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This report describes the work completed during the first project year of this research study. The objective of the study is to identify safe weight and location limits of head-supported devices worn by female aviators during simulated helicopter rides. The working hypothesis is that female pilots will tolerate some range of HSD weight moments beyond which their biomechanical and performance responses will deteriorate. The report contains a review of relevant studies followed by detailed description of the experimental and analytical procedures. This includes discussions of human use issues, test instrumentation hardware, types vibration exposures (random and sinusoidal), and the rationale for the experimental design. The study design calls for 12 subjects to be tested to obtain physiological, biomechanical, and performance data. So far, a complete data set was obtained from one subject only. Therefore, no firm conclusions are drawn at this time. Instead, samples of data that were processed are presented in the appendices to demonstrate the type of the data being collected, and the type of analyses being performed as data are generated. The report concludes by listing some of the problems that were encountered and how they were (or are being) addressed.

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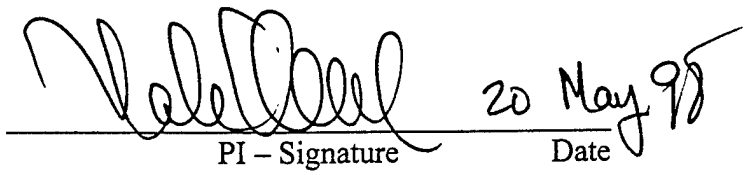

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PREFACE

This report describes the work performed during the first project year of the "Effects of Head-Supported Devices (HSD) on Female Aviators during Simulated Helicopter Missions" research project. During this year, we assembled a research team of skilled engineers and technicians, developed the research protocol and gained its approval, then initiated testing and data collection.

Once the research team was assembled, we reexamined previous HSD studies that were conducted at the U.S. Army Aeromedical Research Laboratory (USAARL) with male volunteers as subjects. Published and unpublished data from previous studies were re-analyzed to justify the use (or non-use) of certain techniques and to improve the quality of the data to be collected in the current study with female subjects. A new literature survey was done to learn what new findings, if any, have been published recently that would be relevant to the current study. Lessons learned from those studies were then applied to prepare a robust experimental design and to develop a new protocol for female aviators. The protocol was then reviewed by the Scientific Review Committee (SRC) and Human Use Committee (HUC) at USAARL. Because the subjects would be exposed to normal levels of whole-body vibrations, and since no invasive procedures were to take place, the protocol was considered to present minimal health risk for the subjects. After some suggestions were incorporated in the protocol, authorization to begin testing was given USAARL Commander.

So far, we have tested two subjects, one of which was done to refine the experimental procedures and validate the data acquisition and analysis methods. Although our initial recruiting efforts have not produced the desired response from the pool of potential military subjects at Fort Rucker, we expect to recruit and complete all testing during the next several months. Since the study design requires data from 12 subjects, no firm conclusions are presented in this report. Instead, we have included a description of the experimental design, test methods and data analysis algorithms, as well as samples of data from the first subject to illustrate the type of data to be collected or analysis to be performed for all 12 subjects.

Our research team, who has worked diligently to support this research effort, includes Dr. Khalid Barazanji and Ms. Janet Dodson, both working on-site at USAARL under contract (UES, Inc., Task Order 6). Dr. Barzanji was instrumental in reviewing previous studies and revising the research protocol. He and Ms. Dodson are the test engineers responsible for ensuring all experimental procedures are carried out with care and precision. Subject preparation, coaching and data collections are performed by SSG Bradley Erickson, SPC Rene Guerrero and SPC Steve Reyes; who are assigned to our research laboratory as biological research assistants. Finally, Mr. Alan Lewis, Mr. Robert Dillard, and Mr. James Burkett, all of the Research Support Division of USAARL, continue to provide the hardware and electronics, and run the multi-axis ride simulator (MARS) facility.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
A-P, L-R, S-I	anatomical axes: anterior-posterior, left-right, superior-inferior
ANOVA	analysis of variance
AOC	atlanto-occipital complex
C3, C4	cervical spine vertebrae
CM	center of mass
cm	centimeter
EAM	external auditory meatus
EMG	electromyography
FFT	fast Fourier transform
FM	frequency modulation
G	acceleration due to gravity
FSH	follicle stimulating hormone
HSD	head-supported devices
Hz	Hertz, samples/second, cycles/second
iEMG	integrated EMG
IMF	initial median frequency
ISO	International Organization for Standardization
LED	light emitting diode
LF-EL	late follicular-early luteal
LH	luteinizing hormone
MARS	multi axis ride simulator
MATB	multiple attribute task battery
MF	median frequency
MVC	maximum voluntary contraction
NVG	night vision goggles
OCP	oral contraceptive pills
Optotrack	three dimensional position measuring system
PT	physical training
RMS	root mean-square
SME	sub-maximal endurance
T1, T3, T4,	thoracic vertebrae
USAARL	U.S. Army Aeromedical Research Laboratory
USAMRMC	U.S. Army Medical Research and Materiel Command
WBV	whole-body vibration

INTRODUCTION

Aviators flying rotary-wing aircraft are exposed to whole-body vibration (WBV) through the seating system causing musculoskeletal stress to the back and neck. These stresses are aggravated when the head is further loaded with a helmet and other head-supported devices (HSD) such as night vision goggles. The obvious challenge for the Army research community is to establish safe limits for mass properties of HSD that can be tolerated by male and female aviators alike.

A series of studies have been conducted recently at the U.S. Army Aeromedical Research Laboratory (USAARL) to evaluate of HSD mass properties on pilot biomechanical and physiological response. The studies concluded that the weight moment of HSD should not exceed 80 Newton-centimeters (N-cm). Since this recommendation was derived from laboratory experiments with male volunteers as subjects, it may not apply to female aviators because of known gender differences in neck size, upper body anthropometry, and physiology.

The study being reported here, which is sponsored mainly by the Defense Women's Health Program, addresses this shortcoming. It is designed to repeat successful aspects of previous HSD studies conducted at USAARL, except that it will use female subjects exclusively. Our working hypothesis states that female pilots will tolerate some range of HSD weight moments beyond which their biomechanical and performance responses will deteriorate. Further, we expect that this tolerance limit is lower than that reported for male pilots.

Thus, the main objective of the study is to identify safe limits of HSD weight moments that can be tolerated by female aviators without adverse effects on their health and performance. The approach is to measure and assess cognitive, biomechanical, physiological, and performance parameters associated with the exposure of female military subjects to simulated helicopter vibration signatures and different helmet configurations.

Ultimately, these limits must be verified during actual helicopter flights. USAARL plans to pursue this goal during the next 5 years.

Military significance

As the US Army enters the 21st century, Force XXI emphasizes the use of head supported devices to enhance the performance of aviation personnel. Systems such as night vision goggles, chemical protective masks, helmet mounted sighting systems, and head-up displays, were critical elements in the decisive victory of the US and allied forces in Operation Desert Storm. However, these HSD and the improvements in helmet crash protection have altered the mass properties to an extent where existing operational and design criteria may no longer apply.

Rotary-wing aircraft aviators are exposed to WBV through the seating system causing musculoskeletal stress to the back and neck. These stresses are exacerbated when the head is further encumbered with a helmet and other head-supported devices. Studies have shown that HSD mass properties, such as mass, location and mass distribution, play important roles in defining safe and tolerable limits. In fact, the Army currently imposes HSD design criteria on helmet manufacturers. More recently, USAARL has provided weight limit guidelines for the RAH-66 Comanche helmet.

Current military helmet design criteria and operational guidelines are derived from existing inventory of HSD and do not account for recently introduced devices, such as night vision goggles. Further, these safe exposure limits are based on male aviators' tolerance and endurance data. They do not address tolerances of female aviators who, because of differences of anthropometry and physiology, are likely to tolerate different exposure levels and endure them for different duration lengths. At the present, female aviators are flying more Army rotary wing aircraft and fulfilling essential roles in forward deployed aviation units. A critical gap in our understanding of the effects of HSD on female aircrew neck physiology, endurance, and performance threatens military readiness, operational effectiveness and sustenance

Aviators in Force XXI are required to develop, maintain and improve their ability for intelligence gathering, battle command, situation awareness, lethality and survivability, while donning newly developed helmets and head-supported devices. The obvious challenge for Army medical community is to define safe limits for mass properties of HSD that can be tolerated by male and female aviators alike. To meet the challenge, first it is necessary to understand the effects of new HSD mass properties on male and female aircrew performance. Then, valid HSD design criteria and useful operational guidelines may be developed to protect both male and female aviators without hindering the performance of their mission. Since some of the required research has already been performed for male aviators, the significance of this study is that it will complement current databases and extend valid models to female aviators. More importantly, the study will establish defensible HSD operational guidelines that provide equal protection for female aviators as they do for their male colleagues.

LITERATURE REVIEW

Research to evaluate the effects of head-supported weights in a whole-body vibration environment has been carried out for many years by investigators at USAARL and elsewhere. The review of the literature presented here is limited to issues that have been identified as relevant to the objectives of the proposed study. The review discusses briefly recent USAARL studies, some publications on muscle fatigue, electromyography and endurance, and the effects of menstrual cycle on women's strength and endurance.

Relevant USAARL Studies

Four recent studies at the USAARL addressed neck muscle electromyographic (EMG) activity under different types of WBV and under different head-supported loads. Butler (1989) studied neck muscle EMG responses under sinusoidal WBV while varying helmet mass and center of mass parameters. Lantz, Alem, and Crisman (1991) used random WBV with a constant helmet mass and center-of- mass while studying neck EMG responses. Moran and Bruckart (1992) initiated a study where neck muscle EMG responses were recorded both before and after exposure to whole-body random vibration with varying helmet masses. Most recently, Alem, Meyer and Albano (1995) studied male neck EMG responses during long duration exposure to whole-body random vibration.

Butler (1992) showed a significant increase in posterior neck myoelectric responses when the total head-supported load exceeded 80 N-cm relative to the atlanto-occipital complex (AOC). Calibrated neck myoelectric responses were shown to exceed the recommended 5-10% maximum voluntary contraction (MVC) level for long duration efforts (Johnson, 1987; Hagberg, 1981). Similar significant differences were shown in head pitch acceleration for helmets under and over the 80 N-cm boundary. No differences were seen for head pitch acceleration or posterior neck muscle responses for the unloaded (no helmet) case compared to the helmets with a weight moment under 80 N-cm. No differences were seen in postural changes of the head and neck for changes in head-supported mass or center-of-mass.

Lantz (1992) concluded that vigilance performance degraded as observed by increased target acquisition times and by greater number of missed targets. These degradations occurred at 45-60 minutes, 75-85 minutes, and 105-120 minutes into the experiment. Posterior neck myoelectric responses showed time-dependent fatigue characterized by shifts in the median spectral frequency following the 2-hour vibration exposure.

Moran and Bruckart (1992) studied EMG activity recorded at two sites on the neck at the fourth cervical vertebrae (C4) level one day before and immediately after the vibration exposure. During the vibration exposure, upper body postural data were obtained using photographs and target acquisition times were recorded for a simple vigilance task. Six subjects were exposed to 2 hours of whole-body random vibration while wearing helmets of 1.1 kg, 2.4 kg, and 4.1 kg,

with a center-of-mass at the SPH-4 center-of- mass. All vibration exposures of individual subjects were separated by at least 24 hours.

Alem, Meyer, and Albano (1995) studied performance of male pilots under long exposure to WBV and under four HSD configurations. Their study showed performance response time was not affected by vibration exposure time for all HSD's; however, it clearly demonstrated that performance response time significantly increased as the weight moment of the helmet increased beyond 78 N-cm. In addition, tracking distance error among all subjects showed an increasing trend as a function of helmet weight moment.

To summarize, USAARL recommended limit of 80 N-cm for the weight moment of HSD have been defined and verified for male but not female aviators. Recent USAARL studies clearly demonstrate that head acceleration and performance reaction time are the most sensitive parameters to helmet weight and center of mass. They also show that neck myoelectric activity and tracking error are important parameters but less sensitive to the mass properties of head-supported devices.

Muscle Fatigue and EMG

In the past decade, electromyography (EMG) has been increasingly utilized as the method of detecting muscle fatigue. Numerous studies investigating the effects of fatiguing exercises on myoelectric signals have been performed. De Luca (1986), reviewing the myoelectric spectral response to localized fatigue, discussed many studies reporting a decrease in the median spectral frequency and an increase in root mean-square (RMS) amplitude, both which are well correlated to a decrease in MVC. The physiologic explanation for this response has not been established, although several factors are believed to be involved. These include central mediated control of motor unit firing rates, synchronization of the motor units due to local reflexive activity, and reduction in the muscle fiber conduction velocities. What ever the exact physiologic cause, reductions in median myoelectric spectral frequencies are consistently seen in isometric fatiguing exercises for levels of effort above 15% MVC.

Myoelectric responses to dynamic exercise have been shown very similar to isometric fatiguing exercises. Using continuous isotonic exercise and regression technique for endurance times vs. percent MVC, Hagberg (1981) showed that a level equals to 7.8% MVC could be maintained for 1 hour. Jonnson (1987), using ergonomic data from wire wrap tool operators, used a similar regression technique and suggested that the level of effort for a 1 hour effort may fall between 2% and 5% MVC. Both Jonnson and Hagberg showed that significant recovery of the myoelectric signals occurred following brief periods of rest.

Ng and Richardson (1996) measured the fatigue rate of the back muscles with the use of the EMG power spectral analysis. In a study to detect respiratory muscle fatigue, Chen et al. (1996) used the power spectral analysis of diaphragmatic EMG and indicated strong correlation between integrated EMG (iEMG) of each inspiration and tidal volume as well as the duration of inspiration.

Mannion and Dolan (1996) found significant relationships between the rate of decline in mean frequency (MF) and the rate of decline in MVC (range: 20-60%), and between each of these parameters and endurance time to fatigue. They suggested that the decline in MF indicate a state of fatigue, where fatigue is defined as the inability to generate the maximum force that can be produced by the muscle in its fresh state.

Oksa *et al.* (1996) measured EMG from the thigh, abdomen, back, and lateral neck to determine fighter pilots' mean and peak muscle strain during aerial combat maneuvering exercises. They found that the mean muscular strain was 5.2-19.8% MVC with the highest mean and peak strain in the lateral neck (i.e., sternocleidomastoid muscles).

West et al. (1995) found that the relationship between endurance time and exercise intensity level was gender sensitive with women having larger endurance times than men.

Menstrual Cycle

Recent reports indicated that changes in menstrual cycle effect muscle strength and fatigue. Phillips et al. (1993) found a peak in the isometric strength of the adductor pollicis around the time of ovulation at which estrogen is present at peak levels. Conflicting to these findings, Davis, Elfors & Jamieson (1991) attributed stronger handgrip strength during the menstrual cycle to the lower estrogen and progesterone levels.

More recently, Sarwar et al. (1996) showed muscle strength and fatigue were altered by changes in menstrual cycle of women who are not taking oral contraceptive pills. Specifically, muscles were stronger, slower and more fatigued at mid-cycle (days 12-18 after menstruation, corresponding to the ovulation phase) of women not taking the oral contraceptive pill. These changes were not seen in women taking the oral contraceptive pill during which estrogen levels were fairly low. The authors attributed the previous observations to the rise in estrogen because this rise takes place around ovulation and eliminated the rise in testosterone and progesterone as possible causes. These findings agree with Phillips et al. (1993).

In a review of studies dealing with the effect of the menstrual cycle on athletic performance, Lebrun (1994) recommended to standardize the menstrual cycle phase for those studies using women as subjects. This issue is addressed in the subject selection.

Summary

In summary, HSD weight moment recommendations have been developed at USAARL based on male aviators exposed to WBV for different head-supported mass configurations. By repeating successful aspects of recent male subjects studies, this time with female subjects, data from this study are expected to yield similar and defensible recommendations for female aviators.

OBJECTIVES

The ultimate goal of this research is to define a safe range of helmet weights and centers of mass that can be tolerated by female helicopter pilots without affecting their health or degrading their performance. This study is focused on the following objectives:

1. Expose female military volunteer subjects to simulated helicopter whole-body vibration environment while wearing HSD with various mass properties.

2. While exposed to those conditions, quantify biomechanical, cognitive and physiological responses of the female subjects. The responses include:

   a. Head accelerations.
   b. Neck and back EMG before, during and after each exposure.
   c. Accuracy of tracking a target in motion.
   d. Speed of acquisition of a randomly appearing target.
   e. Cognitive functions.
   f. Posture.

3. Analyze the collected data to evaluate the effects of HSD and to define acceptable limits for their weight moments.

Scope of Report

Much of the material in this report has been derived from the approved research protocol. This should explain the future tense of the verbs when referring to actions that have already taken place. Additionally, the use of the future tense is a reminder that that most of subject testing, data collection and analysis remains to be completed. The remainder of the report is divided into four parts followed references and appendices.

In *Part 1 (Human Subjects)*, we address all human subjects use issues, such as subject selection criteria, medical screening, volunteer affidavit, menstrual cycle issues, and physical anthropometry. *In Part 2 (Random Vibration)*, we describe the instrumentation and test hardware, the experimental procedures, and the data analysis methods. Since the random vibration phase of the experiment is more complex than other phases, Part 2 of the report reflects such complexity. Thus, this part describes how we prepare subject and what (and how) various physiological, biomechanical, performance parameters are monitored. *In Part 3 (Sinusoidal WBV)*, we discuss the instrumentation, procedures and data analysis algorithms associated with the swept sine vibration exposure. A complete data set from one subject has been collected. Samples from this set are included in *Part 4 (Discussion & Conclusions)* of the report to demonstrate the types of data being collected and to display any trends in the response. No firm conclusions may be drawn until data from all 12 subjects are collected and processed.

PART 1: HUMAN SUBJECTS

METHODS

Subject Pool

Since there is a limited number of female military aviators or aircrew at Fort Rucker, subjects will be recruited from non-aviation female personnel. And because aviators are likely to be more comfortable wearing flight helmets than ground soldiers, the subject pool will be restricted further to ground personnel only. This strategy will reduce the potential bias of results.

Twelve active-duty military female subjects, aged 20-40 will be recruited free of coercion and without bias through personal contacts and distributing an announcement throughout Fort Rucker. Justification for the sample size is given in the section on experimental design and in Appendix A. In order to eliminate as many controllable sources of variation in the sample, the following subject selection criteria will be applied:

1. Subjects' weights can not exceed Army standards for their heights and age.

2. Choose females with similar exercise/conditioning regimes, i.e., with physical training (PT) scores above 210.

3. Exclude females who participate in specific neck and upper-body strengthening exercises.

All other anthropometric measurements will be documented for the purpose of future head dynamics modeling.

Subjects with any type of physical profile that prevents them from performing any physical training according to Army standards will also be considered after approval of the medical monitor.

Screening and Affidavit

Prior to any testing, the candidate subjects will be screened to meet the physical criteria. If the subject meets the criteria, then she will be medically screened to determine the existence of any underlying medical condition that may be aggravated by exposure to WBV. Candidates will be disqualified if they have a significant history of spinal, internal digestive system, head injury, or any reason as judged by the flight surgeon. In addition, candidates may be required to take a pregnancy test under the recommendation of the medical monitor. Pregnant candidates will be disqualified. Once a candidate subject passes the medical screening, she will be instructed about the testing and be asked to sign the Volunteer Agreement Affidavit (Appendix B).

She will also be requested to complete and sign the standard MRMC Volunteer Registry Data Sheet. Each subject will also be medically examined upon completing the study. In addition, each subject will fill out a daily Questionnaire before and after the test to document recent activities, any discomfort or pain, medications, rest level, etc. This data could be useful to identify potential causes for data outliers.

All subjects will undergo two sets of experiments. In one set, subjects will be exposed to random WBV and perform several tasks from which their muscular and performance responses will be measured. During the random WBV exposure, they will be required to wear six HSD configurations, each of which will be tested on a separate day. In the other set, subjects will be exposed to sinusoidal WBV while the biomechanical response of their head is recorded. During the sinusoidal WBV exposure, they will be required to wear twelve HSD configurations, all of which will be tested in one session. Descriptions of both sets of experiments will be presented in Parts 2 and 3 of the report.

Menstrual Cycle

The purpose of measuring hormone levels is to document hormonal status during the tests. Any variability due to hormone levels will be controlled by conducting the experiments at days 10-20 from menstruation, assuming ovulation at day 15. This period corresponds to the LF-EL phase of menstrual cycle. The selection of this test window is based on the fact that menstrual cycle length may vary from one month to another as much as 7-10 days for the same woman (Kirby et al. 1997). Hence, the window between day 10-20 post menstruation is chosen to avoid the discomfort associated with the menses period.

The effect of hormone levels on muscle strength and fatigue is still controversial (Lebrun 1994). Thus, minor variations in the optimal test window (days 10-20) are not likely to affect the outcome to any significant degree. There is no consensus in the literature that changes in hormonal levels in women who are taking oral contraceptive pills (OCP), versus those who are not, will significantly affect the muscular response and measurements. For this reason, and because of the limited pool of volunteer subjects, we will allow participation of subjects regardless of whether or not they are taking OCP.

Hormone levels in urine will be measured by analyzing the urine sample with direct immunoassay using the Abbott IMx* automated benchtop immunochemistry analyzer system. A USAARL study dealing with effects of melatonin on menstrual cycle (Kirby et al. 1997) has reliably used this system to monitor the surge in luteinizing hormone (LH) and follicle-stimulating hormone (FSH). The surge in LH is an indication of ovulation.

The purpose of using such system in this study is to effectively identify the hormone status of each subject on daily basis during the test. The system is proven to be a good alternative measure of hormone levels compared to systems that require blood sample. All urine samples will be stored at 1-4° C in the USAARL biochemistry lab and assayed the same day or kept frozen until analysis.

Anthropometry

Anthropometric measurements will be made of the subjects with an emphasis toward documenting the dimensions of the head and neck. These measurements include subjects' weight, sitting stature, standing stature, head length, head height, head circumference, head breadth, neck link, neck circumference, and bideltoid breadth. Standard anthropometric measurement devices will be used along with standardized measurement techniques according to the method by Gordon et al. (1989. Anthropometric measurements will be used to further enhance the accuracy of numerical models that estimate head center of gravity location and moments of inertia (Becker 1973, Beier et al. 1979 and Clauser et al. 1969).

HEALTH AND SAFETY

All safety precautions in the testing will conform to U.S. Army Medical Research and Materiel Command (USAMRMC) Regulation 70-25, USAARL Policy 70-3, and USAARL Policy 385-11. Vibration levels will not exceed the exposure criterion for safe operation established by International Standards Organization Publication 2631. A "Volunteer Agreement" form explaining the purpose, methods, risks, and benefits of this study is found in Appendix B.

Whole-body vibration exposure will be conducted at USAARL, utilizing its man-rated MARS shake platform to which a UH-60 seat will be attached. Some of the safety features of the MARS facilities include: a fail-safe system that shuts down the hydraulic system at the slightest irregularity, a multiple shutdown switches located around the MARS facility and two close-to-activate safety shutdown switches, one held by a technician and the other held by the safety officer monitoring the subject.

Vibration input to the UH-60 seat will be band-limited and amplitude-limited, producing a vibration signature similar to that of a UH-60 helicopter flying at 125 knots. Accelerations produced at the seat will not exceed that of gravity (1 G). Exposure time to vibration will not exceed 95 minutes per day. Each subject will undergo only one vibration session in a day except for the first day during which she will be exposed to an additional short duration (less than 15 minutes) of swept sine vibration.

Criteria for unscheduled termination of a vibration session include:

a. Failure to complete the neck muscle calibration procedure,
b. Failure to keep the head tracking light beam within the target board for 1 minute,
c. Missing five target acquisition LEDs in a row,
d. Any complaint of neck or back pain,
e. Subject request to end the vibration exposure, and
f. Any system indication to shut down the vibration platform.

A safety officer will watch the subject at all times during the vibration exposure and will be able of shutting down the vibration in emergencies. In all other situations, the MARS technician will ramp down the vibration on the platform, remove hydraulic pressure from the actuators, and the subject will be dismounted from the MARS platform.

All subjects will be required to fill out a Medical Screening Questionnaire. A medical officer will examine the subject and review the questionnaire. Subjects must not be considered "at risk" by the medical officer to be included in this study. Major medical disqualification items include any history of back or neck trauma such as, but not limited to, back injury, whiplash, or slipped disk. The medical officer also will examine each subject as soon as she completes the study.

All trials will be conducted with USAARL medical monitor on call. A medical corpsman will be present at the test site and a physician will be within 10 minutes of the test site using confirmed communications with a radio, pager, or telephone. All subjects will be instructed (Appendix B) on the testing procedures and the risks involved in this type of testing.

The medical monitor who is on duty for this study will not be required to be present at the MARS facility during subject testing. Prior to vibration exposure, telephonic communication will be confirmed with the medical monitor. In the unlikely event of an injury involving the vibration platform, emergency medical treatment is approximately 10 minutes from the testing facility using Lyster Army Community Hospital and approximately 20 minutes from the Medical Center Enterprise Emergency Room. This protocol is similar to previous USAARL studies in terms of head-supported loads. All of these previous studies have been considered minimal risk studies (see for example, Alem, Meyer, and Albano, 1995; Moran and Bruckart, 1992; Lantz, Alem, and Crisman, 1991).

Human Subject Justification

Since this is a study where the chief independent variables are human neck muscle activity, posture, and performance, the use of human subjects is necessary. No human surrogate can be used for this study.

PART 2: RANDOM VIBRATION

Helicopter vibration may be characterized as a sinusoidal vibration superimposed on a low-level random vibration in the range of 1-85 Hz. Random vibration has been chosen for this set of experiments because it more closely resembles vibration signatures of helicopters than does pure sinusoidal vibration.

INSTRUMENTATION

Simulated HSD Platform

To simulate various HSD weight moments, a modified aviator helmet will be utilized for this study. This helmet will allow the investigator to vary its weight and center of mass (CM) precisely and rapidly. The helmet is calibrated for five weights (1.4 to 4.1 kg) and twenty-one center of gravity locations (in the x, y, and z planes). The HSD simulator was used for male subjects in previous USAARL experiments and found to be adequate. A computer program was developed (Barazanji and Dodson, 1998) to determine the proper combination and placement of these weights, given any desired center of gravity and weight configuration of the HSD simulator.

Vibration Signature

Vibration levels will be band limited from 2-35 Hz and at a level similar to that experienced by crewmen in U.S. Army UH-60 and AH-64 helicopters flying at 125 knots. The 2-35 Hz frequency band is a limitation of the Multi Axis Ride Simulator (MARS). This limitation is considered insignificant due to the low resonant frequency of head and neck motion (4-5 Hz). Head pitch response data also has been shown to be band-limited to under 20 Hz (Wilder et al, 1982; and Butler 1992).

Electromyography

Neck and upper-back muscle myoelectric signals will be acquired using standard clinical myoelectric signal conditioners and recorded on 14-track frequency modulated (FM) analog tape. Bipolar surface electrodes, 0.5 cm in diameter and separated by 2 cm, will be attached around the circumference of the neck at the C4 level over the left and right trapezius and left and right sternocleidomastoid muscles. Electrodes will also be placed on the left and right trapezius of the upper-back muscle at the third thoracic vertebrae (T3) level. The electrode leads will be connected to a hand-held transmitter that will transmit the aerial signal to a receiver.

The pre-amplified EMG signals will be amplified further to a range of 2.5 volts, and will be routed to a 14-channel instrumentation VHS tape recorder. Recording speed will be set to ensure at least 250-Hertz recording bandwidth. In addition to the analog tape recording, the signals will be digitized in real-time as they are recorded. A data acquisition software, SnapMaster, will be used for this purpose. The EMG signals will be passed through anti-alias filters prior to digitizing. The SnapMaster will be configured as a virtual instrument to detect different light emitting diode (LED) signals and capture at least 2-second data window (2048 samples). Sampling rate will be set to 1000 samples/second. Each window will be saved on disk for subsequent spectral analysis.

