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TITLE

AN INVESTIGATION INTO THE EFFECT OF +Gz STRESS ON BINAURAL SIGNAL DETECTION PERFORMANCE USING A SPATIAL AUDIO DISPLAY

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AN INVESTIGATION INTO THE EFFECT OF +Gz STRESS ON BINAURAL SIGNAL DETECTION PERFORMANCE USING A SPATIAL AUDIO DISPLAY

Final Report for DCIEM Contract W7711-6-7331/001/SRV

Andrew C. Welker, B.A.Sc.

Welker Audio Consulting
462 Beechwood Place, Unit #2
Waterloo, Ontario, Canada
N2T 1Z1

EXECUTIVE SUMMARY

The Noise and Communications and the Display Systems groups at the Defence and Civil Institute of Environmental Medicine (DCIEM) have previously conducted a number of studies on improving speech intelligibility which have largely focused on investigating the impact of spatialization hardware/software and headset type on binaural signal detection performance. As DCIEM's mandate for the study of binaural signal processing centres around the possible aid or enhancement of signal detection within typical military environments, a positive-gravity (+Gz) physiological stressor was selected to investigate the practicality of using a binaural audio display system within this typical military environment.

In the present study, subjects were exposed to sustained +3Gz while performing a binaural signal detection task. A pulsed white-noise signal was presented in 5 unique spatial positions using a Tucker-Davis Technologies Power DAC running a Russel Martin derived HRTF set while being masked by a filtered pink-noise masker. Subjects were required to depress a switch as long as the pulsed signal could be heard and release it when the signal was no longer audible. A modified Békesy staircase routine was implemented to vary the signal-to-noise ratio and determine auditory threshold values.

Training sessions within a sound-attenuating booth resulted in a maximum average improvement of 6.1dB at an azimuth position of 90 degrees. The same detection task carried out at rest and at +3Gz within the gondola of the DCIEM Human Centrifuge resulted in an average improvement of 6.9dB at 90 degrees. Both of these improvement values represent a significant reduction in the required signal energy for detection. A within subjects, repeated measures ANOVA carried out on the centrifuge session data showed that there is no significant effect of exposure to +3Gz on auditory thresholds. No significant effects due to learning could be found.

Further research should investigate localization performance accuracy rather than detection performance under sustained +3Gz. In addition, a similar task to the one in the present study should be investigated under higher +Gz levels which may necessitate the use of G-suits and highly trained subjects to reduce the risk of G-LOC.

1. INTRODUCTION

The Noise and Communications and the Display Systems groups at the Defence and Civil Institute of Environmental Medicine (DCIEM) have previously conducted a number of studies which have investigated improving speech intelligibility within a communications system context through the use of Spatial Auditory Displays (SADs). These experiments have largely focused on investigating the impact of spatialization hardware/software and headset type on binaural signal detection performance. However, to date all binaural studies at DCIEM have taken place under controlled acoustical conditions and there has been no attempt to investigate the possible contribution of a physiological stressor on binaural signal detection performance. As DCIEM's mandate for the study of binaural signal processing centres around the possible aid or enhancement of signal detection within typical military environments, a positive-gravity (+Gz) physiological stressor was selected to investigate the practicality of using a binaural audio display system within this typical military environment. +Gz stress is a widely encountered phenomenon among military fighter pilots and aviators and as such is an environment within which SAD systems must be able to operate.

In the present study, subjects were exposed to sustained +3Gz while performing a binaural signal detection task. A Tucker-Davis Technologies (TDT)[1] psychoacoustic test suite was chosen for the present study as it represents the highest fidelity system currently available at DCIEM and allows for the implementation of third-party Head Related Transfer Functions. Head Related Transfer Functions (HRTFs) are sets of digital filters that electrically represent the diffraction and separation effects of the human head on sounds entering the ear canal, and the direction dependent filter effects of the outer ear (pinna). Each position in three-dimensional space will have a unique transfer function.

A 1996 investigation undertaken by Welker Audio Consulting[2] to perform a subjective comparison between three hardware/software systems for signal spatialization found that the HRTF set derived by Russel Martin[3] provided the highest binaural improvement values among the HRTF filter sets tested within a speech intelligibility task which measured auditory thresholds (Welker, 1996). Hence, the Martin HRTF sets were chosen for use in

[1] Tucker-Davis Technologies, 4550 NW 6th Street, Gainesville, Florida 32609
[2] Welker Audio Consulting, 462-2 Beechwood Place, Waterloo, Ontario, N2T 1Z1, Tel. (519)746-7312
[3] Russel Martin, Air Operations Division, Aeronautical and Maritimes Research Laboratory, PO Box 4331, Melbourne, Victoria, Australia 3001

the present study. Details of the measurement technique used to derive these HRTFs can be found in Carlile and Pralong (1994).

A modified Békesy staircase routine was implemented to determine auditory threshold values. The maximum time for the determination of threshold was of importance in this study because of the finite time subjects could be subjected to +3Gz in the gondola of the DCIEM Human Centrifuge (HC). Interestingly, given the possible suitability of using binaural systems within a military aircraft environment (Begault, 1993), a review of the literature showed that no past studies have specifically investigated the possible effect of +Gz stress on binaural vs. diotic threshold performance. Previous reports, however, have investigated the effects of hypoxia on both auditory thresholds and localization ability. Studies involving hypoxiated subjects found that localization ability and accuracy was decreased by hypoxia induced by exposure to high altitude, while auditory thresholds were unchanged (Sculthes, 1971; Burkett & Perrin, 1976; Rosenberg & Pollard, 1992). While hypoxia is similar to the blood and hence oxygen loss in the brain caused by +Gz stress, it does not produce the physical stress that is experienced by the internal organs while under +Gz. Since the loss of oxygen to the brain caused by exposure to +Gz is similar to that of hypoxia, G-stress may have little or no effect on auditory thresholds.

2. METHOD

2.1 Subjects

Seven subjects, five women and two men ranging in age from 20 to 42, participated in this study and were compensated according to DCIEM guidelines. Each subject underwent a Békesy audiometric test to confirm that each had no more than 20dB of bilateral hearing loss between 125Hz to 8kHz. In addition, subjects were asked to complete a medical history questionnaire and were screened for +Gz-stress fitness by an in-house military medical officer. Female subjects were also required to provide a blood sample for a blood serum pregnancy test. Of the seven subjects in this study five were university students, one was an in-house military employee, and one was an in-house civilian employee.

2.2 Stimuli

The signal portion of the stimulus consisted of pulsed white-noise. This signal consisted of a series of band-limited (12.5Hz-8kHz) white-noise pulses of 100ms in duration with a 50% duty cycle. The pulses were switched instantaneously with no ramping and were generated using the internal signal generator of a Hewlett Packard 3562A Dynamic Signal Analyzer. A five second segment of this signal was recorded onto Digital Audio Tape (DAT) with a Panasonic SV-3500 DAT Recorder and then transferred digitally via S/PDIF to a Soundtools equipped MacIntosh IIci computer for editing. The resulting edited segment was then transferred to the hard disk of a 486 DX2 IBM compatible computer which controlled the Tucker-Davis devices via fibre optic lines. This segment was then looped in real-time using a TDT AP2 Array Processor card for presentation to the subject. The signal was presented to the subject in either a diotic mode or in a spatialized mode. In the diotic mode, the same signal was presented equally to both ears, while in the spatial mode, the subject perceived that the signal was outside of his/her head at a designated azimuth position in space as determined by the software.

A shaped pink-noise signal was used as the masker in this study. Measurements were made using a Brüel&Kjaer (B&K) Type 4145 1-inch measuring microphone mounted on a tripod inside the gondola of the HC at the approximate location of a seated subject's head while measurements were taken both at rest (+1Gz) and under +3Gz spin. The signals from this microphone were analyzed using a B&K Type 2133 Dual Channel Real-Time Frequency Analyzer and recorded in 1/3rd octaves and stored for later recall. In addition, these measurements were duplicated with the internal fresh-air fans switched on and off. The spectrum of a wide-band pink-noise signal generated by a B&K Type 1405 Noise Generator was shaped using a B&K Type 5612 Spectrum Shaper to match the measured spectrum inside the gondola under a +3Gz spin condition with the fan on (see Figure 1). The spectral matching between the shaped noise masker and the actual measured signal was confirmed using a B&K Type 2133 Frequency Analyzer. Note that during the actual runs in the HC the fresh air fans were turned off due to repetitive bearing chatter which closely resembled the periodic nature of the pulsed white-noise signal and thus may have interfered with the signal detection task.

2.3 Experimental Apparatus

A block diagram of the hardware set-up is shown in Figure 2. The left and right channels of the diotic or spatialized output of the TDT Power DAC was sent to a Kemo VBF/23 low-pass dual-channel elliptical filter set to a cut-off frequency of 9kHz to remove any aliasing noise generated by the TDT D/A converters. The outputs from this filter were connected to two TDT PA4 precision programmable attenuators which allowed the signal to noise ratio of the stimuli to be accurately varied via computer control. The left and right channels of the diotic/spatialized stimuli were combined with the filtered pink noise masker using a TDT SM3 stereo signal mixer which in turn drove the high-voltage amplifier for a Stax SR-Lambda Signature electrostatic headset. Subject responses were logged using a custom-built button box with two paddle switches which was strapped to the subject's thigh such that the left hand could be comfortably positioned over the switches. The box was connected to a TDT PI2 Parallel Interface module which logged the instance of each button press and saved this response data to a text file.

2.4 Conditions

This study consisted of five unique spatial conditions which were presented within two differing environments. The first condition was a diotic presentation of the pulsed white-noise stimulus while the remaining four conditions spatialized the noise signal at virtual positions around the head at 60, 90, 270, and 300 degrees azimuth (where zero degrees is directly in front of the subject and azimuth increases in a clockwise direction). Elevation of the spatialized sound source remained constant at zero degrees on the horizontal plane. The level of the pulsed noise signal was varied according to a modified Békesy staircase routine which initially reduced the level of the signal in discrete 2dB steps until reaching the first reversal whereupon the step size was changed to 1dB. The starting signal-to-noise ratio (SNR) placed the A-weighted level of the signal at 4dB above that of the masker. A measure of the signal detection threshold under each condition was calculated by averaging the values of the last six transitions for that condition. This produced a mean detection threshold for each condition. The overall level of the masker was set 14dB above that of the measured ambient A-weighted level inside the gondola of the HC, thus masking the centrifuge +3Gz spin-induced noise. Each subject carried out all of the 5 conditions within each run.

