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# Effects of Type of Visual Information on Characteristics of Standing Sway

A Dissertation Presented

By

Ann-Patrice Hickey

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Psychology

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This dissertation is dedicated to my family.

# ABSTRACT

## Effects of Type of Visual Information on Characteristics of Standing Sway

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A series of experiments were conducted to investigate the effects of various types of visual information on a subjects lateral sway, as measured by a sway platform and analysed via a Power Spectral Density (PSD) analysis. The subjects were 56 normal young adult subjects, 28 women and 28 men. In the first three of the four experiments conducted, an unusual visual condition; blindfold with eyes open, ganzfeld, or a helmet with an attached visual scene, was compared with a visual condition in which the stimuli were those of the lab room. In the fourth experiment, the helmet with the attached visual scene was compared with another helmet matched for weight and torque loading on the neck but without an attached visual scene. For each experiment two ANOVA's were performed, each over a different frequency range. Each ANOVA utilized a one between-subject variable (gender) and two within-subject variable (condition and frequency), repeated measurement design. Several sign tests were also performed on the data to tease out consistant if small differences between conditions. In addition, the subjects data were pooled by gender and condition and these average records were plotted with PSD vs frequency on a semi-log scale. The plots could be fit by four linear segments. Results suggest that subjects sway less in the ganzfeld condition than in the environmental condition. Gender differences were found in the blindfold vs lab environment experiment and the helmet with the visual scene vs the control helmet experiment but not in the other comparisons, suggesting that gender differences may be either unstable or condition dependent. Results are discussed and a chapter on directions for future research is included.

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# CHAPTER 1

## INTRODUCTION

The series of experiments conducted were part of a preliminary investigation into the effects of various types of visual information on a subject's lateral sway, as measured by a sway platform and analysed via a Power Spectral Density (PSD) analysis. The sway platform is a measure of "whole body" motor output which does not involve lengthy procedures, injection or other invasive techniques, does not cause physical or emotional trama to the subject, and requires a minimum of instruction and other subject preparation. This platform has the potential of becoming a sensitive clinical tool which could be used by non-professionals. For this potential to be fulfilled however, the measurement must be thoroughly explored with various subjects pools under a broad range of conditions. Although the use of the PSD measure for sway analysis was introduced into the field by this lab (Bensel and Dzendolet, 1969), the measurement configuration used here currently has only been in existance for about three years. Thus far this configuration has been used to study the influences of morphology and athleticism (Powell, 1981) and foot placement (Allen,1982), however in each case the measurements were taken only for male subjects and these subjects were always blindfolded. The study described in this paper expands the subject pool to include women and investigates not only the blindfolded but other visual conditions as well. Previous studies in other labs of the effects of visual stimuli on PSD's of sway have focused on anterior-posterior, as opposed to lateral, sway, (Mauritz et al., 1972, Dichgans et al., 1976, Dichgans and Brandt, 1978). Because the organization of muscular action, innervation and structure is spatially different in these two vertical planes, one would suspect that the specific parameters of a sway response to similiar stimuli may also differ between these planes. On the other hand, sway in both planes seems to be a result of interaction of cues from the proprioceptive, vestibular and visual systems. Therefore, information about the general effects of visual stimuli on equilibrium which comes from studies of anterior-posterior sway , as well as other paradigms for investigation of vestibular-visual-proprioceptive interaction, will be discussed in this introduction.

The importance of visual cues for standing equilibrium is dramatically evident in clinical research on patients with disorders of one of the other two systems. Patients with diseases of muscle and joint afferents have great difficulty balancing in the dark, (Andre-Thomas, 1946). The difficulty experienced by patients with bilateral vestibular lesions is less dramatic but still evident in the absence of visual cues, (Dichgans and Brandt, 1974). The influence of visual information on standing can be made apparent in normal subjects by having them experimentally deprived of ankle muscle and joint information (Lee and Lishman, 1975), or by presenting them with visual cues which are discrepant with cues from the vestibular and proprioceptive systems (Lishman and Lee, 1973).

Visual cues are often taken as predominant in cases of experimentally produced conflict between visual and vestibular cues. In studies involving circular or linear vection (Brandt et al., 1963, Nashner and Berthoz, 1978), as well as studies using visual cues artificially stabilized with regard to the subject's head, (Lishman and Lee, 1973), results clearly indicate that the visual information presented, while incorrect, is nonetheless taken as the stationary reference.

The influence of visual information on equilibrium is also demonstrated by severe disorganization of motor control experienced by subjects wearing reversing prism goggles, (Gonshor and Mellvill Jones, 1980). Reversing prism goggles provide full-color, three-dimensional visual information of the surround which is discrepant from a normal view by having its right-left polarity reversed. Chronic prism wearing (2-3 weeks) caused marked disorganization of the subject's equilibrium as well as movement. Standing on a rail after several days of prism wearing was found to be more dificult than walking along it. Subjects showed progressive recovery of motor control during the 2-3 week period of prism wearing but concurrent deterioration of performance on a standing test with eyes closed, even though such a task seemed only to involve "non-visual" systems. Apparently some re-organization of motor control was occurring. After chronic prism wearing, subjects who had become nearly stable with the prisms on, experienced another loss of motor control upon restoration of normal vision.

Visual stimuli which conflict with cues from the other systems, reversing prisms, translating visual environments or artifically stabilized visual environments, seem to have a greater effect on balance or equilibrium than the simple removal of visual cues (blindfolding). Zacharas and Young (1981) hypothesize, on the basis of studies of combined visual and vestibular cues, that the weighting of visual cues may have a complex dependancy upon the level of agreement between cues from the two modalities.

## Aspects of the visual stimulus to be considered.

Peripheral Visual Field. In studies of circular vection, linear vection, balancing under low light conditions and various sorts of visual-vestibular conflict, the peripheral visual field has been found to be the most effective area in which to present visual stimuli which will be influential in equilibrium and motor coordination tasks, (Begbie, 1966, Brandt et al., 1963, Brandt et al., 1972, Brandt et al., 1975, Dichgans and Brandt, 1979, Dickenson and Leonard, 1967, Held, 1975, Huang and Young, 1981). In order to maximize the results in these experiments, the visual stimuli in each condition extended well into the peripheral visual field.

## Luminance threshold

Berthoz et al. (1975) found that thresholds for linear vection are close to absolute luminance thresholds for moving image detection. Kapteyn et al., (1978) found however that the level of illumination affected the induced sway; the more light, the more induced sway was produced by a sinusoidally moving visual stimulus. Kapteyn's study showed that this effect saturated at about 2.3 lum. In order to avoid a confounding of effects due to luminance differences between the light conditions in the experiments all of the light-available experiments were run above 2.3 lumens.

Pattern. It seemed desirable to have the visual stimuli in the stabilized visual scene be as similar to the stimuli in the environment as possible. Most researchers investigating stabilized visual stimuli use a flat, black and white checkerboard pattern (e.g.,Nashner and Berthoz, 1978). Berthoz et al (1975) discovered that a random pattern was a more effective stimulus than vertical stripes. Perhaps the random pattern held the promise of more visual information than did the regularity of the stripe pattern. In the experiment proposed, a "natural" environment (room with chairs, table, and wall poster) was used for the environmental stimulus and a spliced panoramic photographic replica of the same room was used as stimulus in the stabilized condition.

*Eyes open vs. eyes closed.* Begbie (1966) reported results which suggest that having subjects open their eyes under the blindfold might initiate different strategies for the use of cues than having subjects close their eyes. Subjects were directed to keep their eyes open under the blindfold in the experiments reported here.

### *Effects of gender and biological rythyms.*

Men have been found to sway more in the lateral plane and to be more variable in their sway than women (Nashner, 1978). No studies have as yet reported a direct link between the variability in men's sway and their biological rhythms. Women, however, although varying less in their sway over a number of days, have been shown to exhibit a pattern in their variability which is related to their menstrual cycle (Fearing 1924, Graham et al., 1978). Graham et al (1978) found that sway on the first day of menstruation was significantly less than that of both the fourteenth and twenty-first day while the fourteenth and twenty-first days did not differ significantly. The difference in sway was found over the whole range of frequencies rather than at any specific range of frequencies. This argues against the specific involvement of any of the systems of input such as vision which have been thought to have a specific range of effect. There has been no evidence, to my knowledge, yet reported which would indicate that sway response to visual stimuli varies with biological rhythms. Investigators who use both men and women as subjects in visual-vestibular experiments do not report effects due to these factors (e.g.,Luguchi and Hirabayashi, 1979).

Both men and women were used in the following experiments. Gender was used as a between-subject variable in order to reduce the error term of the analysis of variance and to tease out whatever differences may exist in the way women and men make use of visual cues to maintain standing equilibrium.

## Design

In the first three of the four experiments conducted, "unusual" visual conditions, blindfolded with eyes open, ganzfeld, and, helmet with visual scene attached, (helmet-VS), were each compared with a more natural visual condition in which the visual stimuli were those of the laboratory surround. A measure of lateral sway was obtained in each condition via a sway platform and a Power Spectral Density analysis was performed on data from the platform. In previous studies, the frequency range of the PSD of anterior-posterior standing sway which is most affected by the presentation of visual cues has been estimated as below 0.1 Hz (Nashner, 1970), below 1.0 Hz (Mauritz et al., 1972, Dichgans et al., 1976) and below 1.2 Hz (Dichgans and Brandt, 1978). Estimates of the range of visual cue impact on PSD of lateral sway have not yet been established. Therefore, in addition to determining the effects on lateral standing sway of the various sorts of visual information, the ranges over which these effects exert themselves were also sought.

In Powells (1981) investigation into the sway records of blindfolded males, he found that the average records could be fit by eye to three line segments over the range of.02-2.0 Hz. These three segments may be the manifestation of the interaction between three linear functions or they may be a compelling illusion of experimentor perception. In either case the line segments, if they are available under all conditions, do serve as a convenience to the researcher if only by rendering easily discernable and managable , the change of form over various frequencies. For these reasons and for comparison to Powell study, evidence of these line segments was therefore also sought-after in the average records of subjects in these experiments.

The fourth experiment conducted was added as a control for the weight and moment of inertia loading to the head caused by the helmet in the third experiment. In this fourth experiment the helmet with the visual scene which was used in the third experiment was compared with a helmet of equal weight and torque loading but with no visual scene attached (helmet-control). During this control condition subjects viewed the same laboratory environment as that which was used as the environmental stimuli in the first three experiments.

## The Measure

Characteristics of standing sway were measured in these experiments via the use of a sway platform. Briefly, this platform consists of a plywood top with strain gauges attached to support-bars on either side of the platform. The strain gauges are combined as elements of a Wheatstone bridge. A signal is produced by an imbalance of forces between the two sides (Scott and Dzendolet, 1972). Such an imbalance can be produced in two ways. The first type of imbalance is caused by static angular displacement of the subject's center of mass from a position over the center of the platform to a position on one side of the platform. The other type of imbalance of signals is produced when the subject applies force to one side of the platform in the act of returning herself to a vertical position. Some of the older techniques of measuring sway, for instance photographing whole body movements or attaching a stylus to the subjects head or back, focused on the first of these types of imbalance. It should be noted that the system of measurement used in the experiments reported here includes both types of imbalance and therefore produces a signal which is directly proportional to the differential pressures applied to the soles of the subjects' feet by their own motion. Implications of this will be discussed.

# CHAPTER 2

# METHOD

## Subjects

Data from a total of 56 normal adult subjects, 28 women and 28 men, were used in these analyses. Subjects ranged in age from 17-40 with a predominance of 18-24 year-old subjects. Subjects were drawn largely from a population of graduate and undergraduate Umass students enrolled in psychology. Participation was on a volunteer basis. Only data from subjects who reported no history of fainting spells, recent or traumatic head injury, recent or severe leg injury, and who had 20-20 vision (either with contacts or uncorrected) were used in these analyses.

## Apparatus

Sway transducer. Measurement of standing sway was achieved via the use of a sway transducer platform. The top surface of this platform is a square wooden piece which is supported at the center of each side by a steel bar which extends horizontally under the platform from a concentric steel framework. Strain gauges are attached to all four bars but only the the lateral (right and left hand) gauges were electrically connected during these experiments. These two gauges were connected as elements of a Wheatstone bridge. Deformation of the strain gauges occurs when an imbalance is produced between the forces on the two sides of the platform. This deformation of the gauges produces an alteration in the resistance of the gauges, affecting the overall Wheatstone output. This output is sent to two ganged amplifiers (Hewlett-Packard Model 2470A). The amplified signal is next fed into a unity-gain, low-pass Butterworth filter with a cutoff frequency of about 20 Hz to eliminate 60 Hz noise. This filtered signal is then amplified again by a HP 2570A amplifier and fed into an anti-aliasing, low-pass filter with a cutoff of about 2.5 Hz. The signal, thus transformed, is sampled every 0.1 seconds (at 10 Hz) and converted to a digital form by use of a PDP 8/I digital computer with an analog-to-digital converter. For each 2 minute 10 second period of sway sampled by this method, 1300 data points are produced. This data is converted to paper tape and read into Cyber 3600 to be further analysed. The Fourier Transform of the autocorrelation of the data is produced via a FORTRAN program, resulting in a Power Spectral Density (PSD) analysis of the sway data consisting of 125 PSD points; 1 pt/125 frequencies ranging from 0.02-2.50 Hz.

Visual stimuli. In the blindfolded condition subjects were asked to wear partially opaque goggles covered by an opaque cloth blindfold. This two-stage process allowed the subject to keep their eyes open during this condition. The ganzfeld conditon was achieved by having subjects wear goggles in which halves of ping-pong balls had been glued, creating a flat-white visual stimulus. During the environmental condition subjects viewed the laboratory surround which consisted of a table, a chair, a large metal cabinet, an outlet strip which ran the length of the wall across from the subject at about waist height, a poster of a fall meadow scene which was hung across from the subject, and two wooden doors, one which led to the hall and one which led to a closet, both to the left of the subject. For the stabilized visual scene condition (Experiments 3 and 4), a panoramic photographic mosaic of this laboratory surround was hung on a helmet, locking the movement of the scene to the movement of the subjects head. The scene hung on the helmet extended well into the periphery of the subjects' vision (about 190 degrees) and a bib was attached to the helmet, as was a visor, to occlude the subjects' vision of anything other than the scene. For the control helmet condition (Experiment 4), another helmet was constructed which was weighted like the first but did not have a visual scene attached. During this control helmet condition, subjects viewed the laboratory surround already described.

Procedure

Before the first condition I asked the subjects to read and sign an informed consent form. I then requested them to remove their shoes and socks, and to don a pair of shorts. I then showed the subjects the platform and read them a set of instructions. The instructions directed the subjects to stand quietly with their hands clasped in front of them, with their feet in the position set for them by the experimenter, and to repeat to themselves the following sentences while on the platform, "Stand relaxed and steady. Keep my weight evenly distributed on both feet." If the condition was either environmental, helmet-control or the helmet with the visual scene attached, I instructed the subject to look at a point on the poster which was approximately across from them. For the blindfolded and ganzfeld conditions I instructed the subjects to keep their eyes open and look straight ahead. After reading the instructions I asked the subject to step up onto the platform and I adjusted the position their feet until they were slightly separated and parallel to each other. Subjects were reminded to clasp their hands, and I repeated the two sentences which they were to say to themselves. I then left the room during the 2 minute and 10 second measurement period. Each subject took part in one experiment, consisting of two 2 minute 10 second conditions, with a fifteen minute interim period. During the interim period, the subjects answered questions about physical condition and had their height, weight and center of gravity measured.

