	97	98	96
.5 KHz	91	95	97	101	103	104	105	105	104	104
2 KHz	92	97	100	102	103	104	103	104	103	103
1 KHz	96	100	105	107	110	111	113	114	114	113

Los Angeles ARTCC (ZLA)

Power Levels dBm

Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	78	82	86	88	90	92	94	95	95	95
.5 KHz	90	93	97	99	103	103	103	103	103	103
2 KHz	92	96	98	101	102	103	106	106	108	107
1 KHz	96	100	103	105	107	108	108	109	109	108

Anchorage ARTCC (ZAN)

Power Levels dBm

Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	78	83	87	92	95	97	99	100	98	97
.5 KHz	93	97	100	103	105	107	107	107	107	107
2 KHz	97	101	103	106	107	107	107	107	107	107
1 KHz	101	105	110	112	113	113	115	116	116	115

Fort Worth ARTCC (ZFW)

Power Levels dBm

Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	77	81	84	88	91	92	93	93	92	93
.5 KHz	82	86	90	94	96	97	97	97	97	97
1 KHz	84	87	93	97	98	100	100	99	98	97
2 KHz	86	91	95	97	100	103	102	102	102	101

Table IV. Mean/Rounded dB SPL For ARTCCs (Continued)

Houston ARTCC (ZHU)

	Power Levels dBm									
Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	75	81	85	88	90	93	94	93	92	91
.5 KHz	93	96	100	102	104	104	105	103	103	104
1 KHz	94	98	102	104	104	105	107	107	106	106
2 KHz	96	100	103	105	105	106	107	107	107	107

Salt Lake City ARTCC (ZSL)

	Power Levels dBm									
Frequencies	-35	-30	-25	-20	-15	-10	-5	0	5	10
3 KHz	76	81	85	87	90	91	94	95	93	92
.5 KHz	86	91	94	97	98	99	100	99	99	99
2 KHz	86	91	94	97	100	102	101	100	100	100
1 KHz	92	97	102	103	105	106	106	107	107	108

The SPL measurements were recorded for each ARTCC by frequency, position, and power level, and statistics from 4 x 5 x 10 factorial analysis of variance tests were calculated to test the first null hypothesis. Increasing frequencies were identified as 1 through 4, positions were identified as 1 through 5, and increasing power levels were identified as 1 through 10. Degrees of freedom for the corrected total or total variation were 199, 108 for the error, and 91 for the model for each ARTCC. As shown in Table V, the probabilities of obtaining F values as large or greater than the respective F statistics are not significant at the 0.05 level for Positions within the Seattle, Oakland, and Salt Lake City ARTCCs and for the interactions between the position, frequency, and power level factors.

The first null hypothesis required no mean SPL differences between both the frequency and position factors. Although the mean SPL differences were not significant between positions at some ARTCCs, all mean SPL differences between frequencies were significant at 0.05 level of significance. As expected, the mean SPL differences were significant for the power levels, since increases in acoustic levels should have occurred with increasing signal power levels. The probabilities indicated for interactions were not significant for the Position x Frequency, Position x Power Level, and Frequency x Power Level effects, so testing for significant position, frequency and power level main effects was appropriate.

The first null hypothesis was rejected in favor of the alternate; there were mean SPL differences between positions and frequencies within an ARTCC. A single curve could not be used to describe interference tone levels at the frequencies used in each ARTCC.

The second null hypothesis required no significant mean dB SPL differences between positions within each frequency at each ARTCC. The data were sorted by frequency, position and power level, and analysis of variance tests were performed by frequency for within each ARTCC. The probabilities of obtaining values of F as large or greater than the calculated F statistics for differences between positions are listed in Table VI.

The probabilities indicated significant mean dB SPL differences existed between positions within each frequency and for each ARTCC, except for positions in the Seattle, Oakland and Salt Lake City ARTCCs at the 0.5 KHz frequency.