2.5 Task

Prior to the beginning of the first booth and centrifuge experimental session, each subject was given both verbal and written instruction on the required task and were told that they could withdraw from the study at any time. Each subject completed five experimental sessions in the HC in addition to a single +Gz acclimatization run for naive subjects. These centrifuge sessions took place after the completion of two initial sessions which were used to familiarize each subject with the detection task and were conducted in an Industrial Acoustics Company (IAC) sound-attenuating booth. For each session in the booth, the subject was seated while wearing the Stax headset with particular care given to making sure that the subject had donned the headset with left and right channels correctly aligned with the appropriate ear.

Prior to the presentation of the pulsed noise signal for each condition, a warning sound was played over the headset in order to alert the subject that the run was about to begin. The noise masker was played continuously over the headset for the duration of the five conditions. Upon hearing the pulsed noise signal, the subject was asked to hold down the paddle switch until the signal had reduced in level to where it could no longer be reliably detected within the masker. The subject was then asked to release the paddle switch until the signal could be detected again, at which time the paddle switch was again held until the signal could no longer be heard. The duration for each condition was fixed at 40 seconds which allowed sufficient time for a threshold of reasonable accuracy to be determined. The order of presentation of the conditions was generated using a Latin-Square. Each session in the booth consisted of four runs through the set of five conditions. The task for the +3Gz runs in the HC was identical to that of the booth sessions, except that each centrifuge run-type consisted of a single run though the set of conditions.

For each of the four sessions in the HC, the subject applied a set of five electrodes which were connected to a Marquette ECG system in order to constantly monitor heart rate. A continuous printed chart recorded the subject's heart rate in addition to recording the +Gz level within the gondola from the output of a gondola mounted accelerometer. Each subject was tightly strapped into the standard flight seat. For the HC sessions the Stax headset elements were mounted via Velcro strips within a modified flight helmet liner. An adjustable strap was also sewn to the liner which was looped around the flight seat headrest to provide a gentle head movement restraint during centrifuge spin. The subject could be seen at all times while seated in the gondola of the HC by monitoring the video feed from two cameras mounted within the gondola. The video screens also provided numerical readings of subject heart rate and G-level. Verbal communication between the subject and the control room was also possible via a level sensing microphone and loudspeaker system mounted within the gondola. In addition, each subject was briefed on a set of hand signals which were to be used in case of any problems with the communications equipment. A "deadman" switch was held closed by the right hand during the run and could be released in case of any problems during the run to stop the centrifuge.

A single "pre-test" run through the five conditions was performed at the beginning of each centrifuge session with the subject strapped into the gondola at rest. Approximately two minutes after completion of the first run, the HC was smoothly accelerated from rest at 0.1G per second to +3Gz. The warning sound was then played over the headset to begin the run. Upon completion of the run at +3Gz, which took approximately four minutes, the HC was slowly spun down from +3Gz and held at +1.4Gz for three seconds before decelerating to rest in order to reduce the possibility of positive-gravitational deceleration vestibular effects. The first post-test condition was run immediately after the gondola had come to rest, followed by a second post-test run which commenced five minutes after the first post-test run was completed.

One final session in the sound-attenuating booth was performed after the completion of the four centrifuge sessions in order to determine whether there was the possibility of a learning effect on the thresholds.

3.0 RESULTS

At the termination of each run the difference between the level of the masker and that of the signal was calculated as described in section 2.4, resulting in a signal-to-noise ratio (SNR), measured in decibels (dB), for that condition. Differences between the SNRs resulting from the diotic and spatial conditions were then taken as the "Average Binaural Improvement" at each azimuth position. A positive difference (diotic < spatial) represents an "advantage" over diotic presentation, hence a reduction in the required signal level, whereas a negative difference represents a "disadvantage" over diotic presentation, hence an increase in the required level for signal detection.

The average binaural improvement values for the initial four booth sessions are given versus booth run in Figure 3, averaged across subjects. Table 1 shows the descriptive statistics for the data plotted in Figure 1 for each Booth-Run/Azimuth variable. The runs are labelled A, B, C, and D in this table which correspond to Booth Run 1, Booth Run 2, etc. Note that the number of trials (N) for booth runs C and D differs from those of runs A and B as one subject was unable to complete the final booth session. A significant maximal average binaural improvement value of 6.1dB was achieved in the initial booth sessions at the 90 degree azimuth position. A within subjects, repeated measures analysis of variance (ANOVA) showed that there was a statistically significant effect of condition on the average binaural improvement values (see Table 2). Table 2 also gives the results of a Tukey's Studentized Range (HSD) post-hoc analysis which shows that there was no significant difference between signal detection performance for the left and right hemisphere azimuth positions. Interestingly, the 60 degree azimuth position and the Diotic condition were not found to be significantly different.

The average binaural improvement values for the four centrifuge sessions are given versus run type in Figure 4, averaged across subjects. Table 3 shows the descriptive statistics for the data plotted in Figure 4 for each RunType/Azimuth variable. In this table PRE represents the pre-test run performed at rest, GZ represents the run performed at +3Gz, POST1 represents the run performed immediately after the centrifuge returned to rest, and POST2 represents the final run which was performed five minutes after the completion of POST1. Note that the number of trials (N) was 27 rather than 28 for some conditions as Subject 4 experienced General Loss of Consciousness (G-LOC) during the fourth session and was advised by a DCIEM physician to cease participation in the centrifuge sessions. A significant maximal average binaural improvement value of 7.3dB was achieved at the 90 degree azimuth position during the +3Gz run. A within subjects, repeated measures ANOVA showed that binaural improvement values were not significantly affected by exposure to +3Gz. As with the booth sessions, however, there was a statistically significant effect of condition on the average binaural improvement values (see Table 4). The results of a Tukey's Studentized Range (HSD) post-hoc analysis given in Table 4 again shows that there is no significant difference between signal detection performance for the left and right hemisphere azimuth positions. The only significant interaction, also shown in Table 4, was "Runtype*Condition" which is consistent with the data plotted in Figure 4. In all cases the maximal improvement value occurred at the 90 degree azimuth position, although the run type which had the largest improvement value was not consistent across all azimuth positions. This analysis was also performed without the inclusion of data from Subject 4 and was found to be similar to that reported above.

Figures 5 through 11 show the average binaural improvement values by centrifuge run type for each subject, averaged across four sessions. Similarly, Tables 5 through 11 show the descriptive statistics for each RunType/Azimuth variable by subject. Note that the number of trials (N) for Subject 4 was 3 rather than 4 for some conditions as she experienced G-LOC during the fourth session. Maximal average improvement values are seen to occur at the 90 degree azimuth position for all subjects except for subjects 2 and 6 who seemed to achieve higher improvement values at the 270 degree azimuth position.

Heart rates averaged across subjects for all centrifuge sessions are plotted versus run type in Figure 12. This figure shows that heart rates at sustained +3Gz were markedly higher than "standing" heart rates, indicating that subjects were experiencing physiological stress.

Finally, Figure 13 shows a comparison of pre-centrifuge booth session improvement values, within subjects averaged across four sessions, with those from the post-centrifuge booth session. The two curves track very closely, with less than 0.5dB separating the improvement values for each azimuth position, suggesting that learning had little or no effect on threshold values.

4.0 DISCUSSION

The results of this study reinforce the findings of previous studies showing that a reduction in threshold detection level can be achieved through the use of a spatial audio display. A previous study by Welker (1996) resulted in maximal improvement values of 13.3dB at 90 degrees azimuth using the Martin HRTF set. However, in the present study both masker and signal were of wider bandwidth and noise based, rather than speech based as in Welker (1996). The results of the booth sessions resulted in a significant average level reduction of 6.1dB which shows that the binaural improvement effect holds.

The analysis of the centrifuge session data shows that the detectability of a spatialized pulsed noise signal in the presence of a diotic masker is not significantly affected by sustained +3Gz. There are a number of factors which may have resulted in this outcome. If the basic physiological effects of sustained +3Gz are similar to those of hypoxia caused by exposure to high altitude, previous binaural threshold detection studies within hypoxiated environments would suggest that sustained +3Gz should have no effect on auditory thresholds. Also, sustained +3Gz may not be sufficient to have a significant effect on hearing physiology, and hence hearing acuity, to cause a detriment to threshold values. Indeed, a significant reduction in auditory threshold may not take place until severe physiological effects begin to occur from higher G levels, i.e. those that begin to result in greying or darkening of the visual periphery. Since this effect has a very high rate of onset, it may be impossible or impractical to measure auditory thresholds under these conditions.

The average maximum binaural improvement of 7.1dB obtained under +3Gz confirms that a significant reduction in threshold level is possible within this environment. Averages were slightly higher (less than 1.0dB) for the centrifuge sessions compared to the booth sessions, but not significantly so. This may simply be due to better subject familiarization with the detection task for the centrifuge sessions which took place after the completion of the booth sessions.

Differences in the Left/Right hemisphere performance are likely due to level differences in the HRTF set itself which may have been caused by the head and/or pinna shape of the subject on which the HRTFs were measured. A similar effect can be seen in the binaural improvement data in Welker (1996).

The results of the final post-centrifuge booth session shows less than 0.5dB difference between the pre and post centrifuge booth sessions at all azimuth positions which confirms that learning had no significant effect on thresholds.