Seven men and seven women were randomly assigned to each experiment. Subjects were further randomly assigned to condition sequence which was counterbalanced within each experiment. In Experiments 1, 2, and 3 one of the conditions was the environmental visual stimulus. The other condition was the blindfolded condition, in Experiment 1; the ganzfeld condition, in Experiment

2; and the helmet with the visual scene (helmet-VS) in Experiment 3. In Experiment 4 one condition was the helmet-VS condition and the other conditon was the helmet-control condition.

## Data analysis

For each experiment two analyses of variance were conducted over different ranges of the frequency variable, each ANOVA utilizing a two within (condition and frequency ) and one between (gender), repeated measurement design. In the first Anova for each experiment, ten frequencies were chosen between .02 and .92 inclusive, (frequencies.02,.12,.22,.32,.42,.52,.62,.72, Hz), to represent the PSD line for each record. This range was chosen on the basis of previous research which suggested that visual effects on standing sway would make themselves evident in this range.

A second Anova was conducted for each experiment over a smaller range, (frequencies,.12,.16,.20,.24,.28,.32,.36,.40,.42, Hz), in order to de-emphasize the variance due to frequency and examine the other variables more closely.

In addition, several sign tests were conducted to tease out small but consistent differences between conditions. The first group of these sign tests was conducted on PSD values (in dB form), at .42 Hz for all subjects in each experiment. The second group of tests was performed on the mean PSD's of subjects in each condition by gender over the 9 frequencies used in the restricted Anova test. For example, for each experiment, the average PSD value for all the women in one condition were compared to the average PSD values for all the women in the second condition, for each of the nine frequencies.

PSD records of the individual trials were also averaged across subjects within gender and condition, and averaged records were plotted. Standard deviations were also calculated and plotted.

# CHAPTER 3

# RESULTS

## ANOVA on the larger range (.02 to .92 Hz)

BMDP2V was used to conduct an analysis of variance on ten frequencies between .02 and .92 inclusive, for each of the four experiments. In each case, gender was analyzed as a between-subject variable while frequency and condition were analyzed as within-subject variables, in a repeated measures design. Summary tables of these four analyses are presented in tables 1-4.

Results of the Anova for Experiment 1 (environment vs. blindfolded) indicate that only the frequency variable is significant over this range of the data (f=72.82, p$.0001). A significant frequency effect means that much of the variability found in the data is solely due to the change over frequencies regardless of gender or condition. The analysis of Experiment 2 (environment vs. ganz) also reveals a significant effect due to frequency (F=102.25, p$.00001). In addition, the frequency by gender interaction was also found to be significant in Experiment 2(F=1.96, p$.05). This effect suggests that the PSD values change across frequencies in a different way for the two genders. The analysis of Experiment 3 (environment vs. helmet-VS) shows once again a significant effect due to frequency(F=105.34, p$.00001), but also in this case a significant frequency by condition effect (F=3.00, p$.0032), indicating a significant difference between the slope of the PSD by frequency curves of the two conditions. Analysis of Experiment 4 (helmet environment vs. helmet-VS) was by far the most prolific with regard to significance. Gender (F=5.18, p$.0421), frequency(F=93.96, p$.0001), frequency by gender (F=2.12, p$.03), and condition by frequency (F=2.64, p$.008), were found to be significant.

### ANOVA on the four experiments using a reduced range (.12 to .44 Hz).

A smaller range of the data was re-analysed in each experiment in order to reduce the great amount of variance due to frequency, and possibly enhance the presence of other effects. In each case nine points between .12 and .44 Hz were used in this second analysis.

In each experiment, frequency was also found to be significant in this second analysis ( p$.00001, see tables 5-8). Analysis of the reduced range in Experiment 1 (environment vs blind) uncovered a significant effect due to gender (F=6.3, p$.02, men swayed more) but still did not support a condition effect. Experiment 2, when analysed over this range, produced no new significant results and revealed a reduced effect due to frequency by gender interaction (F=1.75, p$.095). Analysis of Experiment 3 revealed not only significant frequency (F=32.02, p$.00001) and condition by frequency(F=3.96, p$.0004) but significance due to condition(F=19.6, p$.0008). The secondary analysis of Experiment 4 confirmed both the gender and frequency effects over this restricted range but failed to show the frequency by gender and condition by frequency effects found in the analysis of the larger range.

## Sign tests

The analysis of variance is a test which is sensitive to the absolute magnitude of a variation from the mean but not to the directionality of the variations. Because we are measuring a signal for which relatively small differences of consistent directionality may be of importance, several sign tests were performed on the data to tease out consistent though small differences between the PSD values produced in response to the various conditions.

Test 1 (conducted between subjects at .42 Hz for each experiment). For each experiment a sign test (Hayes,1974) was performed between subjects across conditions at .42 Hz. Results of these tests are presented in table 9.

Sign test analysis on Experiment 1 shows that across subjects the blindfold condition consistently produced more sway at .42 Hz than did the environmental condition($z=1.8, 1-f(z)=.036$). In Experiment 2 the ganzfeld condition produced consistently less sway than the environmental condition ($z=1.80, 1-f(z)=.036$). Experiment

3 showed consistently higher PSD values in the helmet- VS condition(z=1.8,1-f(z)=.036). The sign test for Experiment 4 at .42 Hz revealed no consistent directionality of the difference between the two helmet conditions.

Test 2 (between conditions for average records at nine frequencies). A second group of sign tests were conducted on the means of the PSD values used in the restricted range anova. This sign test of Experiment 1 indicated a consistent difference between the means of PSD values on the two conditions with the blindfold condition causing higher mean PSD values for both men and women (z=3.8, 1-f(z)=.0001, for women; z=2.0, 1-f(z)=.023, for men). The sign test analysis of Experiment 2 confirmed a small condition difference for both men and women (z=3.8, 1-f(z)=.0001,for both genders). Sign test analysis of the means in Experiments 3 and 4 both show consistently higher values in the treatment conditions (z=3.8, 1-f(z)=.0001, for both genders).

One may conclude, based on a comparison between the results of the analysis of variance and the sign tests that differences between conditions on Experiments 1 and 2 are small but consistent, while those in Experiment 3 are relativly large and consistent and those on Experiment 4 are small and not consistent.

## Standard deviation

The standard deviations of the PSD values were calculated and plotted by frequency for each condition and gender.(See figures 1-5) In the blindfold and helmet-VS conditions, the men showed higher standard deviations than the women over most of the spectrum. In the environmental condition the two genders exhibited very similiar standard deviations across the frequencies. In the helmet and ganzfeld conditions the women varied more from each other than did the men. The standard deviations from the different conditions are based on different numbers of subjects. The environmental condition standard deviation was based on 21 subjects in each gender, the helmet-VS on 14 subjects per gender, the blindfold, ganzfeld and helmet environment on 7 subject per gender.

## Mean Graphs

Subjects were pooled by gender and condition and average records were plotted with PSD vs log Frequency, for ease of comparison with previous data from this lab. (Figures 6a to 10 b) In each case, the curves approximate four linear segments between .02 and 2.5 Hz. The slopes of the segments and the intercepts of the segments as well as the crossover points between segments change over condition and gender (Table 10). Lines were fit by eye to these segments and dB/decade loss (or gain) as well as crossover points were approximated for each average curve. PSD values were read from the fitted lines for points corresponding to 0.1 Hz, 0.7 Hz, 1.4 Hz and 2.3 Hz are reported in Table (10) because they correspond to the visual midpoint of the line segments, and they can be used to convey a sense of the "height" of the segment. The averages are based on different numbers of subjects. The environmental condition had a total of 21 subjects per gender, while the helmet-VS condition had a total of 14 subjects per gender, (7 from Experiment 3 and 7 from Experiment 4) and the blindfolded, ganzfeld and helmet control conditions had 7 subjects each.

PSD values for the men's averaged curves were greater than those for the women's averaged curves for each condition. In Experiment 3, however, the men's PSD values were less than the women's averaged values. For women the lowest PSD values are found in the ganzfeld condition across the spectrum. For women, the highest PSD values are found in the helmet-VS condition for segment 1, and in the blindfolded and environmental conditions for segments 2 & 3, yet the PSD values for the averaged curves for these three conditions are not far different. For men the highest PSD values are found in the blindfolded and helmet control conditions for segments 1, 2 and 3.

Both the crossover points from segment 2 to segment 3, and the dB loss/decade of segment three are similar across both conditions and genders. While the effects which occur in crossover points and and slope, as result of these conditions, appear below 1.1 Hz, in segments 1 and 2, a shift of the height of segment three does seem to occur in the helmet conditions ,for women, and in the ganzfeld condition, for both genders. For both men and women, the environmental condition shows great loss in each segment and a long first segment (refer Figures 6A and 6B and table 10) with a crossover point between segment 1 and segment 2 at around .165 Hz. The ganzfeld and helmet conditions produced a shorter, less negatively sloped segment 1 for the women with a crossover point between segment 1 and segment 2 at about .138 Hz. The average curves for the male subjects show a bit more variability in the crossover points between segment 1 and segment 2, across condition, with the longest segment 1 (after that of the environmental condition) found in the helmet control condition (crossover at about .156 Hz), the next longest in the ganzfeld condition (crossover at about .148 Hz) and the shortest segment 1 in the helmet-VS condition (crossover at about .135 Hz ). The first segment in the average graph for the blindfolded condition for women is somewhat longer than the first segments of the other three unusual condition for women (crossover at about .145 Hz), whereas for men the first segment is somewhat shorter in comparison to the first segments of the other average male graphs (crossover at about .128 Hz). Since the crossover points and slope for segment 3 are fairly consistent, differences between graphs which occur in the first segment are reflected and amplified in the second segment. In the ganzfeld condition, the effect is to greatly reduce the evidence for an independent second segment. For the women especially segments 1 and 2 could be fit fairly well to a single line. This reduction of the presence of segment 2 in the average graphs is also found, although to a lesser extent in the helmet control condition for both genders. On the other hand, the blindfold condition and helmet-VS condition for men and the helmet-VS condition for women show evidence of an enhancement of segment 2.

### Subjective reports.

Subjective reports were not solicited but were noted when volunteered. Comments were made about both the ganzfeld and helmet-VS conditions. Four subjects (three men and one woman ) made statements after the ganzfeld condition to the effect that they felt hypnotised or "spaced" while wearing the goggles. One subject said he kept seeing horizon lines fly away from him. One subject (man) simply said "Wierd". Two subjects (one man and one woman) in the helmet-VS condition asked if the experimentor was moving the platform while they were wearing the helmet. One subject (woman) said that she felt very aware of where the edges between the bottom of the picture on the helmet and the beginning of the bib were.

# CHAPTER 4

## DISCUSSION

A brief synopsis of the results is : a) Significant frequency effects are found in all experiments over the range of 0.02 to .92 Hz; b) Average records for the subjects by gender and condition can be fit by four line segments on a PSD (dB) by log frequency (Hz) curve, where segments 1 and 2 extend from the lowest frequencies up to about 1.2 Hz, segment 3 runs from about 1.2 to about 2.1 Hz and segment 4 runs beyond 2.1 Hz; c)Significant gender effects are found in the anova tests of Experiments 1 and 4; d) Significant frequency by gender effects are found in Experiments 4 and 2; e) Relative variability between genders may depend upon stimulus conditions., f) Condition was found to be significant in Experiment

3, but not in Experiment 4; g) Blindfolded subjects seemed to sway more than subjects did when viewing an environmental visual scene; h) Subjects viewing a ganzfeld stimulus seemed to sway less than when viewing an environmental stimulus; i) The changes in the ganzfeld condition include a shift of the third line segment ( which extends from about 1.2 Hz to about 2.1 Hz).

## Frequency

In each experiment, there were significantly different PSD values found across frequency (for both the large and restricted range tests). Most of the power is found at the low frequencies and drops off as frequency increases. On the PSD (in dB units) vs log frequency curves for average records, this drop-off occurs in 3 linear segments from .02 to 2.0 Hz and power increases again in a fourth line segment from about 2.0 to 2.5 Hz. This linear decrease of power from low to high frequencies with a slight increase at higher frequencies corresponds well to PSD records of other biological motor systems (see Fig. 11, Campbell et al., 1959). Perhaps an examination of even higher frequencies would reveal a second quick drop off as is found in the records of the other motor systems. The expansion of the frequency range of observation would require, however, an adjustment of the observation period and of the mathmatical window used in the analysis.

## Gender

Significant gender effects were found by the analysis of variance tests for Experiment 4 (both large and restricted ranges), and for Experiment 1 (restricted range). Previous studies examining gender differences in their relation to standing anterior-posterior sway have used either environmental or blindfolded conditions and the gender difference found in Experiment 1 verifies that this effect can be found in lateral sway under these conditions as well. Significant results in Experiment 4 suggest that the genders also differ in the way they respond to the weight of the helmet. In both cases, examination of the cell means reveals that the men had higher PSD values in these ranges of frequencies than the women did. When the average curves are examined, PSD values seem to be higher for men than women over the whole range of frequencies observed for these conditions. Significant frequency-by-gender effects were found in Experiment 4 (restricted range tests) and Experiment 2 ( both large and restricted range tests). This implies that a difference between genders in lateral sway can manifest itself as a change of slope of the line segments as well as a difference in the magnitude of values over the entire curve. Lack of a gender effect in

Experiment 3 and, in fact, lower PSD values for men than women in this experiment imply that, as is found in most studies of gender difference, there is a great overlap of the distributions of the values of sway for the 2 populations (Sherman, 1978).

Without a strong model of underlying mechanisms which produce the various segments of the PSD by log frequency curves, it is difficult to decide to what to attribute the differences between the genders. It is possible that the difference between the genders is due to structural or experiential differences. Previous work in this laboratory, with blindfolded men, which fit the data to a single exponential function demonstrated that center of gravity accounted for about 15.8 percent of 1 parameter and 7.8 percent of another (Powell, 1981). Since men and women tend to differ with regard to center of gravity, this factor probably contributes to the differencies found between genders in this study. Data on height, weight and center of gravity was taken for the subjects in this study and examination of these factors will be part of future research in this laboratory.

Athletes in Powell's (1981) study were found to have higher PSD values than sedentary subjects, over the frequencies from 0.02 to 1.2 Hz (or the first two segments) and to have lower PSD values over the frequencies higher than 1.2 Hz (segments 3 and 4). Since men, in general, have had more access to and encouragement to participate in sports than women, this experiental factor probably also contributes to the current finding. It should be noted, however, that the differences between genders occurs over all frequencies, suggesting that the athleticism factor is not the only one operating.

Neither the condition-by-gender interaction nor condition-by-frequency-by-gender interaction were found to be significant over the ranges tested. This indicates that at least over the lower frequencies (.02 to 1.2 Hz), men and women respond similarly to the visual stimuli presented. It is interesting, however, that women seem to have lower PSD values in segment 3 in the two helmet conditions than in the environmental condition while men have very similiar PSD values for segment 3 across those 3 conditions. Since this higher range was found to be a region of disparity between athletes and sedentary types in Powell's (1981) study, there may be an athletisim factor involved here as well.

