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Hair Effects on Aviator Helmet Stability and Sound Attenuation (Reprint)

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Tests were conducted at several U.S. Naval Air Stations to assess the performance of aviator helmets when worn by female aircrew. Helmets included the HGU-68/P, used by the Navy TAC Air community, and the HGU-84/P, used by the Navy rotary-wing community. Tests included a static stability, where the helmets were loaded tangentially and the helmets' resulting angular rotation recorded, and sound attenuation, utilizing the physical ear test method. The female aircrew wore their hair as they normally do while conducting flight operations. While not initially planned, male aviators and aircrew were included to conduct female-to-male comparisons in helmet performance.

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HAIR EFFECTS ON AVIATOR HELMET STABILITY AND SOUND ATTENUATION

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Abstract

An increase in the female population in the U.S. Navy aviator and aircrew community raised concern that the standard issued protective equipment may provide inadequate protection. Of particular concern was the performance of the recently developed aviation helmets. While these helmets met the contractual performance requirements, it was not known what effect hair bulk would have on the more critical operational performance.

Tests were conducted at several U.S. Naval Air Stations to assess the performance of aviator helmets when worn by female aircrew. Helmets included the HGU-68/P, used by the Navy TAC Air community, and the HGU-84/P, used by the Navy rotary-wing community. Tests included a static stability, where the helmets were loaded tangentially and the helmets' resulting angular rotation recorded, and sound attenuation, utilizing the physical ear test method. The female aircrew wore their hair as they normally do while conducting flight operations. While not initially planned, male aviators and aircrew were included to conduct female-to-male comparisons in helmet performance.

Results were consistent in both tests; helmet performance differences between female hairstyles were insignificant, yet differences between gender were significant. It was concluded that hair does not affect helmet performance as greatly as head morphology. This implies that due consideration must be given to female head anthropometry if helmet stability and sound attenuation are important.

Background

Aircrew protective helmets are designed to serve two basic functions. First, they must provide adequate head protection and second, they serve as a mounting platform for audio communications and visual displays. As a mounting platform, it must remain stable in the total flight environment and provide a comfortable fit for the mission duration. Head protection is provided for bump, noise, impact, and windblast exposures. These helmet performance areas may all be affected by excessive hair lengths or female head anthropometry.

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No established guidelines on preferred hair lengths and styles exist for military female aviators. Excessive hair bulk may affect helmet performance throughout the flight profile, especially in the dynamic environments of high "G" maneuvers, catapult assisted take-offs, carrier (arrested) landings, crash landings, or ejections. Female aviators have been left to determine how to manage their hair in the flight environment. Their decision most probably is based on a comfort perspective, not helmet performance or safety considerations. Certain hair styles may expose female aviators to unnecessary risks. This study was developed to determine the effects of female aircrew hair style on helmet stability and sound attenuation.

Introduction

An objective of this project was to obtain helmet performance data on the current female aircrew population. To facilitate access to the limited population, the U.S. Army Aeromedical Research Laboratory (USAARL) sent a research team to several Navy and Marine Corps air stations with large populations of female aircrew assigned to them. Program sponsors from the Naval Air Warfare Center, Aircraft Division (NAWCACDIV), Patuxent River, MD, assisted in determining the current duty stations of female aircrew. The desire was to minimize the number of facilities included in the field evaluation while maximizing the available female aircrew population. Based on information received, the actual sites visited included Pensacola, FL, Milton, FL, Norfolk, VA, San Diego, CA, and Miramar, CA.

The helmet performance data included rotational stability and sound attenuation. Basic demographic data was recorded to describe the volunteer population and the "flight duty" hair styles.

Volunteers

U.S. Navy and Marine Corps female aircrew personnel with experience wearing a flight helmet were the target population. Obtaining a truly random sample from the entire population was difficult to accomplish within the program's time and cost constraints because of the various deployment locations of the female aircrew. Aircrew who were assigned to duty stations outside the continental United States or were deployed on a ship could have only participated in the study if they traveled to one of the selected field test sites within the continental United States. To acquire the sample, USAARL researchers traveled to various "target population rich" Naval and Marine Corps Air Stations to make it easier for subjects to participate in the study. Going onsite relieved the unit commanders from losing the participating aircrew for 3 days if the participants had been sent TDY to USAARL.

A total of 94 Navy and Marine subjects were tested. Originally, this project was designed to include only female subjects. The research protocol was amended after the second test location to include male subjects in the design. A wide variation in female test results was observed and the question of data comparison to the male population was raised. The result was a study sample which included 83 females and 11 males. The age and racial data for one male participant was not recorded and is not reported in all data tables. Incorporation of males into the study allowed a basic helmet performance comparison between gender. Generally, the data for the male subjects are reported with the female subject data for completeness.

A total of five different Navy facilities were visited for data acquisition. These sites and the number of participants from each site are provided in table 1. This table also indicated the gender from each test site. Inspection of table 1 shows no males participated at the Pensacola and Whiting test sites. This was a result of the original test protocol being approved for female volunteers only. At the remaining three test sites, efforts were made to recruit male participants, but most of the emphasis was on recruiting females.

Table 1.
Number of volunteers by test location.

Locations	**Total**		**Female**		**Male**	
	n	**percent**	**n**	**percent**	**n**	**percent**
Pensacola	23	24.47	23	27.71	0	0.00
Whiting Field	12	12.77	12	14.46	0	0.00
Norfolk	25	26.60	23	27.71	2	18.18
San Diego	25	26.60	22	26.51	3	27.27
Miramar	9	9.57	3	3.61	6	54.55
Total	94	100.00	83	100.00	11	100.00

Table 2.
Military rank distribution.

Rank	**Total**		**Female**		**Male**	
	n	**percent**	**n**	**percent**	**n**	**percent**
E3	3	3.19	3	3.61	0	0.00
E4	3	3.19	3	3.61	0	0.00
E5	14	14.89	13	15.66	1	9.09
E6	2	2.13	2	2.41	0	0.00
O1	17	18.09	17	20.48	0	0.00
O2	13	13.83	13	15.66	0	0.00
O3	35	37.23	26	31.33	9	81.82
O4	4	4.26	4	4.82	0	0.00
O5	3	3.19	2	2.41	1	9.09
TOTAL	94	100.00	83	99.99	11	100.00

Table 3.
Total military flight hours accumulated by volunteers.