Because of the two-stage amplification, EMG signals will not be calibrated in terms of microVolts at the skin surface. Instead, a calibration procedure will be applied before every session to allow expressing EMG signals in terms of the MVC of the subject. This MVC-EMG calibration is described in the experimental procedures section.

Performance Measurement Tasks

Performance data will be acquired from a head tracking task, a target acquisition task, and a cognitive task. The head tracking and the target acquisition tasks involve the use of a collimated light source attached to the top of the subject's helmet. This light source is powered by a 200 watt quartz bulb which is connected to the collimated tube through a fiber optic cable. The fiber optic cable is suspended from the ceiling resulting in minimal loading of the helmet and minimal restriction of head motion.

Tracking: In the head-tracking task, the subject points the light source at a target at the center of a moving photocell array placed 2 m in front of her. This target moves horizontally and vertically in a random pattern at a rate of 6 deg/sec measured relative to the subject's eye position. The target array is 32 by 32 photocells, with a resolution of 64 by 64, covering an area of 0.6 m by 0.6 m.

Target Acquisition: In the target acquisition task, the subject is faced with four target LEDs symmetrically located on the corners of a rectangular semi-circular platform. After an LED turns on, the subject has 5 seconds to aim the collimated light beam on her helmet at the target to "acquire" it. A photocell located just below the target turns off the target LED when the light beam strikes it for 0.8 seconds. The targets will be activated in a random order with a random time interval between targets of 5 to 10 seconds. The computer that controls the vigilance circuit records the target acquisition time. A target acquisition signal is also recorded on FM analog tape so that myoelectric activity can be correlated with ballistic head motions.

Cognitive: The Multiple Attribute Task Battery (MATB) will be the primary cognitive performance task. MATB provides a benchmark set of tasks for use in a wide range of laboratory studies of operator performance and workload. This PC-based interactive program is designed to simulate a pilot's environment. Subjects will perform this multiple task using a PC computer system that will be projected on a large screen placed at about 6 feet away. Interaction with the MATB program requires the use of a headphone, joystick and keyboard.

Posture

Head and neck position will be acquired using the Optotrack three-dimensional (3D) position measurement system. This system operates by triangulating on pulsed infrared LED markers and yields 3D coordinates for each marker relative to a user-selected viewing position. Marker pairs will be used to measure helmet position, first thoracic vertebrae (T1) position, sternum position, and seat position. Sampling rates for position data will be 100 Hz per frame (or 1000 Hz per marker for 8 markers, where the 8 markers define one frame). Error measurements for calibrated displacements are on the order of 0.05 mm for objects placed 3 m from the camera position.

Markers over the sternum and T1 will be attached to the skin using 10 gram Plexiglas mounts. These mounts will be attached to the skin using tincture of benzoin, collodion, and sticky pads (to hold the mount in place while the collodion dries). Marker pairs will have a separation of at least 4 cm to allow accurate measurements of relative angles.

PROCEDURES

General Approach

The general approach to this phase of the study will be to expose 12 volunteer female subjects to random WBV and 6 HSD configurations (6 sessions) while measuring neck and upper back muscle myoelectric activity and psycho-physiological performance. The number of subjects is based on three independent statistical designs outlined in Appendix A. All of these designs confirm that a sample size of 12 has at least 90% chance of getting significant agreement between independent variables (e.g. weight moment) and dependent variables (e.g. target acquisition time). Furthermore, based on these designs, the six HSD weight moments intended during the random WBV can be selected in any fashion from a range of 0-300 N-cm without affecting the statistical power. These weight moments selected for this study are 55, 70, 80, 95, 110, and 200 N-cm. This selection will allow comparison to the male study (Alem et al. 1995) in which subjects were tested with the 110 and 200 N-cm helmets. Selecting 6 configurations will increase the precision with which the safe range of HSD weight moment is predicted.

Thus the subject will be tested for a total of six days with one helmet per day except for the first day where the subject will undergo one random WBV session followed by a swept sine WBV session. The order of helmets for each subject will be presented according to a restricted counterbalance design listed in Table 1.

Care will be taken in the experimental design to complete all sessions of each subject in 6 days, within an optimal 10-day window. This window corresponds to late follicular-early luteal (LF-EL) phase of menstrual cycle. Each session will be completed in about two hours allowing to test two subjects in a day, if necessary.

Table 1. Counterbalance design of helmet
weight moment presentation for the random WBV experiments

Subject	Helmet Configuration #
1	1, 2, 6, 3, 5, 4
2	2, 3, 1, 4, 6, 5
3	3, 4, 2, 5, 1, 6
4	4, 5, 3, 6, 2, 1
5	5, 6, 4, 1, 3, 2
6	6, 1, 5, 2, 4, 3
7	4, 5, 3, 6, 2, 1
8	5, 6, 4, 1, 3, 2
9	6, 1, 5, 2, 4, 3
10	1, 2, 6, 3, 5, 4
11	2, 3, 1, 4, 6, 5
12	3, 4, 2, 5, 1, 6

Because there is an optimal 10-day window for testing, tentative schedule of the test will be arranged as soon as the subject signs her consent form. This would provide her with sufficient time to monitor her menstrual cycle so that testing may be scheduled during that optimal window.

Using the standard operating procedures of the MARS facility (Appendix C), the MARS technician will initiate the WBV (both random and sinusoidal). Initial vibration trials of 30-seconds duration will be used to ensure the recording systems are operating. Initial vibration trials will not exceed a total duration exposure of 5 minutes. Following the post sub-maximal endurance routine, the subject will dismount the MARS and the instrumentation will be removed.

Each subject will undergo a series of subtasks as indicated in the daily schedule (Table 2). This series include a 5-minutes MVC determination test, a 5-minutes EMG calibration test, and a 5-minutes pre sub-maximal endurance test. This is followed by a head tracking task, a target acquisition task, and a MATB task, each lasting 30 minutes, ending with a 5-minutes post sub-maximal endurance test.

Table 2. Daily test schedule for 6 helmet configurations and for the swept-sine 12-helmet procedure

Start Time	Activity Or Task	
8:00	Apply EMG electrodes & check impedance	*Daily routine for 6 helmet configurations*
8:05		
8:10	Seat subject	
8:15	Measure MVC	
8:20	EMG calibration	
8:25	Pre SME	
8:30	**Fit helmet**	
8:35	Tracking & Optotrack*	
8:40		
8:45		
8:50		
8:55		
9:00		
9:05	Target acquisition & Optotrack*	
9:10		
9:15		
9:20		
9:25		
9:30		
9:35	MATB setup	
9:40	MATB & Optotrack*	
9:45		
9:50		
9:55		
10:00		
10:05		
10:10	Post SME	
10:15	Ten-minute break (1st day) Test completed (days 2-6)	
10:20		
10:25	Seat subject	*First day only (12 helmets)*
10:30	Fit helmet & bite bar	
10:35	Lateral head photo	
10:40	Swept-sine vibration with Helmets 1-12	
...		
11:45		

* Posture data using the 3-D Optotrack system is acquired simultaneously in 15-seconds epochs every 5 minutes.

During the performance tasks, the helmet, T1, sternum, and seat positions will be recorded simultaneously, in 15-seconds epochs every 5 minutes. During vibration, EMG signals will be measured only during the target acquisition task.

Quality Control Tests (dry runs)

Prior to the experiments, the procedures and instrumentation will be tested out at the MARS facility on one or two subjects recruited from USAARL. These tests are essential preliminary steps for the purpose of getting proper and accurate apparatus readings, improving the quality control of the planned measurements, and ensuring the feasibility of the time schedule.

In these preliminary tests, USAARL volunteers are not expected to undergo WBV. If exposure to WBV becomes necessary during these preliminary tryouts, then the volunteer will be required to undergo the same medical screening, briefing, and be required to sign the Volunteer Agreement Affidavit (Appendix B) and to complete and sign the Volunteer Registry Data Sheet. However, data from these preliminary tests will not be included in the final data analysis.

Training Phase

Each subject will undergo at least two days of training to familiarize her with the different experimental procedures. Two computer stations will be setup at the MARS facility and at the USAARL main building for MATB learning purposes. To eliminate the effects of learning, MATB test will be repeated until scores reach an asymptote. The subject will also practice the tracking and target acquisition tasks at the MARS lab until she feels comfortable performing them. All practices will be done without exposure to vibration and with a helmet mass of 1.33 kg, approximately half the value of an SPH-4 helmet. During this phase, anthropometric data as well as an impression of each subject's bite will be taken. The impression will be fitted with a bite bar for measuring head accelerations. At this time, scheduling for the formal 6-days test series will be finalized.

Simulated Helicopter Vibration

The vibration exposure will be 90 minutes for each session. Each subject will perform one session per day. The triaxial vibration signature to be used was derived from the signal of a UH-60 helicopter flying at 125 knots. Vibration peak amplitudes do not exceed 6.0 m/s^2 in the axial direction and do not exceed 0.6 m/s^2 in the left-right (L-R) or the anterior-posterior (A-P) direction. Prior to the experimental trial, brief additional trials will be needed in order to ensure correct operation of the recording systems and the fidelity of the myoelectric signals. These setup trials will not exceed 30 seconds duration with the total setup vibration not exceeding 5 minutes. All subjects will be exposed to less than 95 minutes of WBV in a day. Exposure to these levels of WBV for these durations are well below health and safety exposure limits specified in the International Organization for Standardization (ISO) guidelines for human exposure to WBV (ISO 2631, 1985).

Subject Preparation

Upon arrival to the MARS building for testing, the subject will be prepared to place EMG electrodes on six muscle groups in the presence of a female chaperone. Neck and upper back muscle locations will be determined by having the subject perform low intensity isometric contractions and palpating for the belly of the muscles of interest. These will be the left and right trapezius at the neck mid-level (C3-C4) and at the upper back at the T3-T4 level, and the left and right sternocleidomastoid, also at C3-C4 level. The electrode attachment site then will be prepared by vigorous rubbing of the attachment site with an alcohol swab for ten cycles. Electrodes will be attached using electrode gel and sticky tape, in accordance with standard clinical practices, and a subject ground will be placed on the right clavicle. Additional skin tape will be used to route the electrode leads to the back of the neck and from there to the preamplifiers. The leads will be routed to allow full freedom of motion of the head and neck. The electrode impedance will be measured systematically using an electrode impedance meter to ensure the resistance does not exceed 5 kW.

The subject will mount the MARS platform, sit in the stiffened UH-60 seat, and strap into the lap and crotch belt only of the standard five-point harness. Use of the shoulder belts in previous experiments on the MARS has interfered with the neck EMG electrodes.

Maximum Voluntary Contraction (MVC) and EMG Calibration

As soon as the subject is seated, she will perform a neck muscle EMG calibration routine for flexion and extension. The calibration procedure is as follows for each motion direction. Each subject will be fitted with a head harness and asked to pull against a stationary tension load cell with her maximum isometric effort, relaxing quickly after she reaches her peak exertion. Three peak loads will be obtained, then averaged to define the 100 percent level of MVC. Note that the 100 percent MVC force will be measured without simultaneous measurement of EMG activities.

Using an analog display at the subject's eye level, the subject will pull against the load cell to produce various levels of force while matching a target force level. The target force will be ramped to cycle three times between 0 and 40 percent MVC at increments of 5 percent MVC and held for 5 seconds at each level. EMG activity will be recorded for the complete ramp cycle and averaged for the three cycles to obtain a MVC-EMG calibration curve. This curve will be used to convert EMG readings to percent MVC.

Submaximal Endurance

Following the calibration task and using the computer monitor as a guide, the subject will pull against the load cell to sustain 50 and 70 percent MVC for as long as she can. The subject will be asked to relax if either endurance time exceeds 2 min. or her pull falls 5 percent below the target force.

Endurance times as well as neck EMG activity will be recorded prior to exposure to vibration and helmet load to obtain baseline values. The subject will repeat this procedure as soon as she completes all performance tasks (i.e., post-SME). The helmet will not be worn and vibration will be off during post-SME.

After the pre-SME procedure, 20 seconds of static myoelectric data will be acquired without a helmet to determine the muscle activity required to support the head. Then the subject will be fitted with a helmet and 20 seconds of static myoelectric data will be acquired to determine the muscle activity required to support the head and helmet.

Performance Measurement Tasks

Upon fitting the subject with the helmet, the vibration table will be turned on. The subject will undergo three performance tasks. During each task, postural data will be recorded every 5 minutes in 15-second epochs. EMG signals will be recorded but only during the target acquisition task.

Tracking. During the 30-minute head tracking task, the subject will point a helmet-mounted collimated light source at a target and keeps the light source as close as possible to the target as it moves. Horizontal and vertical tracking distance errors measured from the center of the target will be recorded at a rate of 20 Hz.

Target Acquisition. In the 30-minute target acquisition task of the test set, the subject will scan for one of four LED targets located in a rectangular arrangement at the periphery of her field-of-view. When the helmet-mounted light beam strikes a photocell just below the LED, the LED turns off. Target reaction times and neck muscle myoelectric responses of the head motions will be recorded.

Cognitive. The MATB has been used in other USAARL studies to measure the performance degradation of subjects who are fatigued because of sleep deprivation in one study, and to study the effects of various drugs in other studies. The procedure will assess the subject's cognitive function by exposing her to both visual and auditory stress tests.

The 30-minute MATB task is structured to simulate an approximate operations environment of aircrew. The battery incorporates tasks analogous to activities that aircraft crew members perform in flight, while providing a high degree of experimenter control, performance data on each subtask, and freedom to use non-pilot test subjects. It consists of four subtasks that provide probability monitoring dials and response time measure, a tracking task using the joystick, a fuel resource management task, and an auditory task. Features not found in existing computer-based tasks include an auditory communications task (to simulate air traffic control communication), a resource management task permitting many avenues or strategies of maintaining target performance, a scheduling window which gives the operator information about future task demands, and the option of manual or automated control of tasks. Performance data are

generated for each subtask. In addition, the task battery may be paused and on screen workload rating scales presented to the subject.

Data acquired from MATB include the following measurements:

(1) For the monitoring task: elapsed time, a code indicating an event requiring a response (e.g.: red light on, green light off, gauges 1-4 out of desired range), and response time.

(2) For the joystick tracking task: elapsed time, level of tracking difficulty (i.e., low, medium, high), sum of squares of pixel tracking error, tracking error sampling rate, and RMS tracking error.

(3) For the communication task: elapsed time, event code (own vs. other, call sign, and channel to switch to), and change of frequency.

(4) For the fuel management task: elapsed time, pump activity (pump number, on-off, failure, repair), and fuel levels in tanks A, B, C, and D.

Posture

The only purpose of measuring position during random WBV is to monitor posture that the subject may change due to fatigue. The postural data and the anthropometric data can be used later to develop a mathematical model to predict the neck muscle contraction forces for various helmet configurations.

Data Analysis

A repeated measure design will be used for these experiments. Twelve female volunteer military aviators will be exposed to 90 minutes of random WBV while wearing each of the six head-supported weight moments. The subjects will be exposed to the helmets based on a counter balance design, as discussed previously and shown in Table 1. Subject 1 will be tested according to the generalized sequence H_1 H_2 H_n H_3 H_{n-1} H_4 H_{n-2} H_5 etc. until convergence ($H_\#$ = helmet configuration number, n = total number of helmets). That is, subject 1 will be presented first with H_1, followed by H_2 H_6 H_3 H_5, and H_4. Subject 2 will be presented with the subsequent helmets, first with H_2, followed by H_3, H_1, H_4, H_6, and H_5. Subjects 3-6 will have similar sequences. Whereas subjects 7-12 will be presented with the reverse order of helmet sequences that of subjects 1-6. For example, the helmet sequence of subject 7 will be in a reverse order of subject 1 (i.e., H_4 H_5 H_3 H_6 H_2 and H_1). The rational behind this arrangement is to present an equally balanced helmet presentation among all subjects without bias.

There are four major tasks in these experiments that each will have its own dependent and independent variables. These include submaximal endurance, tracking, target acquisition, and MATB. Data analysis of each of these tasks is discussed separately below. In addition, a section on EMG signal processing is also presented.

EMG Signals

The EMG calibration data points will be curve fitted with a least square second-order polynomial. The correlation coefficient of the fitting curve and its significance will be computed. Any EMG calibration curve with a p-value more than 0.05 will not be considered.

Using the extension EMG calibration curve, recorded myoelectric activity from the left and right trapezius of the neck and upper back will be expressed as percent MVC. Recorded myoelectric activity from the left and right sternocleidomastoid muscles also will be expressed as percent MVC using flexion EMG calibration curve. Fast Fourier Transform (FFT) will be used to extract the frequency content of the EMG signal and determine the median frequency (MF). The change of MF over time (MF slope) and the initial MF (IMF) will be used as dependent variables. The RMS of the EMG signal averaged over time (average RMS) will also be determined and used as a dependent variable. These EMG dependent variables will be utilized for the submaximal endurance (i.e., pre and post-random WBV) and target acquisition (during random WBV) tasks. Whereas the independent variables are defined dependent on the task conditions, as listed in the corresponding sections below.

Submaximal Endurance

Three way analysis of variance (ANOVA) will be used to determine the significance of endurance time, average RMS, IMF, and MF slope among six helmet weight moments, and two SME states (pre and post). In addition, two way ANOVA will be used to determine the significance of percent change of average RMS, of IMF, and of MF slope from pre to post-SME among six helmet weight moments. This analysis will be repeated for each muscle group (n=6).

Performance Measurement Tasks

Tracking. During the tracking task, horizontal and vertical errors will be recorded. RMS measures of horizontal and vertical tracking errors will be calculated as performance tracking indexes. Curves showing tracking error over time will be plotted for each 3-minute epoch to establish a set of tracking performance degradation curves as a function of head-supported weight moment. Two way ANOVA will be used with head-supported weight moment as one factor (n=6) and time epochs as the second factor (n=10).

Target Acquisition. During this task, target reaction times, the average RMS, IMF, and MF slope for the various movements (i.e., for each target) will be determined. Significance will be detected using two way ANOVA with head-supported weight moment (n=6) as one factor and target location (n=4) as the second factor.

Cognitive (MATB).: The following dependent variables will used for analysis:

(1) For the monitoring task: response time, number of events, number of timed out events, and number of false responses.

(2) For the joystick tracking: RMS tracking error.

(3) For the communications task: time to respond to message, accuracy of channel and frequency changes, missed messages, and responses to others' messages.

(4) For the fuel management task: RMS deviation from target fuel levels A & B and number of user initiated pump activities.

Two way ANOVA will be used with head-supported weight moment as one factor (n=6) and time epochs as the second factor (n=10).

PART 3: SINUSOIDAL VIBRATION

The purpose of this phase of the study is to systematically determine the frequency response of the head motion under different HSD configurations. This procedure was one of the most productive aspects of previous USAARL studies with male subjects. In this study, female subjects will be exposed to swept sine vibration while their head acceleration is recorded.

INSTRUMENTATION

Swept Sine Vibration

Input sinusoidal vibration will be in the axial (vertical) direction and will be increased from 2 to 17 Hertz at the rate of 0.25 Hertz per second, then decreased back to 2 Hertz at the same rate. A constant peak acceleration of 0.35 G will be maintained. The entire up/down sweep will take approximately 2 minutes.

Accelerometers/Bite Bar

Under this vibration exposure, the head will move in a natural nodding motion in the mid-sagittal plane. That is, the motion will consist of a two translations (fore-aft and up-down) and a pitch rotation about the left-right axis. Since this is a three-degree-of-freedom motion, at least three independent measurements (here, accelerometer readings were chosen) will be necessary to completely solve the kinematics problem. However, a fourth redundant accelerometer is added to simplify the equations and to obtain a robust solution. Thus, four miniature uniaxial accelerometers will be mounted strategically on a bite bar, to be held rigidly by the subject in her mouth during the test.

The bite bar consists of a lightweight mount, precision machined out of aluminum alloy, approximately 5 inches long and attached to a U-shaped bite plate. This bite plate is fitted to the subject's teeth using dental molding compound. Because of the exact registration with the subject's teeth, the head-bite bar system can be considered a rigid body, thereby allowing the use the rigid-body kinematics to compute the linear and angular accelerations of the head motion in the mid-sagittal plane. The accelerometers will be Entran model EGAXT, each measuring 0.18 x 0.15 x 0.30 inches and all have a range of 15 G. The bite bar will be used only during the swept sine vibration testing as explained below in the procedure section.

PROCEDURES

General Approach

One session will be dedicated to measure head acceleration of the same 12 subjects in response to sinusoidal vibration and for 12 helmet configurations. This number was chosen to allow comparisons to a similar study by Butler (1992) that used the same HSD configurations on 12 male subjects and shown significance levels. Since each helmet test under swept sine will take approximately 2 minutes, all 12 HSD configurations will be tested in a single session on the first day. The masses and ceters of mass of the twelve helmets are given in Table 3

Table 3. Helmet mass and center of mass parameters for the sinusoidal WBV session only

	Center of Mass (cm)*			
Mass (kg)	!2	0	2	4
2	!2.0**	0.0	2.0	4.0
3	!2.1	0.1	2.3	4.0
4	!2.3	!0.3	2.3	4.3

* Center of mass parameter is measured relative to the head center of mass.

** Desired helmet parameters with actual values of center of mass similar to that by Butler (1992).

Subject Preparation

After a 10-minute break following the first helmet session of random WBV experiments, a bite bar with four accelerometers mounted on top of it will be fitted into the subject's mouth. Using a surgical marking pen, two facial landmarks will be marked with a dot at the lowest point of the orbital cavity and at the upper edge of the external auditory meatus (EAM). By convention, the mid-point between the left and right EAM is taken as the center of the anatomical reference frame, defined by the Frankfort plane. In a previous similar USAARL experiment using male subjects, lateral x-rays from all 12 subjects were obtained to determine an average distance of AOC with respect to the EAM. Similarly, in the present experiments, it will be necessary to take a lateral x-ray of the head of each subject while she bites on the bite bar. In this case, radio opaque pellets will be used as markers at the infra-orbital notch and the EAM. Radiographic facilities at Lyster Hospital are within walking distance from USAARL and will be used to obtain the lateral x-rays.

From the digitized photographs or from the x-rays, the head anatomical center and the Frankfort plane-based anatomical reference frame will be determined. The coordinates of the bite bar accelerometers of the AOC will be measured. Coordinates of head center of mass in the anatomical reference frame will be estimated from models that utilize several head dimensions such as A-P length, L-R breadth, S-I height, and circumference.

Head Acceleration

Swept sine vibration will be applied for 12 helmet configurations and acceleration signals from the bite bar will be recorded. Using the distances from the accelerometers to the AOC obtained from lateral x-rays or digital photographs, and the acceleration readings, the head angular velocity and angular acceleration about the L-R axis and its linear accelerations in the S-I and A-P directions will be computed.

ACCELERATION DATA ANALYSIS

Similar to the data analysis of random WBV, a repeated measure design will also be used for these experiments. The order of helmets for each subject will be presented also according to a counterbalance design listed in Table 4. The resonant frequency and its magnitude will be identified among all subjects and for different helmet configurations. One way ANOVA will be used for the resonant frequency as well as for the resonant peak with the helmet weight moment (n=12) as the independent variable.

Table 4. Counterbalance design of helmet weight moment presentation for the sinusoidal WBV experiments

Subject	Helmet Configuration #
1	1, 2, 12, 3, 11, 4, 10, 5, 9, 6, 8, 7
2	2, 3, 1, 4, 12, 5, 11, 6, 10, 7, 9, 8
3	3, 4, 2, 5, 1, 6, 12, 7, 11, 8, 10, 9
4	4, 5, 3, 6, 2, 7, 1, 8, 12, 9, 11, 10
5	5, 6, 4, 7, 3, 8, 2, 9, 1, 10, 12, 11
6	6, 7, 5, 8, 4, 9, 3, 10, 2, 11, 1, 12
7	7, 8, 6, 9, 5, 10, 4, 11, 3, 12, 2, 1
8	8, 9, 7, 10, 6, 11, 5, 12, 4, 1, 3, 2
9	9, 10, 8, 11, 7, 12, 6, 1, 5, 2, 4, 3
10	10, 11, 9, 12, 8, 1, 7, 2, 6, 3, 5, 4
11	11, 12, 10, 1, 9, 2, 8, 3, 7, 4, 6, 5
12	12, 1, 11, 2, 10, 3, 9, 4, 8, 5, 7, 6

PART 4: DISCUSSION AND CONCLUSIONS

PERFORMANCE MEASUREMENT TASKS

Only two subjects volunteered for this study until now. One complete data set has been collected so far from one subject. Incomplete tests done on the other subject were used as preliminary run to refine our experimental procedures. The study design requires eleven additional subjects to be tested and their data processed. Until then, no firm conclusions can be made. In this part of the report, we are limited to presentation of sample data from both subjects. In addition, successes and difficulties encountered will be discussed. Data from performance tasks (tracking, target acquisition, and cognitive) are given in Appendix D. These are briefly discussed below.

Tracking

Tracking errors during random WBV for subject F01 were obtained under six helmet configurations. These are shown in Figures D-1 through D-6. In these graphs, circles represent 3-minute averages. Vertical error bars represent ± one SD. The sloped solid line represents best linear fit of all data. In general, tracking error increases as the exposure continues.

Target Acquisition

Figures D-7 through D-16 contain graphs of LED target acquisition time (indication of vigilance) from our preliminary subject (#91, also labeled #20). They do not show any degradation with respect to the order of LED appearance (indication of exposure duration). However, acquisition time showed significant differences due to helmet loads as shown in Table D-1. There was a significant difference between acquisition Time for LED 1 and 2 and a borderline significance for LED 3 when all missed LEDs were included in the analysis. A missed LED is one that was not acquired for a period of 5 sec. However, some LEDs were missed when the subject needed to adjust her helmet. Even when the analysis was repeated excluding missed LEDs, the effects of the helmet weights remained significant.

Cognitive

Figures D-17 through D-20 show four MATB variables. These are obtained from our preliminary subject as functions of elapsed time, for two helmet configurations. Only RMS Joystick Tracking and number of errors during Communications subtask showed significant differences between the two helmet configurations. Changes with respect to time showed no significance; except for the communications response time which showed a significance between the 30 min and 10 min averages due mainly to learning effect. As a result of this preliminary run, we increased the difficulty level of MATB from medium to high for the test subjects. We also increased the requirement of subjects to train with MATB for at least 4 sessions.

ELECTROMYOGRAPHY

Appendix E contains sample data from EMG measurement. They include calibration and submaximal endurance test data.

Calibration

Levels of EMG signals vary from subject to subject because of their strengths, skin potential and other factors. They also vary from day to day for the same subject. In order to compare EMG across subjects and tests, the EMG signals are expressed in terms of the maximum voluntary contraction the subject is exerting, or % MVC. The subject's MVC, measured in pound force, is determined at the beginning of every session. A "calibration" exercise is required of each subject when new electrodes are placed, i.e., for each exposure session. During this isometric extension or flexion exercise, the subject pulls against an immovable restraint at a paced force level, up to 70% of her MVC, while EMG signals are recorded and the force measured. The relationships between the EMG signals (expressed in mV) and the exertion level (expressed in % MVC) may then be determined.