### Standard deviation and gender

Although previous studies have found men to be more variable in their sway, (Nashner, 1978), this study indicates that the relative amount of variability may depend upon the stimulus conditions. Men varied much more in their sway in the blindfolded condition over frequencies greater than about .30 Hz. The blindfolded condition is one which is frequently used as a baseline condition in the study of anterior-posterior standing sway and this study indicates that men are more variable in their lateral sway under a blindfold as well. Men also seemed to vary a bit more than women in the helmet-VS condition, from about .5 Hz and higher. However, men and women sampled in this study had very similiar standard deviations across frequencies for the environmental condition. In fact, women sampled in this study were found to be more variable in their sway in the helmet-control and ganzfeld conditions than men were. The helmet-VS condition and the environmental condition standard deviations were based on 14 and 21 subjects per gender, respectively, while the estimates from the other conditions were only based on 7 subjects per gender. Sampling error may be a factor in these results and further research may resolve this question. If, however, such condition dependent variability differences do exist between genders, we are left again with the question of whether the differences in variability are due to experience or to structural differences.

## Condition

**Helmet conditions.** Analysis of variance tests over both the larger and restricted ranges demonstrated a significant condition effect in experiment 3. Subjects, both women and men, swayed more in the helmet condition. Only slight differences were found between means and no consistent difference between PSD values for .42 Hz in Experiment 4. This indicates that most of the difference between conditions in Experiment 3 was due to weight of the helmet itself and not to the visual scene. It could be that the visual scene used in this study was too mosaic in quality (it was composed of cut and pasted photographs) to be taken seriously by the subjects as a visual surround. The slight differences found on the average curves and subjective reports suggest that perhaps this type of visual surround should be studied again with another type of situation.

It is, however, of interest that the wearing of a helmet would cause sway which was significantly different from that in the environmental condition. Since the introduction of the weight of the helmet (less than a pound and a half) to the head would only change the overall center of gravity of the body by a few centimeters, it seems more likely that the differences uncovered were due to change in the loading of the neck muscles and changes in the dynamics of movement of the head. From the average curves, it seems that the addition of the weight of the helmets caused a diminishing of the demarcation between the first and second line segments, producing curves in which the first two segments looked more like a single segment. A change in the dynamics of motion of the head would change visual and vestibular input, (since those organs are located in the head), as well as neck muscle input. The effects of the helmet could therefore be a result of any of the three systems or perhaps more likely, a combination of the three.

Black and white visual fields. Slight but consistant differences were found between conditions for mean values (across subjects) as well as individual PSD values at .42 Hz (within subject) for Experiments 1 and 2. The slight increase in PSD values for lateral sway caused by removal of visual cues (blindfolded) corresponds to results found for anterior-posterior sway, both in direction of the effects and the range over which the effects show themselves (up to about 1.2 Hz). The decrease of sway caused by the ganzfeld condition is, however, a suprise. Furthermore, average PSD records of the ganzfeld condition are different not only in crossover points between segments 1 and 2 and the magnitude of PSD values of these two segments but also in the magnitude of the PSD values of segment 3 (1.2 Hz to about 2.1 Hz). This indicated an effect of a visual stimulus in a range above 1.2 Hz. These results raise two questions. The first question is, why would an apparent reduction of visual cues produce lower PSD values? The second question raised is, is the reduction of PSD values in segment 3 under the ganzfeld condition a visual effect?

In reponse to the first question, I would like to draw upon the subjective responses of several subjects who implied that something like a trance state occurred under this condition. I wonder whether there was, in fact, a change of "state of conciousness" which had its affect upon the subject's sway. In the counter-intuitive nature of the results of the ganzfeld condition, I am reminded of Powell's 1981 results which showed that athletes in his sample swayed more than non-athletes over much of the range of observation. Since his measurement of athleticism depended heavily upon participation in organized sports, his athletes probably had the kind of physical prowess that could be related to an emphasis on strength and a certain tense readiness for action. If a relaxed state produces less sway, perhaps a study of other types of physical prowess which emphasis a "strength without tension", such as yoga, Tai Chi, Alexander or Aikido would produce results which were similiar to those of the ganzfeld condition. Likewise a study of people who meditate might show them to sway less than other subjects, if in fact the ganzfeld truly did produce a trance-like effect.

Response to the second question is more complicated. The change in overall PSD values for frequencies higher than 1.2 Hz in the helmet conditions for women can be attributed to the weight of the helmets as opposed to a visual effect. No such attributions can be made in the case of the ganzfeld condition. To seek the ranges of effect of the various input systems to standing sway is to assume a relative independence of the input, if not the output, of these three systems. Recent neurophysiological data from many species suggests however that the three, broad-ranging "systems" which contribute to standing sway also inform each others neural signals and even share neural "circuitry" in the reticular and cerebellar regions, (Precht,1978). Specific frequency ranges of effect of visual input may depend upon the type of visual information and the level of the central nervous system which is affected by that level of information. It is evident from the results of Experiments 1 and 3 that a flat-black visual field (blindfolded) and a flat-white field (ganzfeld) produce opposite effects on standing sway. The only information difference is at the level of light being available or not, since neither field includes contour, three dimensional information or movement. It seems reasonable that a "no-light" condition could trigger a response to seek more information from other systems, e.g., proprioceptive or vestibular. Sway does stimulate the proprioceptors of the feet, muscle spindle and stretch receptors of the legs, torso and neck, as well as stimulating the vestibular apparatus and, under normal circumstances, the visual system itself, through increased motion of the head. Increased sway may be not only an output caused by a lack of information, but also part of an active search for more information. From this perspective, it is plausible that it is the visual message "no-light" and not the message "no-features" which triggers a search (more sway). From this research it seems that the visual message "light-no-features" causes a state in which there is less sway, less of a search for information. Whether this effect is due to a type of hypnotic change, a simple relaxation or some effect by which a "light-no-features" visual message causes the amplification of signals from vestibular apparatus and proprioceptive systems, internal to the CNS (eliminating the need for a search) is unknown.

It would be interesting to see if an effect similiar to that caused by the ganzfeld could be found in a condition in which a single hue (e.g.,blue) were presented.

### The measure

As noted in the introduction, the sway platform, used as the measuring device in these experiments, produces signals which are directly proportional to the differential pressures applied to the soles of the subjects' feet by their own motion. As explained briefly in the introduction, the changes in the force applied to the platform by the subjects feet have two components; that imbalance of forces due to displacement of the subjects center of gravity and the imbalance of forces caused by the subject "pushing off" from one side to bring the body back into a vertical position. It seems reasonable to assume that the second type of imbalance, under normal circumstances, is somehow related to, possibly a function of, the first. That is, we usually think of the subject's needing to right himself when his center of gravity has gotten to a certain angle of displacement. It may be that the second type of imbalance is caused by a feedforward, as opposed to a feedback,signal. Such a feedfoward signal would be a function of past experience and might be overridden, in unusual circumstances (i.e., unusually large angle of displacement) by a feedback signal which would be a function of the imbalance due to displacement. In any case since the second type of imbalance causes a change in the first (acceleration changes the rate of displacement), the two types of imbalance are not independant. In addition, the second type of imbalance may be not only a righting response during unusual conditions but an information gathering response as well. These two types of imbalance of forces cause two components of the voltage output of the platform. The ratio of these contributing voltages changes over frequency. At 0.2 Hz, the voltage due to acceleration is only about .16 times that due to displacement, whereas at 1.0 Hz , voltage change due to acceleration is about four times that caused by displacement (Scott and Dzendolet, 1972). The visual effects may particularly affect the portion of the signal due to acceleration, since this is a control type of signal. As stated above, though, a change in one type of imbalance will affect the other type as well. What we have then is a complex relationship between two type of forces on the platform, each of which could be responding, for various reasons, to visual information, and this relationship changes over frequency. The line segments found in this study, if in fact they do exist, are some function of the relationship between these two types of imbalance and the differences between conditions and between genders, visible via these line segments, are a result of alterations of that function. It would certainly be helpful if a model of this function could be developed. The data presented here should be of interest to modelers wishing to model standing sway and achieve at least replicative validity (Zeigler, 1976).

## Conclusion

In conclusion , it seems from the results of this study that the ranges of effect of visual conditions, the relative standard deviations of the two genders, as well as the crossover points of the hypothesised line segments and the value of the PSDs of those line segments are complexly dependent upon the type of visual information presented. This research raises as many questions as it poses answers about the relationship between the three systems thought to control standing sway ( the proprioceptive, vestibular and visual). It raises questions as well about the relationship between the two types of imbalance, acceleration and displacement, which are measured by the sway platform.

# CHAPTER 5

# FUTURE RESEARCH

Future exploration into standing sway using the sway platform and PSD analysis could expand along any of the following four dimensions: the design (eg. which conditions are compared), the stimulus used, the measure, and the subject population investigated. Of course many thousands of combinations and permutations of changes in these dimensions exist. This chapter will focus on those combinations which occured to me in the course of running the current experiment.

## The design

Neither the blindfolded and ganzfeld conditions, nor the helmet environment and the environment condition, were made directly comparable (eg. measured within subject) by the design of the current study. Keeping all other variables constant, the stimuli used in this experiment could be further investigated by comparing the conditions which would isolate the variables of black vs white and helmet vs no-helmet. In both cases there is evidence from the current study which indicates that the differences found could be significant.

The discovery of line segments in the average records of subjects in this study, indicates that a regression analysis may provide more information than the ANOVA about the data gathered. With a regression analysis , the question of whether one second order function or four linear first order functions, fit the data best, could be resolved. The gathering of data on more subjects of both genders under each condition would be necessary for such an analysis.

## The stimulus

My suggestions for stimuli to use in future studies fall into two catagories: sensory (visual/mechanical) and psychological (emotional/persuasive).

The first catagory is more obviously an outgrowth of the present study and is ripe with possibility. The effects of static presentation of patterns of black and white (beyond stripes) or other colors, shapes (2-d or 3-d) or single hue fields could be explored. For instance, what effect would the presentation of a visual illusion have on sway records? As an addition to the level of complexity of the stimulus, patterns of motion (eg.circular, sinusiodal or translational) could be added to any of the stimuli studied in the static case to discover something about the interconnection between the sway response to color, light intensity and shape information and the response to motion of the stimulus. It would be especially interesting to look for the relation between the movement of the stimulus and the dynamics of motion of the subject as measured by the sway platform. Other sorts of sensory stimuli which could be investigated either in conjunction with the visual stimuli or alone are: 1) foam under the feet which would alter the feedback from the proprioceptors on the bottom of the feet but not the joint receptors and 2) immobilization of either or both the ankles or knees of the subject which would affect the joint receptors and relative body part dynamics but not the sensitivity of the receptors on the bottom of the feet. Study of these variables is necessary to discern the contribution of each of these sensory sources to the overall standing equilibrium system response.

The second, more psychological, catagory of stimuli is relatively unstudied with regard to effects on standing sway. The internal psychological state of the subject is of course related to blood chemistry and therefore muscle tone and readiness, which affect sway in the present, but perhaps more interesting is the relation of mood, and expectation to the state transition function for various conditions. Stimuli which would produce an emotional state in the subject such as pictures, stories, or experimentor demeanor (eg. authoritarian vs nurturative) could be systematically studied with regard to their affect on sway records. Even without the introduction of evocative stimulus, a simple mood measure questionairre could be included in the course of investigation of other variables, the way a measure of athleticism is currently taken for each subject. Experimentor expectations and persuasiveness could also use some attention as stimuli which could be relevant to the simplest sway study. Evidence is already available in this lab which indicates that the sway measure is sensitive to changes caused by instructional set. What differences exist between a situation where the subject reads the instructions and one where the experimentor reads the instructions? Should instructions be videotaped to provide consistancy?

## The measure

Several different kinds of expansions could be made in the measurement dimension. For instance, a relatively simple change would be to expand the range of frequencies measured and analysed in order to see if the second drop off of Power found in the high frequency range of PSD records of other muscles can be found in the sway records. A great boon to understanding contributions to lateral standing sway could be made if this measure was used in conjunction with other measures, for instance; an anterior measure of sway, some measure of neural signals or muscular action (such as EMG) or measures of the dynamics of body part motion.

Combination and comparison of the lateral and anterior-posterior sway records could give some indication about whether certian conditions affect sway in these two dimensions differentially as well as give a 2-dimensional picture of the dynamics of motion of the pressure on the bottom of the feet under "normal" conditions.

Other external sway or motion detectors which could be combined with the sway platform include records from either mechanical or electrical styluses attached to various parts of the body, (eg. trunk,legs or head). The point of this sort of measure would be to get a picture of the motion of the body parts in relation to each other and to overall sway as measured by the platform (by implication therefore, the relation to the presure stimulating the feet receptors)

In addition to these measures of the external state of the body during standing sway, the sway records could also be combined and correlated to measures of internal state of the subject, whether at the level of muscular action, such as EMG recordings, or at the level of psychlogical state, such as subjective reports. EMG data could be recorded for muscles of the legs, trunk or neck of the subject. Such recording in combination with the sway platform would shed some light on the pattern of muscular activity which plays itself out during standing sway and the relation of that pattern to the pattern of sway behavior externally measurable. At the level of individual muscle groups a system description of the standing sway situation could then be attempted.

The second type of internal measure which I suggest using in combination with the sway platform is subjective report. This could take the form of a mood questionairre, as suggested in the previous section, or a structured interview. Subjective reports gathered informally in the study described in this paper were helpful in understanding the unexpected decrease in sway in the ganzfeld condition. Expectations of, and the assignment of meaning by, the subject to various variables of the experimental situation are important factors to have some knowledge of, since they probably affect the subjects response. Furthermore, as was seen in this study, subjective reports can provide information (such as similarity to other experiences) about the experimental situation which would be difficult to access any other way.

### The subjects

Many features of the subject population could differentially affect sway under various conditions including: age, gender, general morphology, biorhythms, experience and health. Some aspects of gender, morphology, biorhythms (primarily menstral cycles in women), and health (in the form of pathology) have already been studied and these studies could be expanded. Work on biorhythms could be expanded to involve male subjects to see whether their reported higher variability over the course of the month can be seen to follow any pattern. Likewise, thus far only severe mental or physical pathology have been studied as health variables. The well known effects of such health states as the comman cold on muscle fatigue and overall dizziness has not promted much research on effects of such minor illness, nor conditions such as depression or allergies, on sway patterns.

Developmental effects on standing sway offer a rich source of future research ideas. One might suspect that sway under normal stimulus conditions would change with development and aging of the subject. In addition such changes may occur differently for different subject populations, eg. males and females, or during different stimulus conditions. For instance, one gender may not change much over time with regard to their response to sway while blindfolded, whereas the other gender may show change.

Some work on the effects of subject experience, in the form of sports experience, been done in this lab, (Powell, 1981). There are many other aspects of experience which could be investigated. Individual experience in the form of participation in dance of various kinds, TAI CHI or related martial arts, or job related movement experience, such as high steel construction work or highly repetative manual labor, can be seen as analogous to sports activity in that certian patterns of functional relationship between sensory input and motor output are formed and strengthened by practice. Such relationships may manifest themselves in characteristic sway under some conditions. Along the same lines, the presence of culture specific movement patterns is clear to anyone who has tryed to master the dance form of another culture. Families seem to mimic this effect on a smaller scale by having a sort of formal signature of movement patterns. We hold our hands just like our mothers did or shake our heads when we laugh just like our father or grandfather. These patterns may be learned or may be passed on genetically via genetic transmission of morphology and therefore relations between certian muscle groups (such as long legs and a short waist which would favor a certian type of stride). Chances are good that such differences are transmitted via some combination of both routes, and of course, psychology's favorite population for answering such questions, identical twins reared together or apart, could be used to study this. In any case, do such motor pattern tendencies reveal themselves in characteristic sway patterns? Only research with such specific subject groups will tell.