Hours	All		Females		Males	
	n	percent	n	percent	n	percent
0	17	18.09	17	20.48	0	0.00
1-50	9	9.57	9	10.84	0	0.00
51-150	9	9.57	8	9.64	1	9.09
151-300	15	15.96	15	18.07	0	0.00
301-500	11	11.70	7	8.43	4	36.36
501-1000	13	13.83	12	14.46	1	9.09
1001-1500	9	9.57	7	8.43	2	18.18
1501+	8	8.51	6	7.23	2	18.18
Missing	3	3.19	2	2.41	1	9.09
Total	94	99.99	83	99.99	11	99.99

Hair styles

Each female subject's hair style was visually assessed and assigned to 1 of 13 hair styles. These 13 hair styles were then collapsed into 11 styles, placing all styles with hair up in a bun-style together regardless of whether the bun was made of braided, french braided, or loose hair. Hair classification I consisted of these 11 styles plus the male style for all male subjects. Classification II was a generalized grouping scheme based on the styles from the first classification. The hair length, measured from the top of the head to the bottom of the hair in a free state, was the basis of the third system, classification III, as shown in table 4. A few subjects with tight braids, french braids, and buns had recorded measurements that, upon review of the video images, were reassigned to place them in the correct length range. For the entire study, male volunteers were placed in a separate class for hair style classification. Based on the hair style classifications shown in table 4, frequency distributions are provided in tables 5, 6, and 7. Also, the three tables include the average age of the subjects to the nearest year.

Table 4.
Hair style classification schemes.

Classification I	**Classification II**	**Classification III (length)**
Short, straight	Short	Short (< 20 cm) Medium (20 - 29.9 cm) Long (30 - 39.9 cm) Extra long (≥ 40 cm) Male
Short, wavy		
Short, other		
Medium, straight	Medium	
Medium, wavy		
Long (straight)	Long, down	
Pony tail		
Braid, down		
French braid, down		
Up (bun, braid, french braid)	Long, up	
Pinned up		
Male	Male	

Table 5.
Classification I distribution and average age.

Classification I	**Average age (yrs)**	**Number**	**Overall percent**	**Female percent**
Short straight	29	11	11.70	13.25
Short wavy	27	8	8.51	9.64
Short other	31	5	5.32	6.02
Medium straight	25	8	8.51	9.64
Medium wavy	33	5	5.32	6.02
Long (straight)	26	4	4.26	4.82
Pony tail	29	12	12.77	14.46
Braid down	27	5	5.32	6.02
French braid down	25	14	14.89	16.87
Up	25	8	8.51	9.64
Pinned up	23	2	2.13	2.41
Missing	---	1	1.06	1.20
Male	30	11	11.70	---

Table 6.
Classification II distribution and average age.

Classification II	Average age (yrs)	Number	Overall percent	Female percent
Short	29	24	25.53	28.92
Medium	28	13	13.83	15.66
Long down	27	35	37.23	42.17
Up	25	10	10.64	12.05
Missing	---	1	1.06	1.20
Male	30	11	11.70	---

Table 7.
Classification III distribution and average age.

Classification III	Average age (yrs)	Number	Overall percent	Female percent
Short	30	13	13.83	15.66
Medium	27	32	34.04	38.55
Long	26	30	31.91	36.14
Extra long	27	7	7.45	8.43
Missing	---	1	1.06	1.20
Male	30	11	11.70	---

Helmets

Two different helmet configurations were used in this evaluation. These were the "HGU-84/P" and the "HGU-68/P" helmets. Both helmets were new configurations and, at the time, were being fielded by the Navy and Marine Corps. The HGU-68/P helmet is intended for use by the fixed wing aircrew. The HGU-84/P helmet is intended for use by the rotary-wing aircrew. These two helmet configurations are similar, but utilize different earcups, earpads, nape straps, and visor assemblies. These two helmet configurations were used in all of the helmet performance assessments.

Tables 8 and 9 present the size distribution used by the subjects. These helmets were individually fitted to each subject by a U.S. Navy parachute rigger, experienced in helmet fitting. During the fitting process, efforts were made to acquire an adequate "first fit" with each participant. Time constraints prevented the subjects from receiving additional efforts to custom fit the individuals or remove potential "hot-spots" or pressure points and discomfort which may develop over prolonged wear.

Table 8.
HGU-68/P helmet size distribution.

Helmet	Total		Female		Male	
Size	Number	Percent	Number	Percent	Number	Percent
Medium	34	37.36	33	41.25	1	9.09
Large	55	60.44	46	57.50	9	81.82
X-Large	2	2.20	1	1.25	1	9.09
Total	91	100.00	80	100.00	11	100.00

Table 9.
HGU-84/P helmet size distribution.

Helmet	Total		Female		Male	
Size	Number	Percent	Number	Percent	Number	Percent
Medium	46	51.11	42	53.16	4	36.36
Large	42	46.67	36	45.57	6	54.55
X-Large	2	2.22	1	1.27	1	9.09
Total	90	100.00	79	100.00	11	100.00

Sound attenuation

Introduction

Sound attenuation of a circumaural hearing protector is sensitive to the fit or compliance of the earcup to the head of the wearer. The earseal is constructed of a soft compliant material and acts as a comfort interface between the earcup and the head of the user. In order to optimize the fit, the earseal must make direct contact to the head with as much surface area as possible. In areas where objects such as spectacle frames or hair are present, the seal to head contact will be compromised, thereby reducing the effectiveness of the hearing protector. Past experience at this laboratory has shown that sound attenuation is very sensitive to excess hair, causing significant reductions in measured sound attenuation of a hearing protector.

The purpose of the sound attenuation assessment was to determine the effect of "normal flight duty" hair styles worn by female Navy and Marine Corps aircrew. These measurements were completed on each subject while wearing the HGU-84/P, used by rotary wing aircrew, and the HGU-68/P, used by fixed wing aircrew. Hair styles were categorized into three classification groupings: Classification I was based on length, texture, and style; classification II was based on length, gradations of length, and hair worn either up or down; classification III was based on length.

Physical ear noise attenuation test measurements were completed on 78 female Navy and Marine aircrew during August through November 1995 at five Naval air stations. Eleven male aircrew were included in the tests to provide a baseline attenuation for each helmet system.

Each subject aircrew was fitted by Navy personnel trained in the proper fitting techniques of the two helmet configurations.

Methods and instrumentation

The noise attenuation characteristics of the helmets were measured using an objective method. Subjects were placed, individually, in a sound field with a miniature microphone placed in each ear. Each microphone's output was measured and analyzed while the subject was wearing and not wearing the test helmet. The attenuation characteristic was calculated by taking the difference of noise levels measured in each one-third octave band while the subject was wearing and not wearing the helmet. The procedures used for these measurements were essentially in accordance with MIL-STD-912, physical ear noise attenuation testing (PEAT), with the exception of exact compliance with the non-directionality of the sound field. Since the test system was housed in a mobile van, the diffusivity of the sound field requirements were not achievable. The PEAT compares the arithmetic difference, in decibels, between the one-third octave band sound pressure levels of the signals measured by a microphone in the subject's ears with (attenuation) and without (free field) the helmet being worn.