Figures E-1 through E-6 are samples of the relationship between EMG (RMS, mV) and exertion level (% MVC). Clearly this relationship is nonlinear, most likely of a second order nature. In practice, the inverse relationship is needed where the independent variable (known) is the EMG (mV) signal and the Force level (% MVC) is the dependant (unknown) variable. Figures E-7 through E-12 show such inverse relationship. These graphs also show the "best fit" curves, obtained by direct regression of the data. It turned out that regression of the data is not appropriate in many cases, due primarily to the presence of background noise in the EMG signals.

Submaximal endurance

Immediately before and after each exposure to a helmet configuration, the subject performs a test that measures her physical endurance. In this test, she is is requested to pull up to a submaximal level (normally, 80% of her MVC) and hold that level for as long as she can. EMG levels are measured while she is maintaining the pull until she drops the force level. During the test, one-second segments of EMG data are continuously being sampled. Spectral analysis of these data segments were performed to reveal trends in the data over time, as well as differences before and after the WBV and HSD exposure.

Figures E-13 through E-20 are samples of the results of the spectral analyses. Each figure shows the changes, with respect to endurance time, of mean power frequency (MPF) and the root mean squared (RMS). As expected, the general trend is that the MPF decreases with time as the firing of muscle fibers become more synchronized, and the RMS increases with time as the electric potential produce by the contraction of muscle fibers is accumulated. Although differences between the pre- and post-exposure submaximal endurance data may be observed, we cannot determine the statistical significance until all 12 subjects are tested.

HEAD ACCELERATION

Head motion is measured during swept-sine vibration exposures with 12 HSD configurations. The tests were described in the body of the report. The measurement is accomplished with a lightweight bite bar that carries 4 accelerometers. Appendix F contains sample processed and analyzed acceleration data.

Acceleration Signals

Figures F-1 through F-12 are bite-bar acceleration signals Z2 and Z3 obtained from swept-sine tests with subject F01 and 12 helmet configurations. Further analysis has to be performed to reduce the data and to characterize the mid-sagittal head motion as two translations and a pitch rotation. This has not been completed at this point.

Filter and Sampling Issues

Acceleration signals for subject F01 were sampled at 1000 Hz for 2.5 minutes (150 sec.) Since there were 4 accelerometers, each producing a signal consisting of 150,000 samples (data points) and since 12 configurations were tested, the signal processing burden needed to be reduced. Spectral analysis was applied to all acceleration signals from subject F01 to examine the frequencies we expect to find in the signals. This redefined the lowest anti-alias filter that would not eliminate significant frequencies and allowed us to reduce the sampling rate (and size of files) by one half.

The power spectral density function in Matlab was utilized to determine the frequency and amplitude contents of the bite bar accelerations. The length of the Fast Fourier Transform (FFT) window was chosen sufficiently to be 1024 with 50% overlap between windows. The Blackman window was chosen as the windowing function with a length equal to that of the FFT-window. Other functions can be used such as the Hamming or Hanning windows as long as no ripple is present in the passband and stopband. The signals were de-trended linearly to remove the best straight-line fit from the pre-windowed sections.

The criteria for deciding on the appropriate sampling frequency and filter characteristics has to be based on prior knowledge of the measurement on hand from either previous experiments of other researchers or preliminary experiments, as the case for our study. Preliminary experiments were conducted to test the feasibility of our approach to the problem of determining the motion of the head under vibration and to assess the design criteria for the data acquisition and analysis. In this report, the focus will be on the design of the sampling frequency and pre-aliasing filter characteristics. The specifications of the anti-aliasing filter need to be addressed first before deciding the appropriate sampling frequency. The next section describes the procedure for determining the desired frequency ranges, stop-band attenuation, and filter type and order.

Using Matlab, we determined the power spectral density (PSD) as a function of frequency of all of the bite bar acceleration signals (n=4) and for all the helmet configurations (n=12). We also determined the total energy of the signal by integrating the PSD across the entire frequency range (i.e., the area under the PSD curve). The Matlab code is listed in Appendix A. In figures F-13 through F-16, we show the PSD of accelerometers 1-4 for a subject wearing a 4 kg helmet with a distance of 4 cm between helmet center of mass (CM) and head CM. The PSD response clearly shows a fundamental resonance at 6 Hz and a secondary one around 16.5 Hz. Thus as expected, most of the energy (i.e., 97%) occurred below 17 Hz, which is the highest input sinusoid frequency. However, accelerometer 2 and 3 show another peak around 50 Hz, which is probably due to white noise. The frequency responses of all accelerometers were found to exhibit similar responses under other helmet loading as summarized in Table F-1. This table shows the maximum possible frequency of 99% of the energy is about 59 Hz among all helmet configurations and accelerometers. Thus, we selected an anti-alias filter that includes the frequency range of 0-60 Hz as the flat portion of the passband frequency.

The acceleration signals are sampled using the Optotrak in the range of ±10 V corresponding to ±5 g. Since the A/D board is a 12-bit processor, the quantization noise level for the ADC should be higher than 80 dB assuming a full-scale input. The desired stopband attenuation (A_s) is selected to have an aliasing error of less than 0.1% of the signal level in the passband. In decibels, A_s is

$$A_s > -20 \log (0.001) = 60 \text{ dB}$$

Thus an 8-pole Butterworth filter with a 100 Hz cutoff frequency would pass the desired frequency range (0-60 Hz) and give a stopband attenuation of 63.67 dB (i.e., 0.0066% of the signal). Figure F-17 shows the filter curve for different filter orders using the low pass filter equation below expressed in dB.

$$|H(\omega)|^2 = \frac{1}{1+(\omega/\omega_P)^{2N}}$$

where,

$|H(\omega)|$ = magnitude of the signal
ω = frequency in Hz
N = order of the filter
ω_P = the 3-dB cutoff frequency (Hz)

DIFFICULTIES TO RESOLVE

As with most other research studies, several difficulties were encountered in this one. Most of these were resolved satisfactorily, others remain a threat to timely execution of the research plan. Below is a discussion of two serious issues and the options available to us.

Subject Recruiting

Although the research protocol was approved several months ago, giving us the authority to recruit and utilize human subjects, we have tested only two subjects. The first one was necessary to check out our test procedures and data acquisition hardware and software. That proved to be an essential step because several problems were identified and resolved successfully. Our first "real" subject was then recruited from our enlisted soldiers who are assigned to USAARL. That was about three months ago. Since then, we have had only one soldier come forward to volunteer as a subject.

Clearly, the rate of recruiting is not satisfactory. We have stepped up our campaign and had the local "Army Flier" weekly newspaper print out a page-1 feature article about our study and the benefits expected for women aviators. Since this study is a minimal risk, we cannot compensate our volunteers for hazardous duty. At this time, we are discussing other incentives that we may offer our volunteers. We hope to resolve this issue in time to complete the study in a timely fashion.

HSD Simulator

The HSD simulator is a device that was developed by the Air Force more than a decade ago. Although it has been used in previous USAARL studies, we have found that the heavy off-balance weights (H42 and H44 configurations) cause the helmet to rotate over the subject's head, thereby obstructing her view of the moving target board. This problem is particularly noticeable with our second subject, who happens to have a head circumference near the 5th percentile of women in the Army. To counter this rotation, the subject has to adjust it frequently. This is a distraction that affects the MATB test and contaminates any cognitive data that are collected. However, pre- and post-exposure submaximal endurance tests, which produce EMG data, will be valid.

Three options are being considered. The first is to restrict our subjects to those having head circumference between the 40th and 60th percentiles. This option further reduces the size of the pool of volunteer and confounds the subject recruiting issue. Another option de-emphasizes MATB data and relies mostly on EMG endurance data to characterize the effects of HSD. This option also is not desirable because it tends to dilute the robustness of the conclusions regarding the effects of HSD on women aviators. The third option is to replace the helmet shell with an SPH-4 helmet shell and energy absorbing liner that can be custom fitted to each subject. This option is the most attractive and will be pursued.

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APPENDIX A

Statistical Design - Number of Subjects

Statistical Design - Number of Subjects

This appendix describes the statistical procedure in determining number of subjects (sample size). The procedure is based on the statistical work of Kraemer and Thiemann (1987) as well as on previous male experiments.

Three different statistical designs are constructed in order to obtain the sample size without any bias imposed by the assumptions of each design. The designs are based on ANOVA (Design 1), product-moment correlation coefficient (Design 2), and linear regression (Design 3). In all of the designs, it is assumed that the data analysis of the female experiments are similar in nature to the male experiments. The findings of the target-acquisition performance procedure of the last male experiment (see Alem, Meyer, and Albano, 1995) will be used in this analysis since the procedure produced the most sensitive data (reaction time, or dependent variable) to helmet weight moment (independent variable). Their findings may suggest quasi-linearity for weight moments higher than 80 N-cm. Thus, the emphasis of the statistical designs will also be in that range.

Design 1

This design determines sample size based on the comparison of reaction time at two helmet weight moments using the analysis of variance. The desired mean difference (μ_x-μ_y) is selected to be 0.174 sec, where μ_x is the mean reaction time at a particular helmet weight moment and μ_y is the mean reaction time at a smaller helmet weight moment. By design, the value 0.174 is selected since it is the smallest possible difference of means detected in the previous male experiments. The standard deviation (σ) is estimated, also from previous study, to be 0.051 sec. Assuming normal distribution, the number of subjects (n) needed to reject the null hypothesis (H_0: $\mu_x \leq \mu_y$) is determined as follows.

$$\delta = (\mu_x - \mu_y) / \sigma \tag{1}$$

$$\Delta = \delta / (\delta^2 + 1/pq)^{1/2} \tag{2}$$

$$n = \nu + 1 \tag{3}$$

where:

δ is the relative deviation,

Δ is the critical effect size which is defined as "a measure of how strong the theory must minimally be to be important to society" (Kraemer and Thiemann, 1987),

p, q are the proportions of subjects for each helmet,

ν is the sample size obtained from the Master Table of Kraemer and Thiemann (1987) (pages 105-112) based on the value of (Δ), level of significance (α), confidence interval, and whether the test is one or two-tailed, and

n is the actual sample size of the study.

Substituting the selected $(\mu_x-\mu_y) = 0.174$ sec and $\sigma = 0.051$ sec into equation (1) yields:

$$\delta = 0.174 / 0.051 = 3.439$$

Since this is a balanced test, we use $p = q = 0.5$. Equation (2) then gives:

$$\Delta = 3.439 / [(3.439)^2 + 1/(0.5)(0.5)]^{1/2} = 0.864$$

It is assumed that helmet weight moments above 80 N-cm causes degradation and not improvement in reaction time; hence, we use the one- tail test Master Table (Kraemer and Thiemann, 1987, pp. 105-112), and look up the value of ν for $\Delta = 0.864$ at the 1 percent significance level and 95 percent confidence power. Under these conditions, the value ν is < 12. Thus the desired sample size, n, based on this design is 12 subjects.

Design 2

The association of variables rather than their means (as in Design 1) are the focus of this design. Here we assume that the reaction time and helmet weight moment has a minimal correlation, say H_0: $\rho_0 = 0.5$. However, a correlation, $\rho > 0.90$, would indicate an excellent agreement. Using the Pearson product-moment correlation makes no assumption of equal variances between the variables but still assumes bivariate normal distribution. Thus, the number of subjects needed to reject the null hypothesis (H_0: $\rho \leq \rho_0$) is determined as follows.

$$\Delta = (\rho - \rho_0) / (1 - \rho\rho_0) \quad (4)$$

$$n = \nu + 2 \quad (5)$$

Substituting $\rho_0 = 0.5$ and ρ value > 0.90 (use $\rho = 0.91$) in equation (4), we obtain

$$\Delta = (0.91 - 0.50) / [1 - (0.91)(0.5)] = 0.75.$$

From the Master Table of Kraemer and Thiemann (1987), we look up the value of ν for 5 percent significance level, 90 percent confidence power, and one-tailed test. This value is $\nu = 10$. Therefore, the actual number of subjects is 12.

Design 3

There are two methods of associating two measures. The first is by randomly selecting a sample from both measures and estimating their correlation as done in Design 2. The second method, considered in this design, finds the relationship of reaction time (dependent) with respect to helmet weight moment (independent). Based on the results of previous studies, it is safe to assume that, for each subject, this relationship exhibits a linear function of the form

$$Y = \alpha + \beta X + \text{errors} \tag{6}$$

where the errors are independently normally distributed with mean 0 and standard deviation σ_E. The null hypothesis in this case is that increasing helmet weight moment beyond 80 N-cm does not degrade reaction time; hence, H_0: β=0. Power calculations for this hypothesis yield

$$\delta = \rho / [\sigma_x (1-\rho^2)^{1/2}] \tag{7}$$

$$\Delta = \delta / (\delta^2 + 1/s_x^2)^{1/2} \tag{8}$$

$$n = \nu + 2 \tag{9}$$

where:

ρ is the desired correlation, chosen as 0.9.

s_x^2 is a design parameter that is expressed as

$$s_x^2 = \sum_i (x_i - X)^2 / m \tag{10}$$

In Equation (10),

x_i's are the different weight moments,

X is the weight moment mean, and

m is the number of weight moments.

The term s_x^2 can also be approximated as the variance of x, σ_x^2 for large sample size, m. Choosing the x_i's to be 80, 95, 110, and 200 N-cm and using equation (10), $s_x^2 = 2180$.

The standard deviation, σ_x, is calculated and found to be 53.9. Substituting $\sigma_x = 53.9$ and $\rho = 0.9$ in equation (7), we obtain

$$\delta = 0.9 / [53.9 (1 - (0.9)^2)^{1/2}] = 0.281$$

Substituting $\delta = 0.281$ and $s_x^2 = 2180$ in equation (8), the critical effect size is

$$\Delta = 0.281 / ((0.281)^2 + 1/2180)^{1/2} = 0.997$$

From the master table, $\nu < 10$ which suggests number of subjects to be 12 for a 1 percent level, 99 percent confidence and one-tailed test.

Notice that each design has different levels of significance and power, ranging from the good probability of 5 percent level and 90 percent power (Design 2) to the excellent probability of 1 percent level and 99 percent power (Design 3). Thus a sample size of 12 subjects has a 90 percent or better, depending on the design, chance of rejecting the null hypothesis.

Number of helmet weight moments

In this investigation, subjects also will be exposed to helmet weight moments in the lower range (i.e., 20, 50, 65 N-cm). The reason is that upper safety limit for female subjects may occur at a lower level than of male subjects (refer to hypothesis in introduction section); hence, the linearity assumption of Design 3 will not be violated if upper safety limit is between 50 and 65 N-cm. A weight moment of 20 N-cm will be used to provide a broader range of the relationship of weight moment to the measurements. In addition, results from this helmet configuration will be compared to results obtained from a related male study (Alem, Meyer, and Albano, 1995) done on the same helmet configuration.

The above analysis in Design 3 is repeated to include weight moments 50 and 65 N-cm. In this case the x_i's in equation (10) are 50, 65, 80, 95, 110, and 200 N-cm.

Applying equations (7)-(10), Δ is found to be 0.998. Thus, the above finding of having 12 subjects still holds for the new range of weight moments with a 99 percent chance of success of rejecting the null hypothesis.

APPENDIX B

Subject Instructions & Affidavit

Subject Instructions

Mount and dismount the vibration table only when told to do so by the Safety Officer. Follow the Safety Officer"s instructions at all times. This person has a safety switch that will shut down the vibration table in the unlikely event of an emergency, such as a severe vibration or jolt from the vibration table. Such an event has never occurred in the operation of the table and it is very unlikely to occur due to the many safety features of this system. If at any time you feel you want to end the testing prematurely, look at the Safety Officer and tell him that you want to stop the testing. The Safety Officer will shut down the table and you can dismount the table.

DO YOU HAVE ANY QUESTIONS ON THE SAFETY OF THIS TEST FACILITY?

Prior to Experiment

Prior to the testing, a dental molding impression of your bite will be taken on a U-shaped bite plate. This plate will be attached to a lightweight bar to which we have attached four miniature motion sensors. Because of the exact registration with your teeth, we will be able to calculate precisely the location of the sensors relative to anatomical features on the skull.

To do that, we will also need to take a lateral x-ray of your head while biting on the bite-bar. From the x-ray image, the head anatomical reference frame will be determined allowing the precise computation of head vibration. The x-ray facilities at Lyster Hospital are within a walking distance from USAARL building and will be used to obtain the lateral x-ray.

Dependent on the recommendation of the medical examiner, you may be asked to take a pregnancy test. The examiner will provide you with the appropriate test kit. If the results of the pregnancy test are positive, you will not be allowed to participate in this experiment.

Your test sessions will be scheduled at between day 10-20 from your menstruation. Therefore, you need to inform us as soon as your menstrual cycle starts. From the day of menstruation until the end of your participation, you will provide a urine sample on a daily basis. Disposable containers will be provided to you in advance. The purpose of the urine test which will be done at the USAARL biochemistry lab is to monitor your hormone status and will not be used for any other purpose.

DO YOU HAVE ANY QUESTIONS?

Test sessions

You will be asked to sit on a seat on top of a vibration platform. During the main portion of the testing, you will wear a specially designed helmet which allows us to vary the amount and location of helmet weight. You will be exposed to one and a half hours of whole-body vibration. The vibration you will experience is similar to that experienced by a crewmember of a U.S. Army UH-60 (Black Hawk) helicopter.

Before and after the vibration, you will do a series of neck muscle exertions. During the neck muscle exertions and while you are being vibrated, myoelectric measurements will be taken from the muscles around your neck and upper back. To obtain these measurements, electrodes will be placed on your skin over four of the muscles of your neck and two of your upper back. These electrodes measure the electrical activity in your muscles. Measurements of your posture also will be taken during the vibration exposure. To obtain these measurements, markers will be placed on your skin and clothing. In preparation for placement of the electrodes and markers, your skin will be rubbed with an alcohol pad to remove a fine layer of dead skin. You may experience some redness due to the rubbing of your skin, but this should clear up in about a day.

During the vibration, you will be asked to sit in a relaxed posture. You will do a series of performance tasks of equal duration. There are three different types of performance tasks: target tracking, target acquisition, and cognitive performance tests.

Target Tracking: For the tracking task, you will move your head as needed to keep the light beam mounted on your helmet at the center of a moving board in front of you. Whenever your light beam moves off the target, a computer will record the amount of error.

Target Acquisition: For the target acquisition task, you will move your head as needed to locate targets in front of you when they light up. The target lights will turn off when you aim the light beam from your helmet at the target. A computer will record the amount of time you take to turn off the targets.

Multiple Attribute Task Battery (MATB): The overall purpose of this task is to understand human performance during varying levels of "busyness." You may think of this task as an arcade game which requires the use of a joystick, a keyboard, and reading a computer screen. The task is a computerized simulation of tasks that pilots perform. Each window of the screen represents a different task: System monitoring, tracking, communications and resource management. While eventually you will be asked to perform all of these tasks at the same time, to become familiar with the different tasks you will be introduced to each task one at a time. Prior to testing, you will be given the opportunity to practice the MATB until your improvement in your score becomes small.

DO YOU HAVE ANY QUESTIONS AT THIS POINT?

MATB - System Monitoring

This task consists of two parts: lights and dials. You will be monitoring the two lights at the top of this window for any changes. You will also be monitoring the four dials beneath them for any directional changes in the fluctuation of the pointer. During normal conditions, the left light is on in green, but occasionally, this green light will go out. When this happens, you must press the "F5" key as indicated next to that light. With the mouse version, you must move the mouse cursor within the rectangular green light area and press a mouse button. You will receive feedback in that the light will immediately turn back on. Normally, the second light is off, but occasionally, a red light will turn on in this position. To respond to this, you must press the "F6" key, also indicated next to that light or move the mouse cursor to the red light area and press a mouse button. Again, as soon as you respond correctly, the red light will disappear.

The second part of this task consists of monitoring the four dials below the lights. Normally, the yellow pointers fluctuate from one unit below to one unit above the center line. Your task is to monitor these four dials and detect any change from the normal fluctuation of the pointer. In other words, if the pointer of one of these dials fluctuates either above or below the normal range, you must respond. The correct response is the key that is indicated below the dial which is out of range. If you are using the mouse, simply move the mouse cursor within the out-of-range dial area and press either mouse button.

You'll notice that feedback to a correct response is given by the presence of a yellow bar at the bottom of the dial that was out of range and a return to center of that dial pointer. Again, the abnormal fluctuation can occur in either direction - above or below - but there is only one response per dial.

MATB - Tracking

The overall purpose of this task is to keep the airplane symbol, represented by the green circle, within the dotted rectangular area in the center of this window. If you do not control the plane with the joystick, the plane will drift away from the center. You must control the plane with movements of the joystick. Basically, you must compensate for this random drifting by pulling the plane back to center with corresponding movements with the joystick. For example, if the plane is drifting to the right, moving the joystick to the left will return the ship to center. Most of the time, however, you will be working in two dimensions: horizontal and vertical; so you will be making many diagonal movements.

DO YOU HAVE ANY QUESTIONS ON THE MATB-TRACKING?

MATB - Communications

The overall purpose of this task is to discriminate between audio signals which will be presented through head-phones and to respond as indicated.

The messages that you will hear begin with a six-digit call sign followed by a command. These call signs consist of three letters followed by three numbers. You must respond only when you hear your personal call sign which is NGT504. This number will remain on the screen at all times as a reminder to you. Any other call sign is not meaningful to you.

The second part of the message involves a command and you must respond to those that follow your call sign only. Do not respond if the message begins with a different call sign. The second part of the message is a command requiring you to change one of the frequency numbers listed on the screen. There are four channels listed in the left column on the screen: NAV1, NAV2, COM1, COM2. These will be referred to in the audio message as: First Navigation, Second Navigation, First Radio and Second Radio. Notice that COM 1 and COM2 are referred to as radio channels. In the right column are the frequency numbers that correspond to each channel.

In order to change the frequency numbers, you must use the left and right arrow keys (click on these areas with the mouse). The right arrow key increases the number by intervals of 0.2 and the left arrow key decreases the number by intervals of 0.2.

Remember, the overall goal of this task is to distinguish correctly messages beginning with your call sign and respond to those commands.

MATB - Resource Management

This task is considered a fuel management task. The rectangles are tanks which hold fuel, the green levels within the tanks that increase and decrease are fuel, and along the lines which connect the tanks are pumps which transfer fuel from one tank to another in the direction that is indicated hy the arrow. The numbers underneath four of the tanks represent the amount of fuel in units for each of these tanks. This number will be increasing and decreasing as these levels change. The capacity for the main tanks, A and B, is 4000 units each. The supply tanks, C and D, contain a maximum of 2000 units each. The supply tanks on the right of each three-tank system have an unlimited capacity - they never run out.

Your overall goal with this task is to maintain the levels of fuel in tanks A and B at 2500 units. This critical level is indicated by the tick mark in the shaded area on the side of each of these tanks. This level is also indicated by the numbers underneath each tank. It is acceptable to keep the level of fuel within the shaded area between 2000 and 3000 units. However, optimum performance is obtained when tanks A and B are at 2500 units.

In order to meet this criterion, you must transfer fuel to tanks A and B because tanks A and B lose fuel at the rate of 800 units per minute (default; select at setup). So you can see that with their present levels of approximately 2400 units each, these tanks would become empty in slightly more than 3 minutes without the transfer of additional fuel. Tanks C and D only lose fuel if they are transferring fuel to another tank. The process of transferring fuel will be demonstrated to you.

Head motion

After a 15 minute break following the first helmet session, you will be asked to hold a bite bar in your mouth while seated on the vibration table. To ensure a good fit for the bite bar, dental molding compound will be applied to the mouthpiece of the bite bar to fit it to your mouth. This fitting procedure will be done several days prior to the testing. You will remove and re-insert the bite bar, as needed, throughout the test. Using a surgical marking pen, two facial landmarks will be marked. While wearing the helmet and biting on the bar, a lateral photo will be taken using a high-resolution digital camera. The picture will be examined to ensure the landmarks are visible and the quality is acceptable. From the two landmarks, the head reference frame can be identified.

With the helmet on, you will be exposed to 12 vibration sessions. Each vibration session will be about 1 minute. After each exposure, the configuration of the helmet you are wearing will be changed by adjusting the weight and center of mass. So, at times the helmet may feel heavier and at other times it may feel lighter. The vibration session you will experience will gradually change from low to high frequency.

THIS IS THE END OF THE BRIEFING

DO YOU HAVE ANY QUESTIONS?

VOLUNTEER AGREEMENT AFFIDAVIT

For use of this form, see AR 70-25 or AR 40-38; the proponent agency is OTSG.

PRIVACY ACT OF 1974

Authority:	10 USC 3013, 44 USC 3101, and 10 USC 1071-1087
Principal Purpose:	To document voluntary participation in the Clinical Investigation and Research program. SSN and home address will be used for identification and locating purposes.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; adjudication of claims; and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this investigational study.

PART A -- VOLUNTEER AFFIDAVIT

Volunteer Subjects in Approved Department of Army Research Studies

Volunteers under the provisions of AR 40-38 and AR 70-25 are authorized all necessary medical care for injury or diseaese which is the proximate result of their participation in such studies.

I, _____ SSN _____
having full capacity to consent and having attained my _____birthday, do hereby volunteer to participate in ***The research protocol entitled "Effects of Head-supported Devices on Female Aviators During Simulated Helicopter Rides"***
under the direction of ***Dr. Nabih M. Alem, Research Biomedical Engineer***
conducted at ***the U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL 36362-0577***

The implications of my voluntary participation; the duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by a member of the USAARL research team:

❑ ***Dr. Alem*** ❑ ***Dr. Barazanji*** ❑ ***Ms. Dodson*** ❑ ***SSG Erickson***

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or study-related injury, I may contact: ***The Command Judge Advocate***

located at ***Headquarters, United States Army Medical Research and Materiel Command, Fort Detrick, Maryland. Telephone: DSN 343-2065 or Commercial (301) 619-2065***

WITHDRAWAL: I understand that I may at any time during the course of the study revoke my consent and withdraw from the study without further penalty or loss of benefits; however I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of the attending physician, such examinations are necessary for my health and well-being. My refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

PART B -- TO BE COMPLETED BY INVESTIGATOR (page 1 of 2)

INSTRUCTIONS FOR ELEMENTS OF INFORMED CONSENT: *(Provide a detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.)*

The U.S. Army Aeromedical Research Laboratory (USAARL) is conducting research to evaluate the effects of various helmet configurations on neck fatigue and task performance in women during simulated helicopter rides. This research effort will take place in building S713A, Fort Rucker, Alabama. You underwent medical and physical screening to determine your fitness to participate in this study and were found to meet the requirements.

Your participation in this project will involve eight sessions lasting about 2 hours each. You will be seated in a modified UH-60 seat mounted on top of the Multiaxis Ride Simulator (MARS) which has been programmed to produce whole-body vibration similar to those experienced in a UH-60 and elsewhere. None of the vibration will exceed the safety levels specified by the International Organization for Standardization (ISO 2631, 1985).

Prior to the vibration test, you will be fitted with a bite bar which feels similar to a sports mouth guard. To ensure a good fit for the bite bar, dental molding compound will be applied to the mouthpiece of the bite bar to fit it to your mouth. You will be asked to hold this bite bar in your mouth. We will take one x-ray of your head with the bite bar.

In one of the test sessions, you will be exposed to sinusoidal vibration during which head acceleration data will be collected as you hold the bite bar in your mouth. We will take a profile photograph of your head with the bite bar inserted for the purpose of analysis. You will remove and re-insert the bite bar, as needed, throughout the test.

During this experiment, you will wear a helmet simulation device and you will be asked to maintain a relaxed posture. Prior to the testing, this helmet will be custom fitted to your head using thermoplastic liner (TPL™). The helmet weight and the distribution of the weight will be varied to simulate different configurations. While you are exposed to whole-body vibration, you will conduct a series of performance tasks. These tasks include a target tracking, a target acquisition, and a performance task. Prior to the testing, you will be asked to come to the lab to practice these tasks until you feel comfortable performing them.