## Modeling

The sway platform and PSD analysis result in a record of the relationship of power to frequency of a subjects sway. Variables which may either shape that function or change the shape of that function fall into three catagories; biochemical, structural, and experiential. Biochemical variables which might figure into a model of systems which impact upon the subjects sway are: hormone level, fatigue, drugs, metabolism, allergies, etc. Variables of importance at the structural level are: morphology (ratios of the lengths, widths and depth of muscles, bones and ligiments), parameters and transfer functions of all the neural pathways involved in all the sensory and motor systems which impact upon the subjects sway, stance of the subject upon the platform, or structural history (broken bones, sprained muscles, disease, or nerve pinches). The experiential variables which may be of importance are: historical experience (family and cultural movement pattern, individual movement history, history in experimental situations, or training), present experience (experimental conditions, self image of health, mood, interpretation of experimentor expectations, or seriousness about the study), and experience of the future (expectations, developmental predictions or state of degenerative desease known to the subject, or interpretation of future benifit attached to study). Models proposed to explain the interconnection and relative importance of these variables could be tested via a multiple regression upon the curves found in subjects records.

# REFERENCES

Allen, B., (1982), Unpublished Dissertation. University of Massachusetts.

Andre-Thomas, (1940): Equilibre et equilibration. Paris: Massion.

Begbie, G. H., (1966): The effects of alcohol and of varying amounts of visual information on a balancing test. Ergonomics, 9, 325-333.

Brandt, Th. and Dichgans, J., (1972): Circularvection optishe Pseudocoriolis-Effekte unter optokinetischen Nachnystagmus. Albrecht y Graefes Arch. Klin. Exp. Opthal., 184, 42-57.

Brandt, Th., Dirner, H.H., and Dichgans, J., (1975): Motion sickness induced through angular oscillations of the body and the visual surround in normals and after labyrintine lesions. XXII International Congress of Aviation and Space Medicine, Acapulco, Mexico.

Dichgans,J. and Brandt, T., (1974): The psychophysics of visually induced perception of self motion and tilt. In; The neurosciences: Third Study Program. Schmitt, F., O., and Worden, F., editors-in-chief. Cambridge, Mass: MIT Press, 123-129.

Dichgans, J., Mauritz, K., Allum, J., and Brandt, Th., (1976): Postural sway in normals and ataxic patients: Analysis of the stabilizing and destabilizing effects of vision. Aggressologie, 17c, 15-24.

Dickison,D. J., and Leonard, J. A., (1967): The role of peripheral vision in static balancing. Ergonomics, 10(4), 421-429.

Fearing, F. S., (1924): Factors influencing static equilibrium. J. Comp. Psychol., 4, 91-121, 163-185.

Gonshor, A., and Melvill-Jones, (1980): Postural adaptation to optical reversal of vision in man. Brain Research, Vol 192(1), 239-248.

Graham, S. E., Thornton, H. and Altha, J., (1978): The effects of menstruation and Microgynon 30 on sway behavior. Agr:19 b>>, 55-56.

Held,R. Dichgans, J., Bauer, J. (1975): Characteristics of moving visual scenes influencing spatial orientation. Vision Res. 15, 357-365.

Huang, J. and Young, L.R. (1981): Sensation of rotation about a vertical axis with a fixed visual field in different illuminations and in the dark. Exp. Brain Res., 41,172-183.

Kapteyn, T.S., Bles, W., Brandt, Th., and Wist, E. R. (1979): Visual stabilization of posture effect of light intensity and stroboscopic surround illumination, Aggressologie, 200, 191-192.

Lee, D. N. and Lishman, J. R., (1975): Visual proprioceptive control of stance. J. Human Movement Studies, 1, 87-95.

Lishman, J. R., and Lee, D. N., (1973): The autonomy of visual kinasthesis. Perception, 2, 287-294

Mauritz, K. H., Dichgans, J., and Hufschmidt, A. (1979): Quantitative analysis of stance in late cortical cerebellar atrophy and other forms of cerebellar ataxia. Brain, 102, 461-482.

Nashner, L. M., (1970):Sensory feedback in human posture control. MIT 70-3, Cambridge, Mass. Man Vehicle Laboratory, MIT.

Nashner, L. M. and Berthoz, A. (1978): Visual contribution to rapid motor responses during postural control. Brain Res. 150: 405-407.

Powell, J, (1982): Unpublished Dissertation. University of Massachusetts.

Sherman, J. A. (1978): Sex-related cognitive differences: An essay on theory and evidence. Charles C. Thomas Publishers, Springfield, Illinois, USA.

Zacharis and Young, L. R. (1981): Influence of combined visual and vestibular cues on human perception and control of horizontal rotation, Exp. Brain Res., 41, 159-171.

Ziegler,B. (1976): Theory of modeling and simulation. Wiley and Sons, New York.

# APPENDIX

Table 1

Analysis of Variance
Summary Table

Experiment 1
10 points
(.02-.92Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 188.66 | 1 | 188.66 | 2.77 | .12 |
| Error | 816.58 | 12 | 68.04 | | |
| Condition | 37.37 | 1 | 37.37 | 2.96 | .11 |
| Cond by Gender | 1.42 | 1 | 1.42 | .11 | .74 |
| Error | 154.81 | 12 | 12.90 | | |
| Frequency | 2665.77 | 9 | 296.19 | 72.82 | .0000 * |
| Frequency by Gender | 17.66 | 9 | 1.96 | .48 | .88 |
| Error | 439.26 | 108 | 4.06 | | |
| Condition by Frequency | 7.53 | 9 | .83 | .61 | .78 |
| Cond. by Freq. by Gend. | 18.32 | 9 | 2.03 | 1.48 | .16 |
| Error | 148.8 | 108 | 1.37 | | |

Table 2

Analysis of Variance Summary Table

Experiment 2
10 points
(.02-.92Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 45.70 | 1 | 45.70 | .20 | .66 |
| Error | 2765.20 | 12 | 230.43 | | |
| Condition | 34.55 | 1 | 34.55 | 1.23 | .28 |
| Cond. by Gender | .41 | 1 | .41 | .01 | .90 |
| Error | 337.12 | 12 | 28.09 | | |
| Frequency | 2794.80 | 9 | 310.53 | 102.25 | .0000 * |
| Frequency by Gender | 53.56 | 9 | 5.95 | 1.96 | .05 |
| Error | | | | | |
| Condition by Frequency | 5.81 | 9 | .64 | .70 | |
| Cond. by Freq. by Gend. | 7.65 | 9 | .85 | .92 | |
| Error | 99.26 | 108 | .92 | | |

Table 3

Analysis of Variance
Summary Table

Experiment 3
10 points
(.02-.92Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 20.68 | 1 | 20.68 | .23 | .64 |
| Error | 1089.80 | 12 | 90.81 | | |
| Condition | 20.37 | 1 | 20.37 | 2.63 | .13 |
| Cond. by Gender | .26 | 1 | .26 | .03 | .85 |
| Error | 92.97 | 12 | 7.74 | | |
| Frequency | 2131.77 | 9 | 236.86 | 105.34 | .0000 * |
| Frequency by Gender | 19.49 | 9 | 2.16 | .96 | .4745 |
| Error | 242.83 | 108 | 2.24 | | |
| Condition by Frequency | 30.12 | 9 | 3.34 | 3.00 | .0032 * |
| Cond. by Freq. by Gend. | 9.12 | 9 | 1.01 | .91 | .52 |
| Error | 120.67 | 108 | 1.11 | | |

Table 4

Analysis of Variance
Summary Table

Experiment 4
10 points
(.02-.92Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 433.16 | 1 | 433.16 | 5.18 | .042 * |
| Error | 1004.36 | 12 | 83.69 | | |
| Condition | 8.24 | 1 | 8.24 | .17 | .68 |
| Cond. by Gender | 2.21 | 1 | 2.21 | .05 | .83 |
| Error | | | | | |
| Frequency | 2839.57 | 9 | 315.50 | 93.96 | .0000 * |
| Frequency by Gender | 64.05 | 9 | 7.11 | 2.12 | .033 * |
| Error | | | | | |
| Condition by Frequency | 28.04 | 9 | 3.11 | 2.64 | .0084 * |
| Cond. by Freq. by Gend. | 4.97 | 9 | .55 | .47 | .89 |
| Error | 127.57 | 108 | 1.18 | | |

Table 5

Analysis of Variance
Summary Table

Experiment 1
9 points
(.12-.44Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 315.52 | 1 | 315.52 | 6.31 | .027 * |
| Error | 600.25 | 12 | 50.02 | | |
| Condition | 40.44 | 1 | 40.44 | 1.89 | .19 |
| Cond by Gender | 1.52 | 1 | 1.52 | .07 | .79 |
| Error | 256.17 | 12 | 21.34 | | |
| Frequency | 270.56 | 8 | 33.82 | 17.78 | .0000 * |
| Frequency by Gender | 1.93 | 8 | .24 | .13 | .99 |
| Error | 182.59 | 96 | 1.90 | | |
| Condition by Frequency | 3.32 | 8 | .41 | .80 | .60 |
| Cond. by Freq. by Gend. | 5.06 | 8 | .63 | 1.21 | .30 |
| Error | 50.18 | 96 | .52 | | |

Table 6

Analysis of Variance
Summary Table

Experiment 2
9 points
(.12-.44Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 12.79 | 1 | 12.79 | .06 | .81 |
| Error | 2787.13 | 12 | 232.26 | | |
| Condition | 49.91 | 1 | 49.91 | 1.80 | .20 |
| Cond by Gender | 5.25 | 1 | 5.25 | .19 | .67 |
| Error | 332.56 | 12 | 27.71 | | |
| Frequency | 315.23 | 8 | 39.40 | 123.41 | .0000 * |
| Frequency by Gender | 4.47 | 8 | .55 | 1.75 | .09 * |
| Error | 30.65 | 96 | .31 | | |
| Condition by Frequency | 1.21 | 8 | .15 | .59 | .78 |
| Cond. by Freq. by Gend. | 2.48 | 8 | .31 | 1.21 | .30 |
| Error | 24.72 | 96 | .25 | | |

Table 7

Analysis of Variance
Summary Table

Experiment 3
9 points
(.12-.44Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. | |
|---|---|---|---|---|---|---|
| Gender | 32.89 | 1 | 32.89 | .48 | .50 | |
| Error | 825.29 | 12 | 68.77 | | | |
| Condition | 108.90 | 1 | 108.90 | 19.63 | .0008 | * |
| Cond by Gender | 3.51 | 1 | 3.51 | .63 | .44 | |
| Error | 66.58 | 12 | 5.54 | | | |
| Frequency | 206.74 | 8 | 25.84 | 32.02 | .0000 | * |
| Frequency by Gender | .17 | 8 | .02 | .03 | 1.0 | |
| Error | 77.47 | 96 | .80 | | | |
| Condition by Frequency | 9.34 | 8 | 1.16 | 3.96 | .0004 | * |
| Cond. by Freq. by Gend. | .72 | 8 | .09 | .31 | .96 | |
| Error | 28.31 | 96 | .29 | | | |

Table 8

Analysis of Variance
Summary Table

Experiment 4
9 points
(.12-.44Hz)

| | Sum of Squares | DF | MS | F | Tail Prob. |
|---|---|---|---|---|---|
| Gender | 341.32 | 1 | 341.32 | 4.61 | .05 * |
| Error | 888.48 | 12 | 74.04 | | |
| Condition | 27.02 | 1 | 27.02 | .93 | .35 |
| Cond by Gender | 2.42 | 1 | 2.42 | .08 | .77 |
| Error | 347.39 | 12 | 28.95 | | |
| Frequency | 264.19 | 8 | 33.02 | 33.60 | .0000 * |
| Frequency by Gender | 10.55 | 8 | 1.31 | 1.39 | .2320 |
| Error | 94.37 | 96 | .98 | | |
| Condition by Frequency | 6.09 | 8 | .76 | 1.63 | .1253 |
| Cond. by Freq. by Gend. | 6.42 | 8 | .80 | 1.72 | .102 |
| Error | 44.73 | 96 | .46 | | |

Table 9 Comparison of Average Graphs

| | Helmet-Cntl | Helmet-VS | Ganzfeld | Blindfolded | Environment |
|---|---|---|---|---|---|
| FEMALES | | | | | |
| -Seg 1 | | | | | |
| --PSD .1Hz db | 3.8 | 3.7 | 2.6 | 4.2 | 2.5 |
| --loss db/dec | 6.5 | 4.5 | 5 | 4.5 | 4 |
| --cross over | .165 | .145 | .138 | .138 | .135 |
| -Seg 2 | | | | | |
| --PSD .7Hz db | -1.6 | -1.4 | -3 | -1.7 | -2.5 |
| --loss db/dec | 16 | 10 | 9 | 13 | 10.5 |
| --cross over | 1.2 | 1.15 | 1.1 | 1.15 | 1.1 |
| -Seg 3 | | | | | |
| --PSD 1.4 Hz | -7.5 | -7.8 | -9 | -8.5 | -8.5 |
| --loss | 40 | 40 | 38 | 40 | 38 |
| --cross over | 2.0 | 2.05 | 2.0 | 2.0 | 2.1 |
| -Seg 4 | | | | | |
| --PSD 2.3 Hz | -13.5 | -13.5 | -14 | -13.5 | -14.2 |
| --gain | 25 | 30 | 26 | 37 | 24 |
| MALES | | | | | |
| -Seg 1 | | | | | |
| --PSD .1 Hz | 4.8 | 6.1 | 4.5 | 6 | 5.7 |
| --loss | 7.5 | 4.5 | 6.6 | 5 | 6.3 |
| --cross over | .165 | .128 | .148 | .135 | .156 |
| -Seg 2 | | | | | |
| --PSD .7 Hz | -1 | -.6 | -2.8 | -1 | -1 |
| --loss | 15.5 | 12 | 14.5 | 12 | 8.5 |
| --cross over | 1.25 | 1.15 | 1.2 | 1.25 | 1.05 |
| -Seg 3 | | | | | |
| --PSD 1.4 Hz | -6.8 | -6.5 | -9.1 | -6.5 | -6.5 |
| --loss | 39 | 39 | 39 | 37 | 42 |
| --cross over | 2.1 | 2.1 | 2.1 | 2.04 | 2.04 |
| -Seg 4 | | | | | |
| --PSD 2.3 Hz | -12.5 | -12.2 | -15 | -12.6 | -12.5 |
| --gain db/dec | 36 | 36 | 32 | 27 | 26 |

# Table 10

## Summary of Sign-Tests

Where z = ( |P-p| - 1/2N ) / SQRT( pq/N )

P(z) = Portion of the distribution beyond z

Test 1 ( on PSD values between conditons for all subjects at .42 Hz. )

| Exp | z | P(z) | Significant? |
|---|---|---|---|
| 1 | 1.8 | .036 | Yes |
| 2 | 1.8 | .036 | Yes |
| 3 | 1.8 | .036 | Yes |
| 4 | .26 | .397 | No |

Test 2 ( between conditions for records averaged over Gender at nine frequencies. )

| Gender: | Female | | | Male | | |
|---|---|---|---|---|---|---|
| Exp | z | P(z) | Signif.? | z | P(z) | Signif.? |
| 1 | 3.8 | .0001 | Yes | 2.0 | .023 | Yes |
| 2 | 3.8 | .0001 | Yes | 3.8 | .0001 | Yes |
| 3 | 3.8 | .0001 | Yes | 3.8 | .0001 | Yes |
| 4 | 3.8 | .0001 | Yes | 3.8 | .0001 | Yes |

Z)

Figure 1: Standard deviation vs frequency is plotted for both genders in the environmental condition (21 females and 21 males) on a linear scale. Standard deviation varies between about 2.0 and 2.3 dB for both genders.