The PEAT measurement system was located in a mobile research utility van. The noise spectrum, generated by a Larson Davis Laboratories' Real Time Analyzer, model 3100, was amplified by a McIntosh amplifier, model 2505. Output from the amplifier was input to four BOSE loudspeakers, model 2001, producing a sound pressure level of approximately 105 dB. The speakers were placed at 45 degrees, 135 degrees, 225 degrees, and 315 degrees relative to the subject's head location. Knowles electret microphones, model 1832, were used to measure the noise level at each ear of the subjects. An acoustic reference signal produced by a Bruel and Kjaer 4220 piston phone was recorded through the system, analyzed on the Larson Davis Real Time Analyzer 3100 RTA, to calibrate the system to provide sound pressure levels referenced to 20 micro pascals. The electret microphones were calibrated using the General Radio 1562A sound level calibrator. The acoustic reference signals were stored on data files on the control computer.

An insert hearing protector, the Silaflex moldable earplug, manufactured by Flents Products, was used to provide hearing protection for the subject and served as a mounting base for the microphones in the area of the ear canal. The subject was seated in a chair placed in the center of the sound field. A single freefield noise measurement was completed without the test helmet being worn, unoccluded, analyzed into one-third octave bands, dBA, and linear levels, and stored in files located on the personal computer (PC) system. The subject fitted the helmet, as they do during normal flying duties, being careful not to change the position of the electret microphones in the ears. A noise measurement was completed, analyzed and stored on the PC in a manner like the freefield measurement. Two additional measurements were completed with the subject removing and refitting the helmet between each measurement.

Results and discussion

Comparison of attenuation results for each helmet was made, along with comparisons for gender and hair style classification. The mean and standard deviation of the sound attenuation measurements are shown in figures 1 through 7. The overall data, figure 1, shows higher attenuation for the HGU-84/P than the HGU-68/P with the exception of the 500 and 630 Hertz bands. The male subjects show greater mean values and lower standard deviations for the HGU-84/P for all frequencies except 800 and 1000 Hertz. Male subjects show greater mean values for the HGU-68/P for frequencies greater than 1000 Hertz. Beyond this cursory view, none of the other data comparisons show substantial or statistically significant differences.

Perhaps the easiest method to assess the effectiveness of a hearing protector is to directly determine the noise exposure an individual would incur while wearing the device in a noise environment. The effective exposure level (EEL) is a calculation which combines the attenuation reduced by one standard deviation with A-weighting and the noise environment to arrive at an estimate of the dBA level at the ear. The effects of hair style were assessed in terms of EEL, calculated while wearing the test helmet in a variety of noise exposure conditions. The noise environments used to calculate EELs are contained in a noise database, consisting of about 500 records, covering all Army and some Navy helicopters for positions occupied by aircrew during normal operational flying conditions.

Cumulative distributions of the EEL values calculated for the noise environments for each of the helmet conditions are shown in figures 8 through 14. Included on each graph is the distribution of the unprotected noise environments and a vertical bar showing 85 dBA. Data shown in figure 8 indicates the HGU-84/P provided about a 2 dBA reduction in noise exposure over the HGU-68/P helmet. Both helmets indicate less than 30 percent of the subjects' attenuation data are below the acceptable noise exposure level of 85 dBA.

Sound attenuation data for the HGU-84/P, shown in figure 9, indicate significant differences between females and males. Protected levels are above 60 percent for males and about 30 percent for females. This helmet has earcups designed to attenuate low frequency sounds. The helmet reduces the noise levels in the rotary-winged aircraft by about 16 dBA for males and about 12 dBA for females relative to 50 percent protection at 85 dBA. Figure 10 shows the data for hair style classification II with the HGU-84/P. The range of protection between hair styles at 50 percent is about 6 dBA. Protected levels for all hair styles in classification II range from 40 percent down to 25 percent. Hair style classification III for the HGU-84/P, shown in figure 11, indicates the range of protection is about three dBA at 50 percent. Protected levels for all hair styles in classification III range from 40 percent down to 15 percent.

Figure 12 indicates the HGU-68/P female and male attenuation data are about equal. As a reminder, the HGU-68/P is a fixed wing helmet and does not have noise attenuating earcups as the HGU-84/P. Leakage paths for noise outside the HGU-68/P helmet appear to be equivalent for the low frequencies. Higher frequency spectra found in fixed wing aircraft may be attenuated to a greater degree by the HGU-68/P.

Figure 13 shows the data for hair style classification II with the HGU-68/P. The range of protection between hair styles is about 3 dBA. Statistical tests indicate this difference is not significant. Protected levels for all hair styles in classification II are below 30 percent. Hair style classification III for the HGU-68/P, shown in figure 14, indicates the range of protection differences is about one dBA and is not significant. Protected levels for all hair styles in classification III are below 20 percent.

Conclusions

Sound attenuation of circumaural hearing protectors is degraded by hair. The hair of the user will allow for sound to enter into the earcup by creating leakage paths from the outside. Any hair between the earseal and head will prevent full conformance and will become the limiting factor in achievable attenuation of the hearing protector.

Helmet stability

Methods

The helmet stability test consisted of measuring a helmet's rotation when loaded tangentially from the front and rear. These upward loads were applied individually with a handheld tension gage. Helmet rotation measurements were made at loadings incremented by 2 pounds from 0 to a maximum of 10 pounds. An electronic protractor was mounted on the helmet to determine its angular position during the loading process. Each test was repeated three times and averaged.

This test required the volunteer to maintain a constant head position during measurement readings. The volunteer was aided in maintaining a consistent head position by aiming a reflected light image onto a predefined target area. The reflection was accomplished by mounting a mirror at an angle onto a bite bar. The basic test setup is illustrated in figures 15 and 16. The mirror was located approximately 3 to 4 inches in front of the volunteer's face. A light shield, located on top of the mirror and bite bar, provided a barrier between the light source and the volunteer's eyes.

Results and discussion

During the data acquisition phase, the applied load was often removed at the 8-pound level, prior to obtaining the final 10-pound level. There were several reason for stopping the test. These varied from physical limitations, poor helmet performance, and obvious hair influence. Physical limitations included a choking feeling, reaching the volunteers' physical limit in regard to neck and upper body strength, and the inability to maintain or relocate the reflected light on the target because of excessive upper body movement and general head movement. Poor helmet performance appeared in situations where the chinstrap became too tight (choking feeling), or allowed too much fore or aft rotation. During rearward loadings, the helmet frequently rotated forward over the wearer's eyes which impaired their ability to maintain the proper head position. Obvious hair influence could be observed with some subjects because of excess slippage, which prevented the next level of loading from being reached because the helmet would actually not stop moving or slipping.