We will measure the electromyographic (EMG) activity of your neck and upper back muscles during the vibration exposure. To measure neck muscle EMG activity, electrodes will be taped to your skin around the circumference of your neck and upper back. These electrodes pick up the electrical energy produced by your muscles when they contract. In order to make good electrical contact with your skin, a technician will vigorously rub the areas where the electrodes will be placed with an alcohol pad. A conductive paste will be applied to the electrode before it is taped down to improve electrical contact even further. This preparation is absolutely essential; movement of the electrodes during the experiment will ruin the data.

We will measure your posture during the vibration exposure. To do so, markers will be attached to your skin on your chest over the sternum, at the back of your neck over the thoracic vertebrae, on the helmet, and on the seat back. In order to place the markers over the thoracic vertebra and sternum, a technician will vigorously rub the areas with an alcohol pad and then with tincture of benzoin. Collodion, an adhesive substance, will be applied to a plexiglass mount for the markers and will be glued to your skin. This glue will be removed from your skin following the testing using acetone, the same active ingredients found in nail polish remover.

A safety officer will monitor you at all times during vibration. If, at any time, you feel you would like to terminate a testing session, you can tell the safety officer of your request and the testing will end. Also, if you cannot complete the tasks that you are required to perform, the vibration will end. You may withdraw from this study at any time without prejudice.

PART B -- TO BE COMPLETED BY INVESTIGATOR (page 2 of 2)

CONFIDENTIALITY: All data and medical information obtained about you as an individual will be considered privileged and held in confidence. However, complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or Command authorities. In addition, applicable regulations indicate the possibility that U.S. Army Medical Research and Materiel Command (USAMRMC) officials may inspect the records.

BENEFITS: No benefits can be guaranteed as a result of your participation; however, the data from this study may lead to design or training improvements to make the soldier of the future more effective. Data which you help generate also may lead to design or training standards to make flight with a head-supported mass safer and less fatiguing.

RISKS: There is a possibility of a mild skin irritation from the preparation of the skin on your neck for the electrodes and markers. The vibration you experience may be annoying at times, and it may cause mild discomfort. The vibration system is like any other mechanical system - it can fail. In the event of a failure, you may experience a jolt of up to five times that of gravity (5 G). This may cause you some concern and may result in injury. The chance of this happening is very remote because of the many redundant safety features of the vibration system. No injury has occurred while operating this system in the 15 years of its use. There is a possibility that you may experience some stiffness and fatigue in your neck muscles after the testing. In any case, medical attention will be available within 5 minutes in the unlikely event of an accident or injury. A medical officer may require you to undergo a physical examination or other medical tests if he/she suspects you may have been injured in any way during the testing.

If you have any questions regarding this study or your participation, ask them. They will be answered to the best of our ability. No data from this study will be released with information identifying you personally without your express consent. Photographic data from your session with your picture may be used in communicating the results of this study.

(Check one & initial) _____

☐ I do ☐ do not consent to the inclusion of this form in my outpatient medical treatment record.

_____ _____

Signature of volunteer Date

_____

Permanent address of volunteer

_____ _____ _____

Witness name Witness signature Date

APPENDIX C

Multi-Axis Ride Simulator (MARS) Facilities

Multi-Axis Ride Simulator (MARS) Facilities

1. The MARS consists of the following equipment:

   a. Two hydraulic pumps, operating in parallel, each rated at 80 gallons per minute at 3000 pound per square inch (psi) with a 200 gallon reserve.

   b. Three orthogonally-mounted transnational hydraulic actuators having a 3-stage valve system. Actuators are connected to the driven mass through drive links and flexures.

   c. A hydraulic accessory module for each axis, which switches hydraulic oil flow to the actuators.

   d. Fail-safe valves for each axis, capable of shutting down oil flow to the actuator within 20 milliseconds of the command to "FAIL/SAFE."

   e. Shock absorbers are used to stop the mass in a controlled manner.

   f. A three-channel digital servo-controller (Schenck/Pegasus Model 5900-OTF).

   g. Pentium PC system connected by high-speed fiber optic link to the 5900 controller.

2. The MARS capabilities and specifications are as follows:

   a. Up to 600-pound test load.

   b. Frequency response of 5 - 40 Hz, +/- 1 dB.

   c. Up to 4 G peak acceleration, limited by displacement for frequencies below 6 Hz.

   d. Peak-to-peak displacement, approximately 4 inches useful.

   e. Shutdown of the entire system occurs within 20 milliseconds of "FAILSAFE" command from any of the following parameters:

      (1) External overhead "paddle" switches

      (2) Front-panel safety switches on 5900 servo controller(3) AC power interruption

(3) Preset displacement or acceleration limit excedance

(4) Anticipation "look-ahead" feature limit excedance

(5) Data signal/reference signal comparison

(6) Accelerometer signal loss

(7) Inner or outer loop LVDT signal loss

(8) Subject/Medical Safety Officer/Operator switches

3. Control of the MARS table is accomplished as follows:

a. The excitation signals stored in the PC are routed to the MARS actuators through the multi-channel servo-controller.

b. Command "drive" signals are applied to the first stage of the 3-stage valve of each axis. The first stage consists of a "force motor" which is a pendulum secured within the field of the force motor transformer. When excitation is applied in the form of a command signal, the pendulum moves back and forth, and the end of the pendulum moves between two ports. This allows oil to flow through these ports proportionally to the excitation. The oil thus ported is used to move a spool valve which, in turn, ports oil at a higher pressure to move a larger spool valve which, in turn, ports oil at operating pressure to move the hydraulic actuator RAM. The movement of the RAM thus is proportional to the excitation signal.

c. The on-line transfer function compensation feature of the 5900 controller differs from methods used in other digital control systems. The reduction of the control error is performed on-line, with the compensation of the desired acceleration signal being done in the time domain. This contrasts to older systems that do their compensation off-line, and in the frequency domain. The actuator command signals are corrected immediately after the occurrence of a control error by a comparison between the achieved response and the desired response signal. Iteration continues until the system reaches pre-set limits of signal quality.

d. Acquisition, identification, iteration, editing, and output of signals are accomplished by versatile software contained in the PC and in the 5900 controller. In addition to the multi-channel control application, the system also can be used to analyze test data or to generate drive signals.

4. Head Tracking Apparatus

A unique helmet-mounted tracking task evaluates human performance. This task requires the subject to point a helmet-mounted light source at a moving target placed in front of the subject. The target board consists of a 16"x16" photosensitive array with a small white light located at the center. The target moves along a horizontal and vertical arc to maintain a target-to-eye distance of 80". Target rates are user programmable up to 12 degrees per second. During testing, the subject keeps the helmet-mounted light spot pointed at the target white light. Data acquired from this task is stored on a PC computer and consists of a trial header with the horizontal and vertical location of the helmet-mounted light spot measured relative to the lower left corner of the target board. Typical measures of performance include average vertical and horizontal error, crest factor, and RMS error.

APPENDIX D

Samples of Performance Data

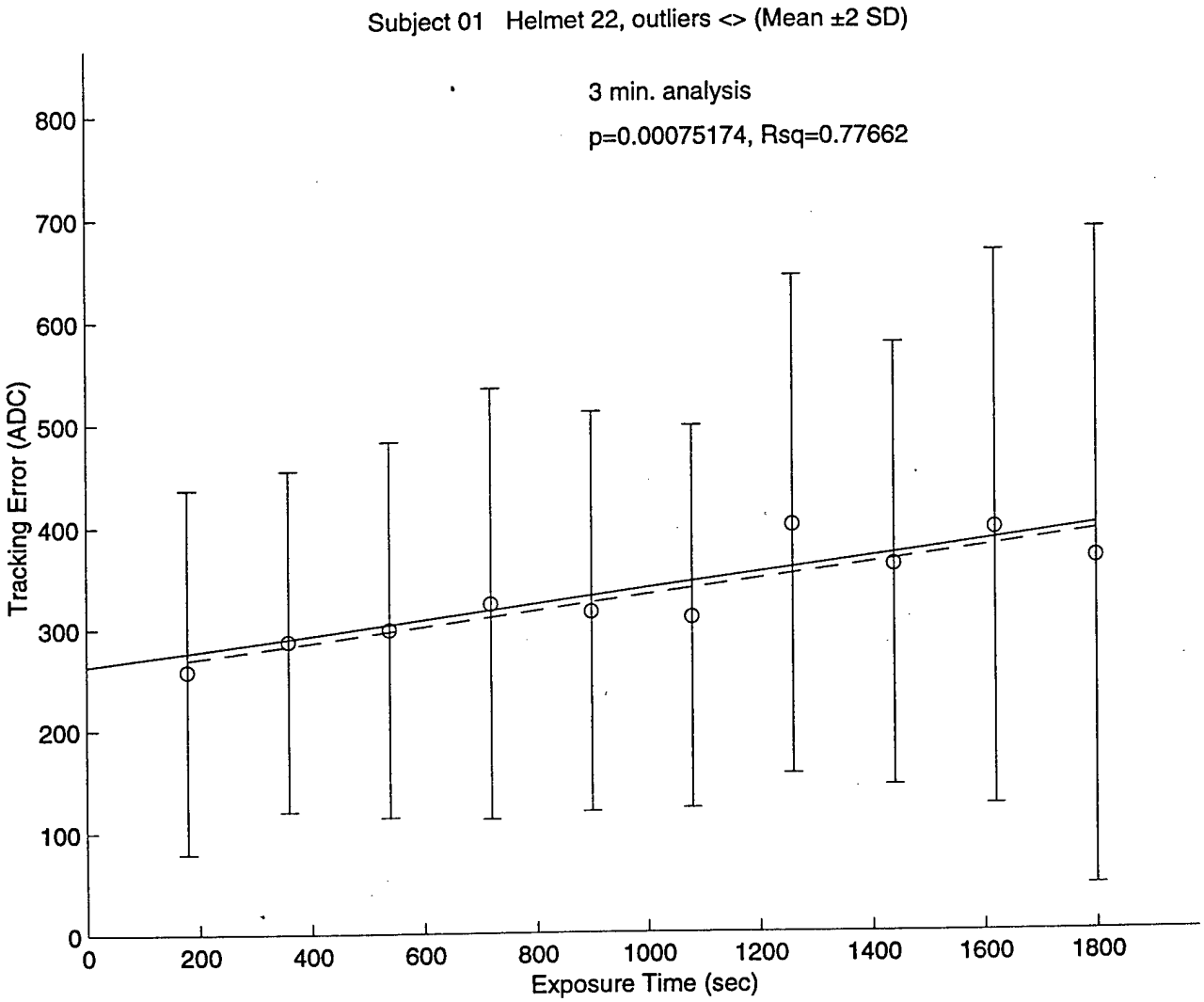

Figure D-1. Tracking error during random WBV for subject 01 wearing helmet 22. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

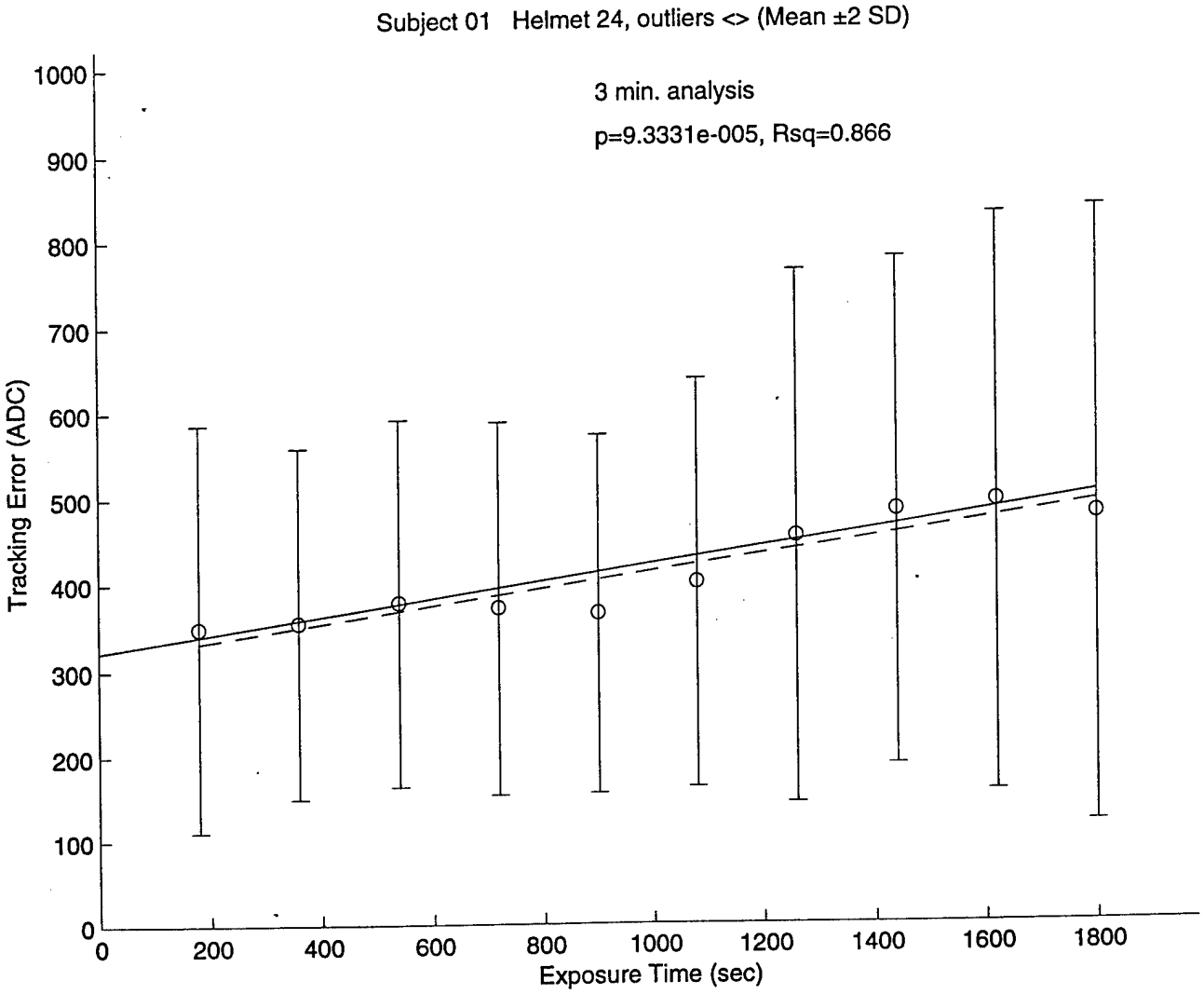

Figure D-2. Tracking error during random WBV for subject 01 wearing helmet 24. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

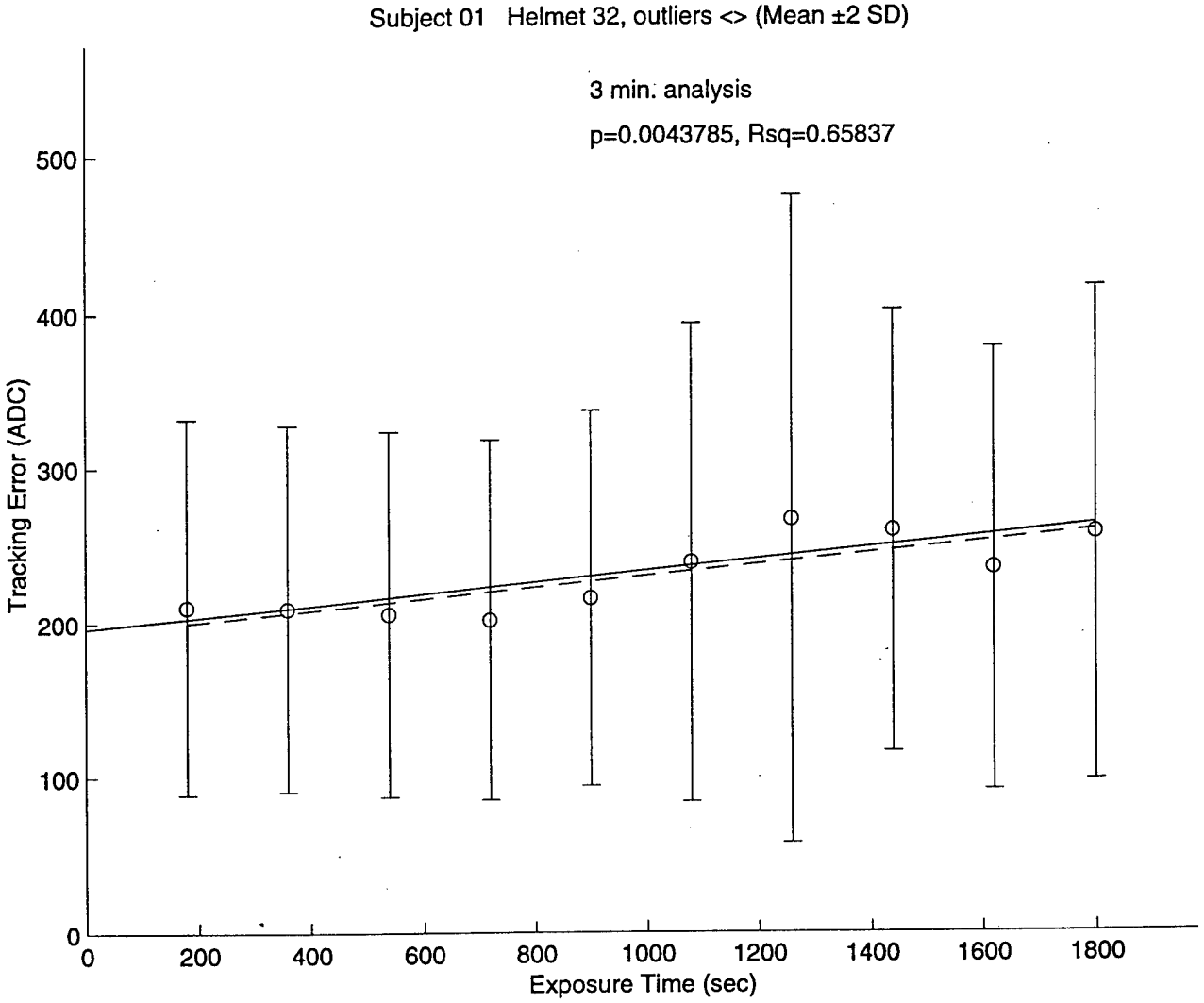

Figure D-3. Tracking error during random WBV for subject 01 wearing helmet 32. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

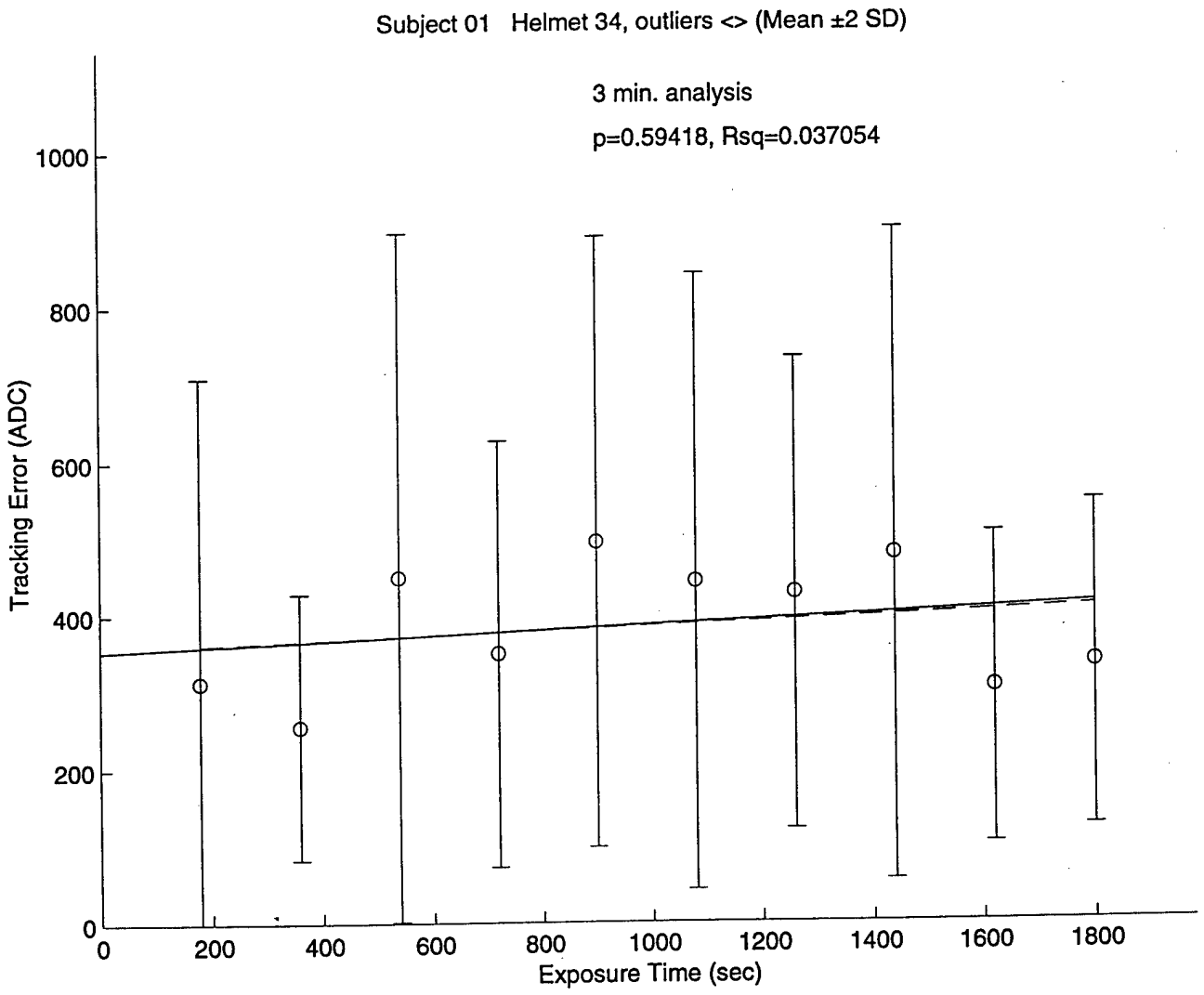

Figure D-4. Tracking error during random WBV for subject 01 wearing helmet 34. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

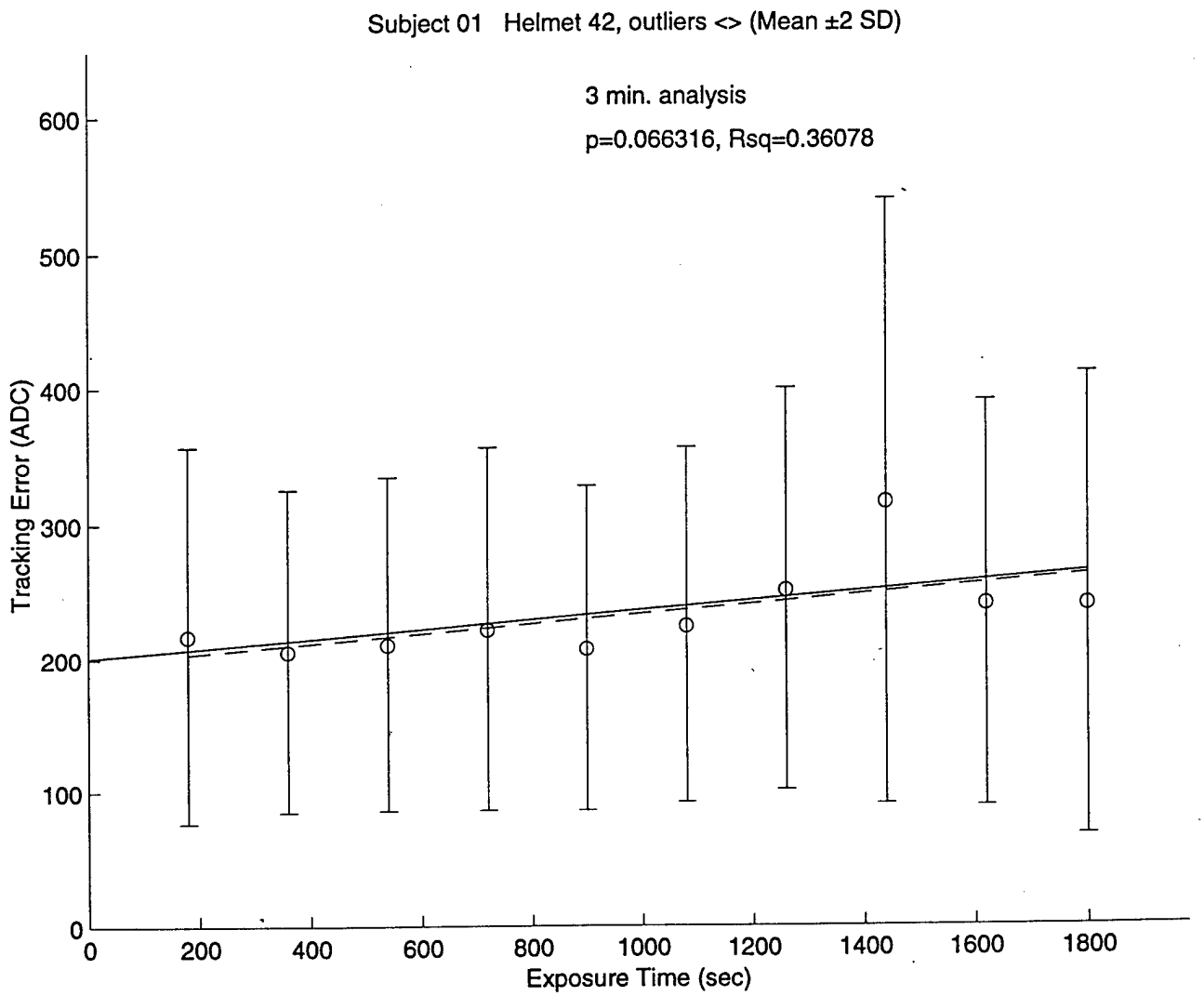

Figure D-5. Tracking error during random WBV for subject 01 wearing helmet 42. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

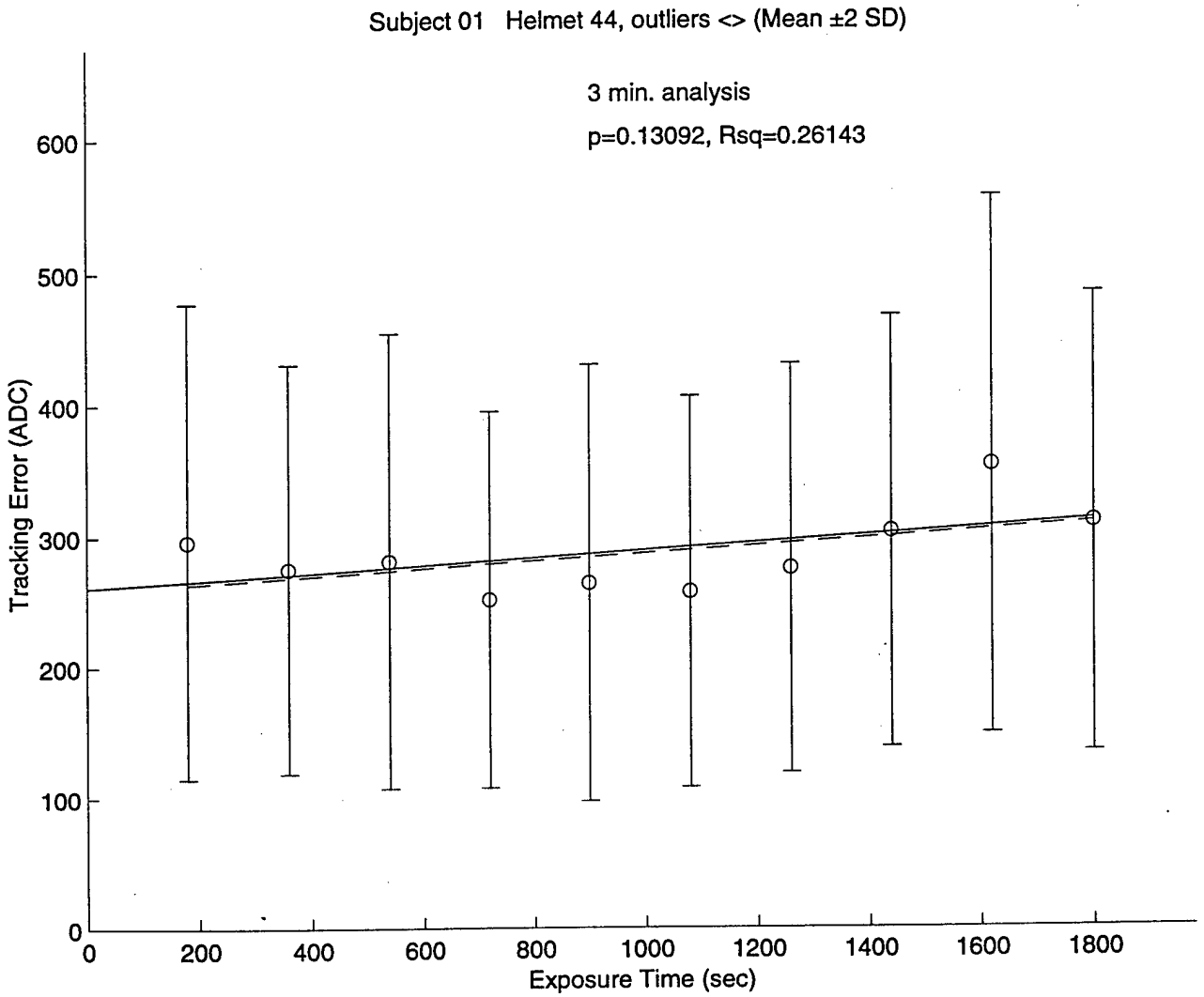

Figure D-6. Tracking error during random WBV for subject 01 wearing helmet 44. Circles represent 3-minute averages. Vertical error bars represent ± one SD. The solid sloped line represents best linear fit of all data. The dashed line is the best linear fit of the averaged values.