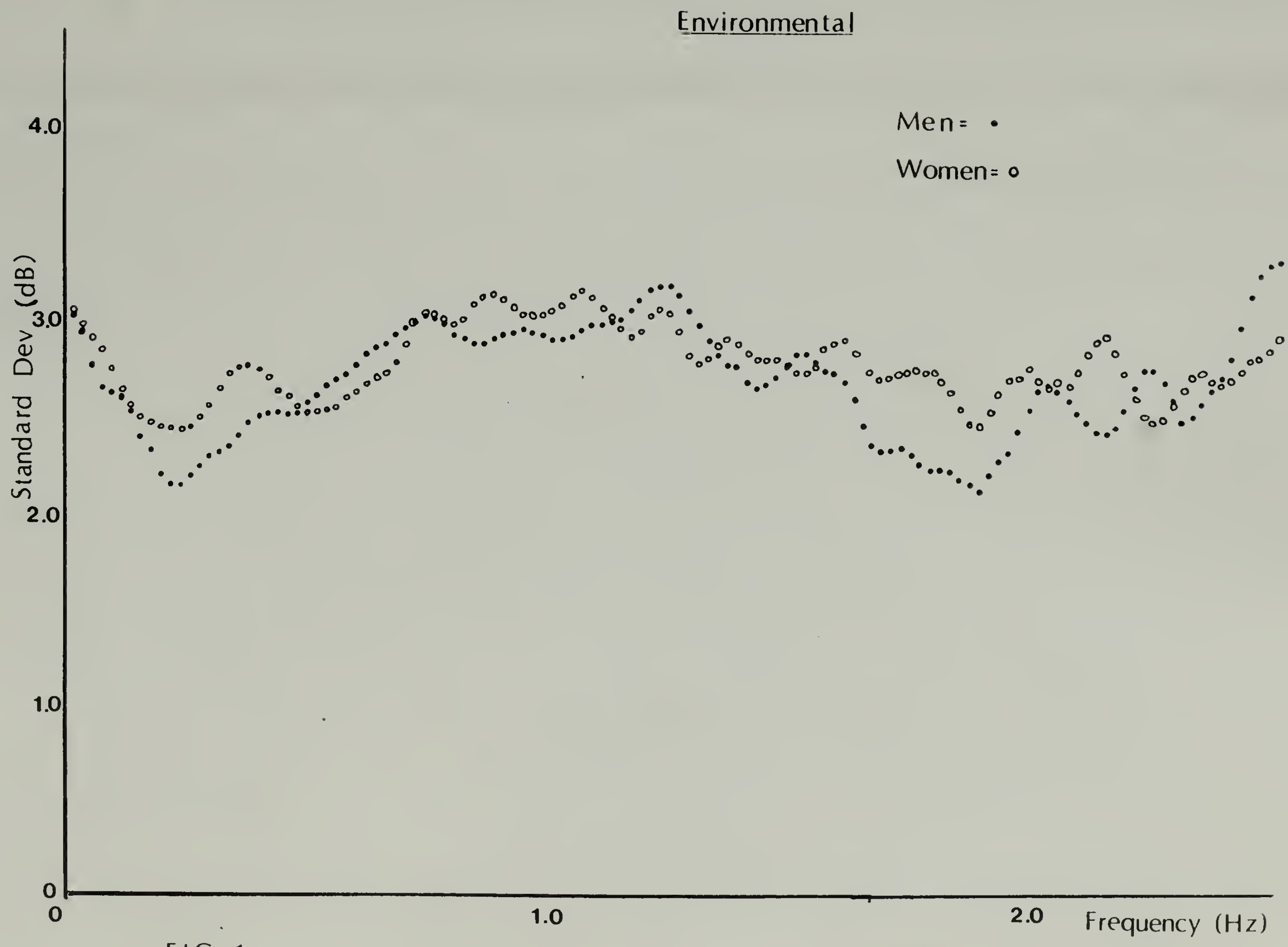
Environmental
Men= •
Women= o
Standard Dev (dB)
4.0
3.0
2.0
1.0
0
0
1.0
2.0
Frequency (Hz)

FIG. 1

Figure 2: Standard deviation is plotted here for both genders (7 males and 7 females) in the blindfolded condition. From about .3 to about 2.5 Hz the standard deviations of the males sampled in this condition, are higher than those of females.

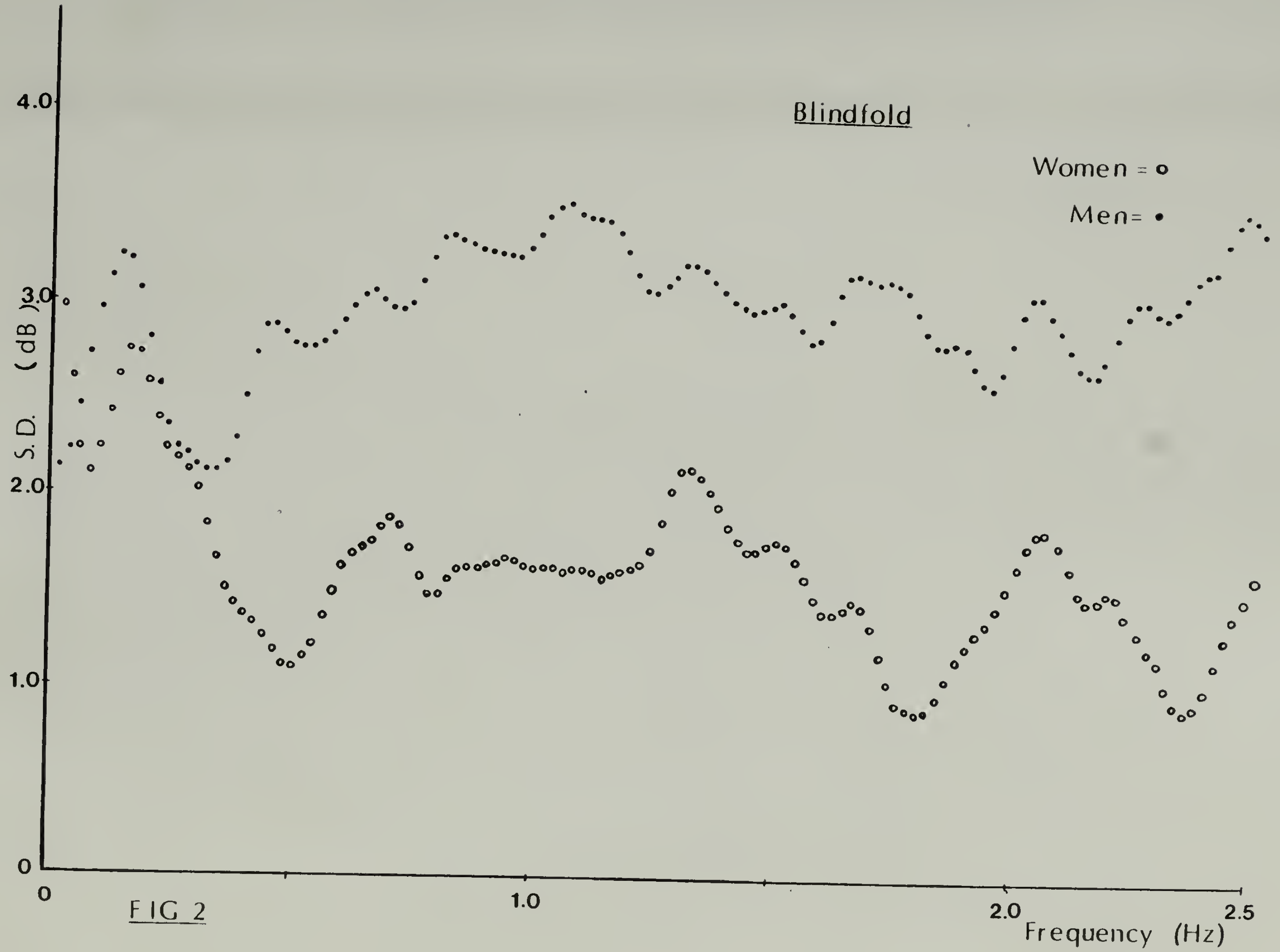

FIG 2

Figure 3: Standard deviation vs frequency is plotted for both genders (7 males and 7 females) in the ganzfeld condition. The standard deviations for the females sampled in this condition are higher than those for males, over most of the frequencies.

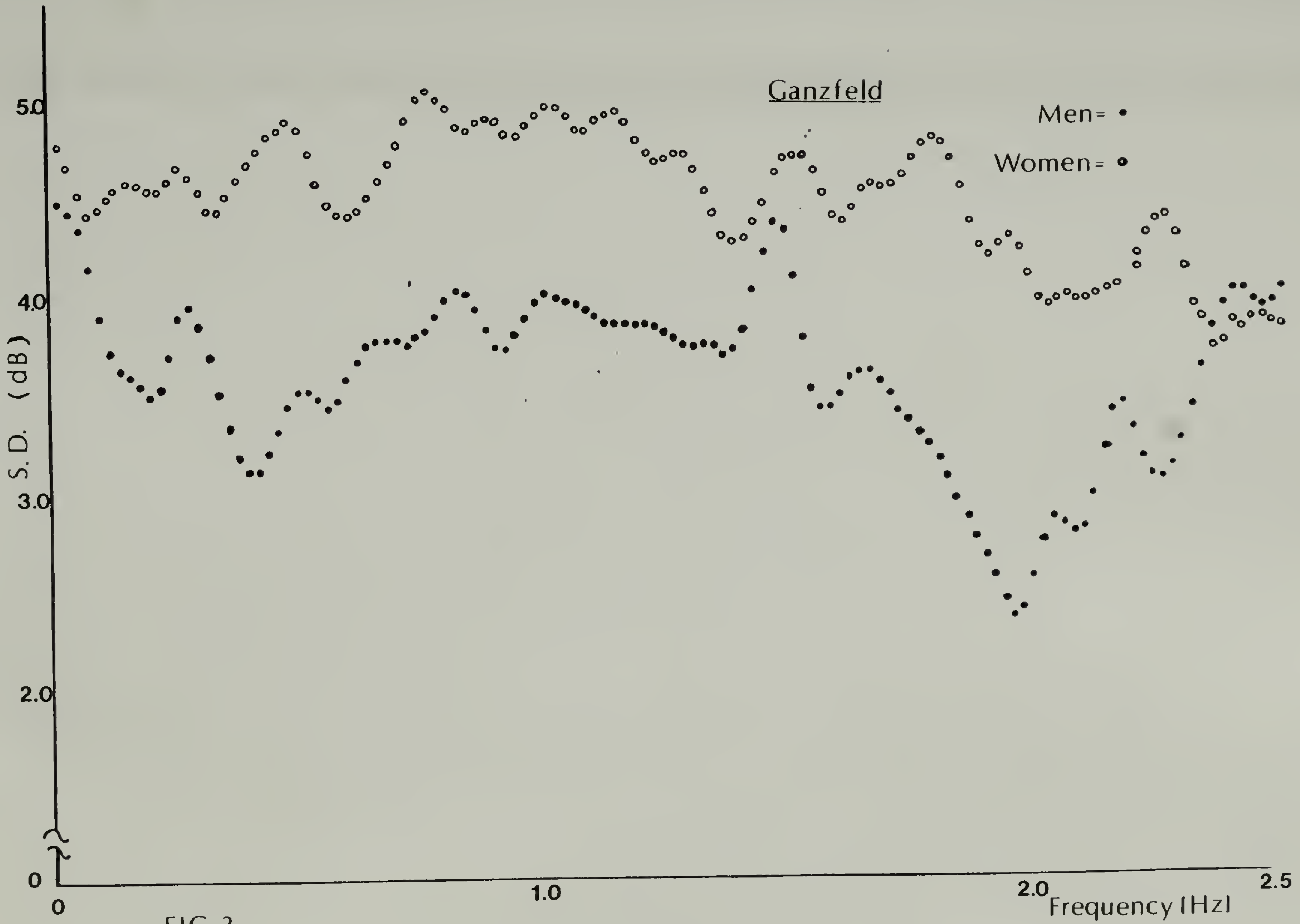

FIG 3

Figure 4: Standard deviation vs frequency is plotted for both gender in the helmet-control condition. Standard deviations are higher for the females sampled in this condition (7 males and 7 females) than those of the males over the range of.02 to about 1.3 Hz.

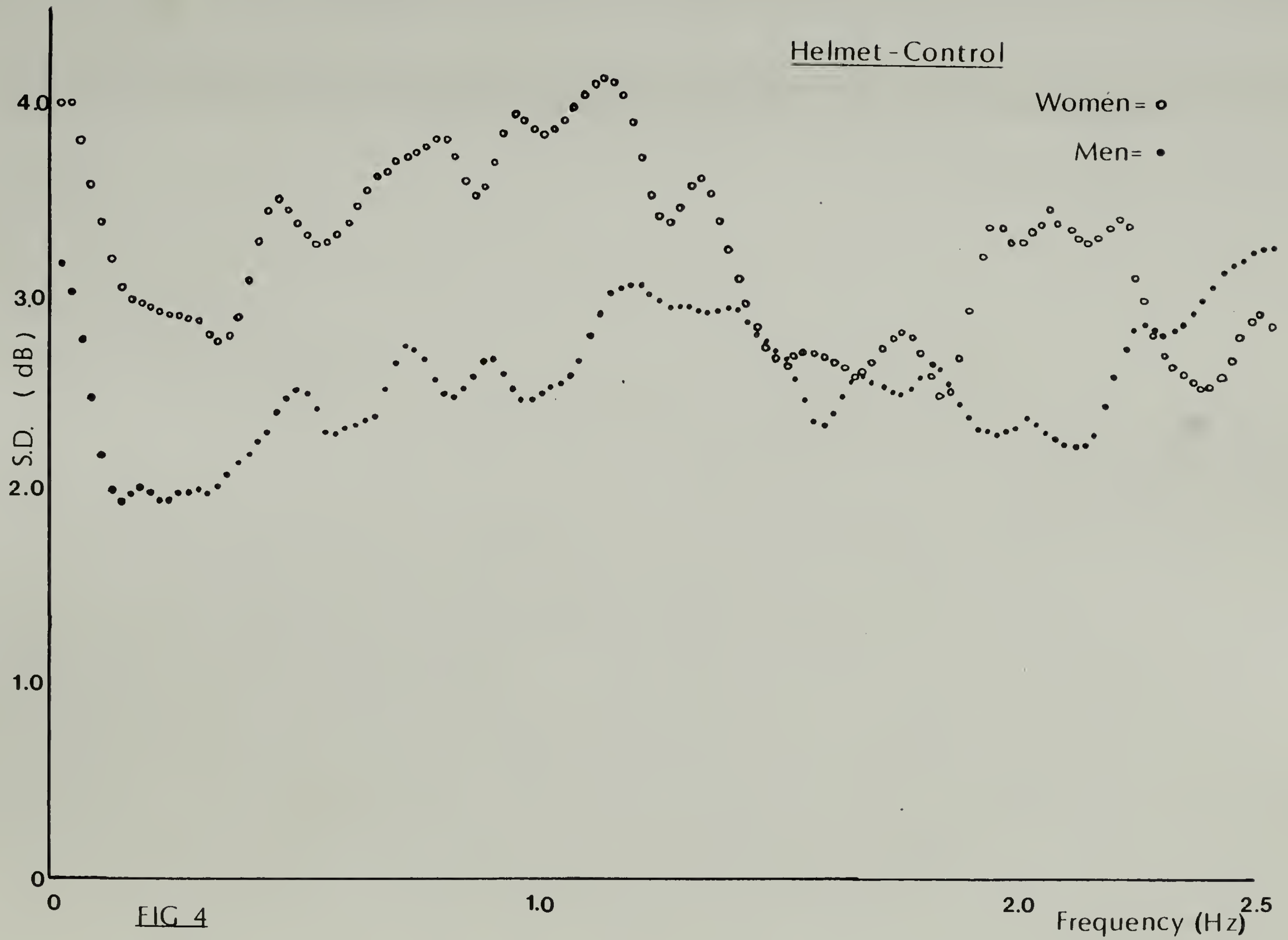
Helmet - Control
Women = o
Men = •
4.0
3.0
2.0
1.0
0
S.D. ( dB )
0
1.0
2.0
2.5
Frequency (Hz)

FIG 4

Figure 5: Standard deviation vs frequency is plotted for both genders in the helmet-VS condition (7 females and 7 males ). Standard deviation is higher for males than females for frequencies .5 to 2.5 Hz.