5.0 CONCLUSIONS

This study investigated the effect of sustained +3Gz on auditory thresholds. Training sessions within a sound-attenuating booth resulted in a maximum average improvement of 6.1dB at an azimuth position of 90 degrees. The same detection task carried out at rest and at +3Gz within the gondola of the DCIEM Human Centrifuge resulted in an average improvement of 6.9dB at 90 degrees. Both of these improvement values represent a significant reduction in the required signal energy for detection. A within subjects, repeated measures ANOVA carried out on the centrifuge session data showed that there is no significant effect of exposure to +3Gz on auditory thresholds. No significant effects due to learning could be found.

Further research should investigate localization performance accuracy rather than detection performance under sustained +3Gz. The results of such a study would further expose any similarities between hearing physiology under G and within hypoxiated environments.

In addition, a similar task to the one in the present study should be investigated under higher +Gz levels which may necessitate the use of G-suits and highly trained subjects to reduce the risk of G-LOC.

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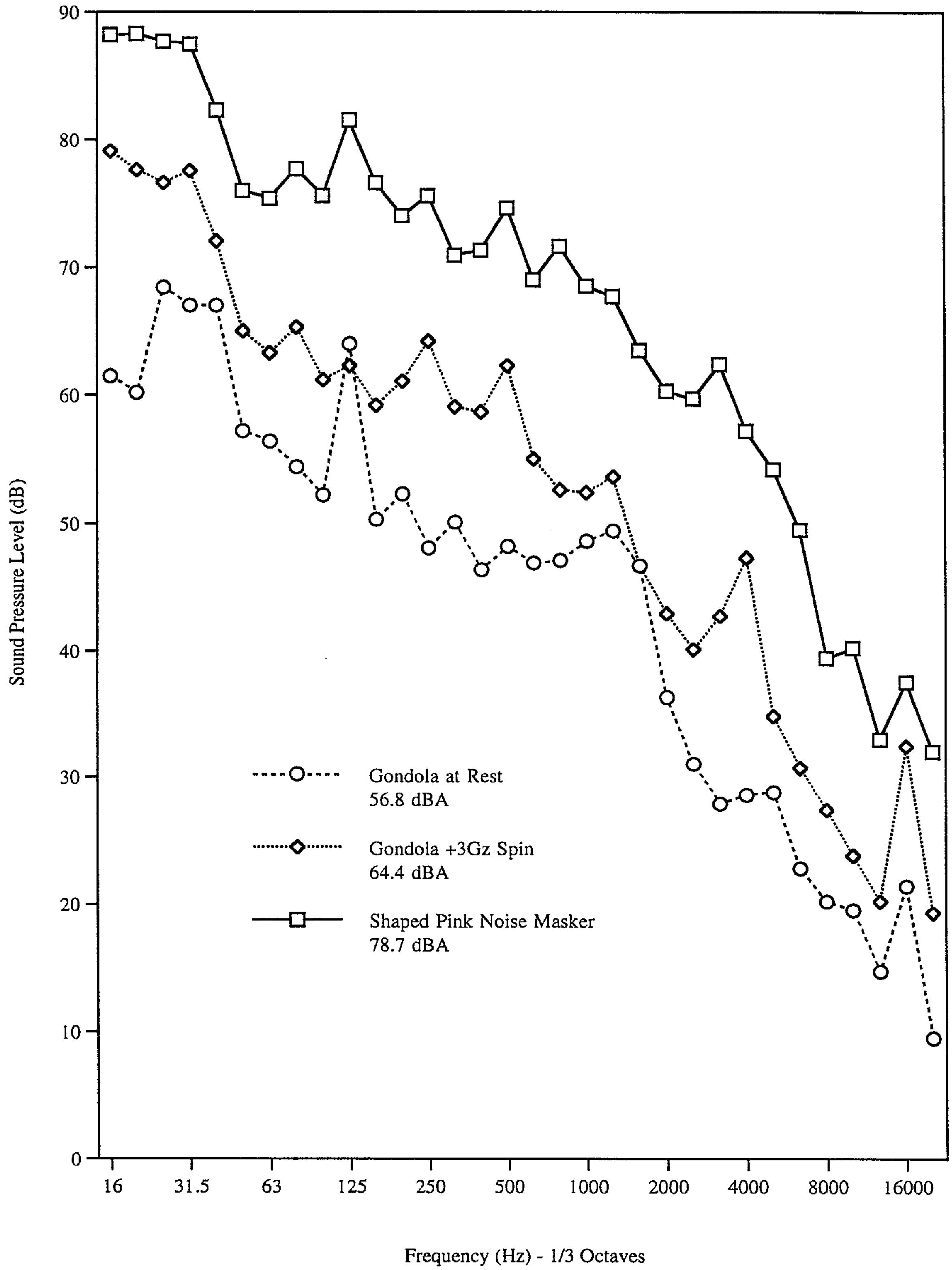
Figure 1: Centrifuge Noise Frequency Responses