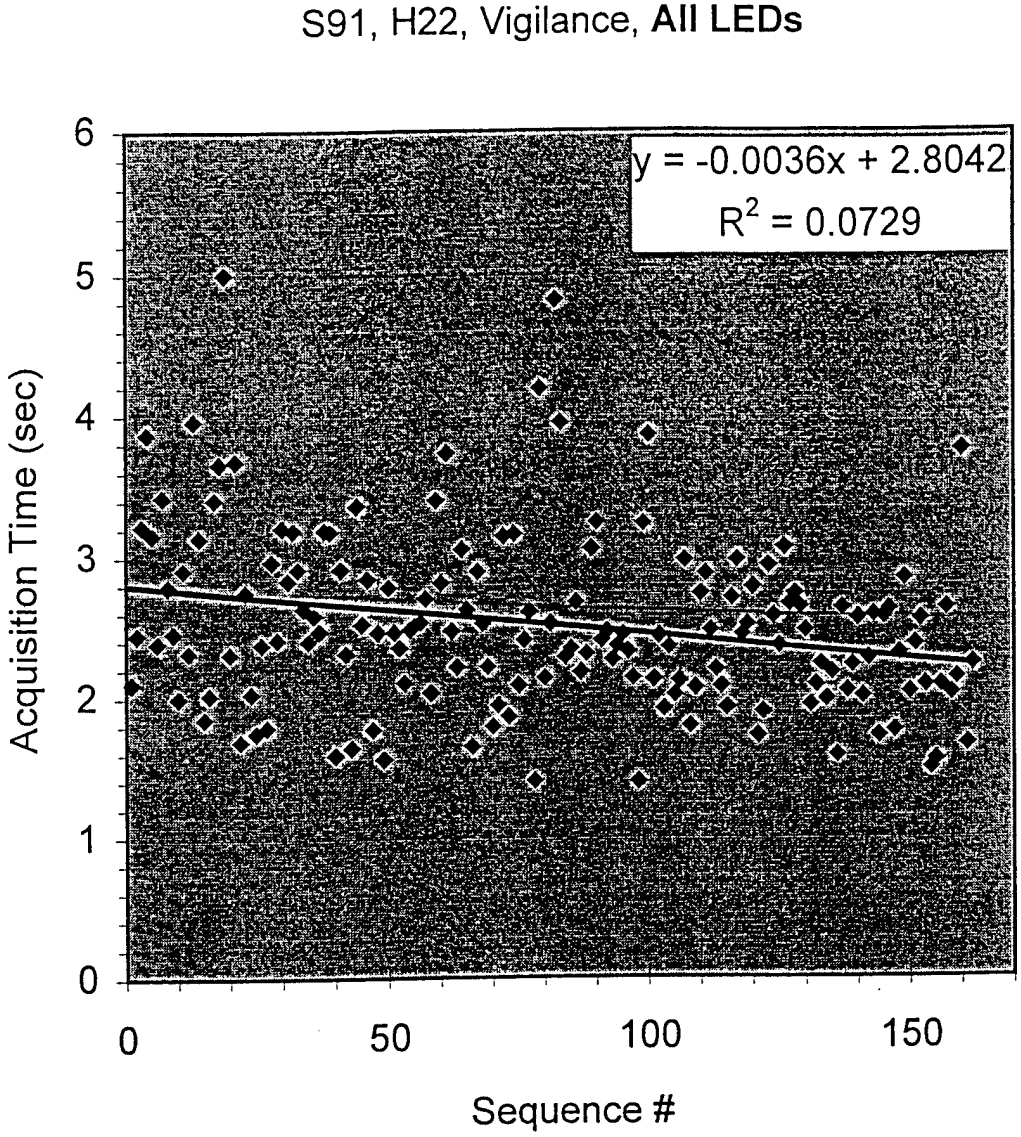

Figure D-7. Acquisition time of all LED's during random WBV for our preliminary subject wearing helmet 22. Sequence # is the order of LED appearance, which is indicative of exposure time.

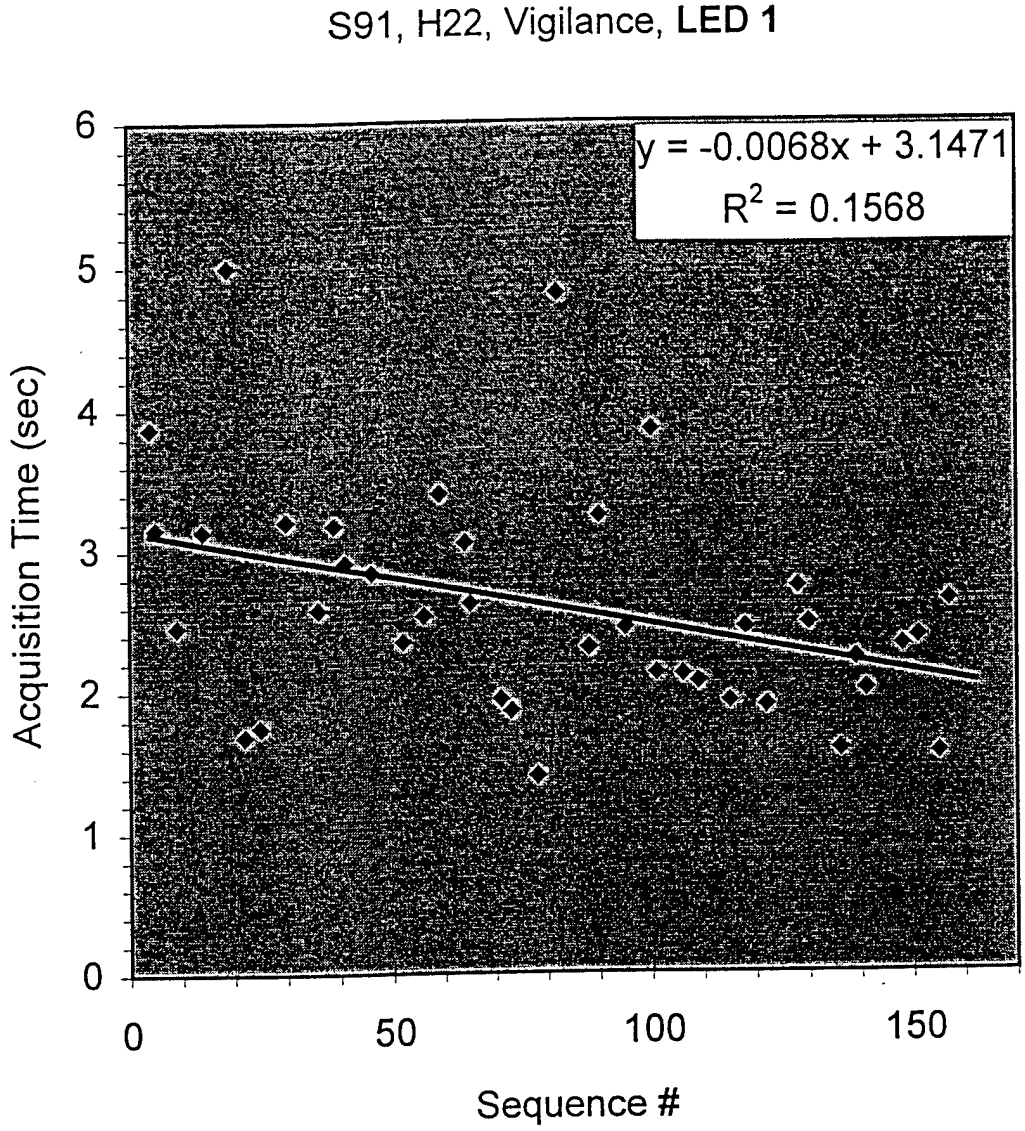

Figure D-8. Acquisition time of LED No. 1 during random WBV for our preliminary subject wearing helmet 22. Sequence # is the order of LED appearance, which is indicative of exposure time.

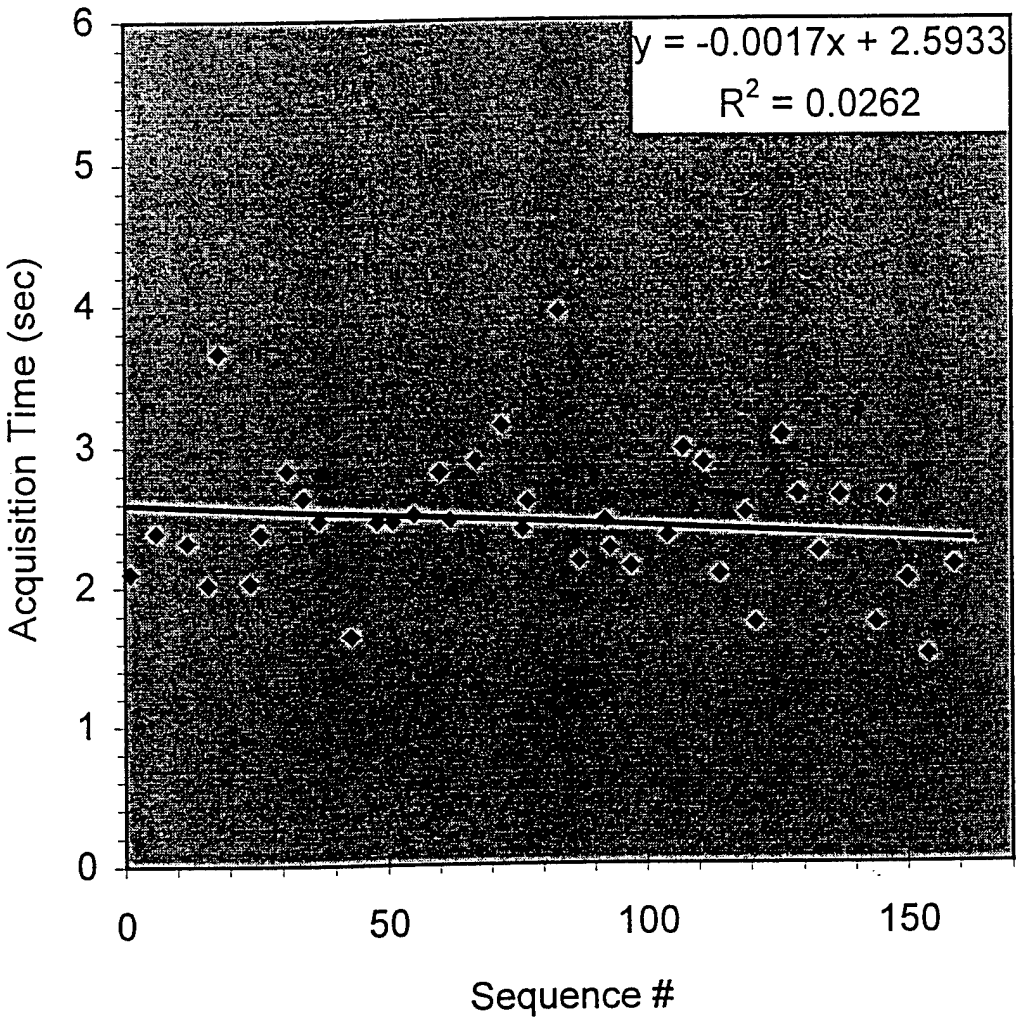

Figure D-9. Acquisition time of LED No. 2 during random WBV for our preliminary subject wearing helmet 22. Sequence # is the order of LED appearance, which is indicative of exposure time.

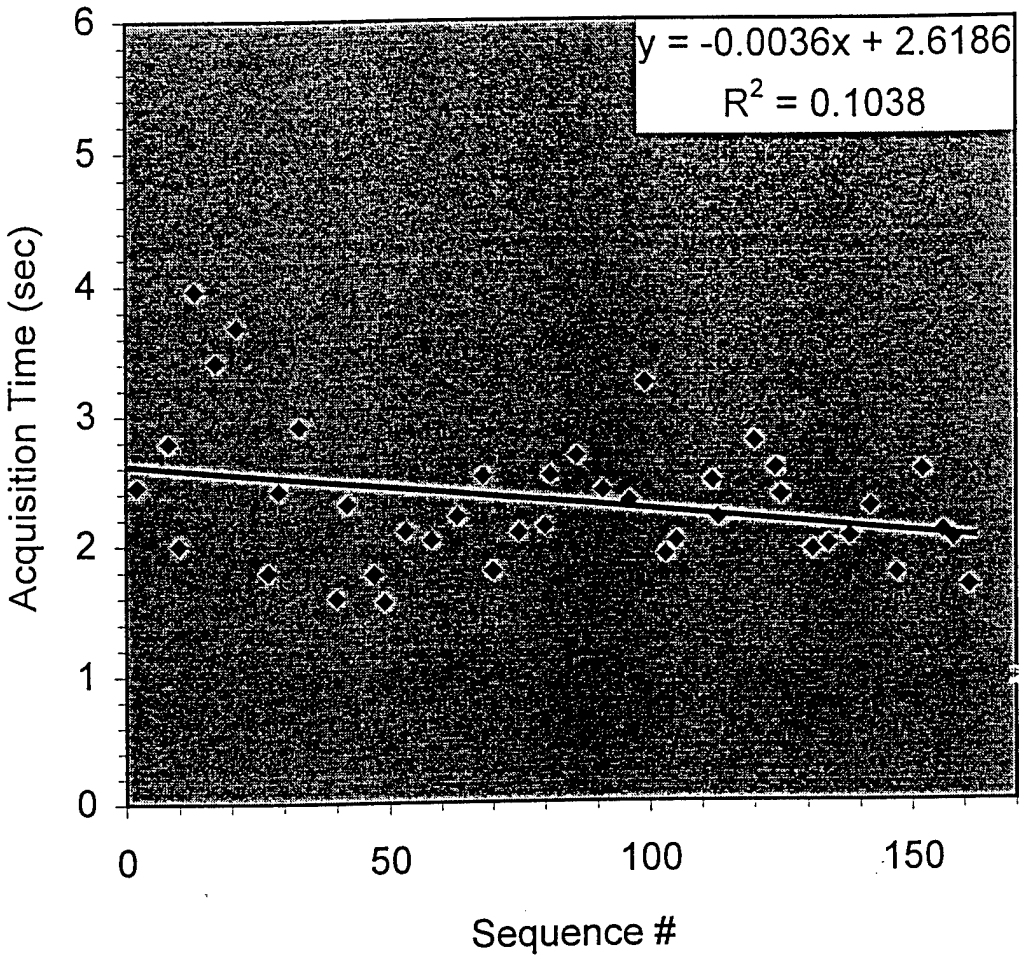

Figure D-10. Acquisition time of LED No. 3 during random WBV for our preliminary subject wearing helmet 22. Sequence # is the order of LED appearance, which is indicative of exposure time.

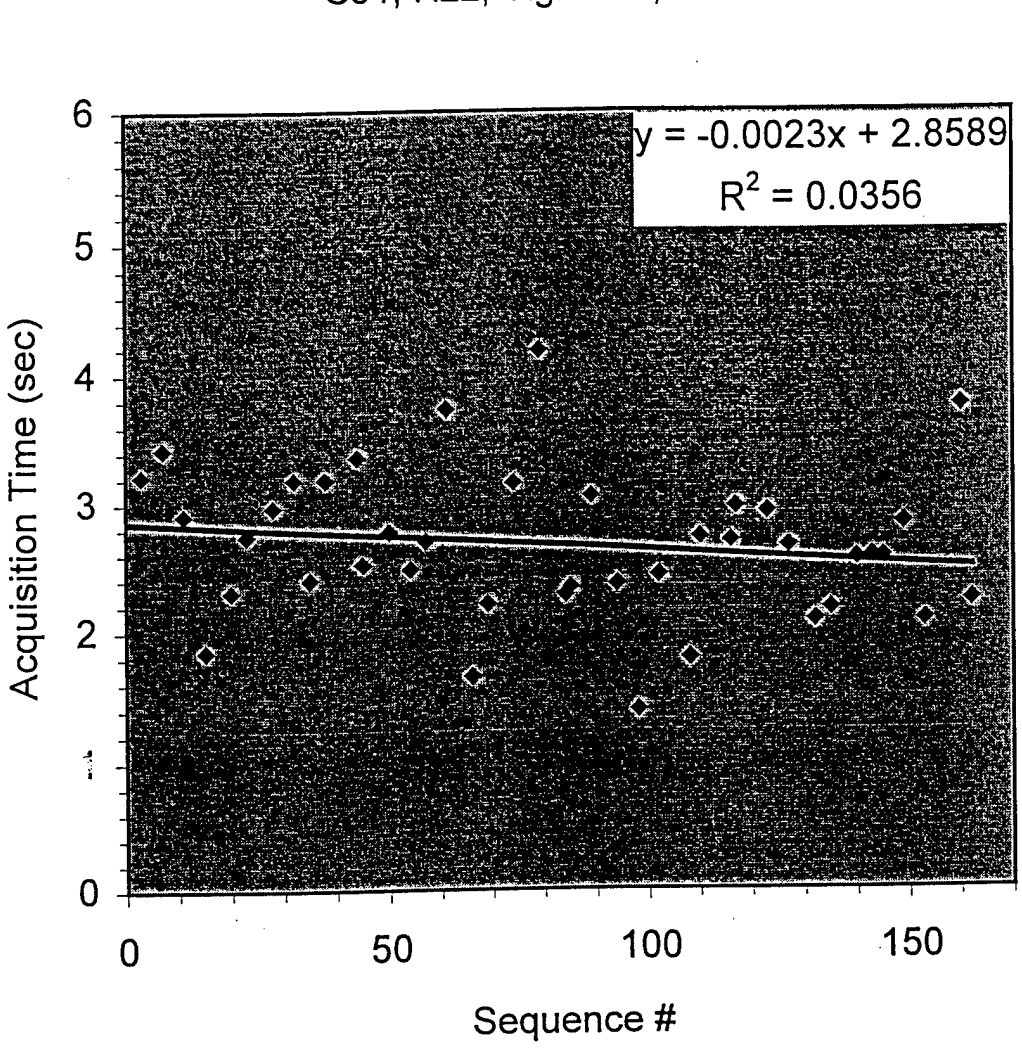

Figure D-11. Acquisition time of LED No. 4 during random WBV for our preliminary subject wearing helmet 22. Sequence # is the order of LED appearance, which is indicative of exposure time.

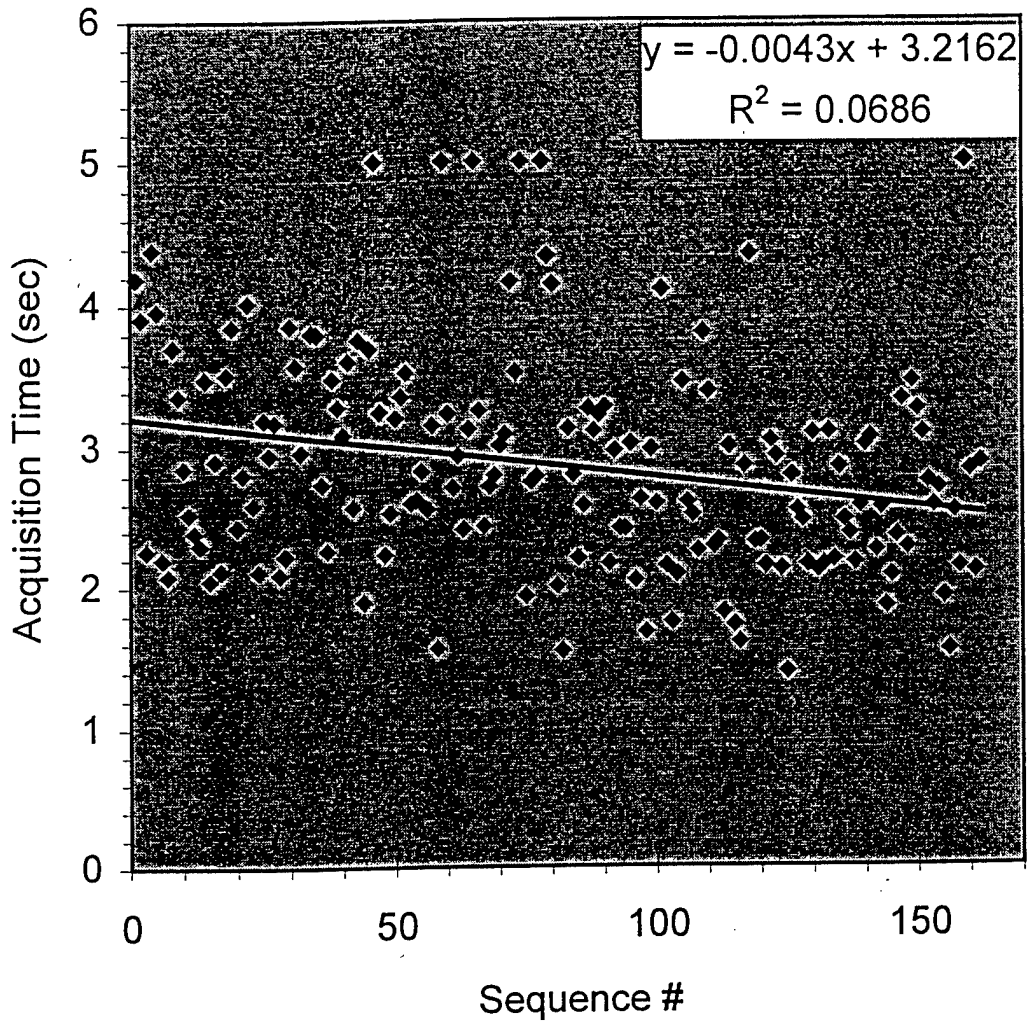

Figure D-12. Acquisition time of all LED's during random WBV for our preliminary subject wearing helmet 42. Sequence # is the order of LED appearance, which is indicative of exposure time.

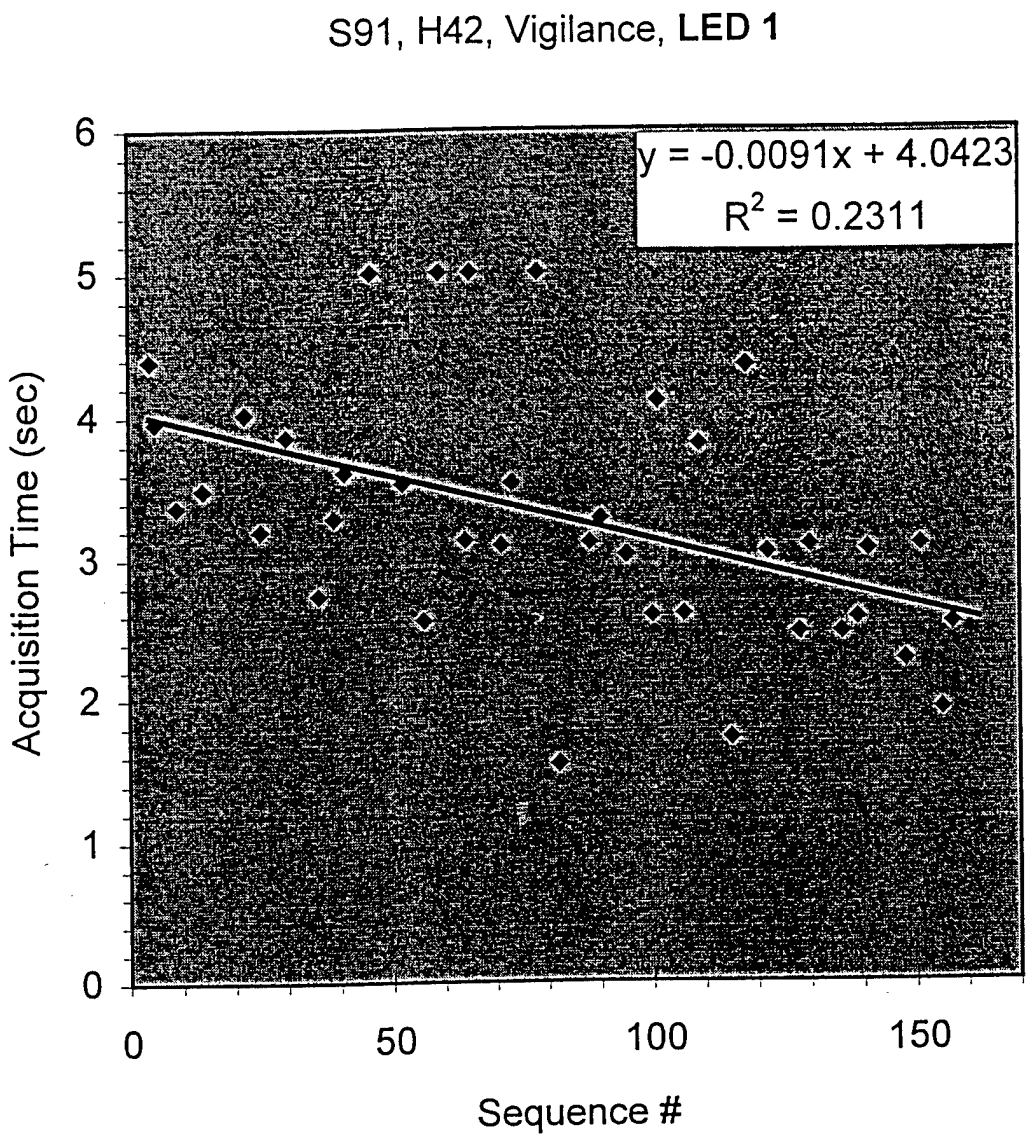

Figure D-13. Acquisition time of LED No. 1 during random WBV for our preliminary subject wearing helmet 42. Sequence # is the order of LED appearance, which is indicative of exposure time.