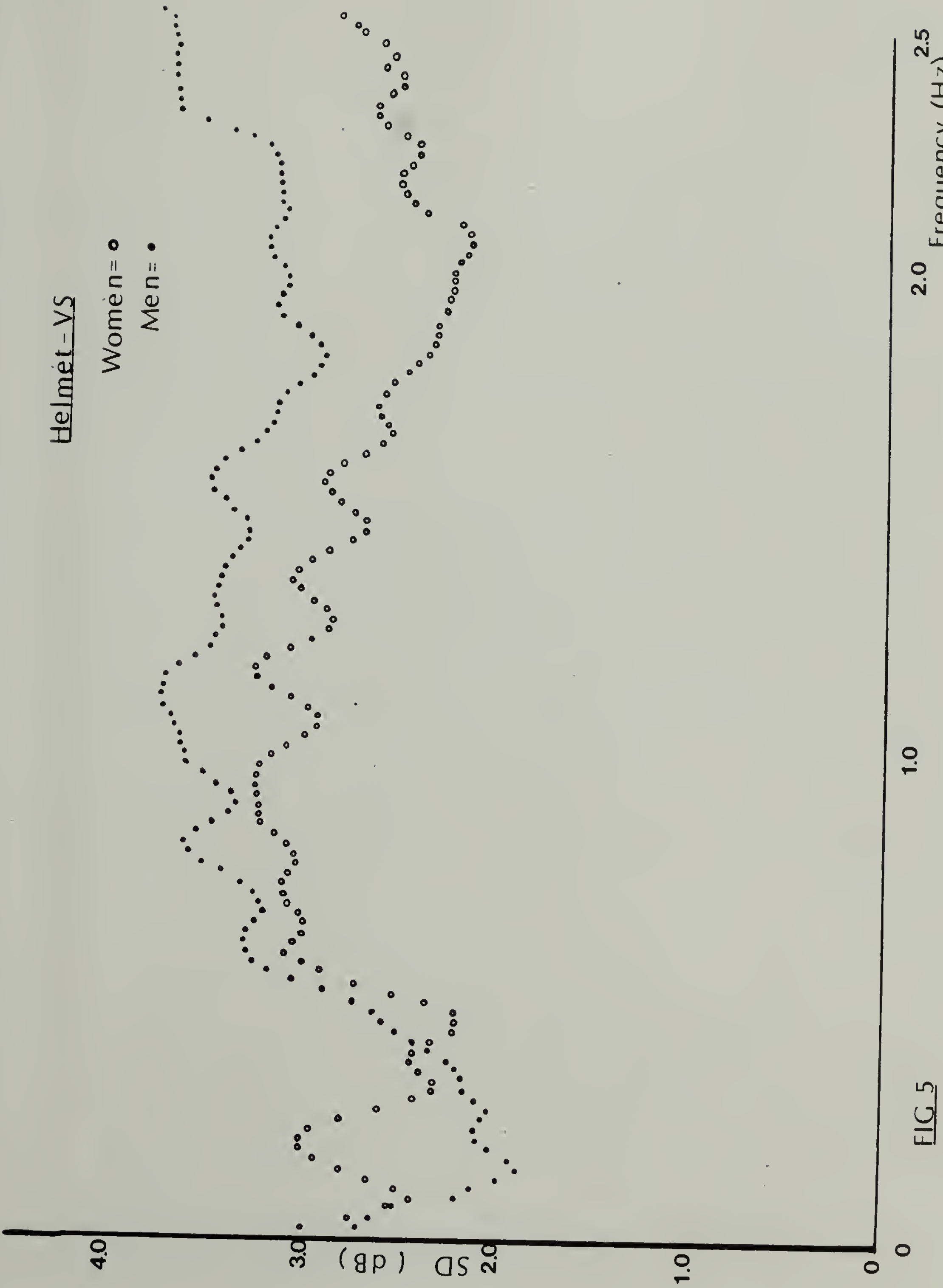

FIG 5

Figure 6A: This graph represents a PSD vs Frequency record (plotted on a log-linear scale) averaged over the records of the 21 female subjects in the environmental visual condition. Note the relatively long first segment, with a crossover point between segment 1 and segment 2, at about .165.

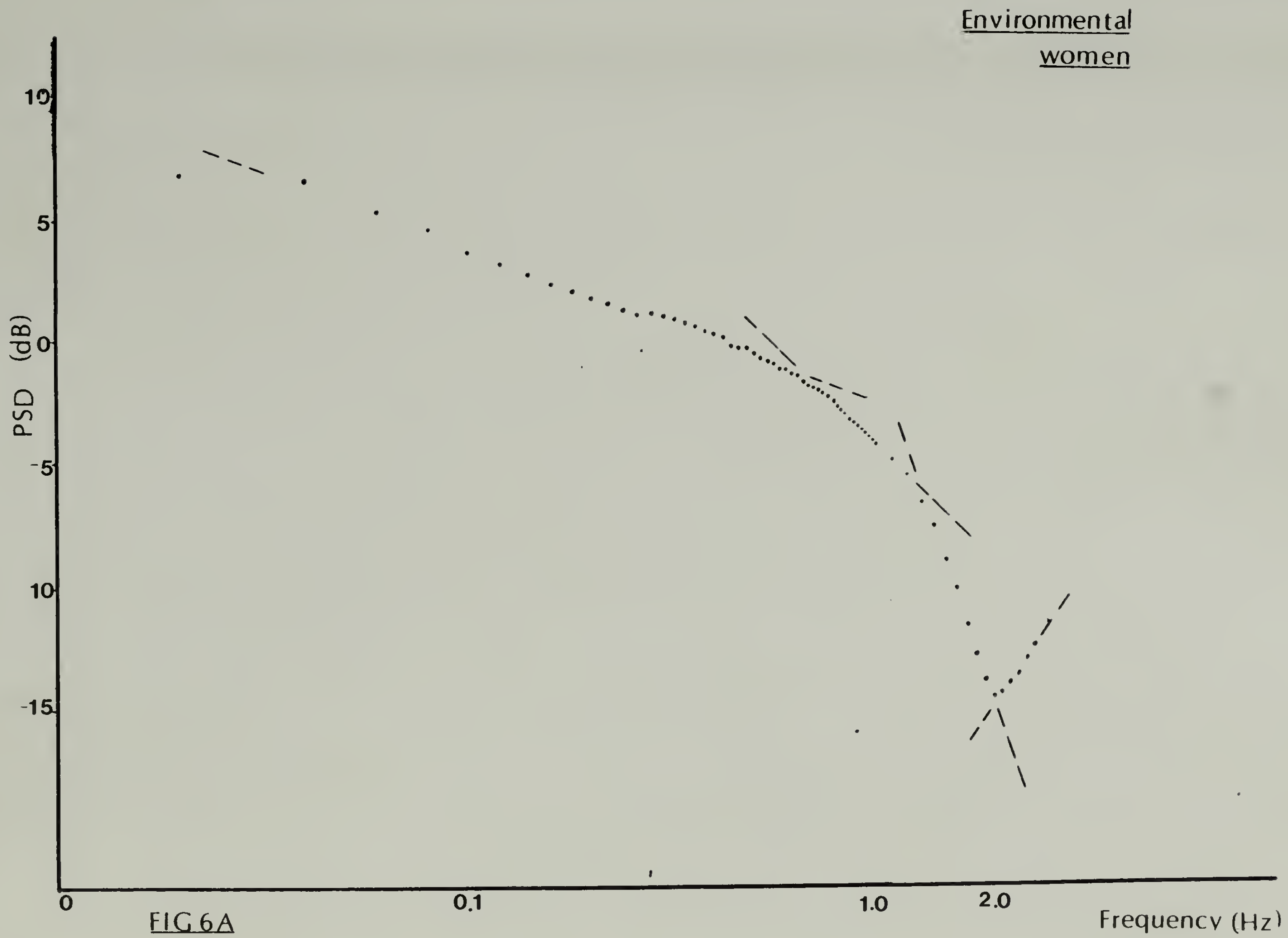
Environmental
women
10
5
0
-5
10
-15
PSD (dB)
0
0.1
1.0
2.0
Frequency (Hz)

FIG 6A

Figure 6B: This graph represents a PSD vs Frequency record (plotted on a log-linear scale) averaged over the records of the 21 male subjects in the environmental visual condition. Overall PSD values are higher than those of the averaged record for females in this condition. As was the case with the records for females in this condition, the first segment is long compared to that of other conditions.

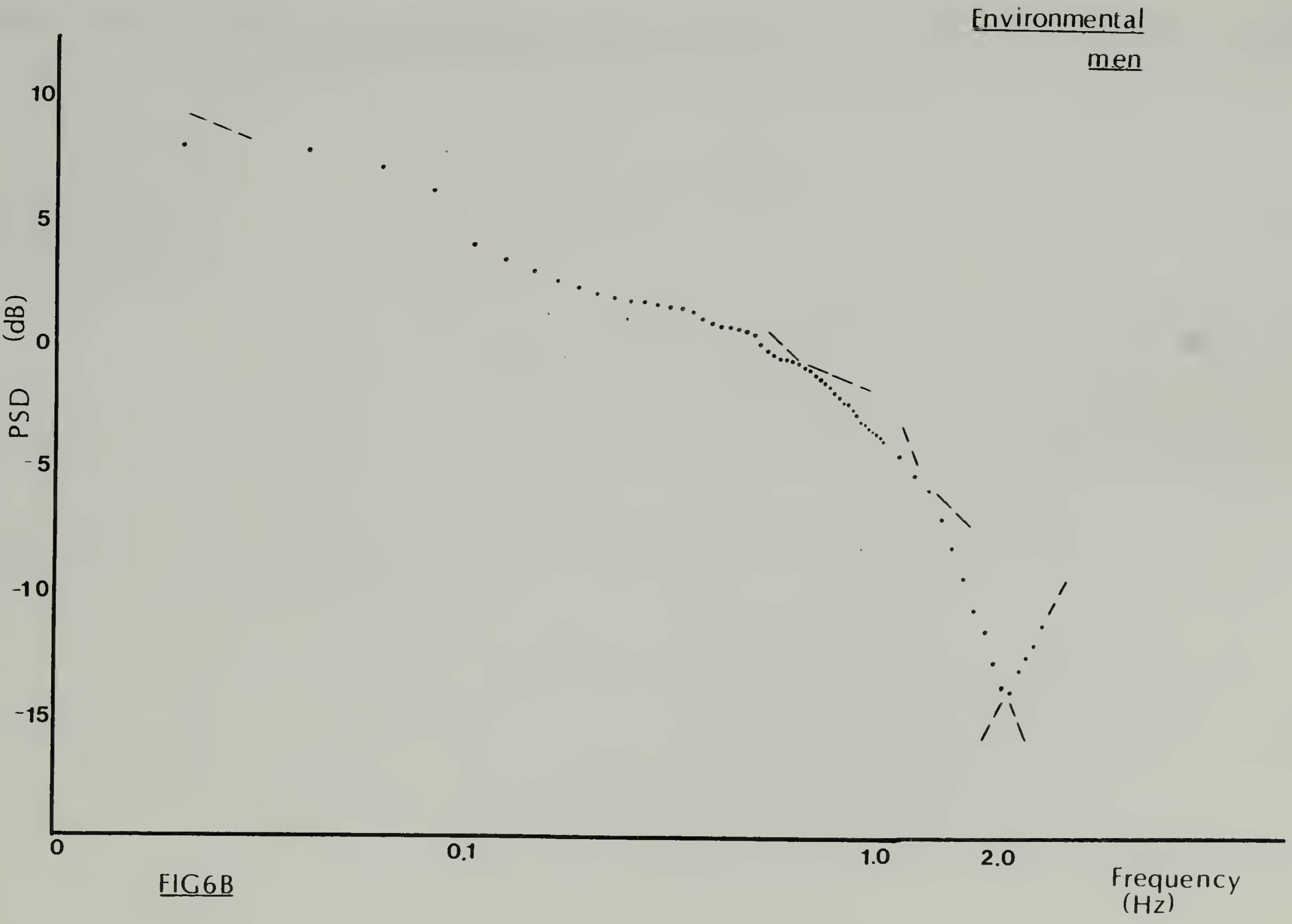

FIG6B

Figure 7A: A PSD vs Frequency record (plotted on a log-linear scale) averaged over the records of the 7 female subjects in the blindfolded condition. Overall PSD values corresponding to frequencies from about .10 to 1.2 are higher here than in the environmental condition.

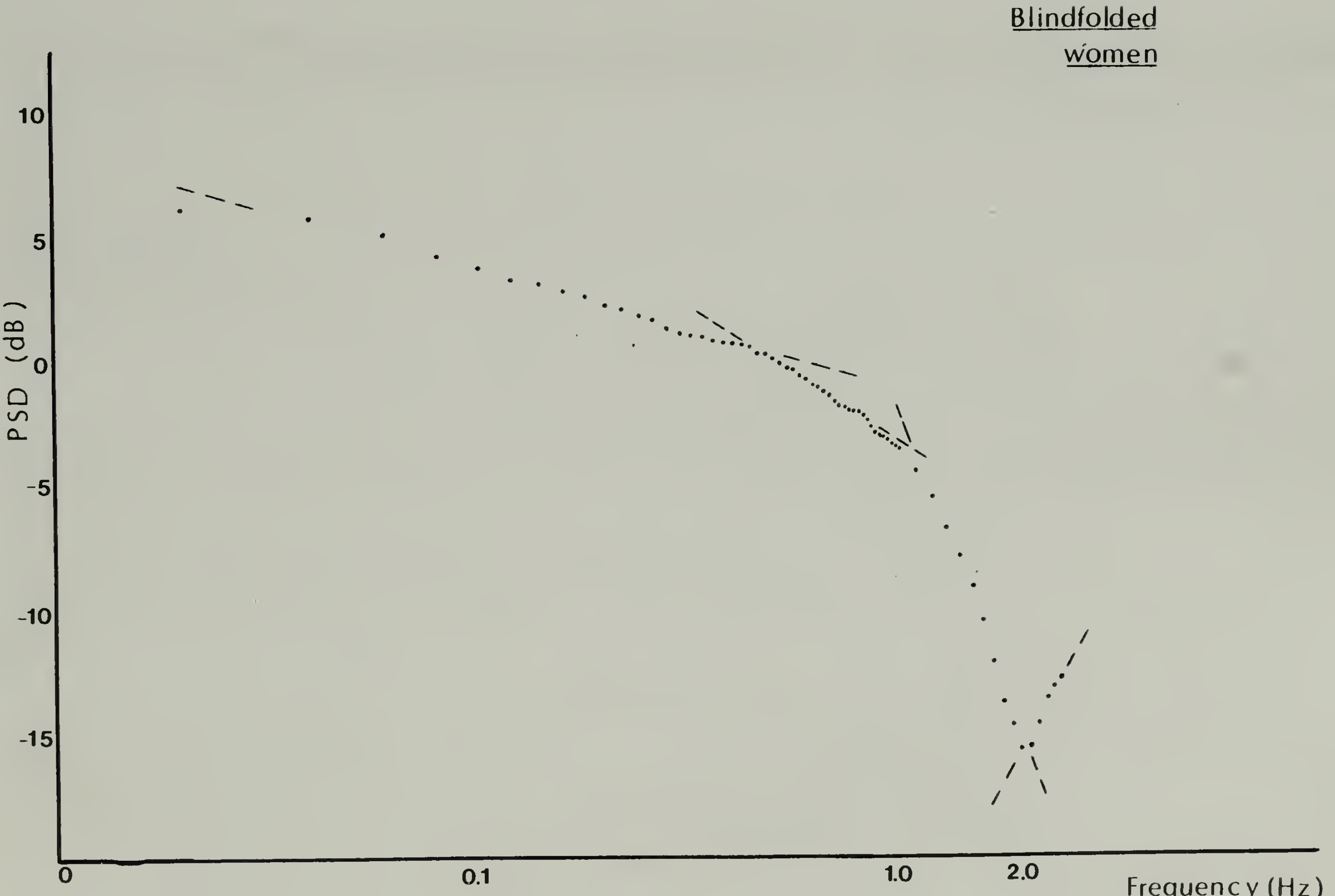

FIG 7A

Figure 7B: This is a PSD vs Frequency record (plotted on a log linear scale) averaged over the records of the 7 male subjects in the blindfolded condition. PSD values are higher over the entire record than those of the females in this condition.