Tavle V. Probabilities of F Statistics Within Each ARTCC

Source	ZSE	ZOA	ZLA	ZAN	ZFW	ZHU	ZSL
Model	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Positions	.1498	.2350	.0361	.0025	.0079	.0001	.1490
Frequencies	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Power Level	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Position x *Frequency*	.6561	.7236	.6105	.2401	.2960	.3411	.3438
Position x Power Level	.5138	.5865	.3415	.6235	.5051	.5580	.5939
Frequency x Power Level	.5057	.6310	.7060	.4434	.6591	.5563	.6766

Table VI. Probabilities for F Statistics Within Frequencies

	Probabilities of F Statistics Between Positions						
Frequency	ZSE	ZOA	ZLA	ZAN	ZFW	ZHU	ZSL
0.5 KHz	.7733*	.6288*	.0001	.0001	.0001	.0001	.4203*
1 KHz	.0001	.0001	.0030	.0001	.0088	.0001	.0017
2 KHz	*.0001*	*.0001*	*.0041*	*.0001*	*.0188*	*.0001*	*.0001*
3 KHz	.0001	.0001	.0001	.0082	.0001	.0001	.0001

*** No significant difference between positions within frequencies at the alpha = 0.05 level**

With three exceptions and at the 0.05 level of significance, the second null hypothesis was rejected in favor of the alternate; there were significant mean dB SPL differences between positions within each frequency at each ARTCC. Except for the 0.5 KHz generated tones in the ZSE, ZOA, and ZSL, potential use of the four curves, one for each frequency, to indicate levels of interference tones could not be developed.

The dB SPL values were averaged for the 0, 5, and 10 signal power levels at each position for each frequency. The averaged dB SPL measurements were sorted by frequency, ARTCC, and position, and analysis of variance tests were performed by frequency. The probabilities for obtaining values of F as large or greater than the calculated F statistics are listed in Table VII.

Table VII. Probabilities of F Statistics At The Three Highest Power Levels

	Probabilities of F Statistics	
Frequency	ARTCCs	Positions
0.5 KHz	.0003	.0065
1 KHz	.0001	.0001
2 KHz	.0001	.0001
3 KHz	.0001	.0001

The third null hypothesis, that there are no mean dB SPL differences between ARTCC and between positions within each frequency at the three highest power levels, was rejected at the 0.05 level of significance. Maximum levels of generated interference tones could not be determined for the 7 ARTCCs in this manner. This finding also could have been anticipated since maximum levels varied between 100 and 114 dB SPL for the 0.5 KHz tones, between 99 and 122 dB SPL for the 1 KHz tones, between 101 and 118 dB SPL for the 2 KHz tones, and between 93 and 109 dB SPL for the 3 KHz tones. The Houston ARTCC was the only facility in which one of these least or highest levels was not obtained.

Interference Tone Effects

The effects of simulated ATCS interference tone exposures at specific sound levels, frequencies and durations were studied to evaluate the potential of TTSs in HTLs. Increasing amounts of TTSs are usually detected following excessive stimuli of higher levels and the same duration, as well as following an excessive stimulus at the same level with longer durations. The maximum TTS should be detectable at 2 minutes following the stimuli and with an audiometer test tone that is approximately 1.5 times the frequency of a pure tone stimulus. Maximum TTSs are usually detected with the 4 KHz audiometer test tone for most people exposed to excessive levels of broadband type noise (8). In response to a constant excessive level of a stimulus, most TTSs increase asymptotically with time, and except for the first 2 post-stimulus minutes and TTSs less than 40 dB, recovery is linear in log of time (9). Maximum amounts of TTS detected during this study should be indicated by positive HTL increases on initial post-stimuli audiograms and, with recovery, TTS should not be detectable on the last post-stimulus audiograms. A TTS indicated following a shorter duration of reversed communication/tone stimuli, also should increase with longer tone durations.

The audiologist interpreted HTLs were recorded in dB for each audiometer test tone frequency and audiogram number. Test sessions were designated as treatments 1 through 3, 4 through 6, 7 through 9, and 10 through 12 for the 5, 60, and 145 seconds durations of the 0.5, 1, 2, and 3 KHz tone stimuli. Audiograms were recorded as 1 for the pre-test audiogram and 2 through 6 for the five post-stimuli audiograms. The HTLs were recorded in dB for each frequency, 0.5, 1, 2, 3, and 4 KHz, and listed under 1 through 5 for each the audiometer test tone.