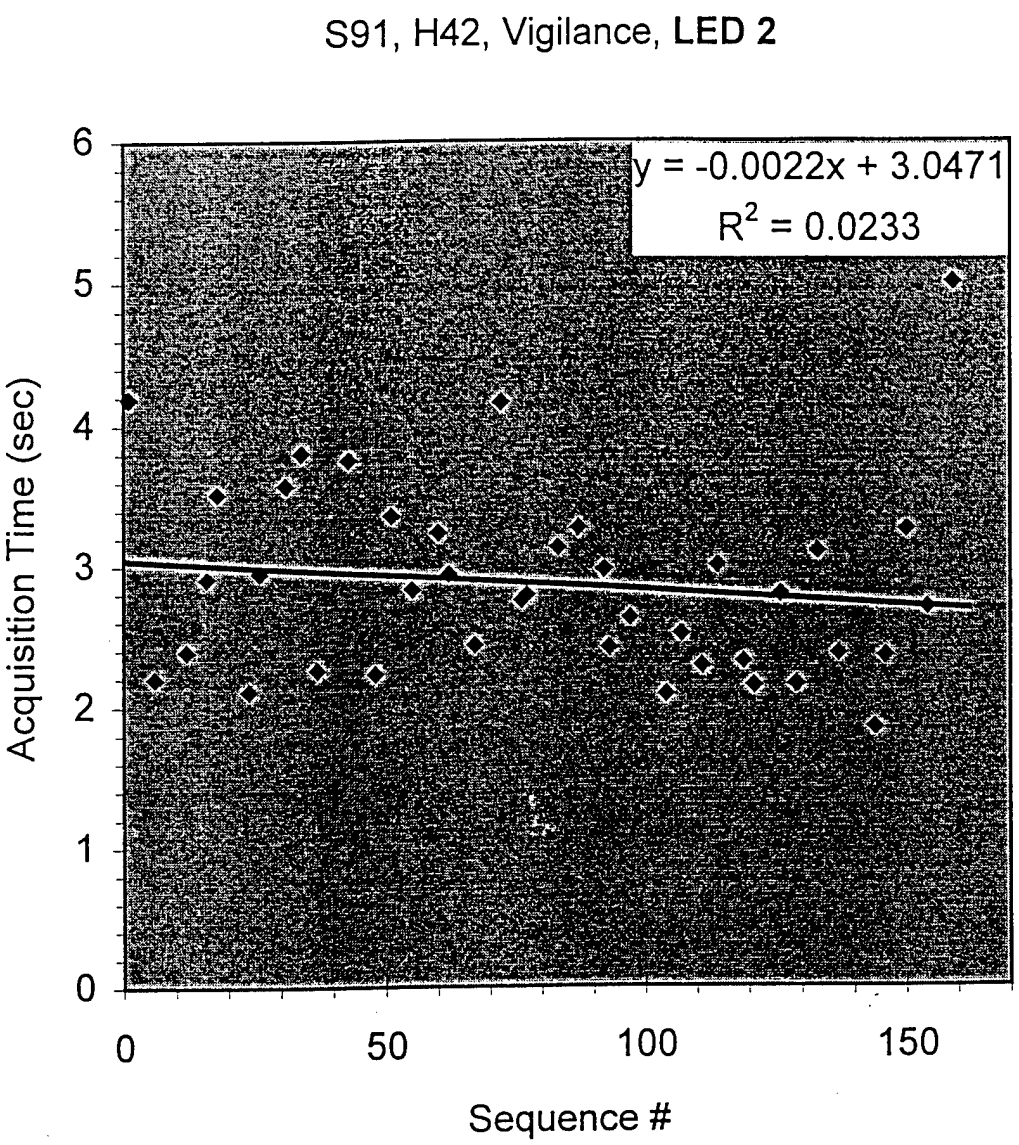

Figure D-14. Acquisition time of LED No. 2 during random WBV for our preliminary subject wearing helmet 42. Sequence # is the order of LED appearance, which is indicative of exposure time.

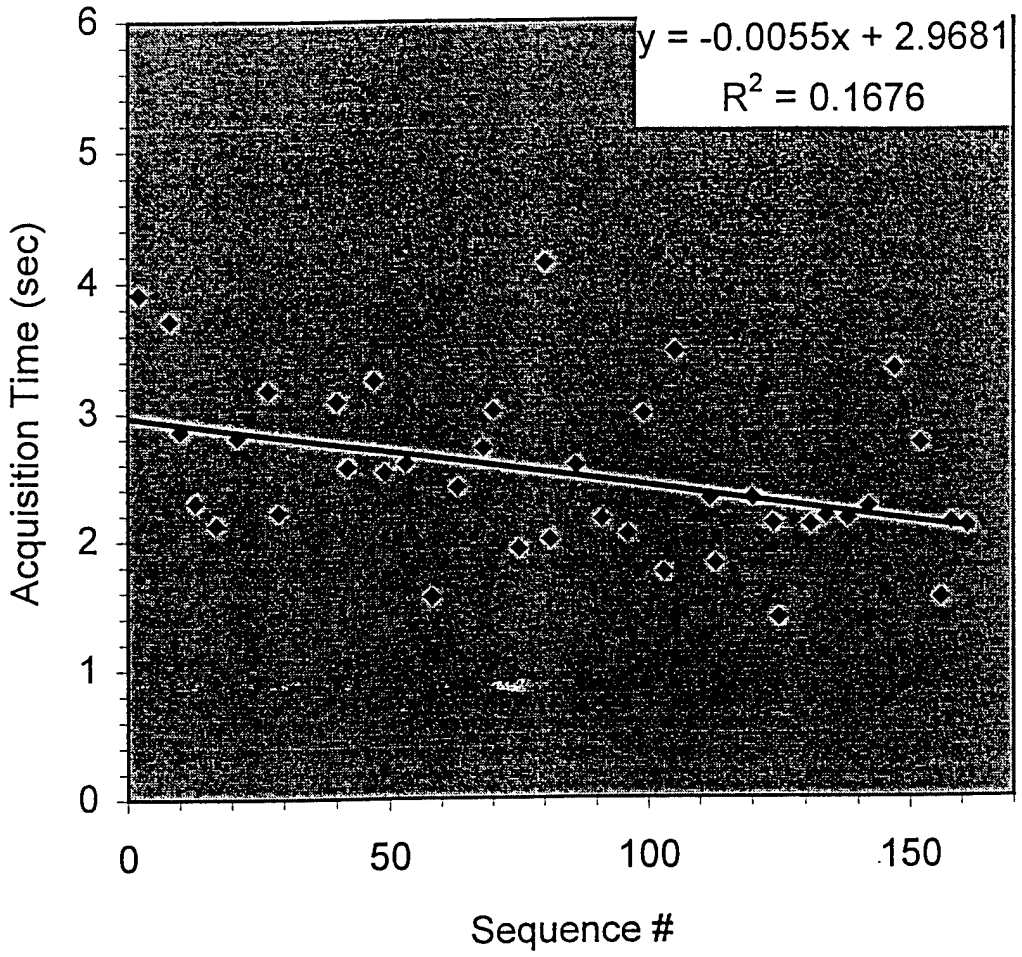

Figure D-15. Acquisition time of all LED No. 3 during random WBV for our preliminary subject wearing helmet 42. Sequence # is the order of LED appearance, which is indicative of exposure time.

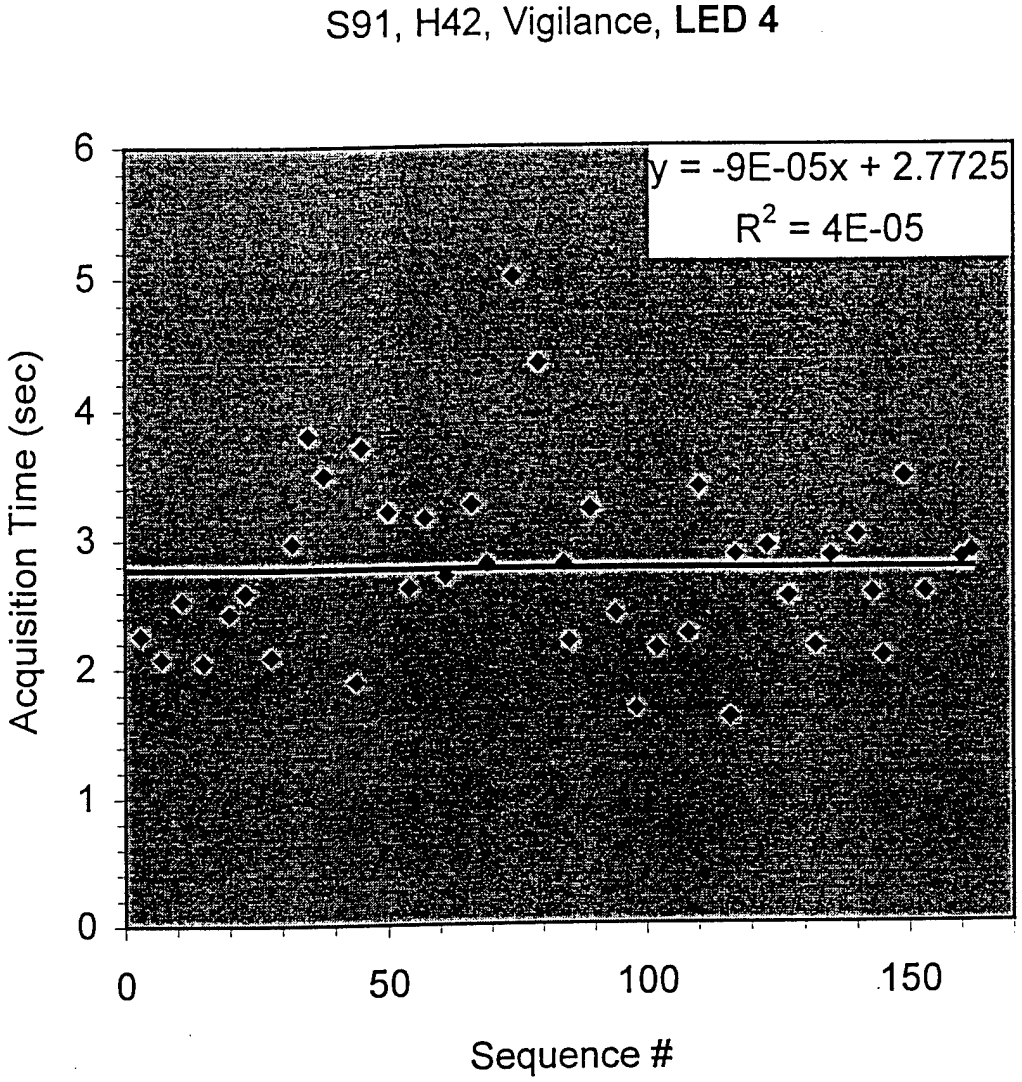

Figure D-16. Acquisition time of all LED No. 4 during random WBV for our preliminary subject wearing helmet 42. Sequence # is the order of LED appearance, which is indicative of exposure time.

Table D-1. Comparison of acquisition time (vigilance) between helmets H42 and H22.

Acquisition Time **including** missed LEDs

Average	H22	H42	p value
All LEDs	2.511667	2.874691	**0.0000**
LED 1	2.5995	3.292051	**0.0005**
LED 2	2.45525	2.8675	**0.0027**
LED 3	2.322439	2.570488	**0.0881**
LED 4	2.670244	2.765122	**0.5024**

Acquisition Time **excluding** missed LEDs

Average	H22	H42	p value
All LEDs	2.496211	2.77871	**0.0001**
LED 1	2.537949	3.117778	**0.0007**
LED 2	2.45525	2.812821	**0.0047**
LED 3	2.322439	2.50975	**0.1598**
LED 4	2.670244	2.70925	**0.7665**

3-minute Analysis Subject # 20 Date: 11-21-97
Script File: 30MMED Helmet 22 Session 1 Time: 1400

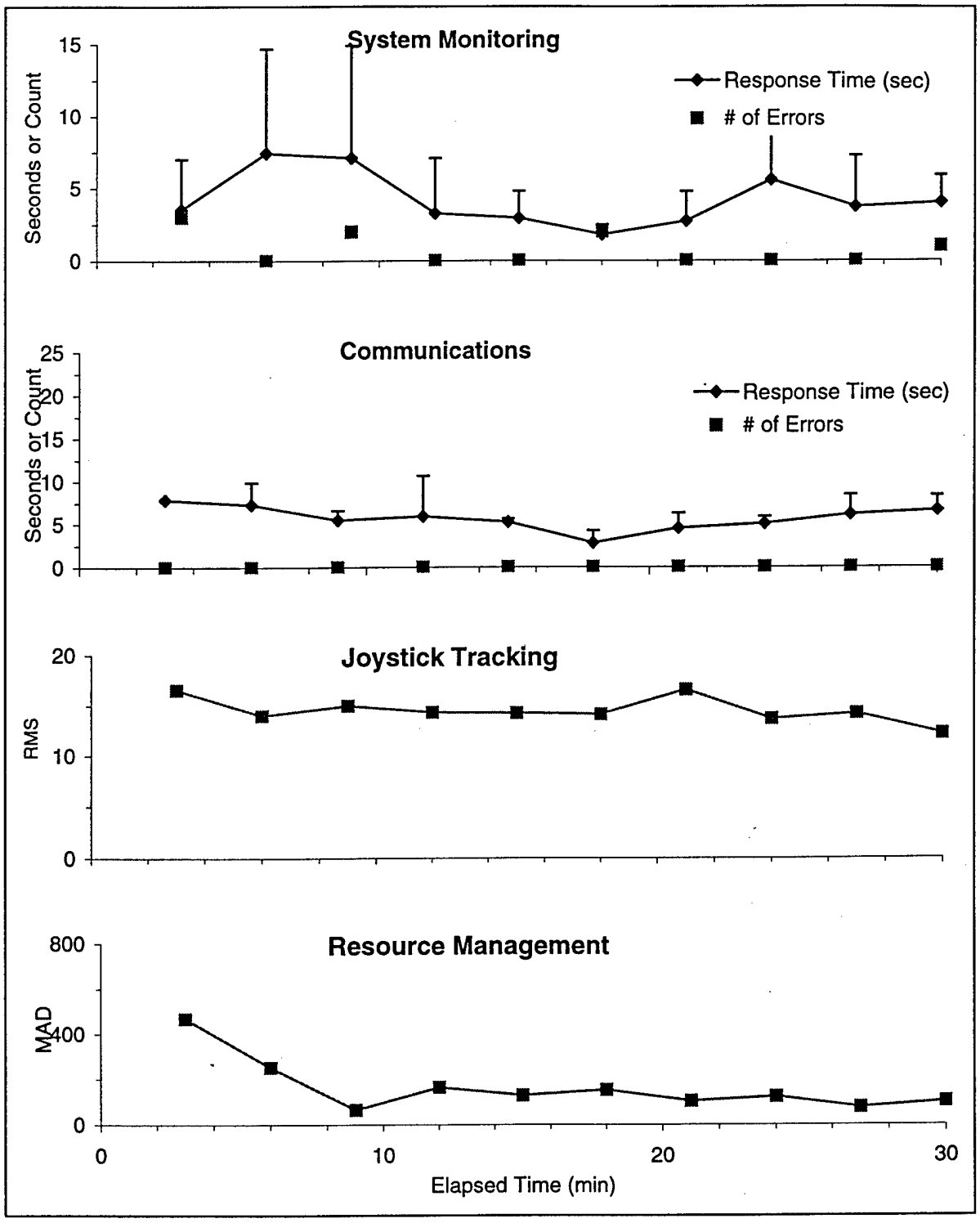

Figure D-18. MATB variables during vibration for our preliminary subject wearing helmet 22. Data points represent 3-minute average. MAD is defined as the mean absolute deviation of tanks A and B from 2500.

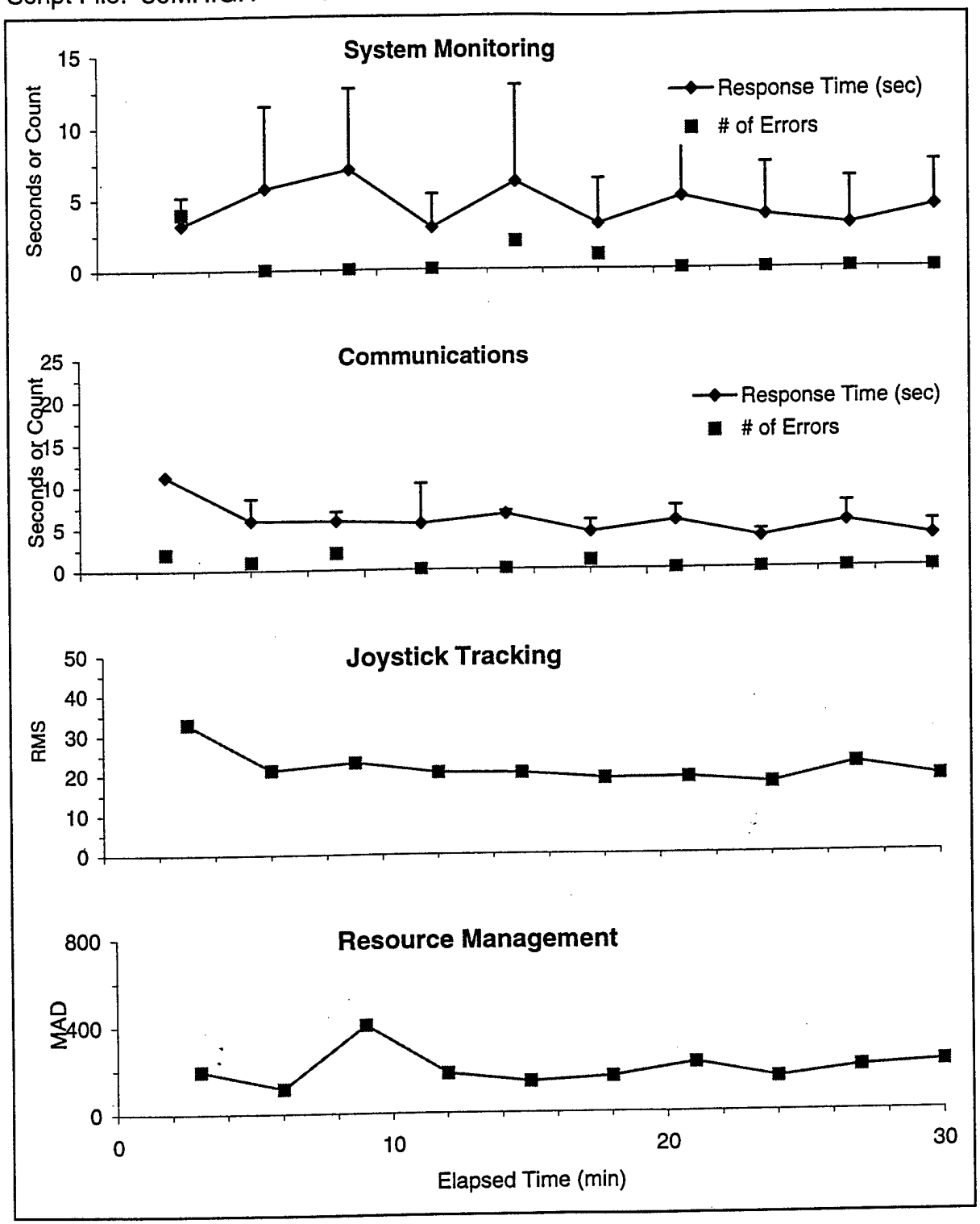

Figure D-17. MATB variables during vibration for preliminary subject wearing helmet 42. Data points represent 3-minute average. MAD is defined as the mean absolute deviation of tanks A and B from 2500.

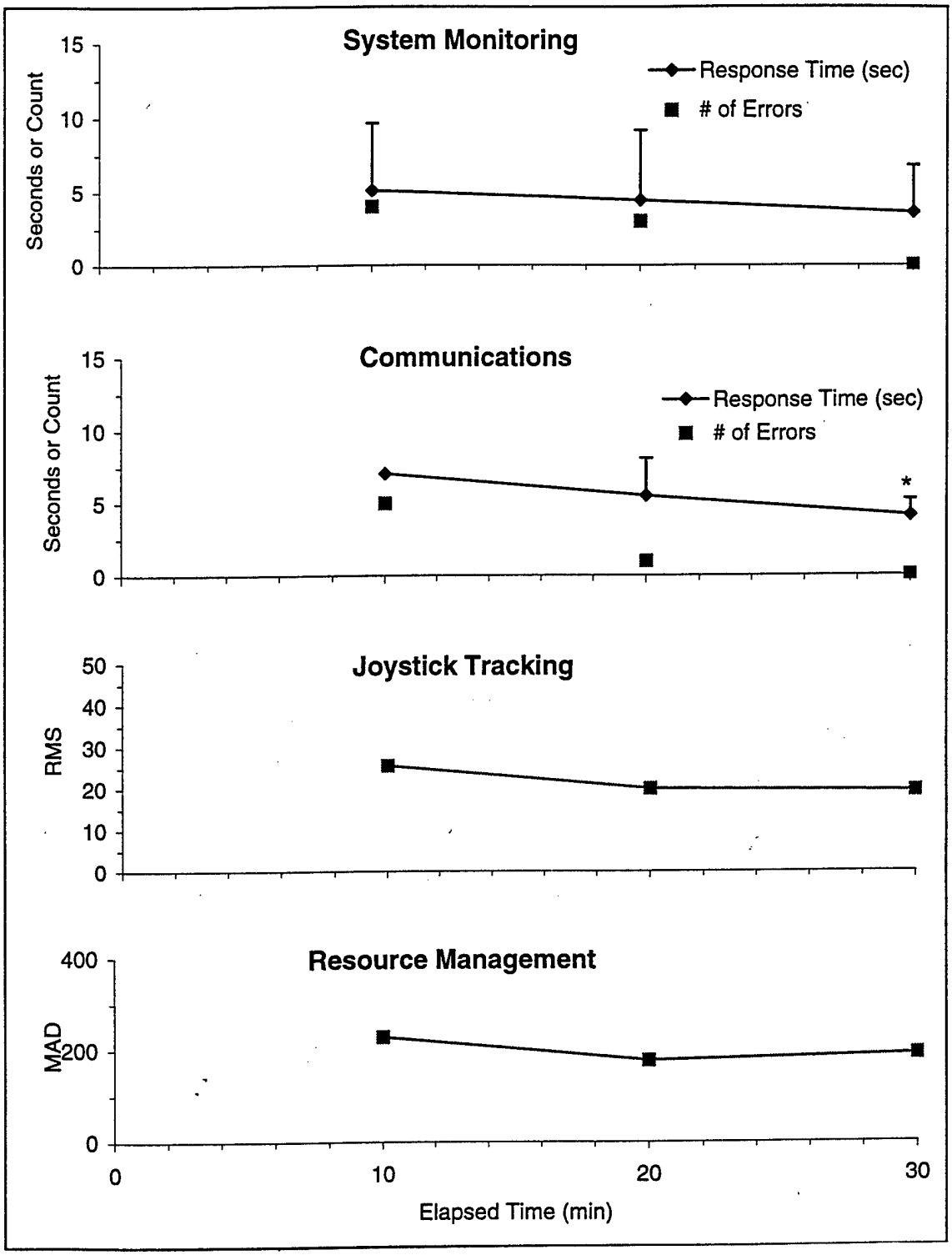

Figure D-19. MATB variables during vibration for our preliminary subject wearing helmet 42. Data points represent 10-minute average. MAD is defined as the mean absolute deviation of tanks A and B from 2500.

10-minute Analysis Subject # 20 Date: 11-21-97
Script File: 30MMED Helmet 22 Session 1 Time: 1400

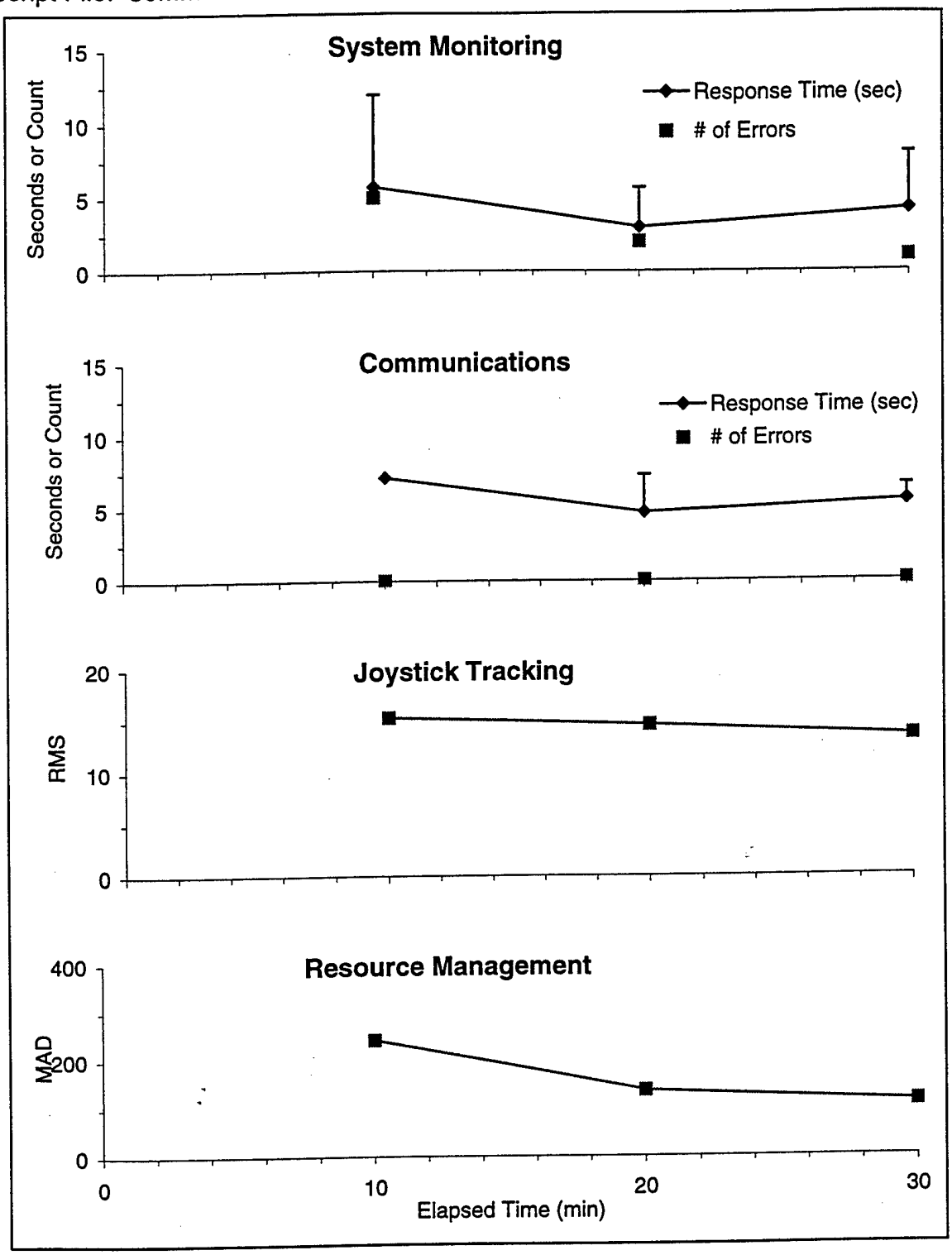

Figure D-20. MATB variables during vibration for our preliminary subject wearing helmet 22. Data points represent 10-minute average. MAD is defined as the mean absolute deviation of tanks A and B from 2500.