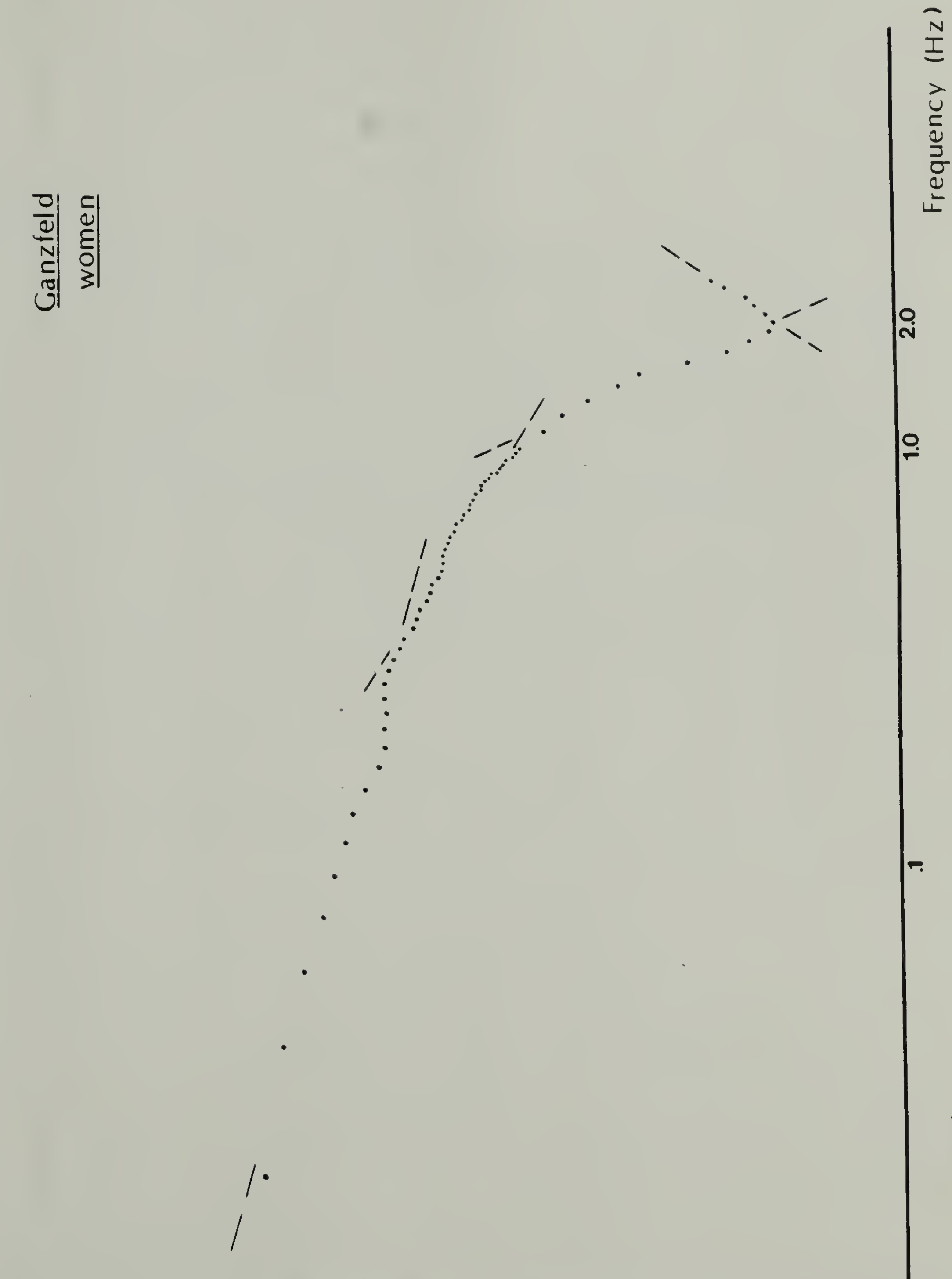

FIG8A

Figure 8A: A PSD vs Frequency (plotted on a log-linear scale) record averaged over the records of the 7 female subject in the ganzfeld condition. PSD values are the lowest in this condition. Also the distinction between segment 1 and segment 2 is harder to distinguish here than in the environmental condition.

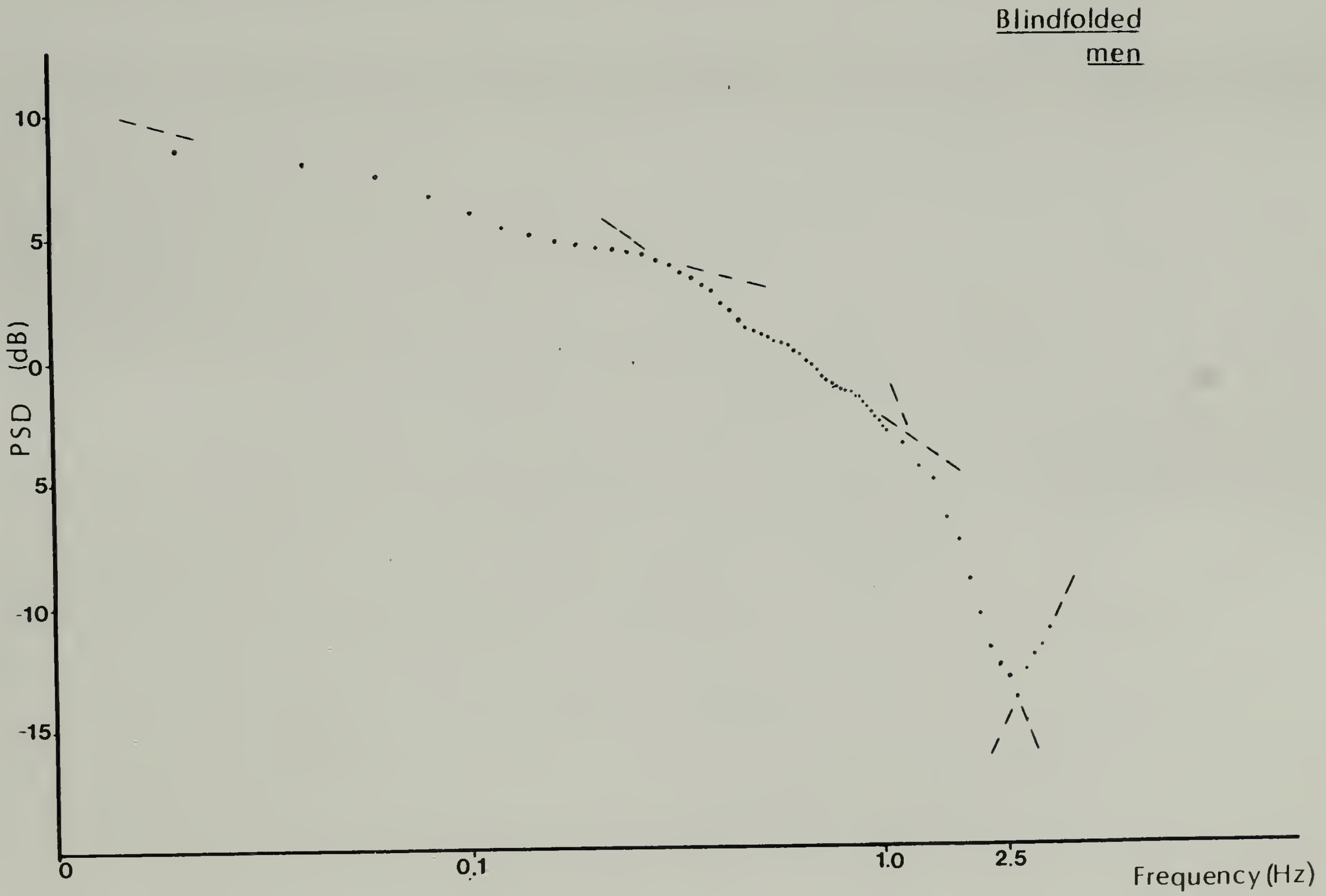

FIG 7B

Figure 8B: A PSD vs Frequency (plotted on a log-linear scale) record averaged over the records of the 7 males in the ganzfeld condition. Although PSD values are somewhat higher for males than females in this condition, this is the record with the lowest values for the males. As with the record for females in this condition, the distinction between segment 1 and segment 2 is reduced.

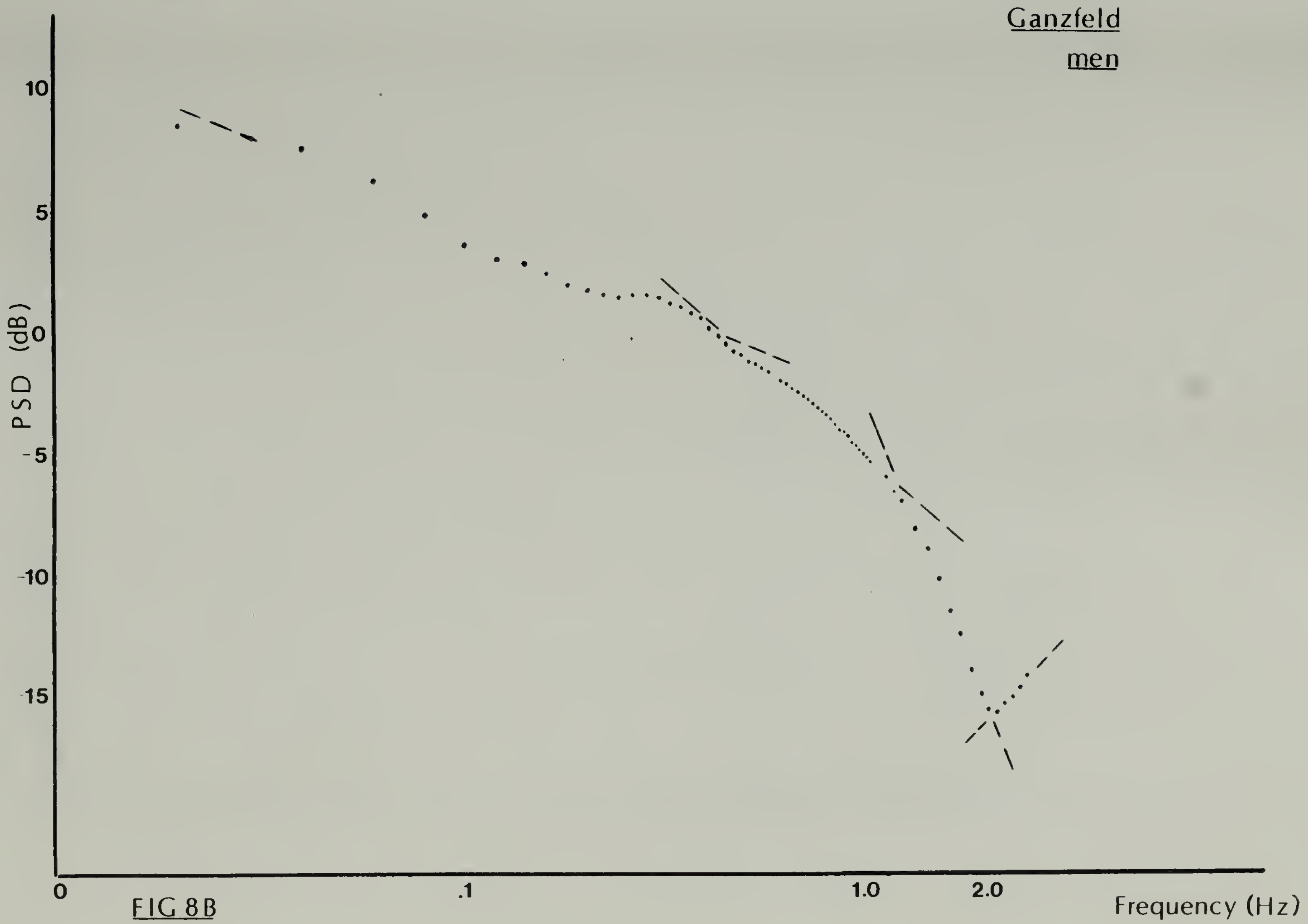

FIG 8B

Figure 9A: A PSD vs Frequency record (graphed on a log-linear scale) averaged over the records of the 14 females subjects who took part in the helmet-VS condition. Compared to the record for the females in the environmental condition, this record shows somewhat higher PSD values in the first segment and somewhat lower PSD values in the third segment.