In general, the female tests resulted in greater helmet rotations than the male. This generalization is true for both helmet types, regardless of loading direction or female hair classification scheme. Inspection of figures 17 and 18 reveal the male rotational data to be less than the female. In the HGU-84/P front loading plots, a few of the female styles resulted in lower average rotations than the males. This is an artifact of the test procedure to cease testing based on the volunteer experiencing a choking sensation, inability to maintain head and torso position, or excessive helmet rotation.

Statistically, no female hair style was significantly different from another except within hair classification III, at the 8-pound frontal load test with the HGU-68/P helmet. In this test condition, the long hair (30 to 39.9 cm) was different from the other three female hair lengths. The male subjects resulted in a high number of significant differences as illustrated in table 10.

Table 10.
Summary of helmet rotation, significant differences between gender.

Gender	**Front**					**Rear**				
Male vs female	**2**	**4**	**6**	**8**	**10**	**2**	**4**	**6**	**8**	**10**
HGU-68/P	n	n	y	n	n	n	y	y	y	y
HGU-84/P	n	y	y	y	n	y	y	y	y	y

Significant differences ($p < 0.05$)

Conclusions

While it is not stated that the helmet rotation performance recorded from the male volunteers is ideal or the desired rotation values, all of the female hair styles evaluated produced results which were poorer than the males. No one female hair style performed consistently 'better' or 'more like the male style' throughout the stability test data analysis. The significant differences between gender is the most obvious result of the helmet rotation tests.

No single female hair style or hair length was determined to be the overall best hair style as an indication of hair style directives. It was found that the two helmet types did allow rotation for certain female styles that was significantly different from the male volunteers in this study. All differences with the female data is in the excess rotation direction. Relatively no significant difference in performance between the female hair styles was determined.

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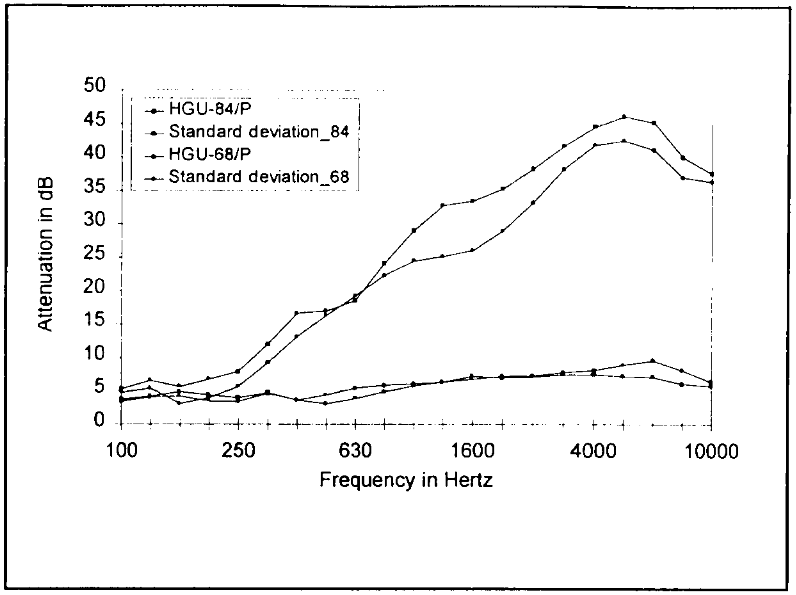

Figure 1. Sound attenuation of the HGU-68/P and HGU-84/P helmets.

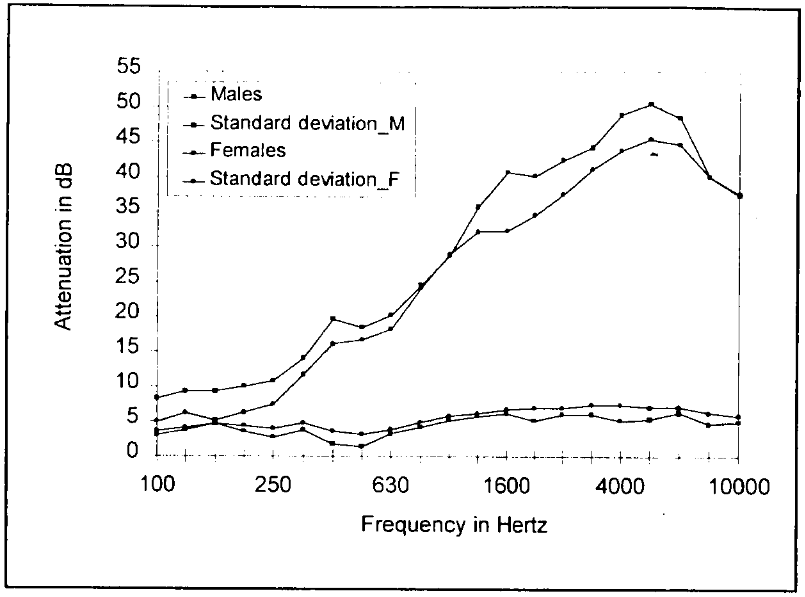

Figure 2. Sound attenuation of the HGU-84/P, gender.

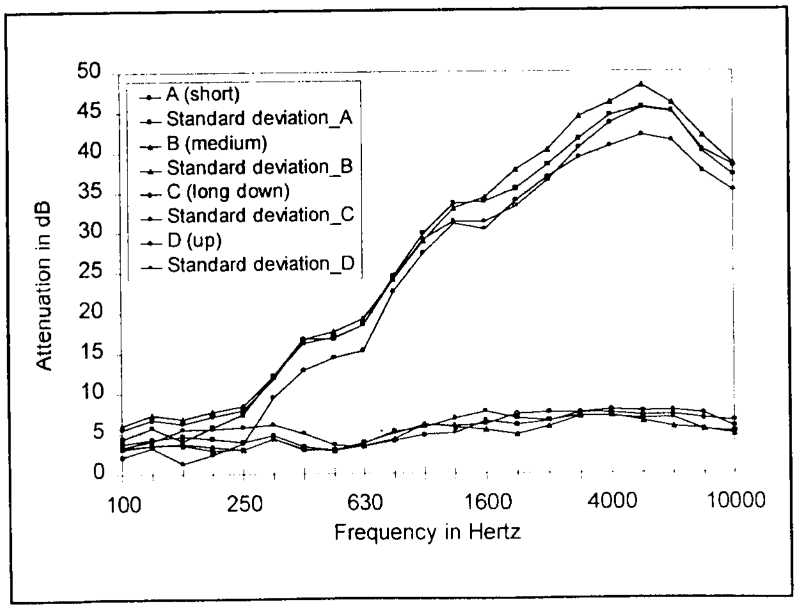

Figure 3. Sound attenuation of the HGU-84/P, hair style classification II.