APPENDIX E

Sample of Processed Electromyographic Data

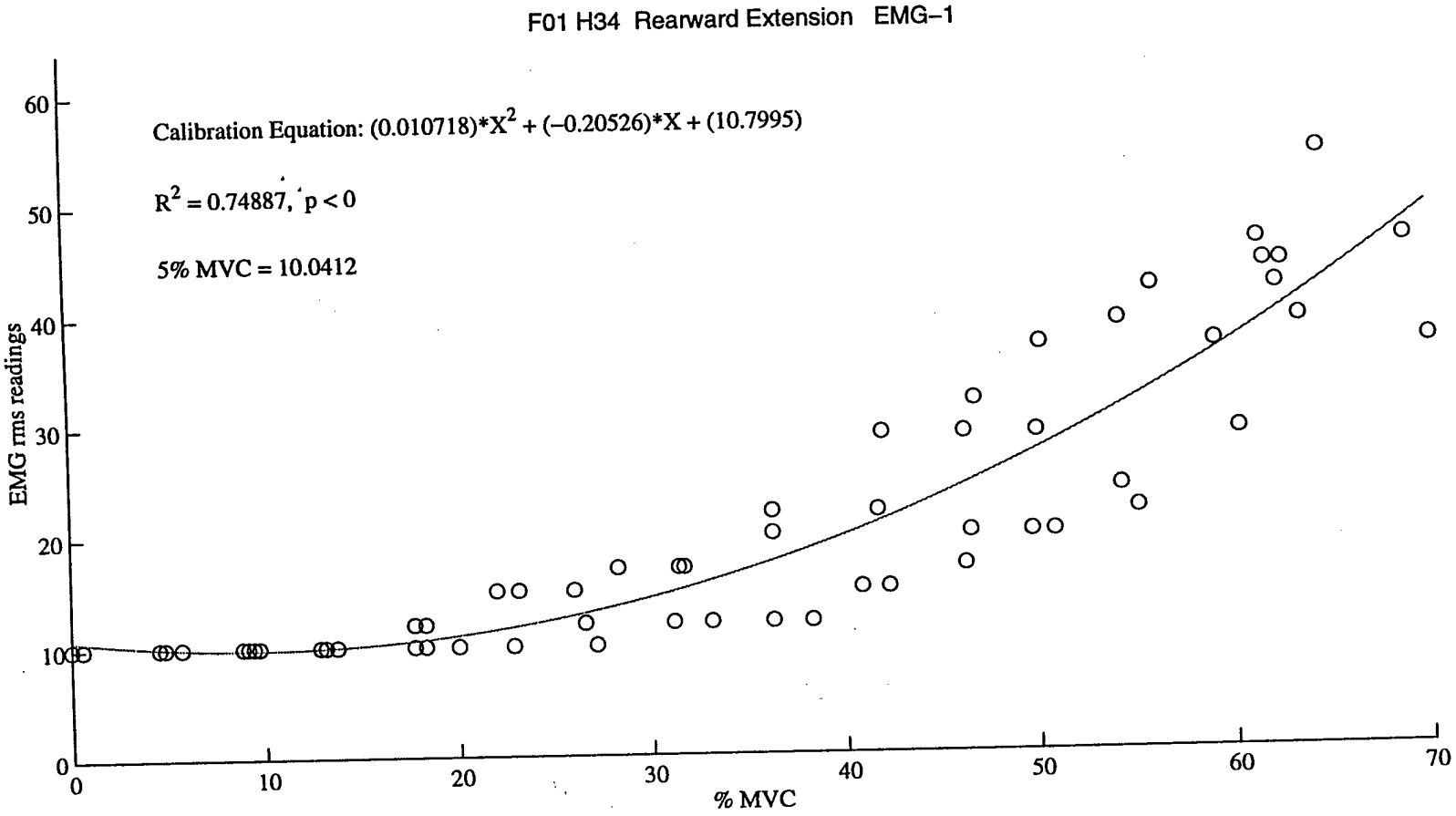

Figure E-1. Calibration curve of left splenius capitis muscle (EMG-1) for subject F01 prior to exposure to vibration and helmet number H34.

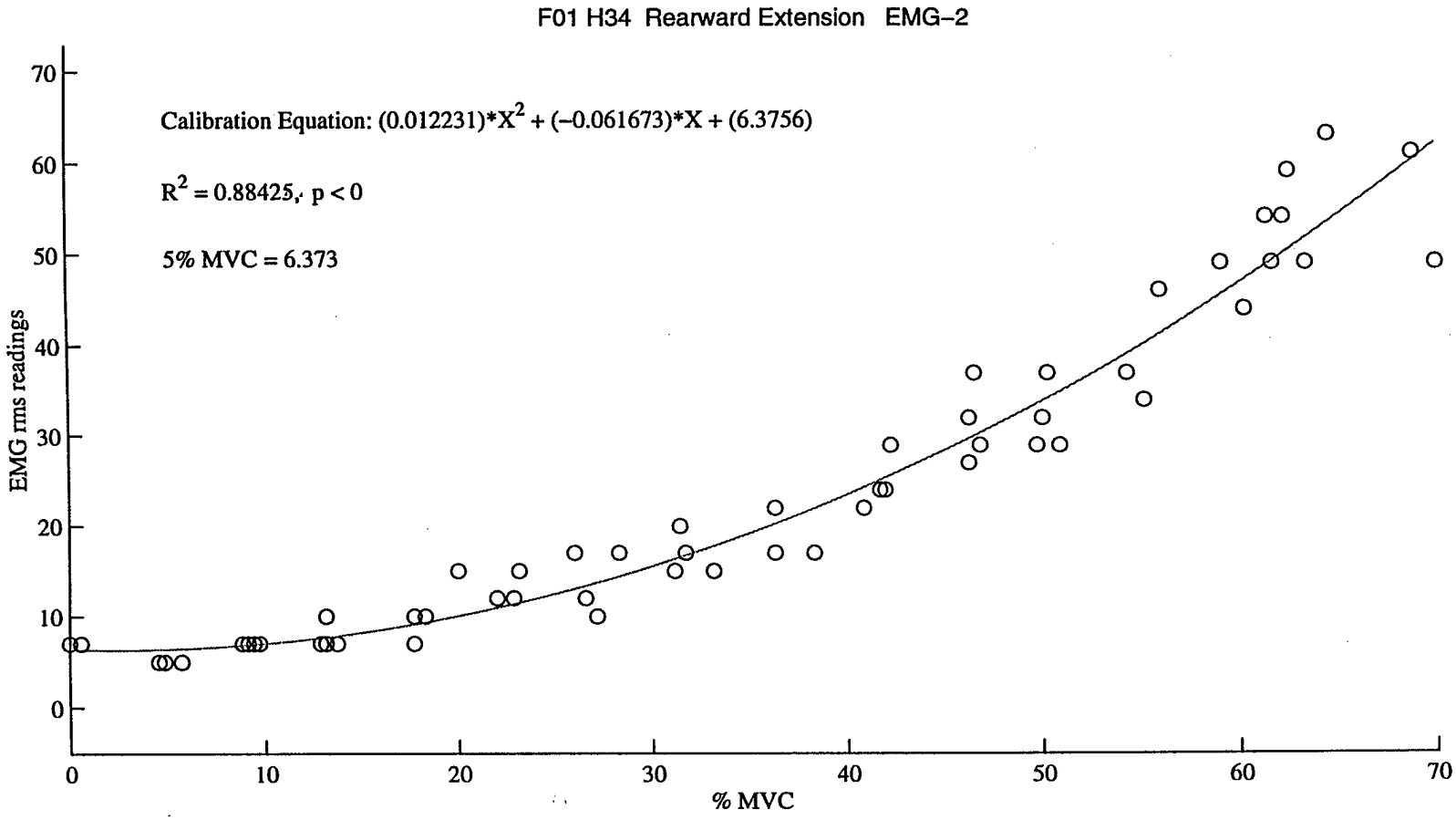

Figure E-2. EMG vs. MVC calibration curve of right splenius capitis muscle (EMG-2) for subject F01 prior to exposure to vibration and helmet H34.

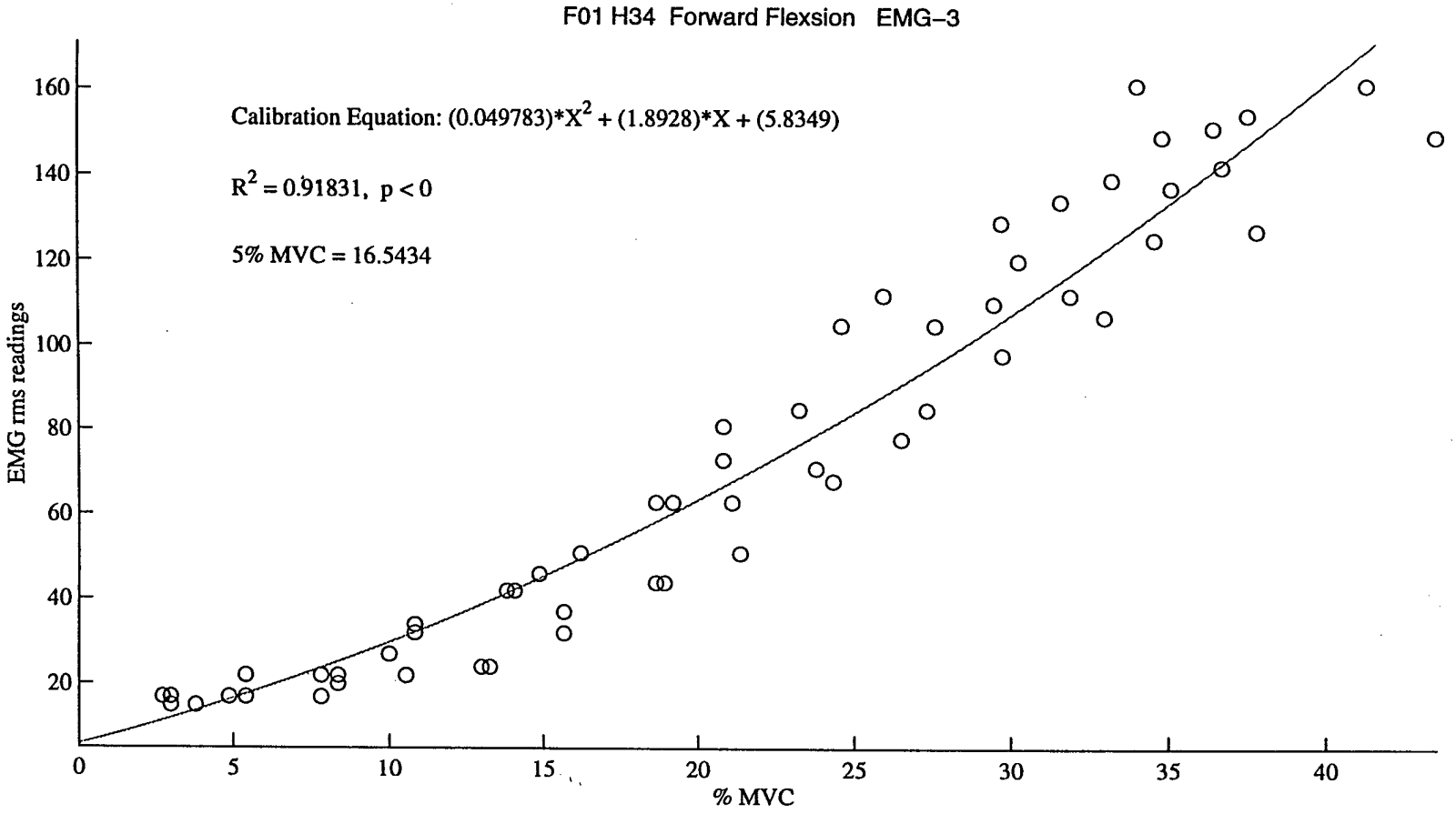

Figure E-3. EMG vs. MVC calibration curve of left sternocleidomastoid muscle (EMG-3) for subject F01 prior to exposure to vibration and helmet H34.

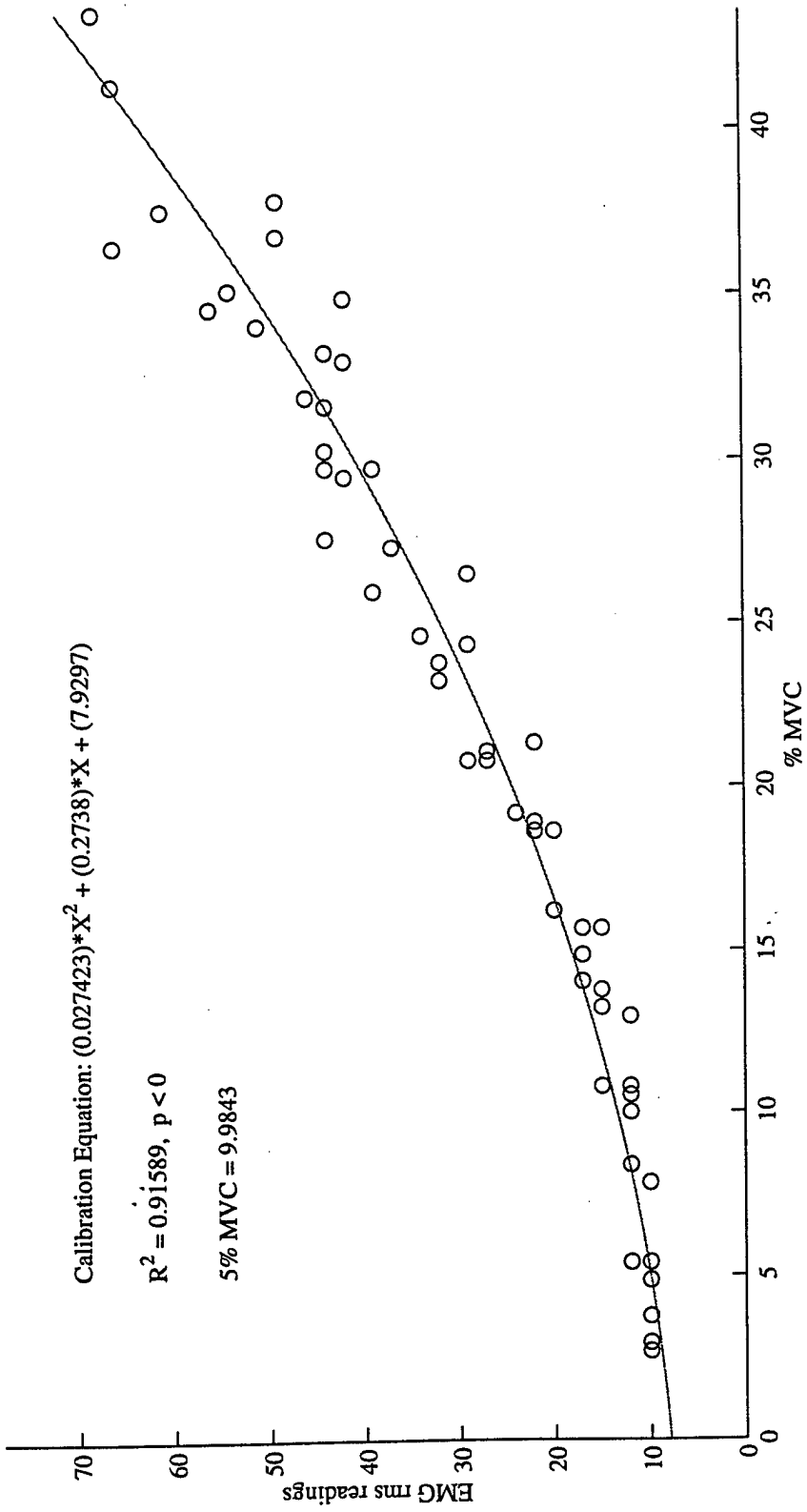

Figure E-4. Calibration curve of right sternocleidomastoid muscle (EMG-4) for subject F01 prior to exposure to vibration and helmet H34.

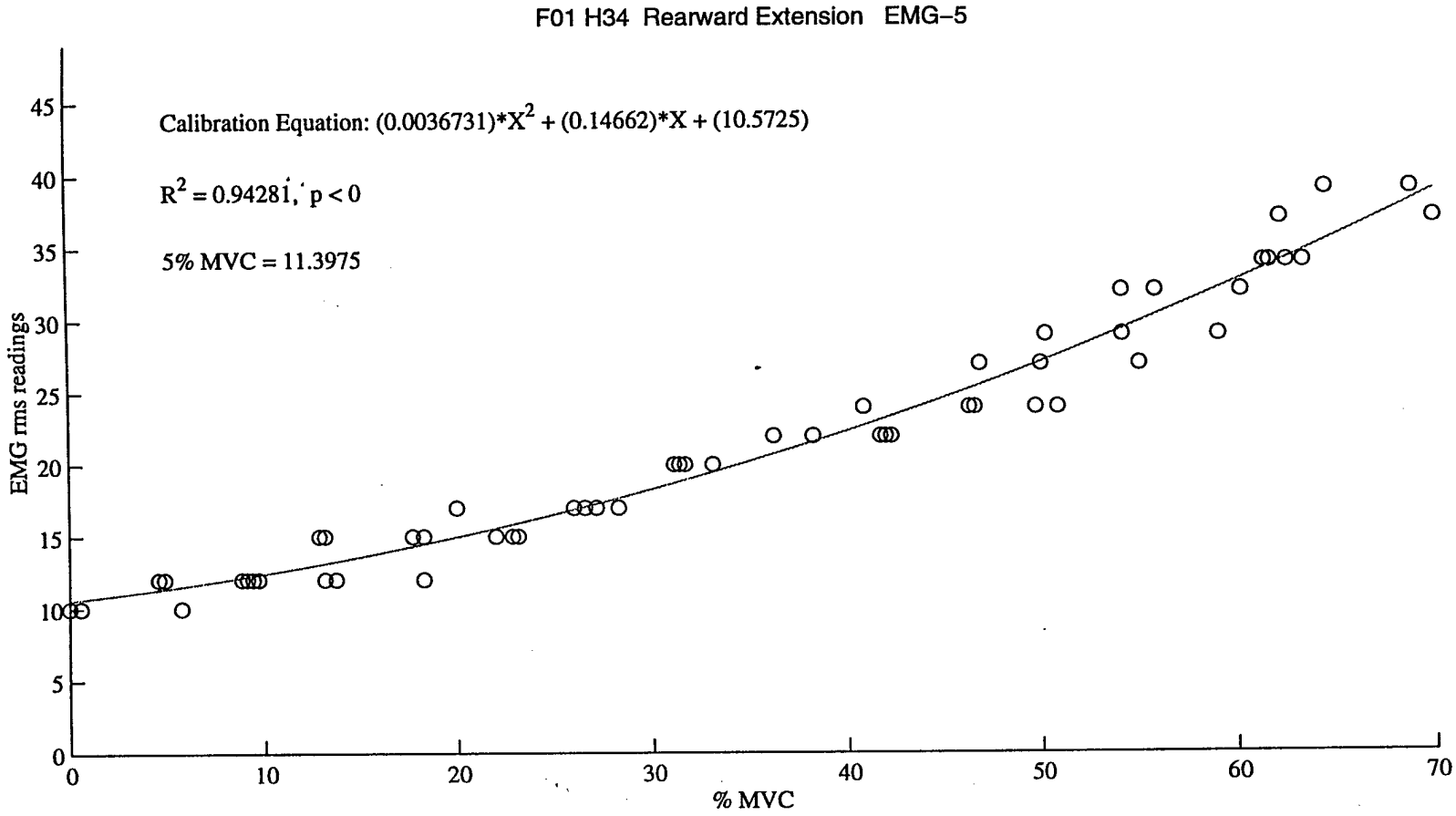

Figure E-5. MVC vs. MVC calibration curve of left trapezius muscle (EMG-5) for subject F01 prior to exposure to vibration and helmet 34.

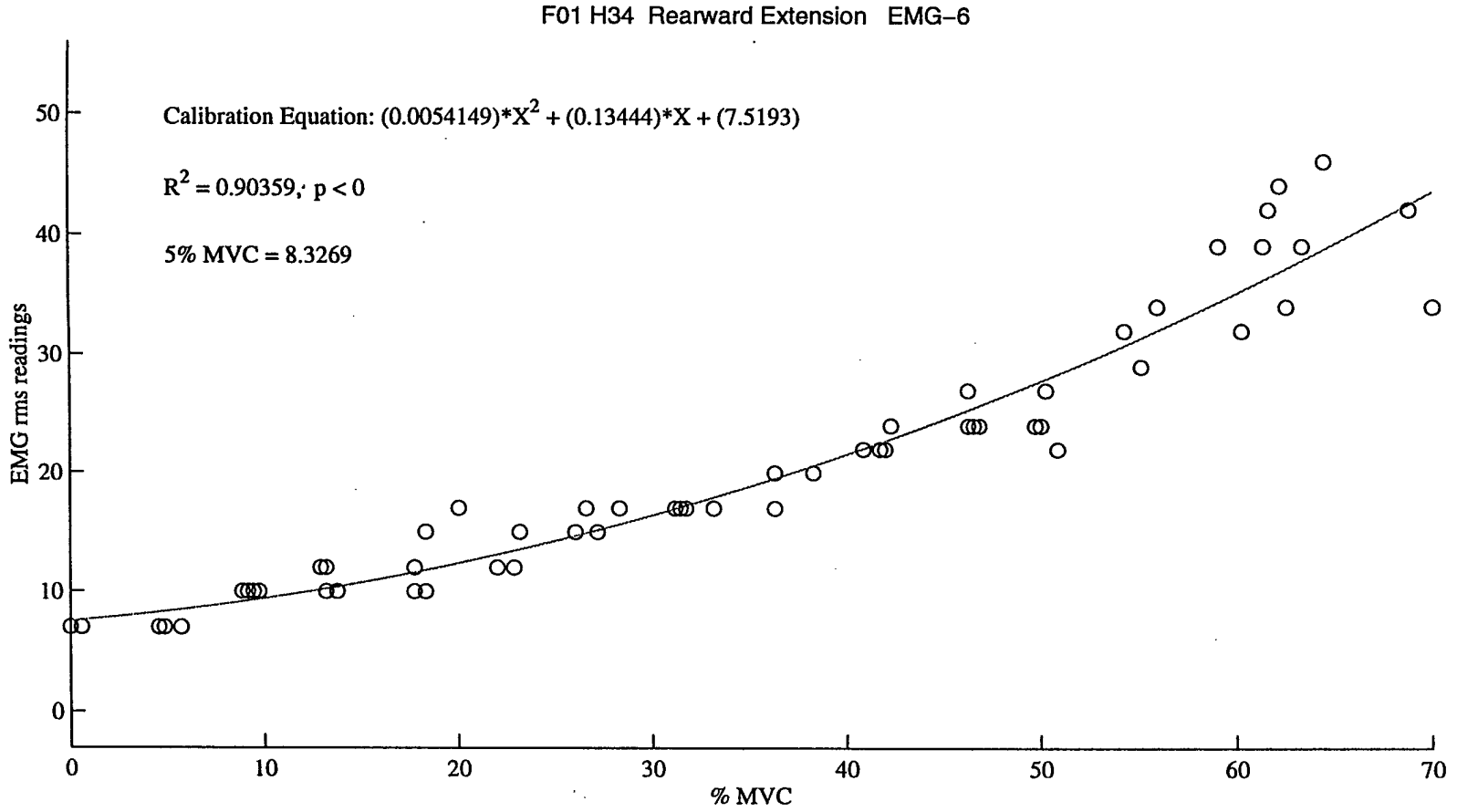

Figure E-6. EMG vs. MVC calibration curve of right trapezius muscle (EMG-6) for subject F01 prior to exposure to vibration and helmet H34.

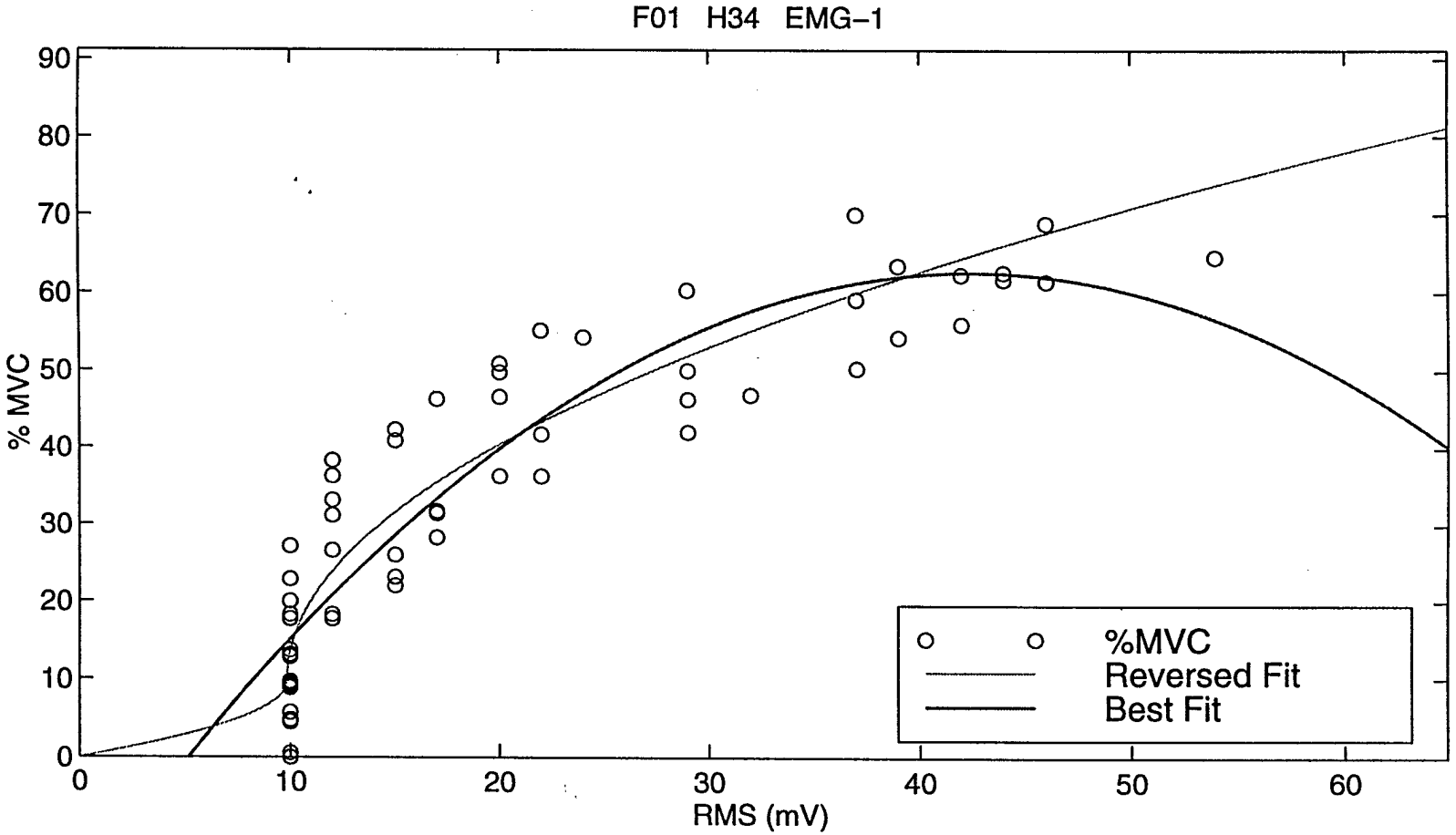

Figure E-7. Reversed calibration curve for left splenius capitis muscle (EMG-1) for subject F01 prior to exposure to vibration and helmet H34.