The dB values for all subjects and each treatment were sorted by audiometer test tone frequency and audiogram number. Analysis of variance tests were performed for each treatment and audiometer test tone frequency to calculate F statistics. The probabilities of obtaining values of F as large or greater than the calculated F statistics are listed in Table VIII.

Table VIII. Levels Of Significance For Between Audiograms

Treatment Number	Duration Seconds	Audiometer Test Frequency, KHz				
		0.5	1	2	3	4
1-.5 KHz	5	.9425	.9822	.9208	.9927	.9835
2	60	.9973	.9960	.9986	.9962	.9933
3	145	.9422	.9903	.9473	.9210	.9213
4-1 KHz	5	.9882	.9424	.9863	.9893	.9878
5	60	.8523	.0001*	.0001*	.9425	.9863
6	145	.9923	.0001*	.0001*	.0001*	.9199
7-2 KHz	5	.9204	.9908	.9593	.9908	.9897
8	60	.9525	.9880	.7630	.0283*	.7410
9	145	.9705	.9392	.0001*	.0001*	.0001*
10-3 KHz	5	.9522	.9908	.9868	.9927	.9651
11	60	.9729	.9368	.9328	.3582	.9631
12	145	.9713	.9880	.9868	.5584	.0048*

* Mean HTL differences significant at the 0.05 level

The value of the resultant probabilities were used to determine the significance of mean HTL differences between audiograms for each treatment to test the first null hypothesis, i.e., there are no mean HTL differences between audiograms at a given audiometer test frequency within each treatment. The potential of a treatment producing a TTS was used as the basis for the first null hypothesis.

Following treatments 1, 2, 3, 4, 7, 10 and 11, the mean dB or HTL differences between the 6 audiograms were not significant at the 0.05 level for each audiometer test tone frequency, causing failure to reject the first null hypothesis. There were no mean HTL differences indicated between pre-test and post-stimuli audiograms following these treatments when checked with the 0.5, 1, 2, 3, and 4 KHz audiometer test tones.

Following treatments 5, 6, 8, 9, and 12, the mean HTL differences were significant between audiograms for some audiometer test tones. Following the 1 KHz/114 dB/60 seconds exposure, differences were significant when HTL were checked with the 1 and 2 KHz audiometric test tone. The mean HTL differences also were significant when checked with the 1, 2, and 3 KHz audiometer test tones, following the 1 KHz/114 dB/145 seconds exposure. Following the 2 KHz/108 dB/60 seconds exposure, mean HTL differences were significant when checked with the 3 KHz audiometer test tone. The mean HTL differences also were significant following the 2 KHz/108 dB/145 seconds exposure and HTLs were checked with the 2, 3, and 4 KHz audiometer test tones. Following the 3 KHz/99 dB/145 seconds exposure, mean HTL differences were significant when checked with the 4 KHz audiometer test tone.

The first laboratory study null hypothesis was rejected in favor of the alternate; there were mean HTL differences between audiograms for these five treatments and the listed audiometer test tones at the 0.05 level of significance.

Although some subjects may have experienced some HTL shifts, TTSs were not indicated following all 5 second tone exposures, following all 0.5 KHz/109 dB SPL exposures, and following the 3 KHz/99 dB SPL/60 seconds exposure. The audiograms of one subject indicated a TTS following the 3 KHz/99 dB SPL/60 seconds exposure, but not following the 3 KHz/99 dB SPL/145 seconds exposure and HTLs were checked with the 4 KHz audiometer test tone.

The second laboratory null hypothesis was: there are no mean HTL differences between durations within a frequency/level stimuli when checked with the same audiometer test tone. The HTL values for the 0.5 KHz/109 dB stimulus were combined and sorted by duration or treatment number, audiometer test tone frequency and audiogram number. This procedure was repeated for the 1 KHz/114 dB, the 2 KHz/108 dB, and the 3 KHz/99 dB stimuli. Factorial analysis of variance tests were performed for each frequency/level stimulus. The probabilities of obtaining values of F as high or greater that the calculated F statistic are listed in Table IX.