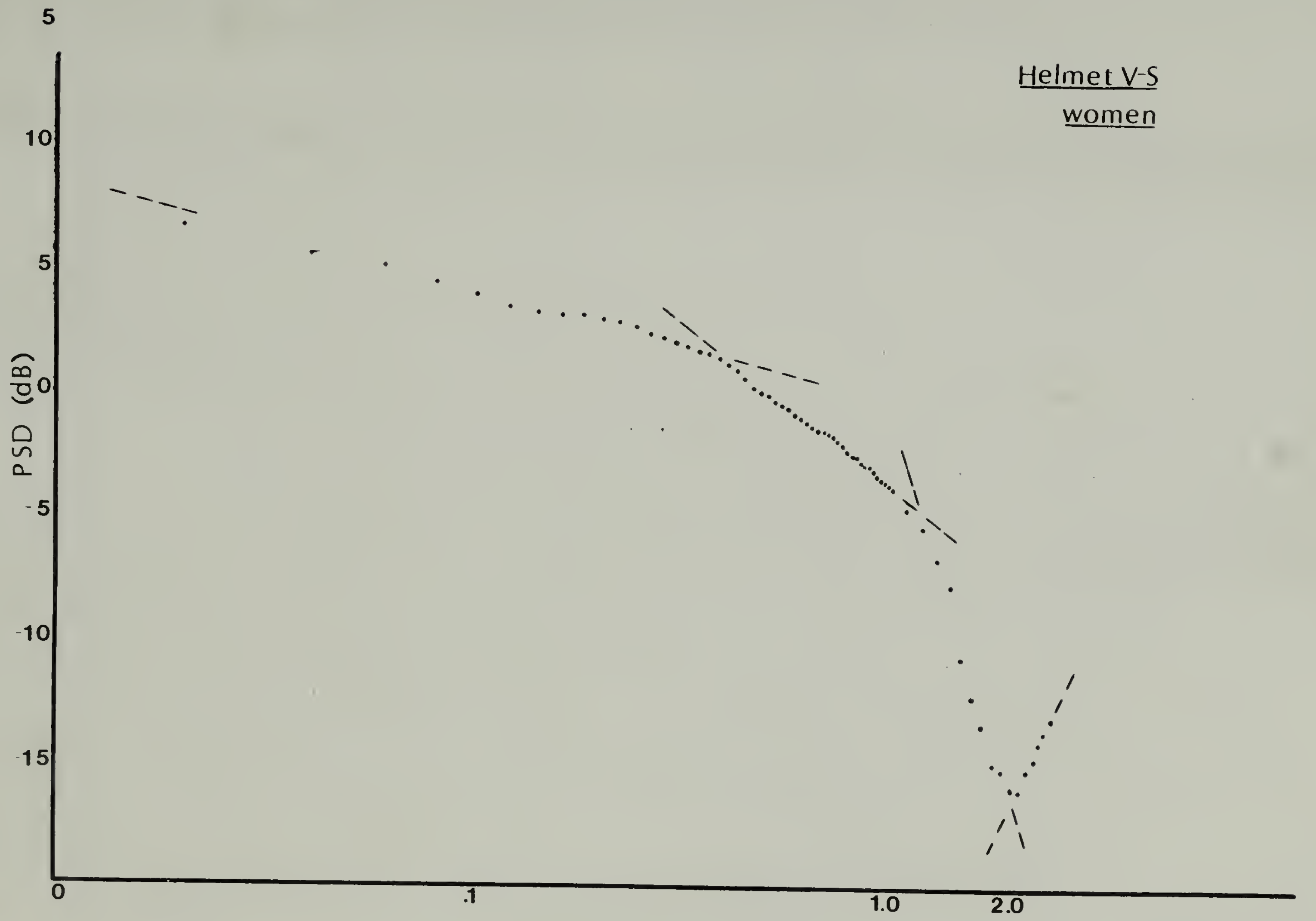

FIG 9A

Figure 9B: A PSD vs Frequency record (plotted on a log-linear scale) averaged over records from the 14 males who experienced the helmet-VS condition. As with the females records, the PSD values in this record seem higher in the first segment and lower in the third segment, when compared to those of the environmental condition.

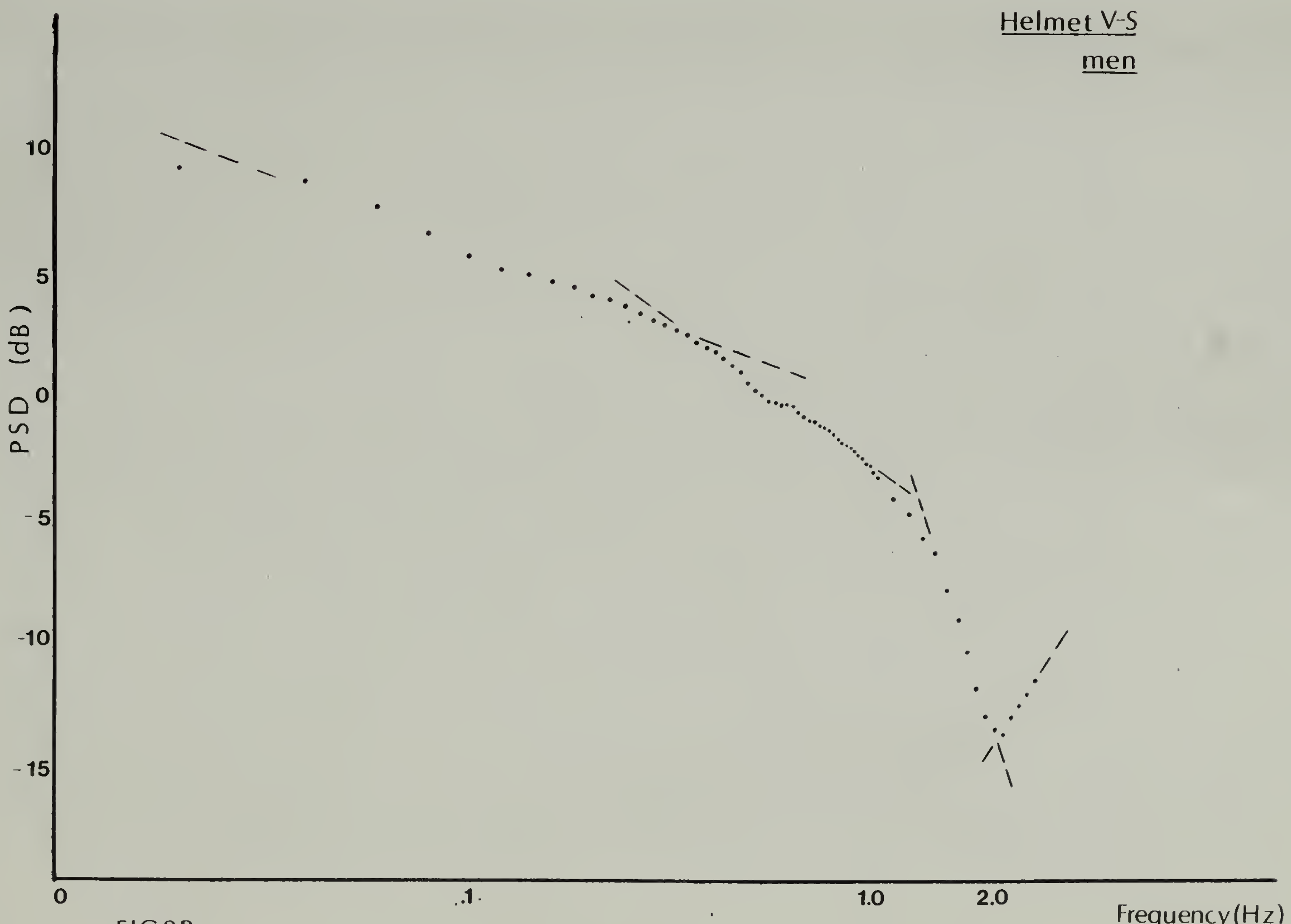

FIG.9B

Figure 10A: A PSD vs Frequency record (plotted on a log-linear scale) averaged over the records of the 7 females in the helmet-control condition. The distinction between the first two line segments in the record is not as great as that found in the record for males from the environmental condition.

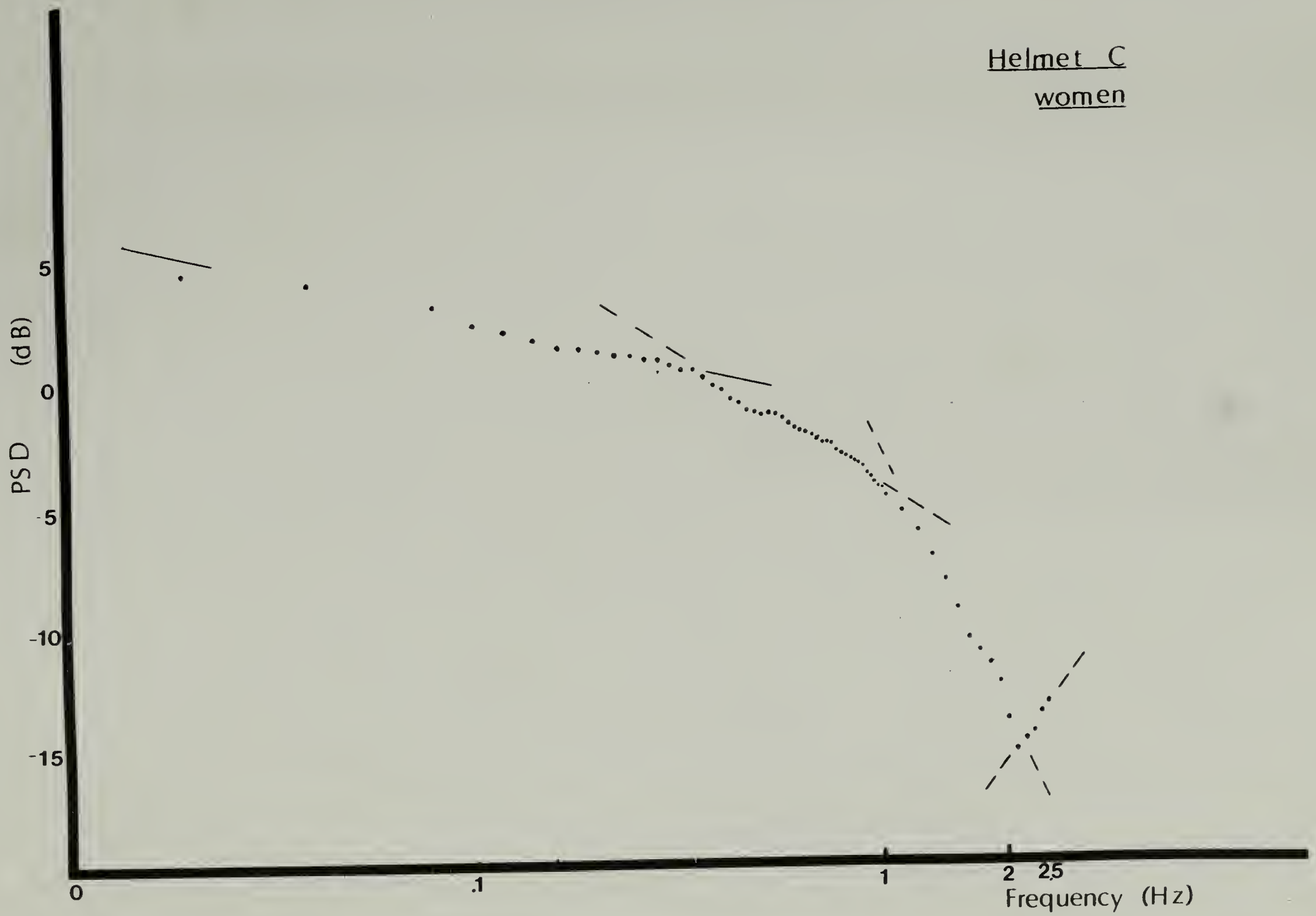

FIG 10A

Figure 10B: A PSD vs Frequency record (plotted on a log linear scale) averaged over the records of 7 males from the helmet-control condition. As was true for the females records, the distinction between the first two segments in this record is not as great as that of the record for males in the environmental condition.

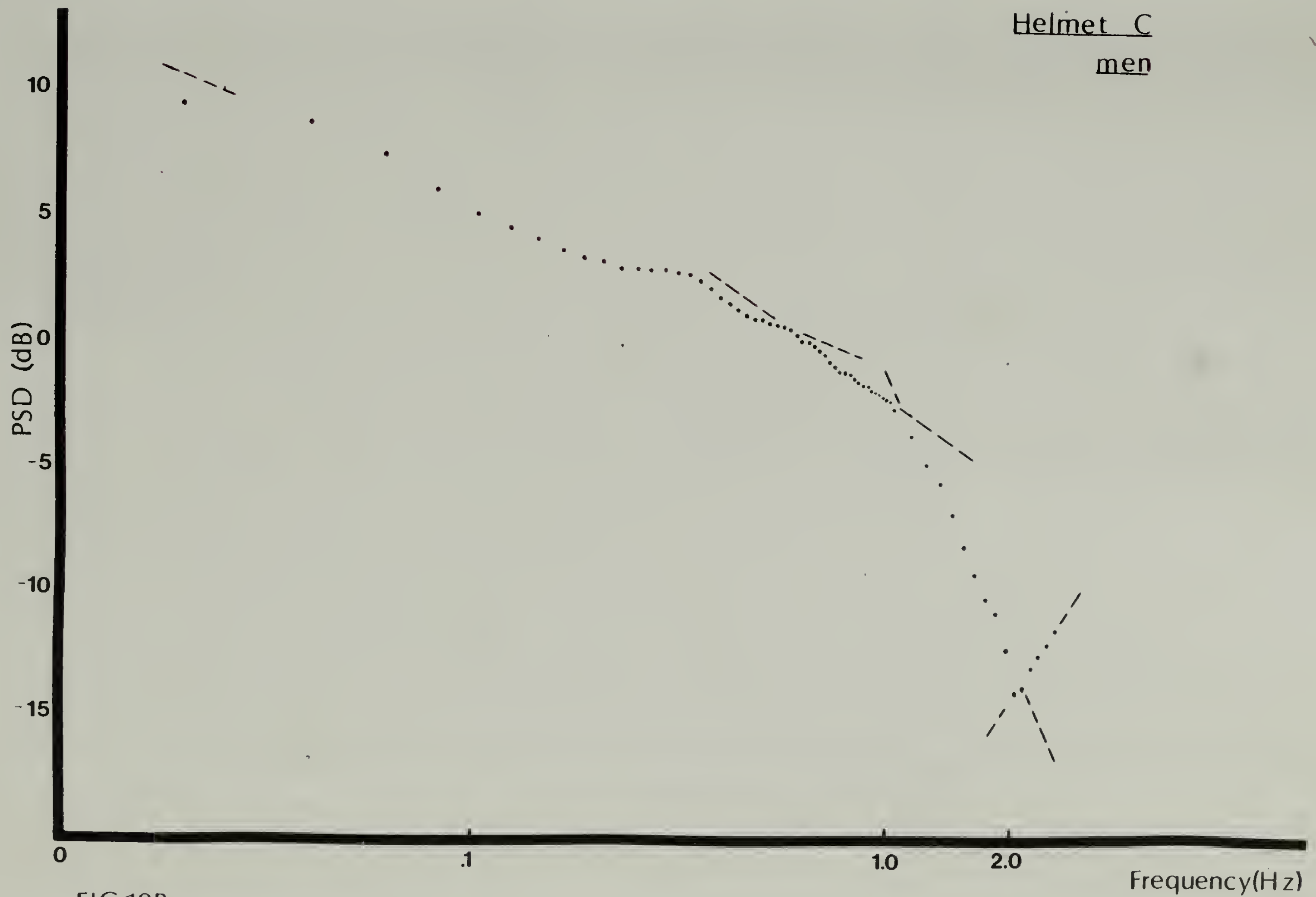

FIG 10B

Figure 11: PSD vs frequency records for several motor control systems, (from Campbell, 1976).

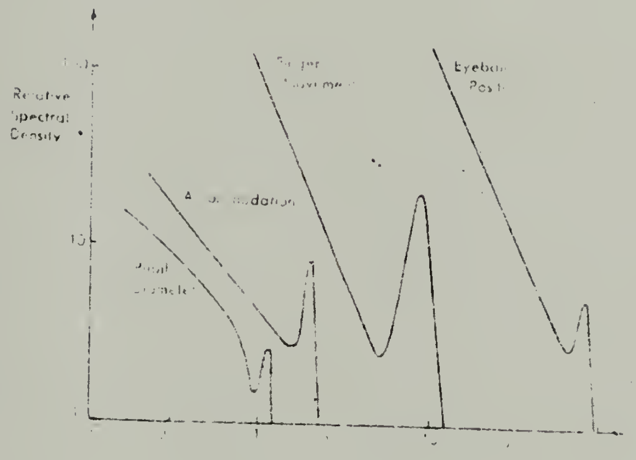
100
Relative
Spectral
Density
10
1
Pupil
Diameter
Accommodation
Finger
Movement
Eyeball
Position

FIG 11