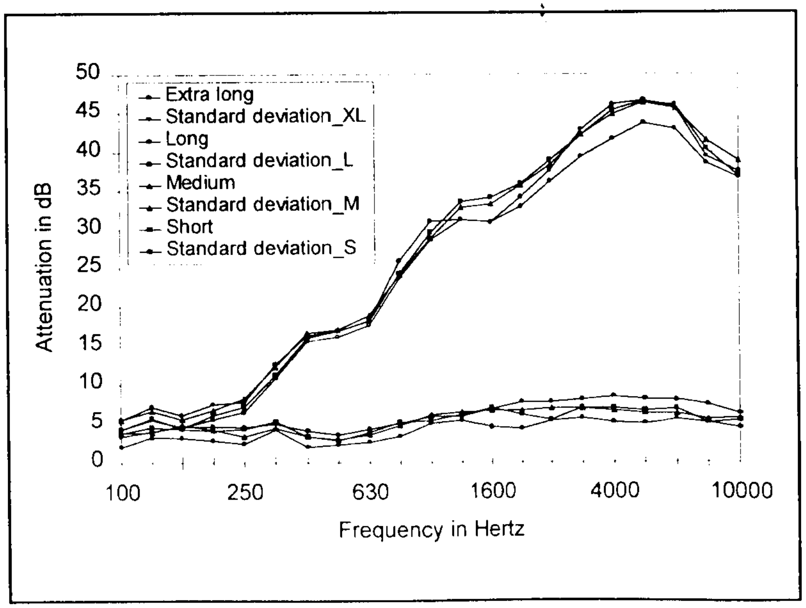

Figure 4. Sound attenuation of the HGU-84/P, hair style classification III.

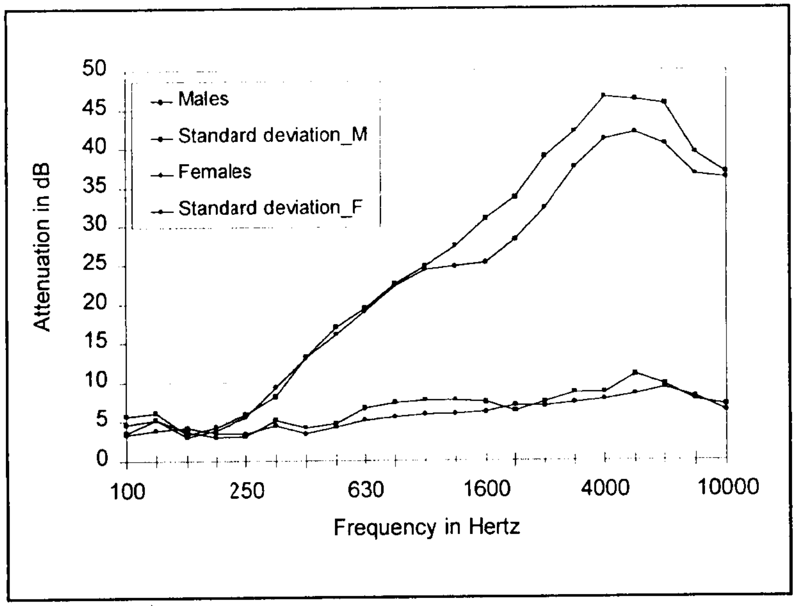

Figure 5. Sound attenuation of the HGU-68/P, gender.

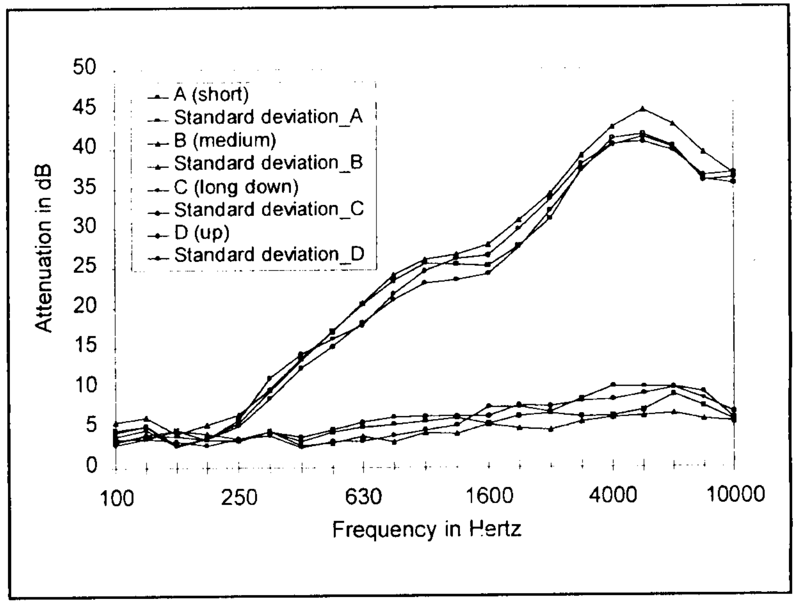

Figure 6. Sound attenuation of the HGU-68/P, hair style classification II.

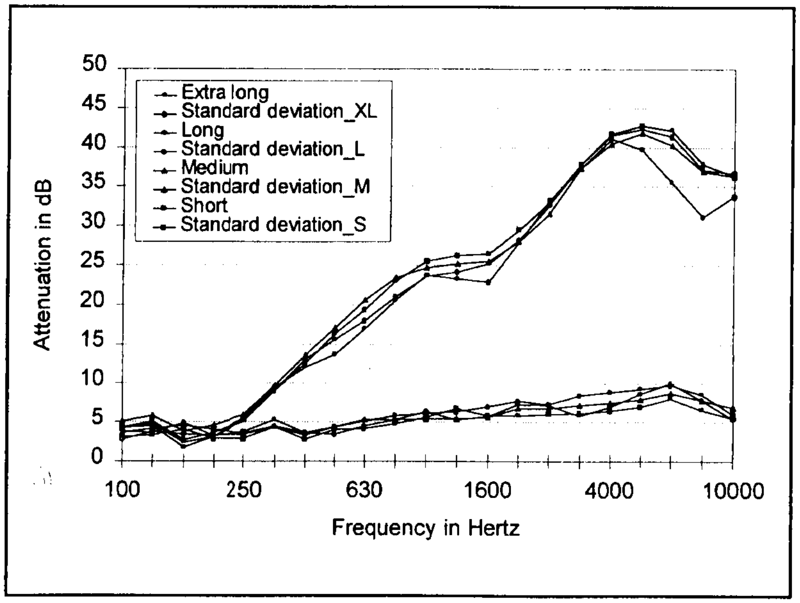

Figure 7. Sound attenuation of the HGU-68/P, hair style classification III.