Table IX. Probabilities Of F For Mean HTL Differences Between Each Variable And Two-Way Interactions

	Frequency/Level Stimuli			
Variables	.5 KHz/109 dB	1 KHz/114 dB	2 KHz/108 dB	3 KHz/99 dB
Durations	.9553*	.0001	.0001	.0385
Test Tones	.0001	.0001	.0001	.0001
Audiograms	.9966*	.0001	.0001	.7503*
Durations x Test Tones	1.0*	.0001	.0149	.9802*
Durations x Audiograms	1.0*	.0001	.0001	.9962*
Test Tones x Audiograms	1.0*	.0001	.0057	.9996*

*** Mean HTL differences not significant at the 0.05 level**

Table X. Probabilities Of F For Within Durations

	1 KHz/114 dB Stimulus Seconds Duration			2 KHz/108 dB Stimulus Seconds Duration		
Variables	5	60	145	5	60	145
Test Tone	.0001	.0001	.0001	.0001	.0001	.0001
Audiograms	.9959*	.0001	.0001	.9988*	.7554*	.0001
Test Tones x Audiograms	1.0	.0001	.0001	1.0	1.0	.0001

*** Mean HTL differences not significant at the 0.05 level**

The probabilities listed in Table IX indicated differences were consistently significant at the 0.5 level for mean HTL values between audiometric test tones within each frequency/level stimuli. Differences for mean HTL values between durations were not considered significant for the 0.5 KHz/109 dB stimulus and were significant for the other three stimuli. Differences in mean HTL values between audiograms, however, were considered significant for the 1 KHz/114 dB and 2 KHz/108 dB stimuli. When differences between audiograms for the 3 KHz/99 dB stimulus were considered, the value of the calculated F statistic was relatively small and not within the critical region. Differences between audiograms were considered significant for the 3 KHz/99 dB stimulus only when HTLs were checked with the 4 KHz audiometer test tone.

The levels of interaction indicated by the two-way variable combination test results were considered not significant for the 0.5 KHz/109 dB and 3 KHz/99 dB stimuli. The mean HTL values obtained by combining HTL results for each audiogram for this test implied that variances for each audiogram were not significantly different between the 6 audiograms. The level of significance for interaction between each of the two-way variable combinations inferred determination of the sources of the interaction were needed for the 1 KHz/114 dB and 2 KHz/109 dB stimuli.

The HTL values for the 1 KHz/114 dB and 2 KHz/109 dB stimuli were respectively combined and factorial analysis of variance tests were performed by durations. The probabilities of obtaining values of F as high or greater than the F statistic are listed in Table X.

These probabilities indicated differences between audiometer test tones could again be considered significant. The probabilities also indicate significant differences between audiograms and levels of interaction for the 60 and 145 seconds durations for the 1 KHz/114 dB stimulus and for the 145 seconds duration of the 2 KHz/108 dB stimulus. Differences between the audiograms were not considered significant for the 5 seconds durations and for the 60 seconds duration of the 2 KHz/108 dB stimulus. Differences between audiograms were considered significant for the 2 KHz/109 dB/60 seconds exposure, only when HTLs were checked with the 3 KHz audiometer test tone.

Differences between audiograms were significant when HTLs were checked at 1 KHz and 2 KHz for the 60 and 145 seconds durations of the 1 KHz/114 dB stimulus and at 3 KHz for the 145 seconds duration. This occurred when HTLs were checked with the 2, 3, and 4 KHz audiometer test tones following the 2 KHz/108 dB/145 seconds exposure. The level of Test Tones x Audiograms interaction also was significant.

It was suspected that the increased HTL values on the initial post-stimuli audiograms for the above treatments may have been the cause of the significant level of interaction. The HTL values from the first post-stimuli audiograms were eliminated for the 1 KHz/114 dB and 2 KHz/108 dB stimuli, and the HTL values from the second post-stimuli audiograms were eliminated for the 1 KHz/114 dB/145 seconds exposure. Factorial analysis of variance tests were repeated for each exposure duration. The probabilities of obtaining values of F as high or greater than the calculated F statistic are listed in Table XI.