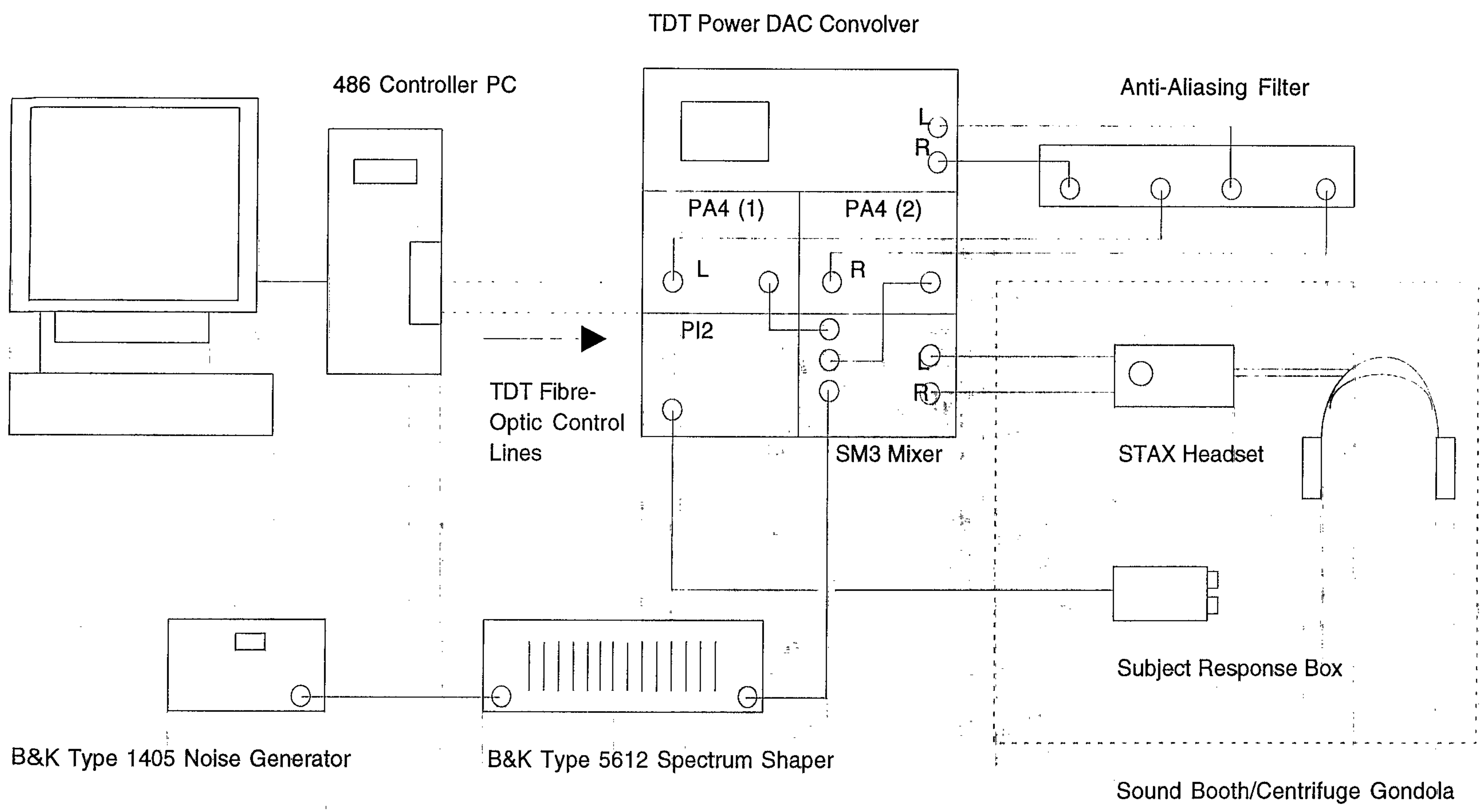


Figure 2: TDT Hardware Layout

Figure 3: Overall Average Binaural Improvement Values by Booth Run

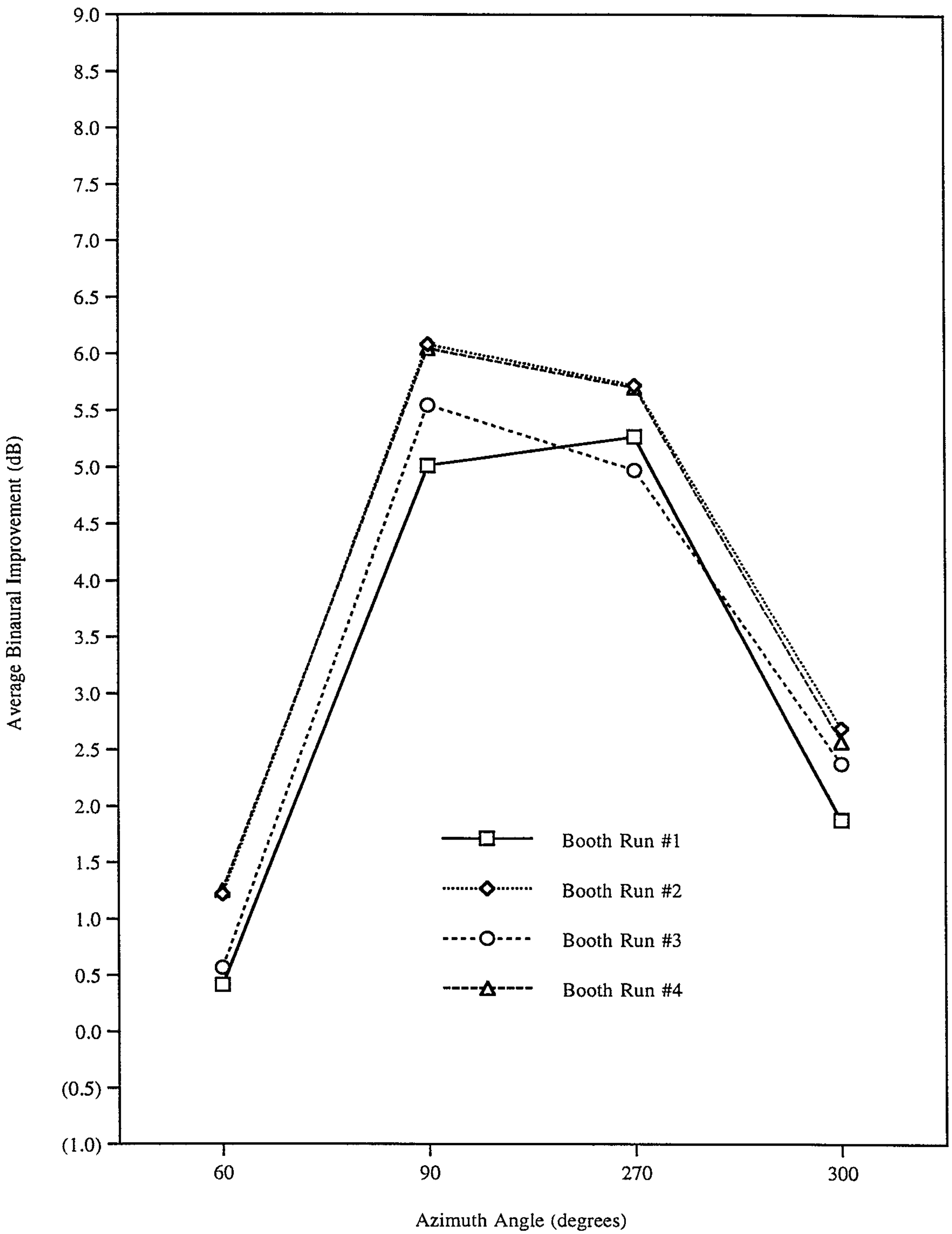


Table 1: Booth Descriptive Statistics Across Subjects

Variable	N	Mean	Std Dev	Std Error
AD	39	0.000	0.000	0.000
A60	39	0.414	1.892	0.303
A90	39	5.013	2.236	0.358
A270	39	5.264	2.036	0.326
A300	39	1.875	1.894	0.303
BD	39	0.000	0.000	0.000
B60	39	1.218	1.867	0.299
B90	39	6.081	2.984	0.478
B270	39	5.714	2.438	0.390
B300	39	2.688	1.447	0.232
CD	38	0.000	0.000	0.000
C60	38	0.566	2.380	0.386
C90	38	5.544	2.814	0.457
C270	38	4.970	2.234	0.362
C300	38	2.373	1.669	0.271
DD	38	0.000	0.000	0.000
D60	38	1.250	1.790	0.290
D90	38	6.044	2.426	0.394
D270	38	5.693	2.626	0.426
D300	38	2.569	2.614	0.424

Note: The letters A through D represent booth runs 1 through 4 while D, 60, 90, etc. represent azimuth position.

Table 2: Booth Anova Results

Variable=Condition; $F(4,16)=20.35$, $p<0.001$, $\alpha=0.05$

Tukey Grouping*		Mean	N	Condition
	A	5.6688	154	Az90
	A			
	A	5.4112	154	Az270
	B	2.3754	154	Az300
	B			
C	B	0.8613	154	Az60
C				
C		0.0000	154	Diotic

*Note: Means with the same letter are not significantly different.

Figure 4: Overall Average Binaural Improvement Values vs. Centrifuge Run Type

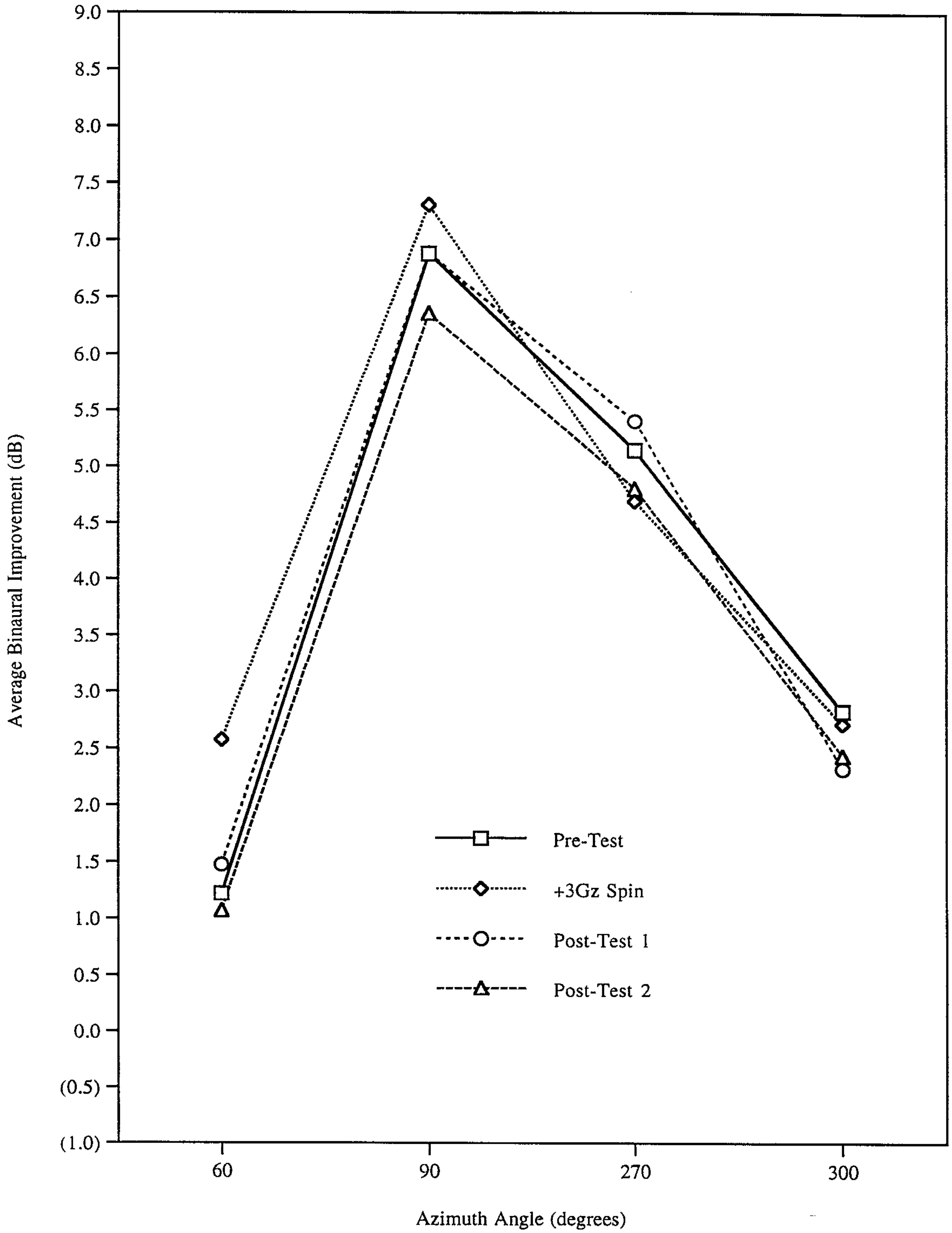


Table 3: Centrifuge Descriptive Stats Across Subjects

Variable	N	Mean	Std Dev	Std Error
PRED	28	0.000	0.000	0.000
PRE60	28	1.221	1.798	0.340
PRE90	28	6.882	2.457	0.464
PRE270	28	5.144	2.056	0.389
PRE300	28	2.828	1.958	0.370
GZ3D	28	0.000	0.000	0.000
GZ360	27	2.573	2.713	0.522
GZ390	27	7.308	2.230	0.429
GZ3270	27	4.691	2.739	0.527
GZ3300	27	2.716	2.474	0.476
POST1D	28	0.000	0.000	0.000
POST160	27	1.475	2.022	0.389
POST190	27	6.888	2.238	0.431
POST1270	27	5.401	2.813	0.541
POST1300	27	2.321	2.155	0.415
POST2D	28	0.000	0.000	0.000
POST260	27	1.074	2.052	0.395
POST290	27	6.359	2.015	0.388
POST2270	27	4.803	2.376	0.457
POST2300	27	2.438	1.866	0.359

Table 4: Centrifuge Anova Results

Variable=Condition; $F(4,20)=24.04$, $p<0.001$, $\alpha=0.05$
Variable=Runtype*Condition; $F(12,60)=3.85$, $p<0.001$, $\alpha=0.05$

Tukey Grouping*		Mean	N	Condition
	A	6.8593	109	Az90
	A			
	A	5.0106	109	Az270
	B	2.5779	109	Az300
	B			
C	B	1.5824	109	Az60
C				
C		0.0000	109	Diotic

*Note: Means with the same letter are not significantly different.