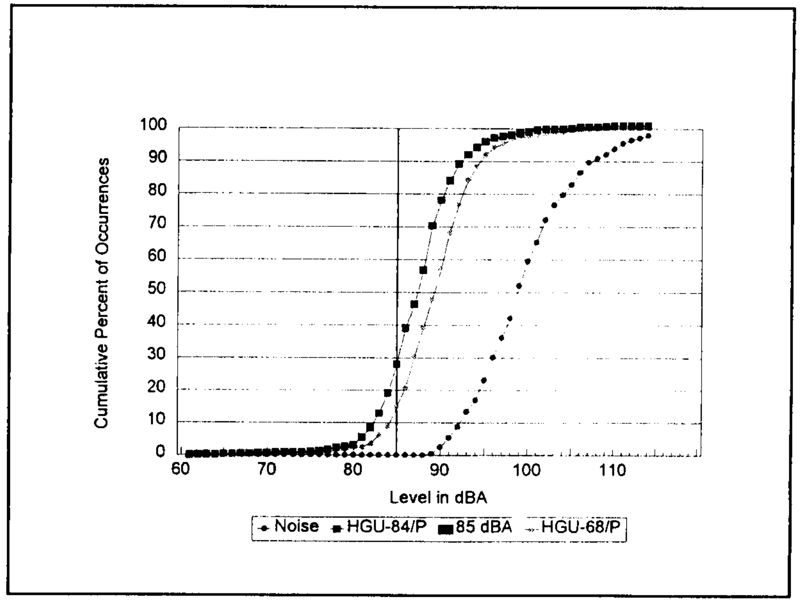

Figure 8. Noise exposure distribution of the HGU-68/P and HGU-84/P helmets in rotary wing aircraft.

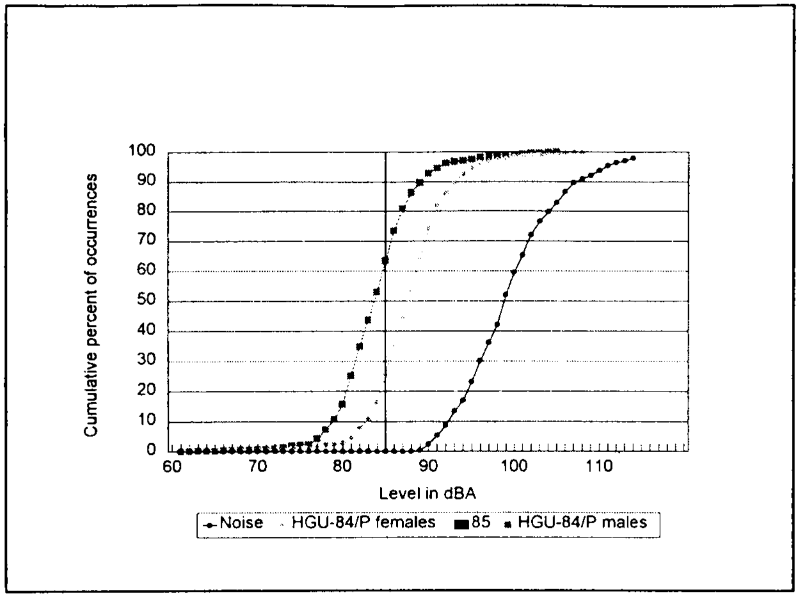

Figure 9. HGU-84/P noise exposure distribution in rotary wing aircraft, gender.

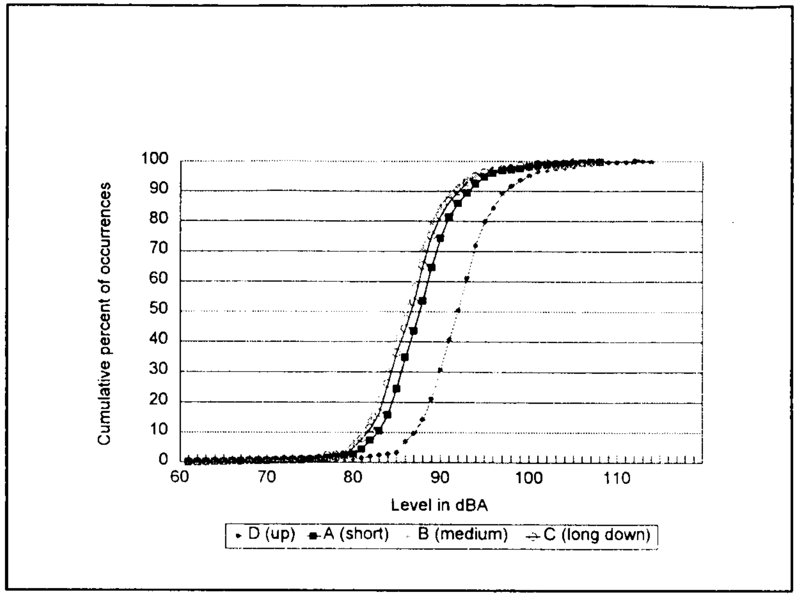

Figure 10. HGU-84/P noise exposure distribution in rotary wing aircraft, hair style classification II.

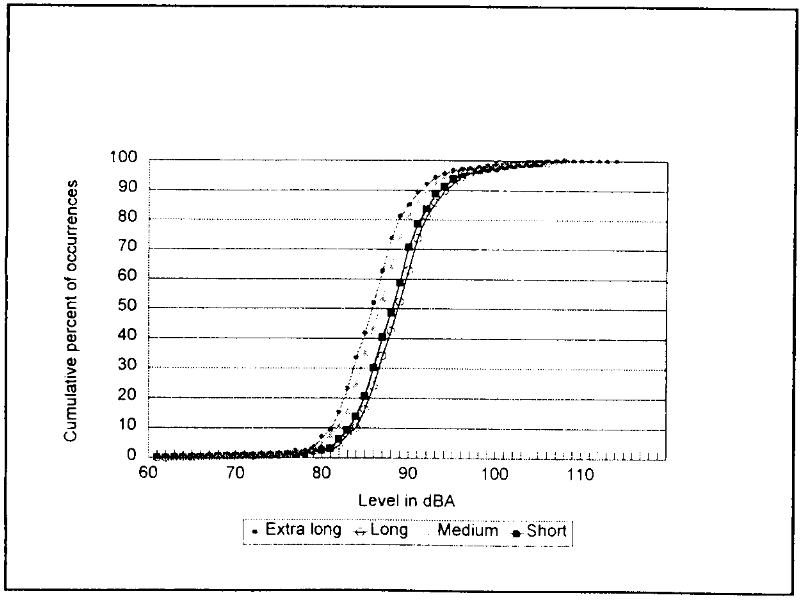

Figure 11. HGU-84/P noise exposure distribution in rotary wing aircraft, hair style classification III.