The results in Table XI were consistent with the audiometric test tone frequency results listed in Tables IX and X. However, the results for between audiograms were changed to no apparent significant differences. The implied level of interaction for the two-way variable interaction also was reduced.

Table XI. Probabilities Of F For Within Durations, Unbalanced Data

	1 KHz/114 dB Stimulus Seconds Duration			2 KHz/108 dB Stimulus Seconds Duration		
Variables	5	60	145	5	60	145
Test Tones	.0001*	.0001*	.0001*	.0001*	.0001*	.0001*
Audiograms	.9959	.9565	.5953	.9988	.7554	.9658
Test Tones x Audiograms	1.0	.9994	.8575	1.0	1.0	1.0

*** Mean HTL differences that are significant at the 0.05 level**

Testing the second null hypothesis was based on the significance of differences between durations as shown in Table IX. The second laboratory null hypothesis, i.e., that there are no mean HTL differences between durations within a frequency/level stimuli with the same audiometer test tone, was rejected at the 0.05 level of significance. There were mean HTL differences between durations with the 1 KHz/114 dB, 2 KHz/108 dB, and 3 KHz/99 dB stimuli. Failure to reject the null hypothesis at the 0.5 level of significance occurred with the 0.5 KHz/108 dB stimulus.

At least two sources of error were noted with the HTL checks in the laboratory study. These were associated with variability in subjects' responses when their listening for audiometer generated pure-tone signals at or near their HTL required learning. The HTLs also did not remain stable, especially when TTS recovery occurred during the HTL check interval. Randomization of the twelve treatments for each subject and audiologist interpretations of HTL values to the nearest 5 dB were used to limit these sources of error.

Some investigators consider that, due to variability in an individual's baseline HTLs, a minimum increase of 10 dB is necessary to conclude that a TTS effect was detected (10). Other investigators consider that mean HTL differences of less than 2 dB demonstrate a detectable TTS effect (11).

A maximum mean TTS of 5.75 dB was detected when HTLs were checked with the 1 KHz audiometer test tone following the 1 KHz/114 dB/60 seconds exposure. The maximum mean TTS was 11.5 dB when checked with the 2 KHz audiometer test tone and following the 1 KHz/114 dB/145 seconds exposure. When HTL were checked with the 3 KHz audiometer test tone, the maximum mean TTS was 1.25 dB following the 2 KHz/108 dB/60 seconds exposure and 7.75 dB following the 2 KHz/108 dB/145 seconds exposure.

CONCLUSIONS

The results of the field study demonstrated that the level of interference tones could not be described by the dB SPL measurements of one frequency. The results also demonstrated that the acoustic levels of one frequency could not be used for describing tones of the same frequency and power level at different ARTCCs and between positions within the same ARTCC for most tones.

Maximum sound levels were measured within the range of the signal power levels used for testing headsets; however, no single maximum mean sound level was applicable for each interference tone frequency or for maximum signal power level. The mean maximum levels measured in the ARTCCs also were consistently lower than the levels measured by testing headsets following interference tone incidents. The results of this study indicated the level of a generated interference tone must be determined at the same signal power level and frequency within the same ARTCC and except for the 0.5 KHz tones in 3 ARTCCs, at the same position within the ARTCC.

Results of the laboratory study indicated temporary threshold shifts could not be detected following an ample response time (5 seconds) for removing the headset insert type ear piece. Shifts were detected following 60 and 145 seconds exposures to the 1 KHz/114 dB and 2 KHz/108 dB stimuli, and a 145 seconds exposure to 3 KHz/99 dB stimulus. These exposures are within the current DOL Occupational Safety and Health Administration (OSHA) promulgated Noise Standard (29 CFR 1910.95) for continuous noise exposures. Of the 20 subjects who completed the twelve test sessions, 18 had positive HTL shifts that were detected when the tone duration was 145 seconds. Exposures of that duration would not be anticipated in the field.

Increased levels of TTS were detected with three tones, but only when the durations were extended for far longer-than-expected exposures. It would be extremely unlikely that an air traffic control specialist or pilot would be required to keep the ear piece inserted into the ear canal more than the first few seconds of an interference tone.

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