Figure 5: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 1)

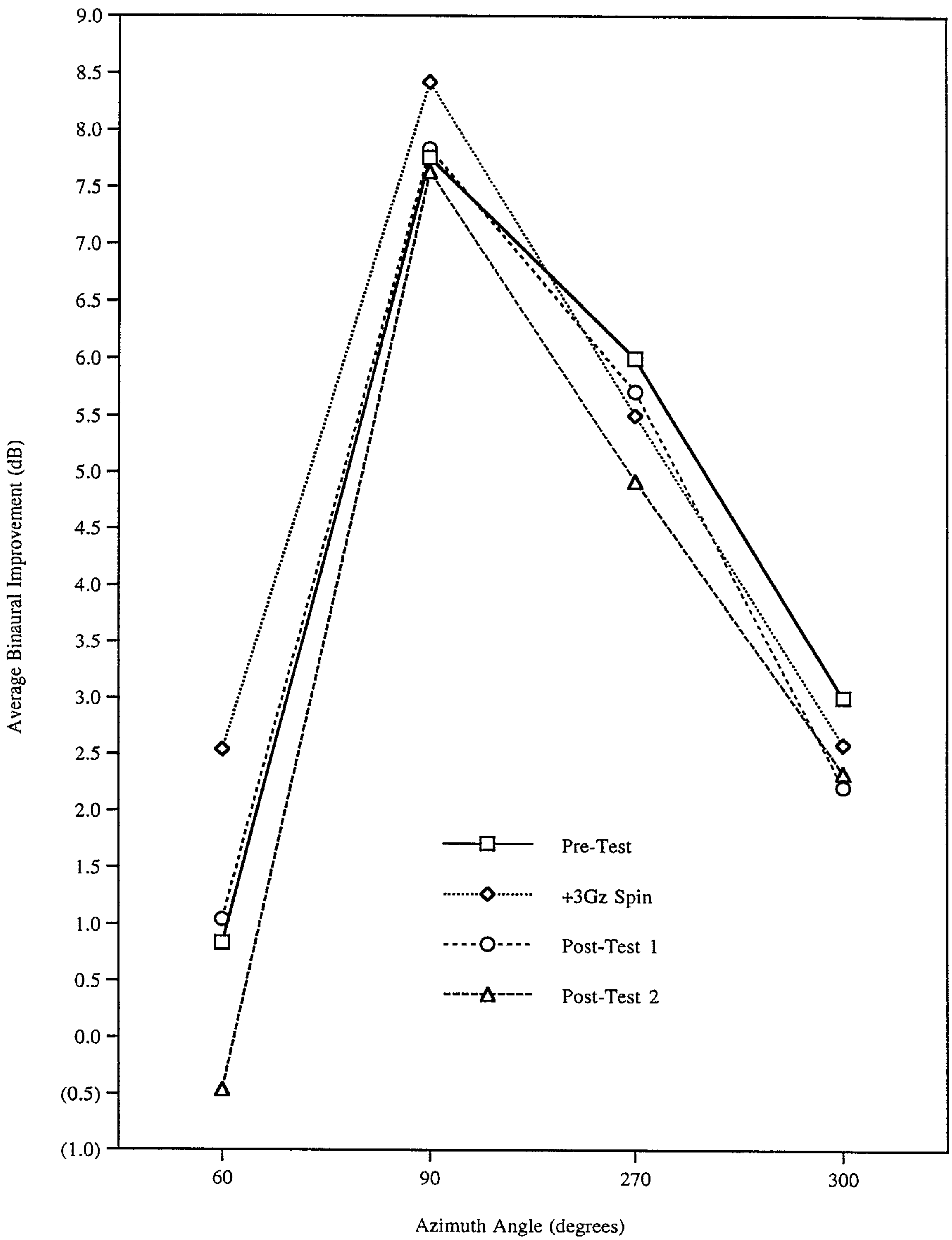


Table 5: Centrifuge Descriptive Statistics (Subject #1)

SUBID	Variable	N	Mean	Std Dev	Std Error
1	PRED	4	0.000	0.000	0.000
	PRE60	4	0.835	1.652	0.826
	PRE90	4	7.753	1.755	0.878
	PRE270	4	6.000	1.081	0.540
	PRE300	4	3.000	0.993	0.497
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	2.540	3.231	1.616
	GZ390	4	8.418	1.611	0.806
	GZ3270	4	5.500	1.942	0.971
	GZ3300	4	2.583	1.223	0.612
	POST1D	4	0.000	0.000	0.000
	POST160	4	1.040	2.208	1.104
	POST190	4	7.833	1.472	0.736
	POST1270	4	5.708	2.807	1.404
	POST1300	4	2.210	1.866	0.933
	POST2D	4	0.000	0.000	0.000
	POST260	4	-0.460	0.783	0.391
	POST290	4	7.628	1.519	0.759
	POST2270	4	4.918	1.681	0.840
	POST2300	4	2.333	1.221	0.611

Figure 6: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 2)

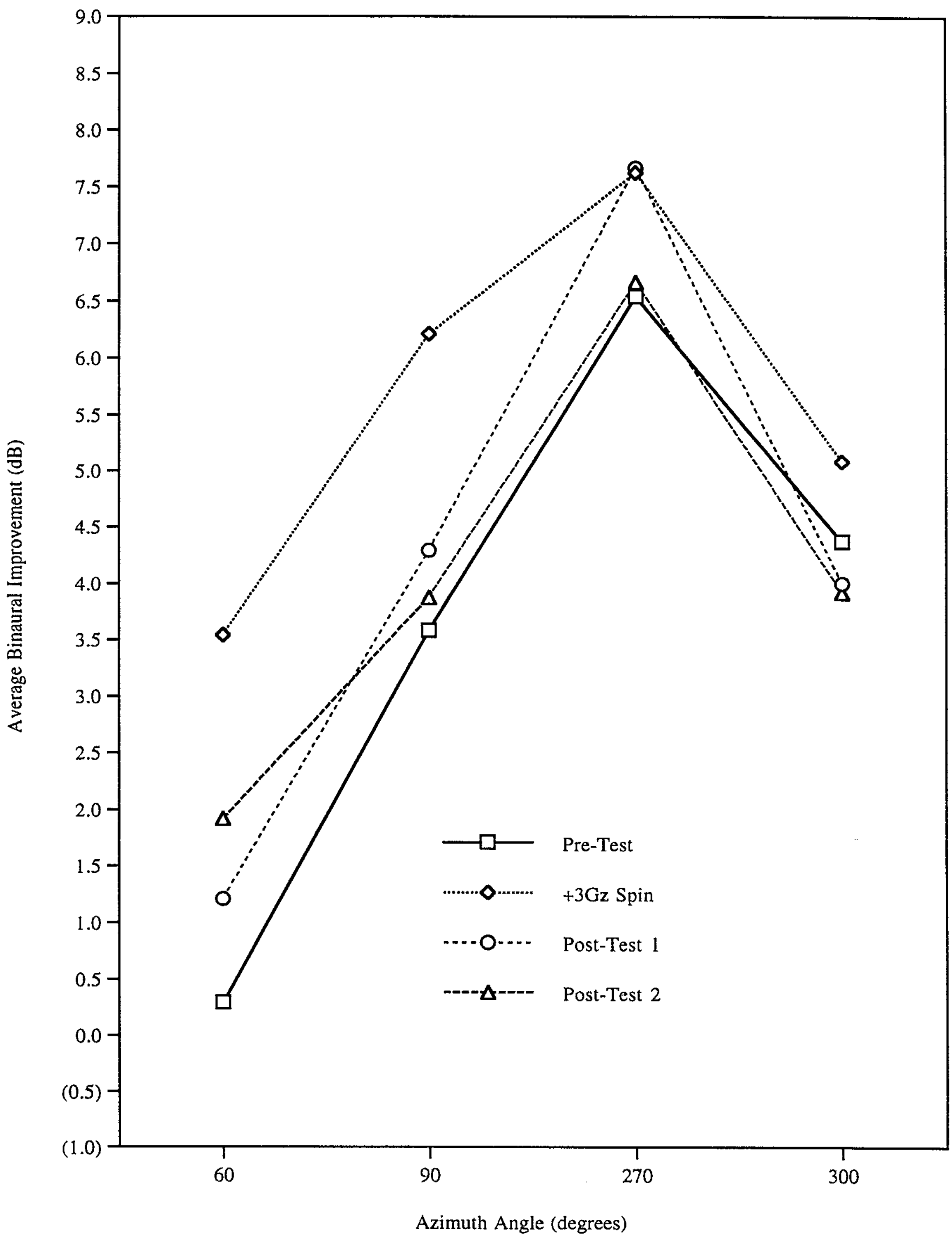


Table 6: Centrifuge Descriptive Statistics (Subject #2)

SUBID	Variable	N	Mean	Std Dev	Std Error
2	PRED	4	0.000	0.000	0.000
	PRE60	4	0.293	0.955	0.477
	PRE90	4	3.583	0.554	0.277
	PRE270	4	6.540	0.493	0.247
	PRE300	4	4.375	1.216	0.608
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	3.540	0.797	0.399
	GZ390	4	6.208	1.883	0.942
	GZ3270	4	7.625	0.761	0.381
	GZ3300	4	5.085	1.292	0.646
	POST1D	4	0.000	0.000	0.000
	POST160	4	1.208	1.790	0.895
	POST190	4	4.290	2.094	1.047
	POST1270	4	7.668	1.644	0.822
	POST1300	4	4.000	2.380	1.190
	POST2D	4	0.000	0.000	0.000
	POST260	4	1.918	0.440	0.220
	POST290	4	3.875	2.404	1.202
	POST2270	4	6.665	1.341	0.670
	POST2300	4	3.918	0.165	0.083

Figure 7: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 3)