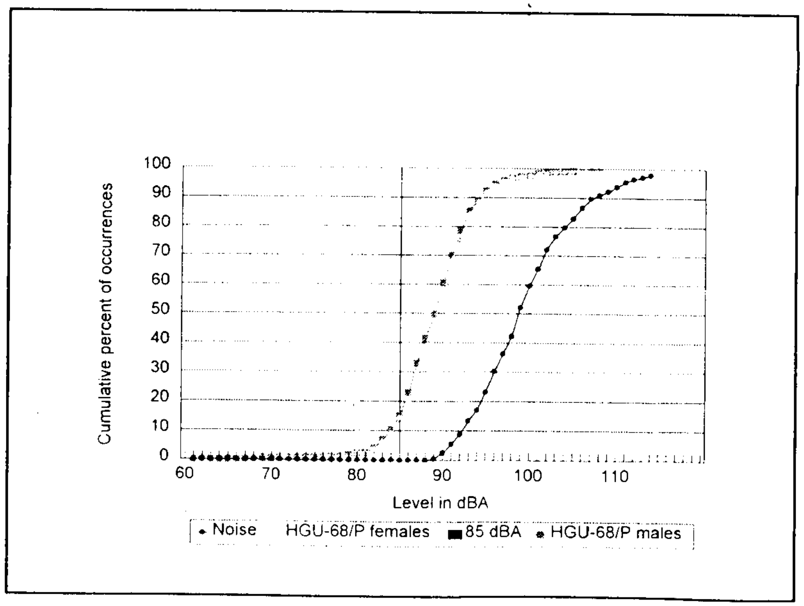

Figure 12. HGU-68/P noise exposure distribution in rotary wing aircraft, gender.

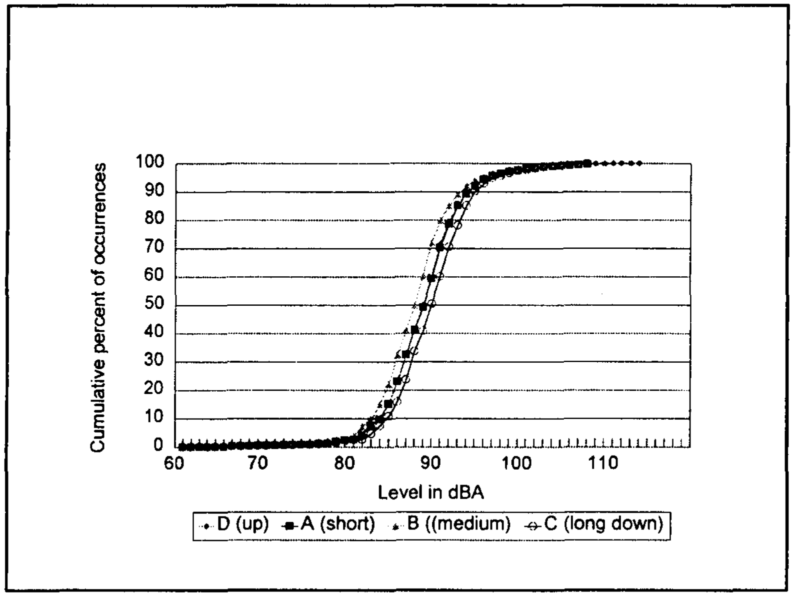

Figure 13. HGU-68/P noise exposure distribution in rotary wing aircraft, hair style classification II.

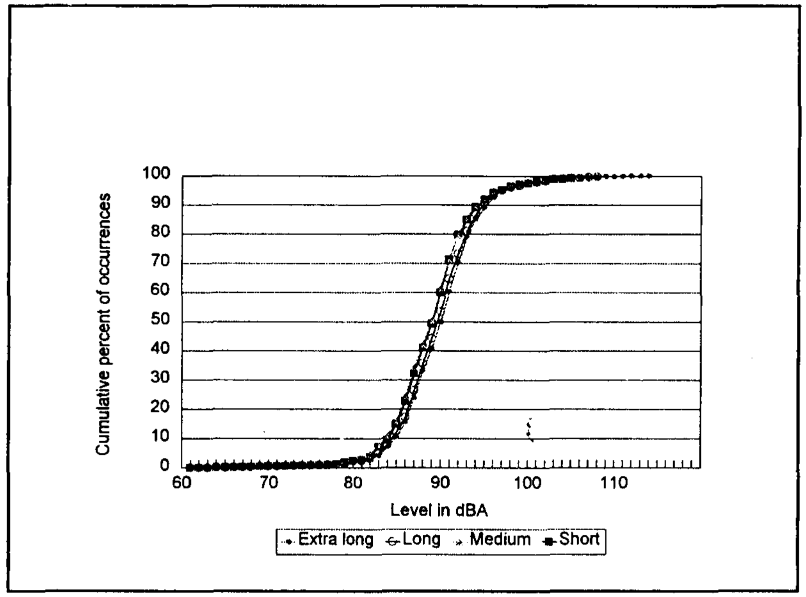

Figure 14. HGU-68/P noise exposure distribution in rotary wing aircraft, hair style classification III.