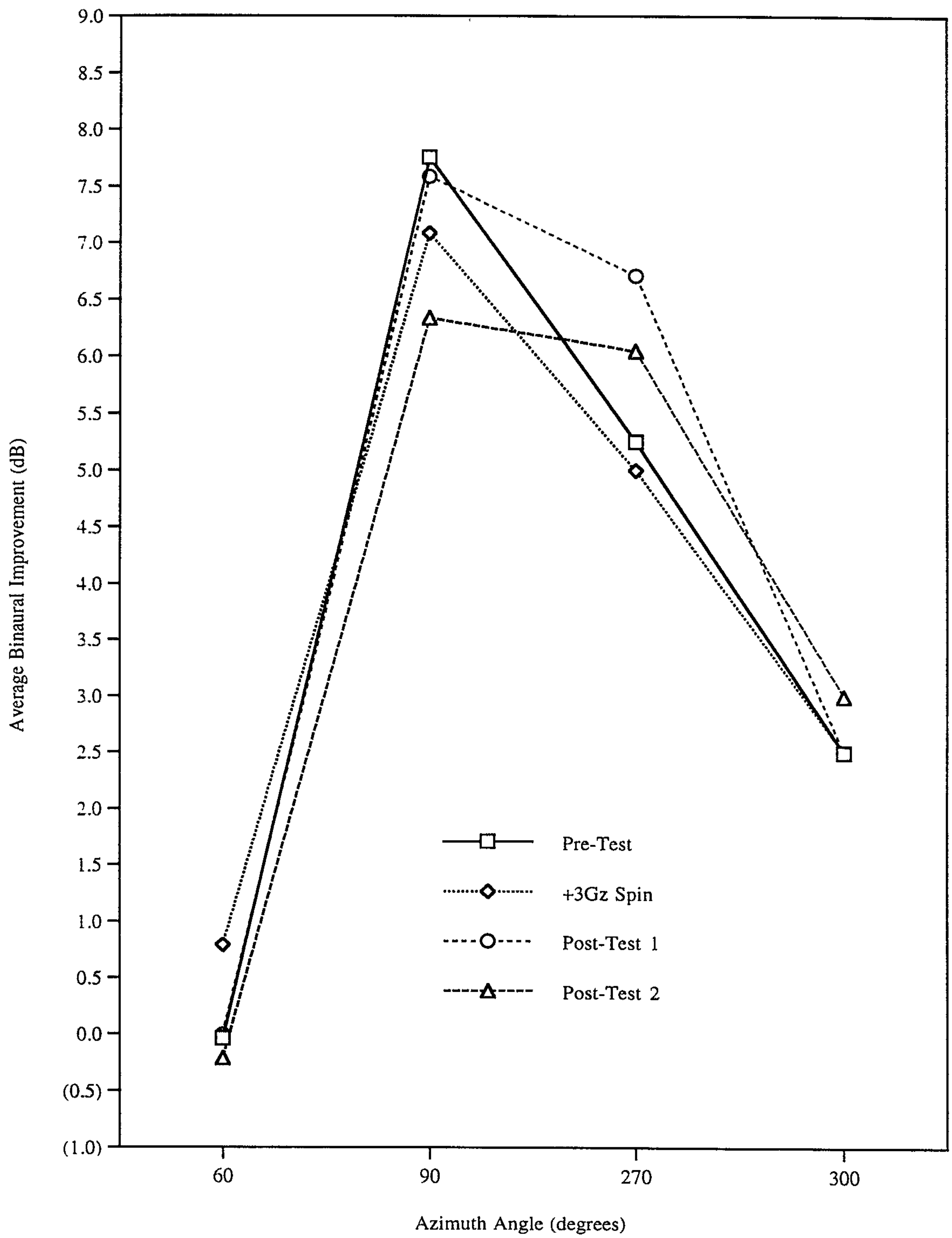


Table 7: Centrifuge Descriptive Statistics (Subject #3)

SUBID	Variable	N	Mean	Std Dev	Std Error
3	PRED	4	0.000	0.000	0.000
	PRE60	4	-0.038	1.228	0.614
	PRE90	4	7.753	1.880	0.940
	PRE270	4	5.253	1.344	0.672
	PRE300	4	2.500	0.815	0.408
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	0.790	1.456	0.728
	GZ390	4	7.083	1.316	0.658
	GZ3270	4	4.998	1.223	0.612
	GZ3300	4	2.500	0.577	0.289
	POST1D	4	0.000	0.000	0.000
	POST160	4	-0.003	1.444	0.722
	POST190	4	7.583	2.790	1.395
	POST1270	4	6.708	0.713	0.357
	POST1300	4	2.500	1.162	0.581
	POST2D	4	0.000	0.000	0.000
	POST260	4	-0.210	0.856	0.428
	POST290	4	6.333	1.304	0.652
	POST2270	4	6.043	1.063	0.531
	POST2300	4	2.998	0.953	0.476

Figure 8: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 4)

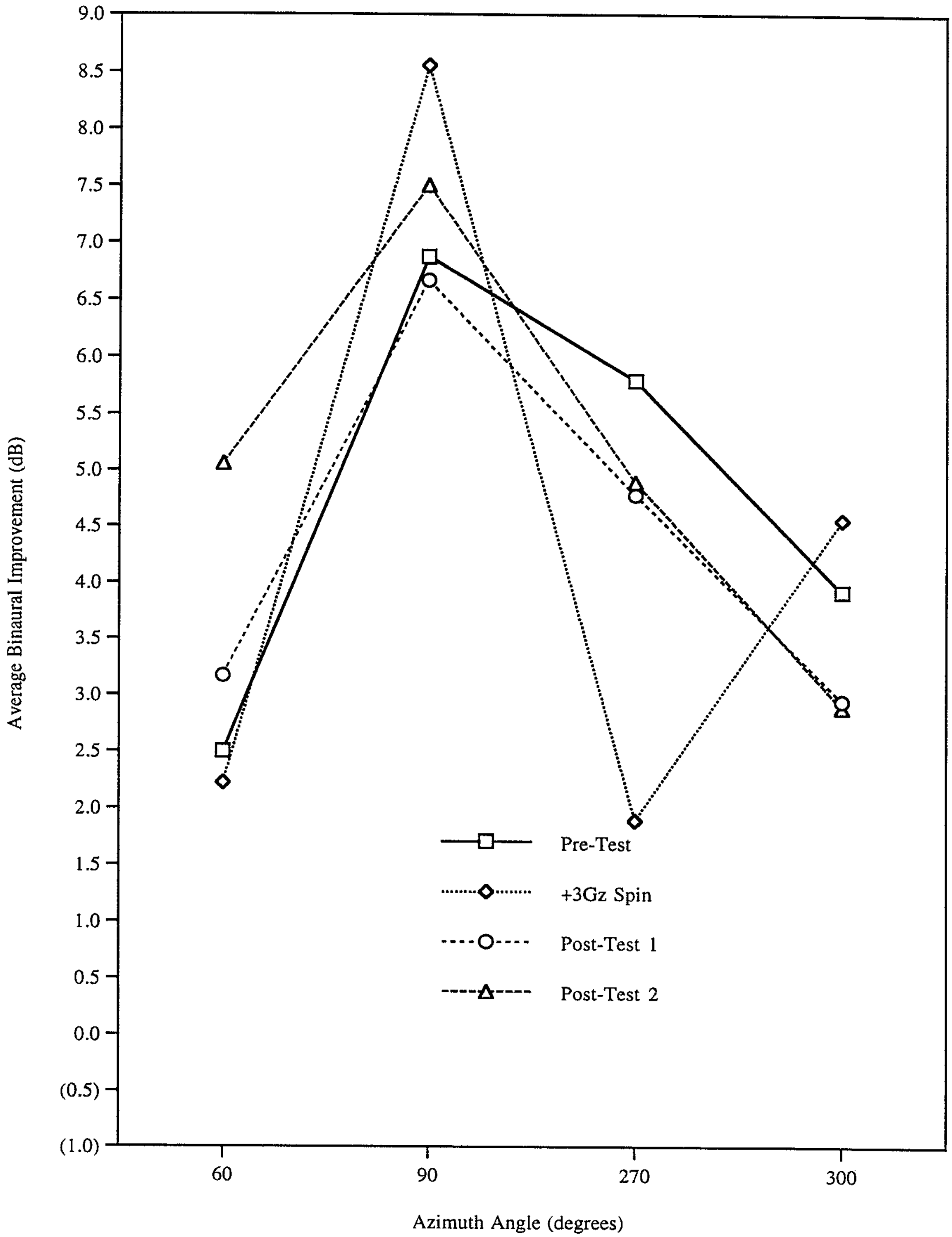


Table 8: Centrifuge Descriptive Statistics (Subject #4)

SUBID	Variable	N	Mean	Std Dev	Std Error
4	PRED	4	0.000	0.000	0.000
	PRE60	4	2.500	1.438	0.719
	PRE90	4	6.875	2.300	1.150
	PRE270	4	5.793	1.552	0.776
	PRE300	4	3.918	1.918	0.959
	GZ3D	4	0.000	0.000	0.000
	GZ360	3	2.220	5.673	3.275
	GZ390	3	8.553	3.670	2.119
	GZ3270	3	1.890	1.397	0.806
	GZ3300	3	4.553	2.222	1.283
	POST1D	4	0.000	0.000	0.000
	POST160	3	3.167	0.335	0.193
	POST190	3	6.667	1.609	0.929
	POST1270	3	4.777	2.340	1.351
	POST1300	3	2.947	1.421	0.820
	POST2D	4	0.000	0.000	0.000
	POST260	3	5.057	1.204	0.695
	POST290	3	7.500	1.605	0.927
	POST2270	3	4.890	2.439	1.408
	POST2300	3	2.890	1.000	0.577

Figure 9: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 5)

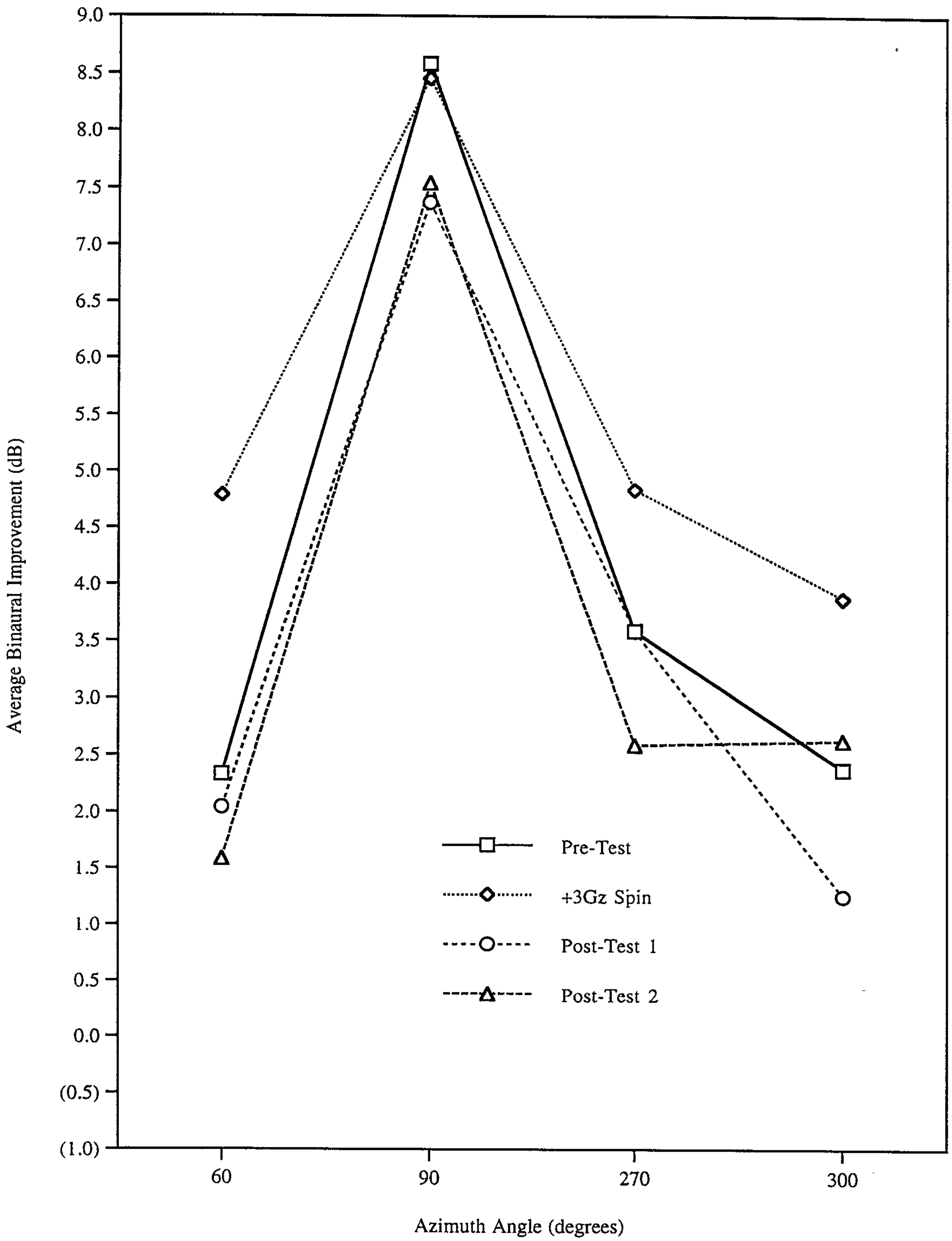


Table 9: Centrifuge Descriptive Statistics (Subject #5)

SUBID	Variable	N	Mean	Std Dev	Std Error
5	PRED	4	0.000	0.000	0.000
	PRE60	4	2.333	1.291	0.645
	PRE90	4	8.585	1.025	0.513
	PRE270	4	3.585	1.915	0.958
	PRE300	4	2.375	1.974	0.987
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	4.790	2.567	1.284
	GZ390	4	8.455	1.234	0.617
	GZ3270	4	4.833	2.804	1.402
	GZ3300	4	3.875	3.199	1.599
	POST1D	4	0.000	0.000	0.000
	POST160	4	2.043	2.551	1.275
	POST190	4	7.373	1.250	0.625
	POST1270	4	3.580	3.356	1.678
	POST1300	4	1.250	3.127	1.563
	POST2D	4	0.000	0.000	0.000
	POST260	4	1.585	2.510	1.255
	POST290	4	7.545	1.238	0.619
	POST2270	4	2.628	2.940	1.470

Figure 10: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 6)

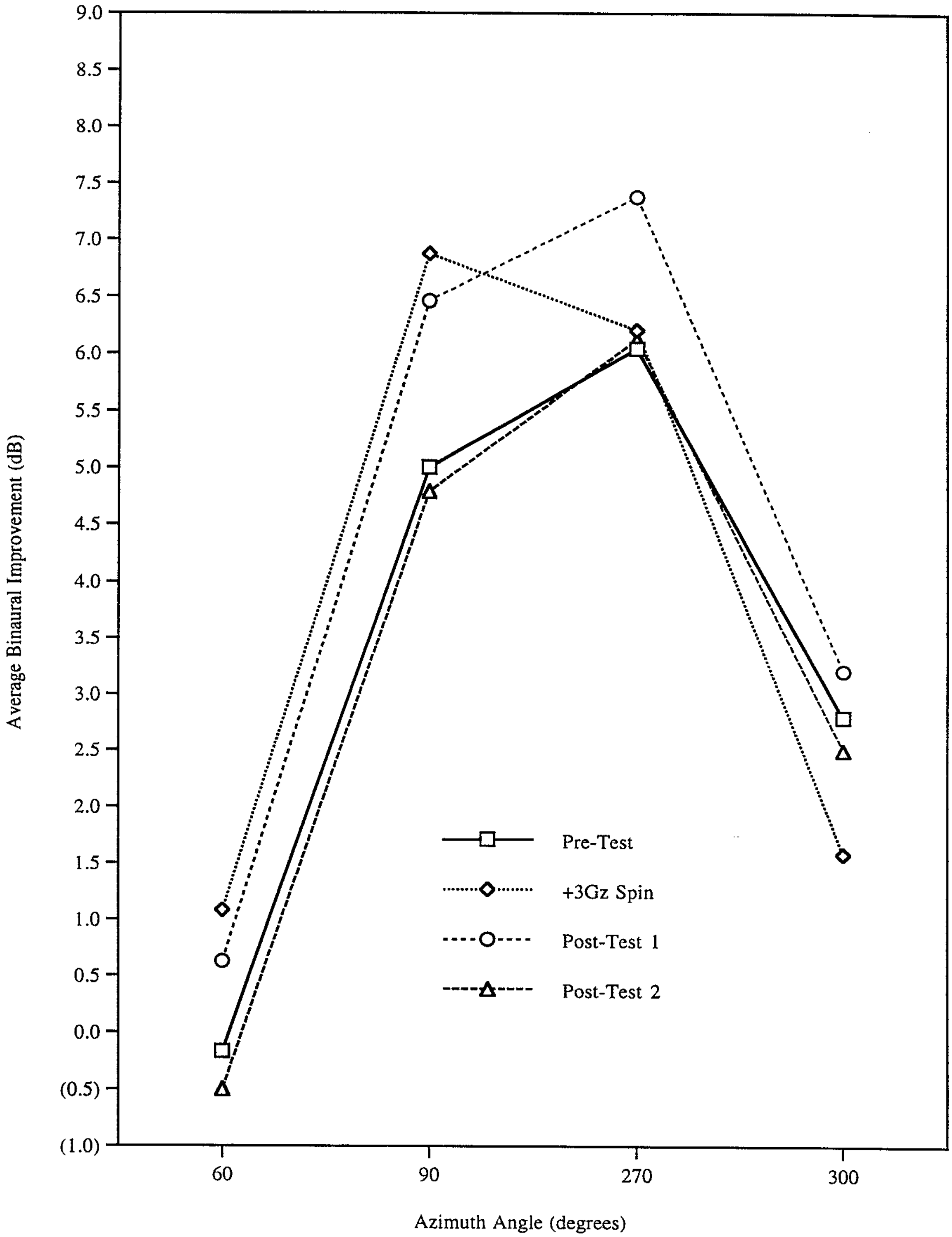


Table 10: Centrifuge Descriptive Statistics (Subject #6)

SUBID	Variable	N	Mean	Std Dev	Std Error
6	PRED	4	0.000	0.000	0.000
	PRE60	4	-0.165	1.161	0.581
	PRE90	4	5.000	1.904	0.952
	PRE270	4	6.043	0.885	0.443
	PRE300	4	2.793	1.286	0.643
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	1.080	1.573	0.787
	GZ390	4	6.873	2.269	1.135
	GZ3270	4	6.205	2.496	1.248
	GZ3300	4	1.580	1.623	0.812
	POST1D	4	0.000	0.000	0.000
	POST160	4	0.625	1.649	0.825
	POST190	4	6.458	1.251	0.625
	POST1270	4	7.375	1.904	0.952
	POST1300	4	3.205	1.301	0.650
	POST2D	4	0.000	0.000	0.000
	POST260	4	-0.500	1.115	0.557
	POST290	4	4.790	1.315	0.658
	POST2270	4	6.123	1.602	0.801
	POST2300	4	2.498	1.942	0.971

Figure 11: Average Binaural Improvement Values vs. Centrifuge Run Type (Subject 7)