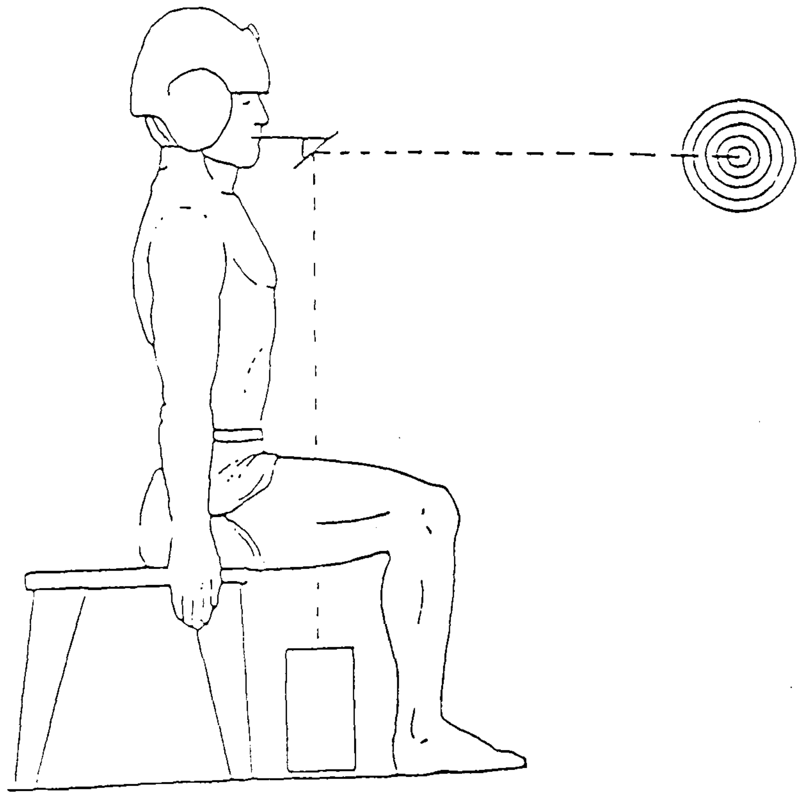

Figure 15. Helmet stability test set up.

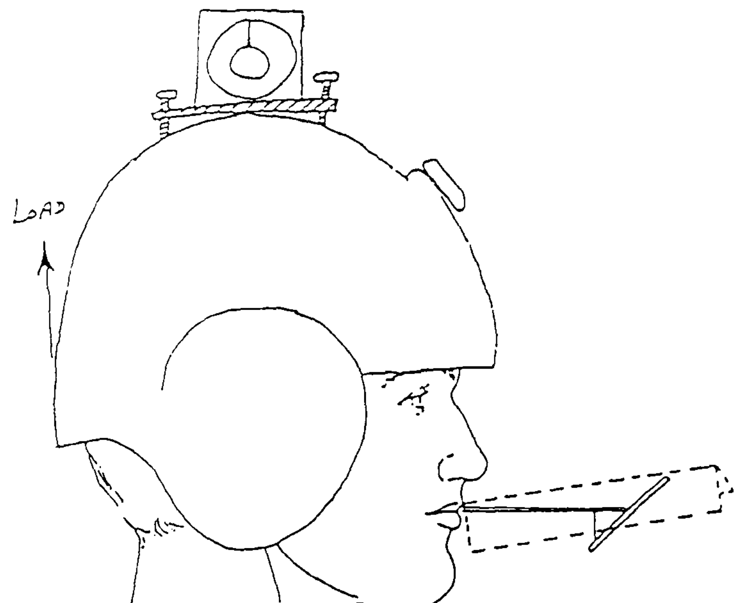

Figure 16. Helmet stability test instrumentation and bite bar.

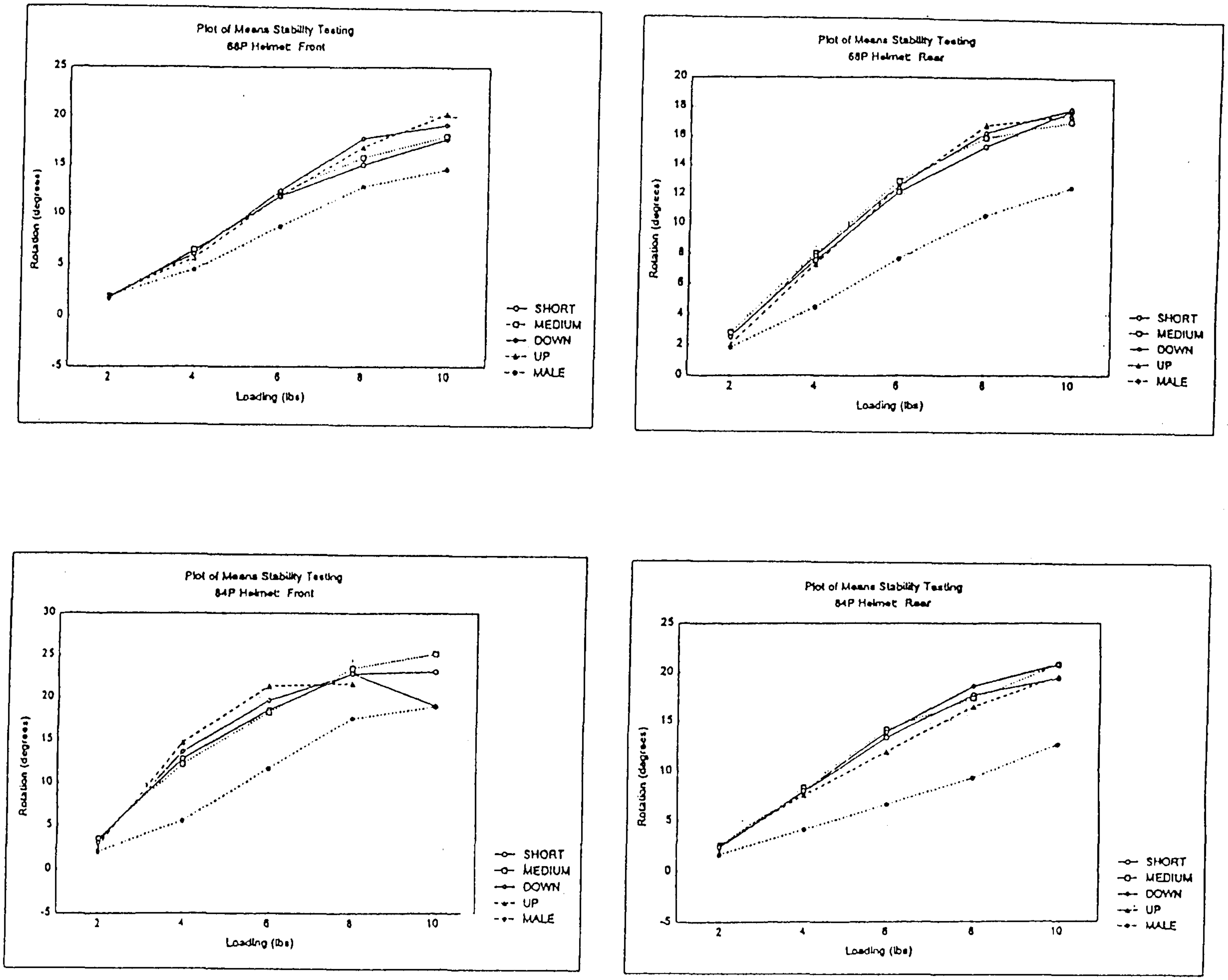

Figure 17. Helmet stability results for hair style classification II.