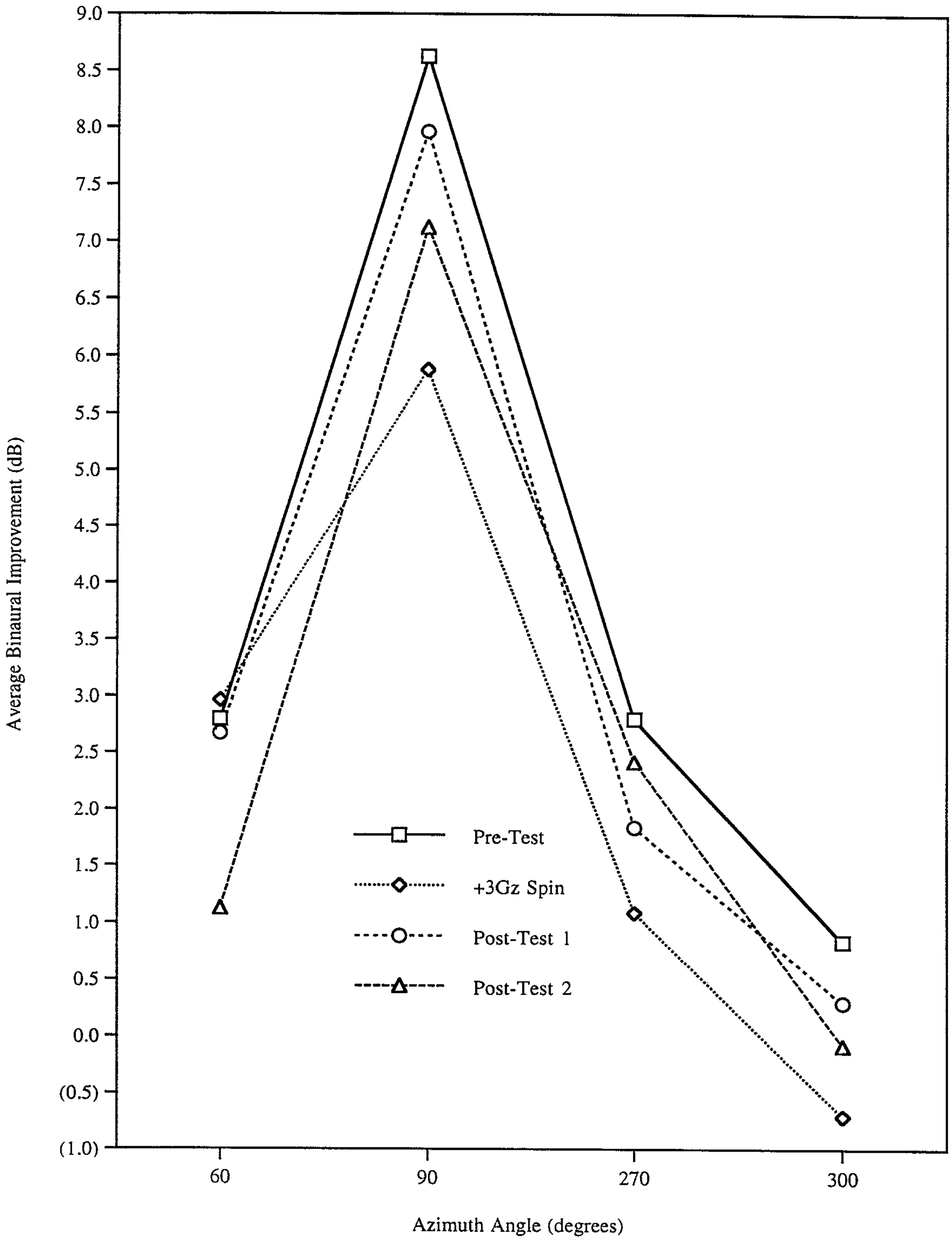


Table 11: Centrifuge Descriptive Statistics (Subject #7)

SUBID	Variable	N	Mean	Std Dev	Std Error
7	PRED	4	0.000	0.000	0.000
	PRE60	4	2.793	2.391	1.196
	PRE90	4	8.625	2.874	1.437
	PRE270	4	2.793	3.481	1.741
	PRE300	4	0.833	3.406	1.703
	GZ3D	4	0.000	0.000	0.000
	GZ360	4	2.960	2.175	1.087
	GZ390	4	5.878	3.155	1.577
	GZ3270	4	1.085	1.745	0.873
	GZ3300	4	-0.708	1.816	0.908
	POST1D	4	0.000	0.000	0.000
	POST160	4	2.668	2.561	1.281
	POST190	4	7.960	3.357	1.679
	POST1270	4	1.835	1.656	0.828
	POST1300	4	0.295	2.164	1.082
	POST2D	4	0.000	0.000	0.000
	POST260	4	1.125	0.797	0.398
	POST290	4	7.125	1.672	0.836
	POST2270	4	2.418	2.129	1.065
	POST2300	4	-0.085	1.602	0.801

Figure 12: Average Monitored Heart Rate vs. Centrifuge Run Type

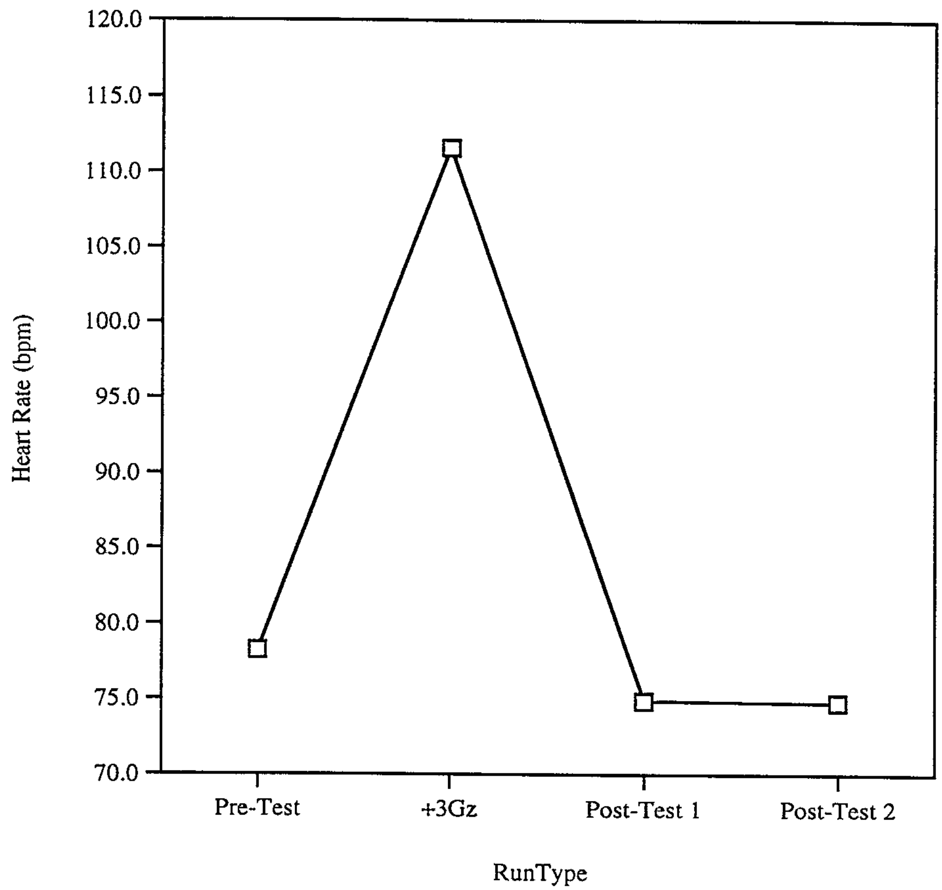
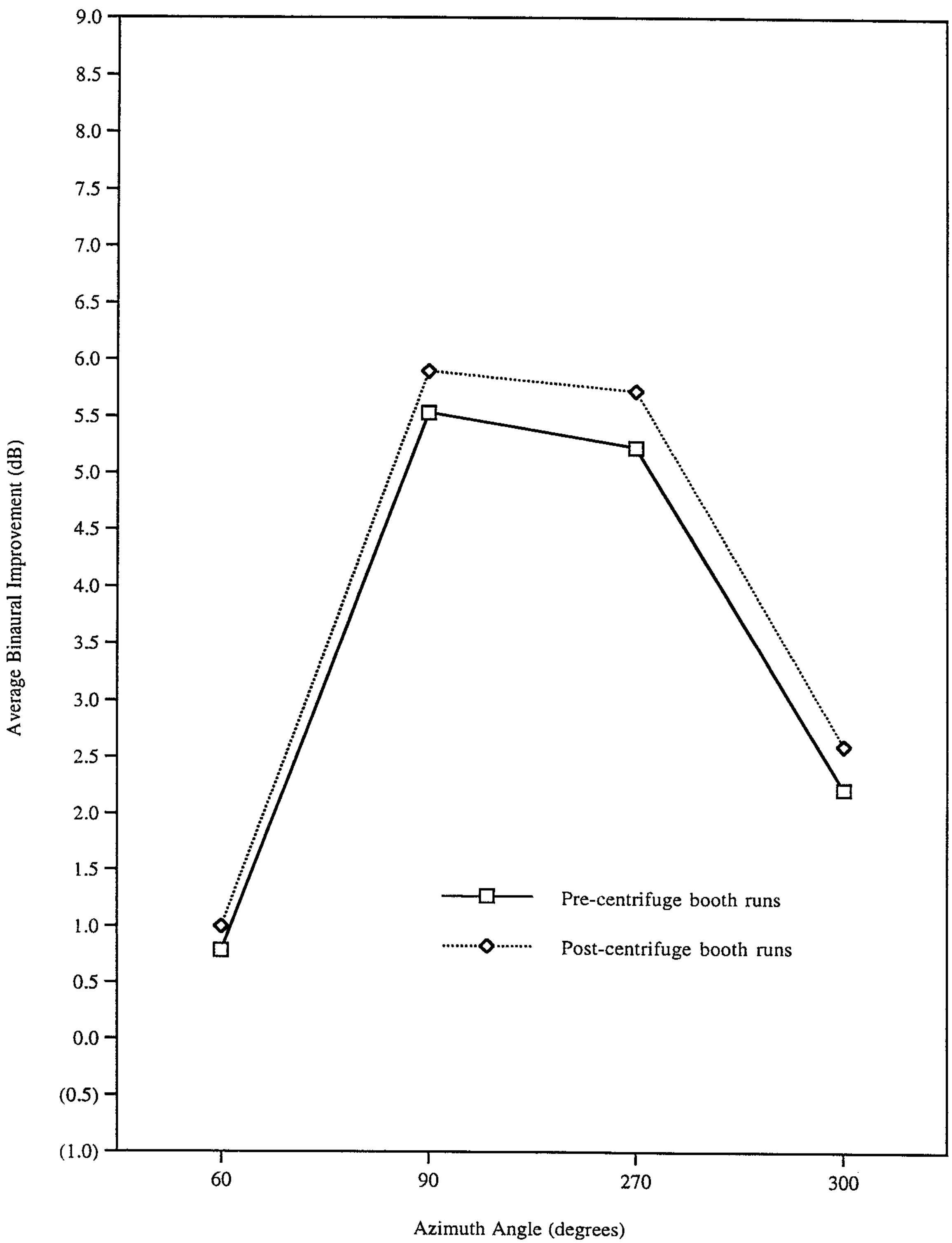


Figure 13: Overall Average Binaural Improvement Values by Booth Session



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