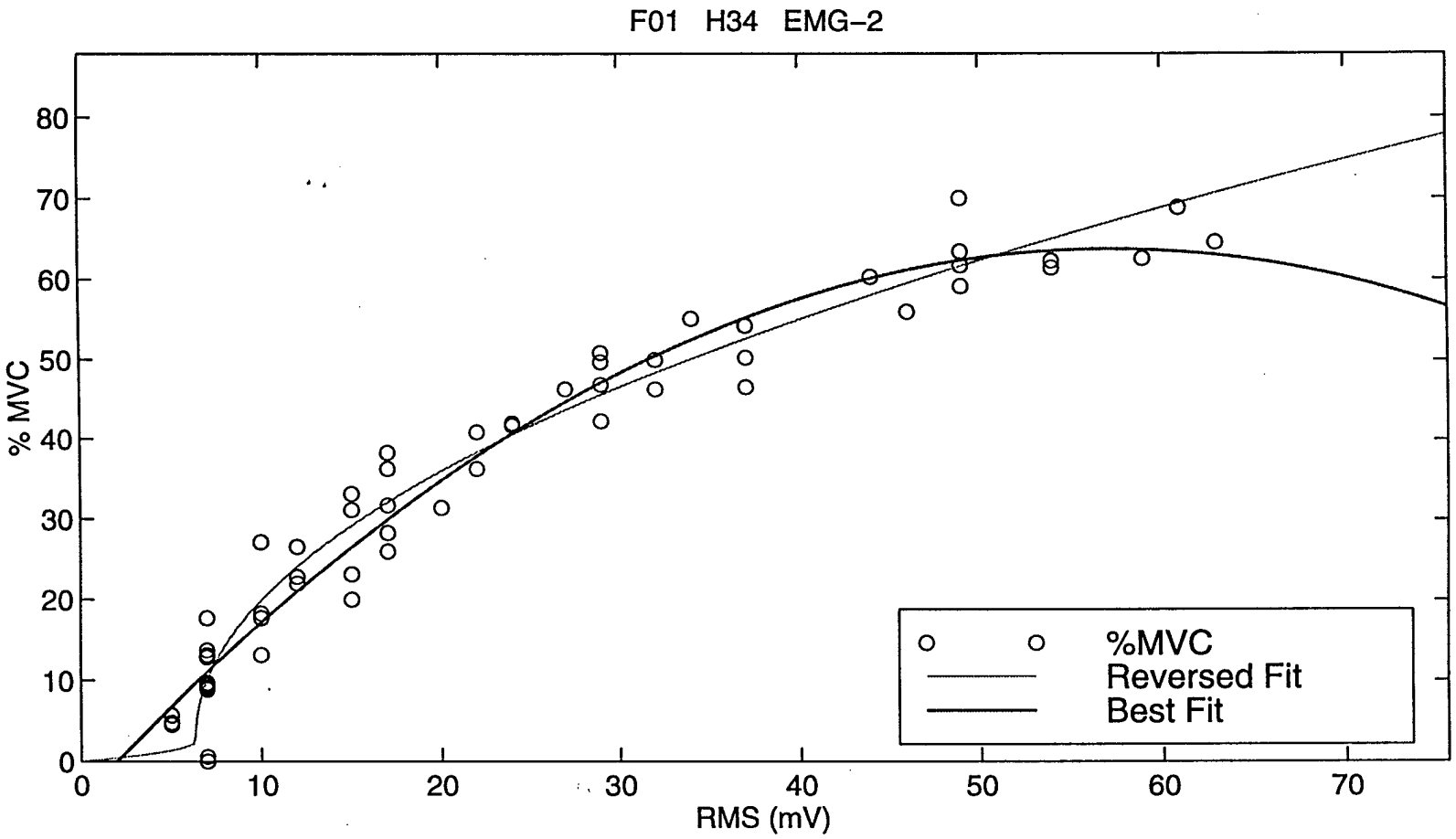

Figure E-8. Reversed calibration curve for right splenius capitis muscle (EMG-2) for subject F01 prior to exposure to vibration and helmet H34.

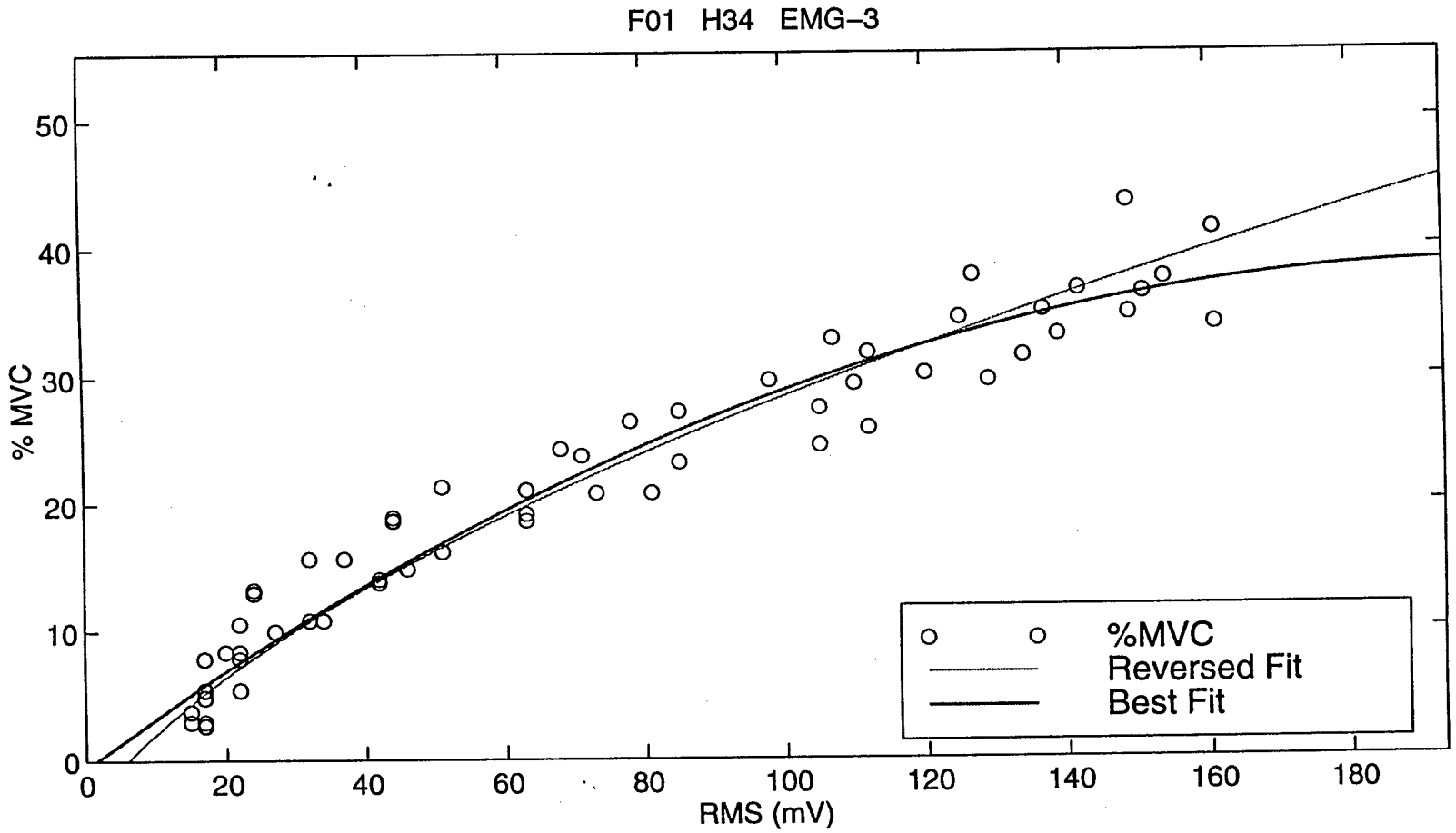

Figure E-9. Reversed calibration curve for left sternocleidomastoid muscle (EMG-3) for subject F01 prior to exposure to vibration and helmet H34.

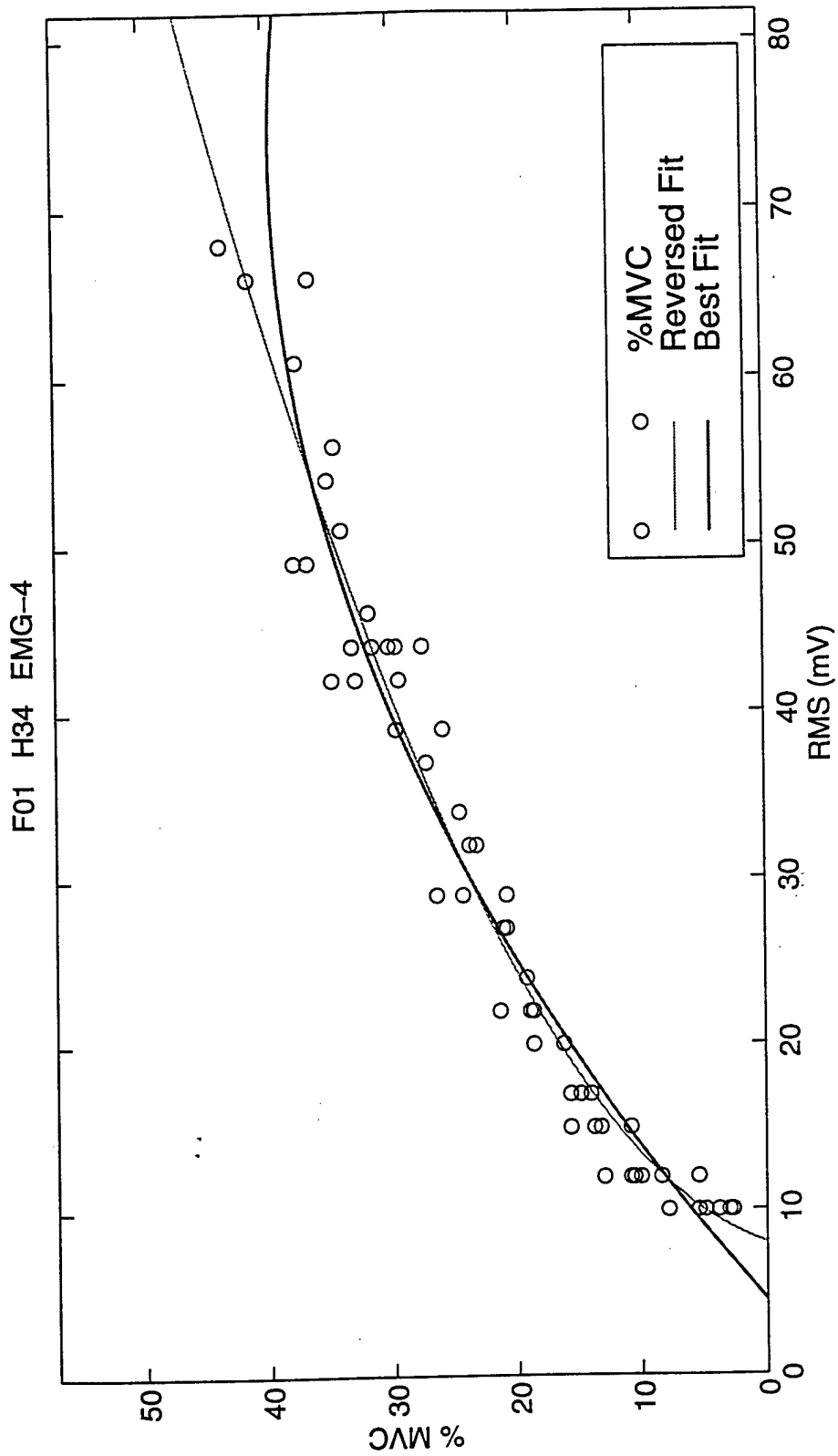

Figure E-10. Reversed calibration curve for right sternocleidomastoid muscle (EMG-4) for subject F01 prior to exposure to vibration and helmet H34.

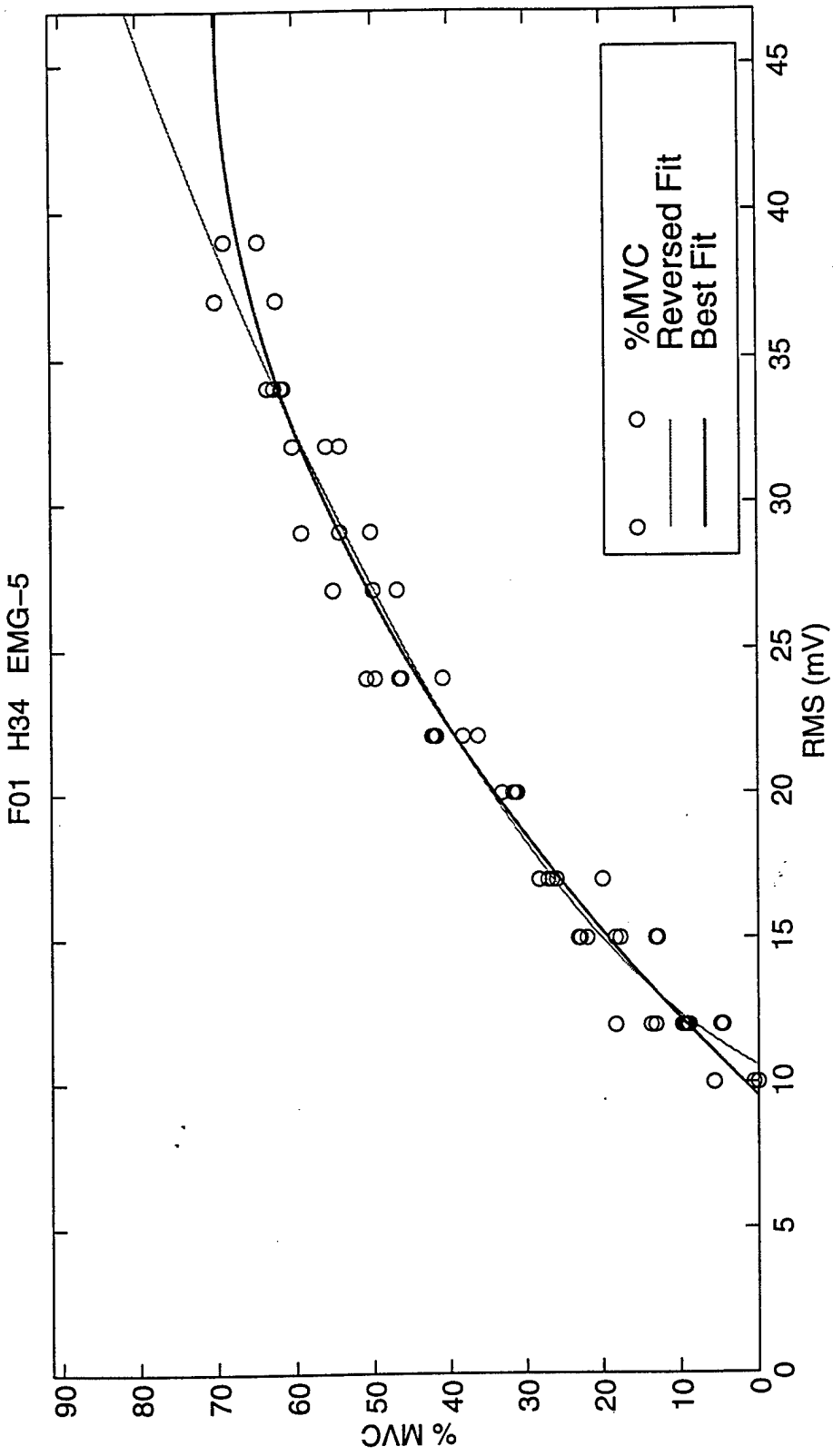

Figure E-11. Reversed calibration curve for left trapezius muscle (EMG-5) for subject F01 prior to exposure to vibration and helmet H34.

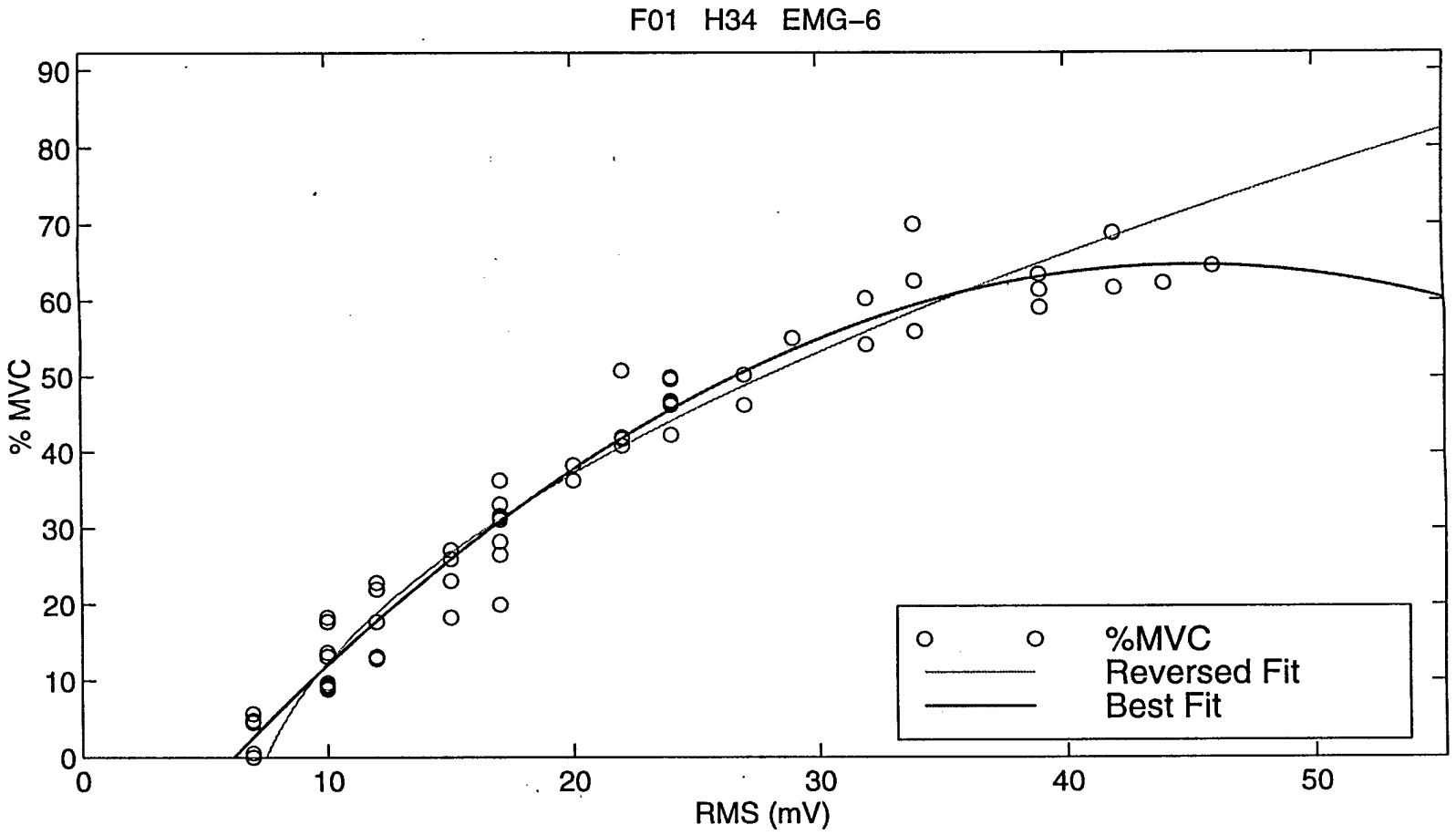

Figure E-12. Reversed calibration curve for right trapezius muscle (EMG-6) for subject F01 prior to exposure to vibration and helmet H34.

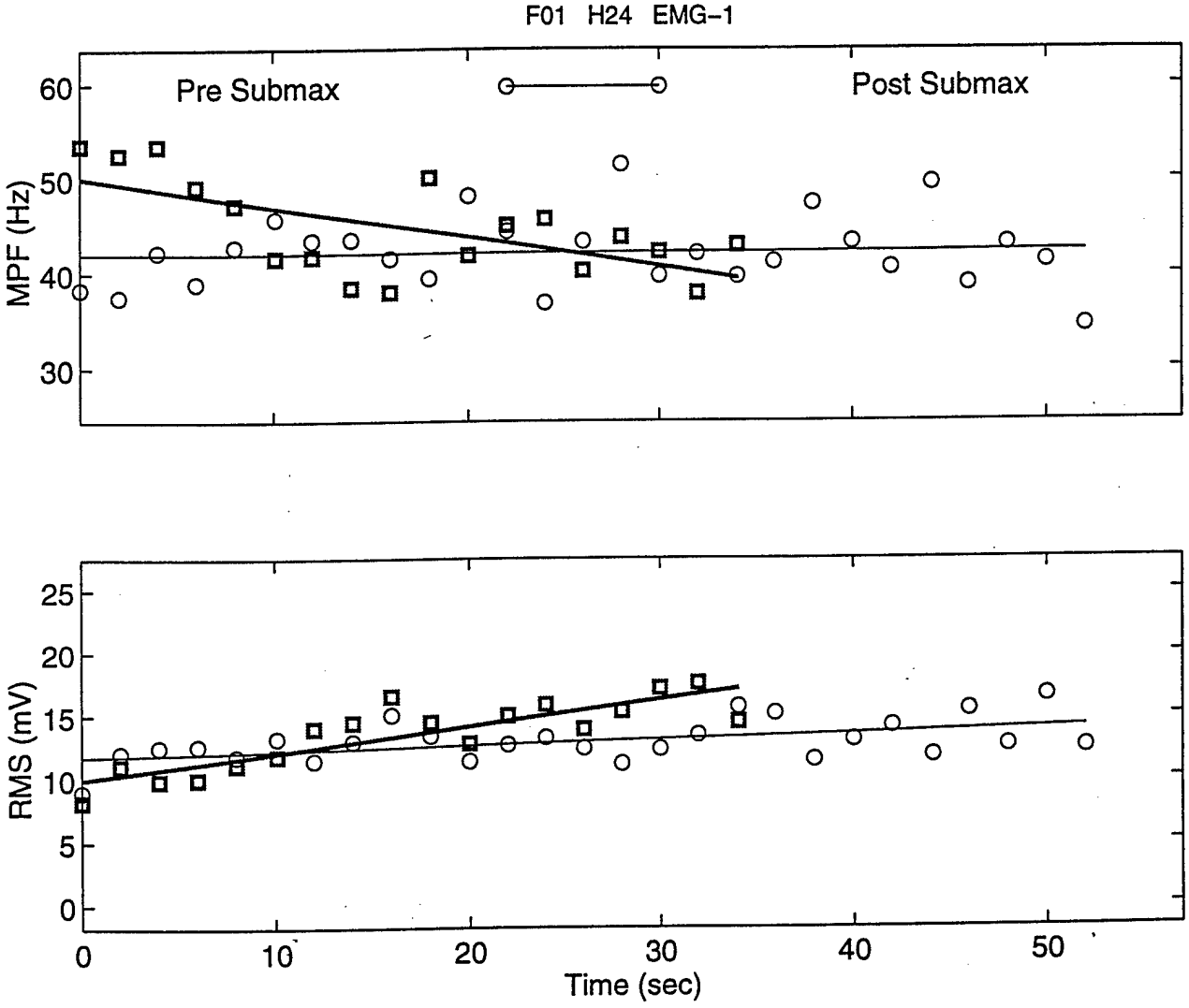

Figure E-13. Mean power frequency (MPF) and root mean squared (RMS) of EMG-1 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H22.

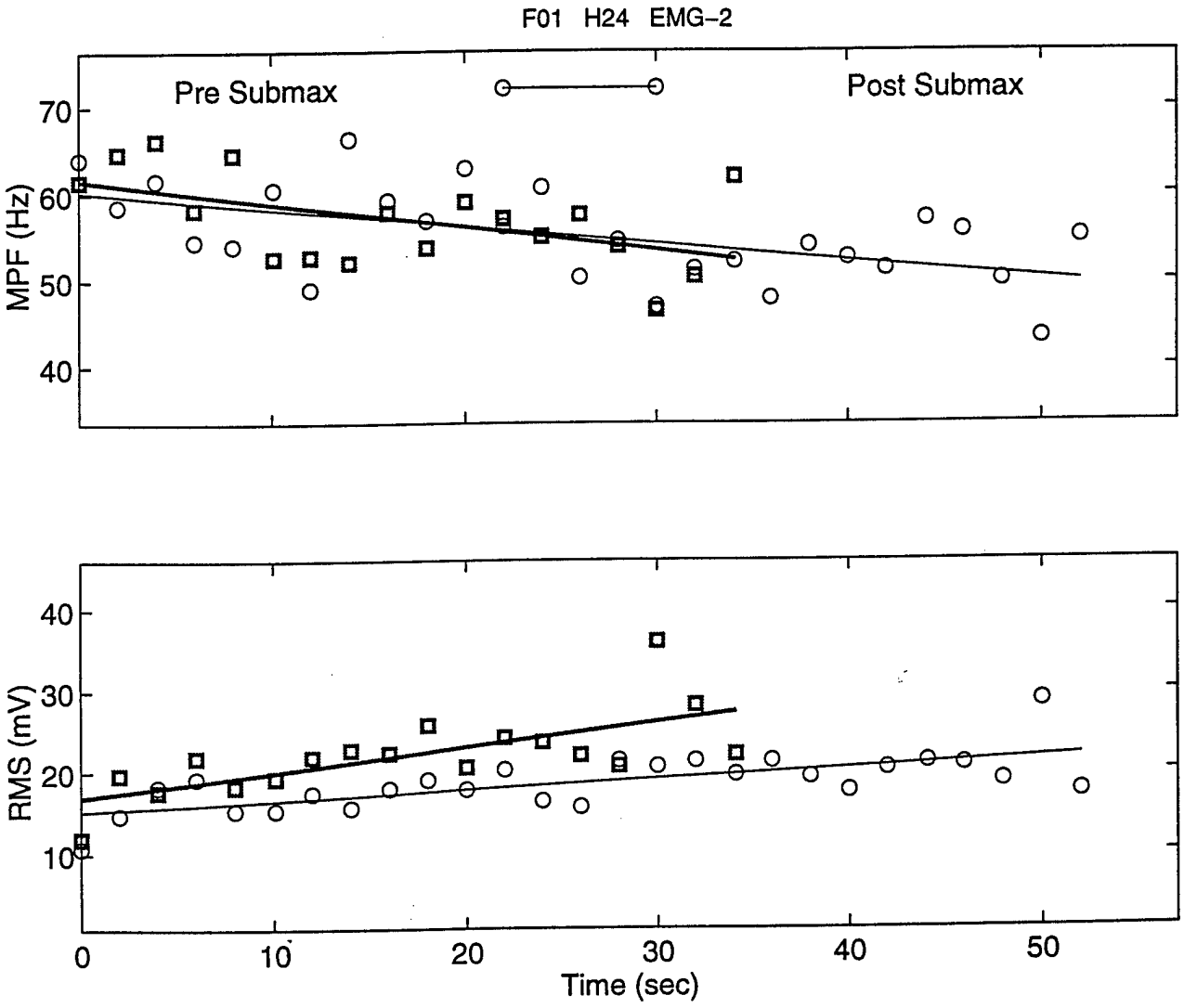

Figure E-14. Mean power frequency (MPF) and root mean squared (RMS) of EMG-2 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H22.

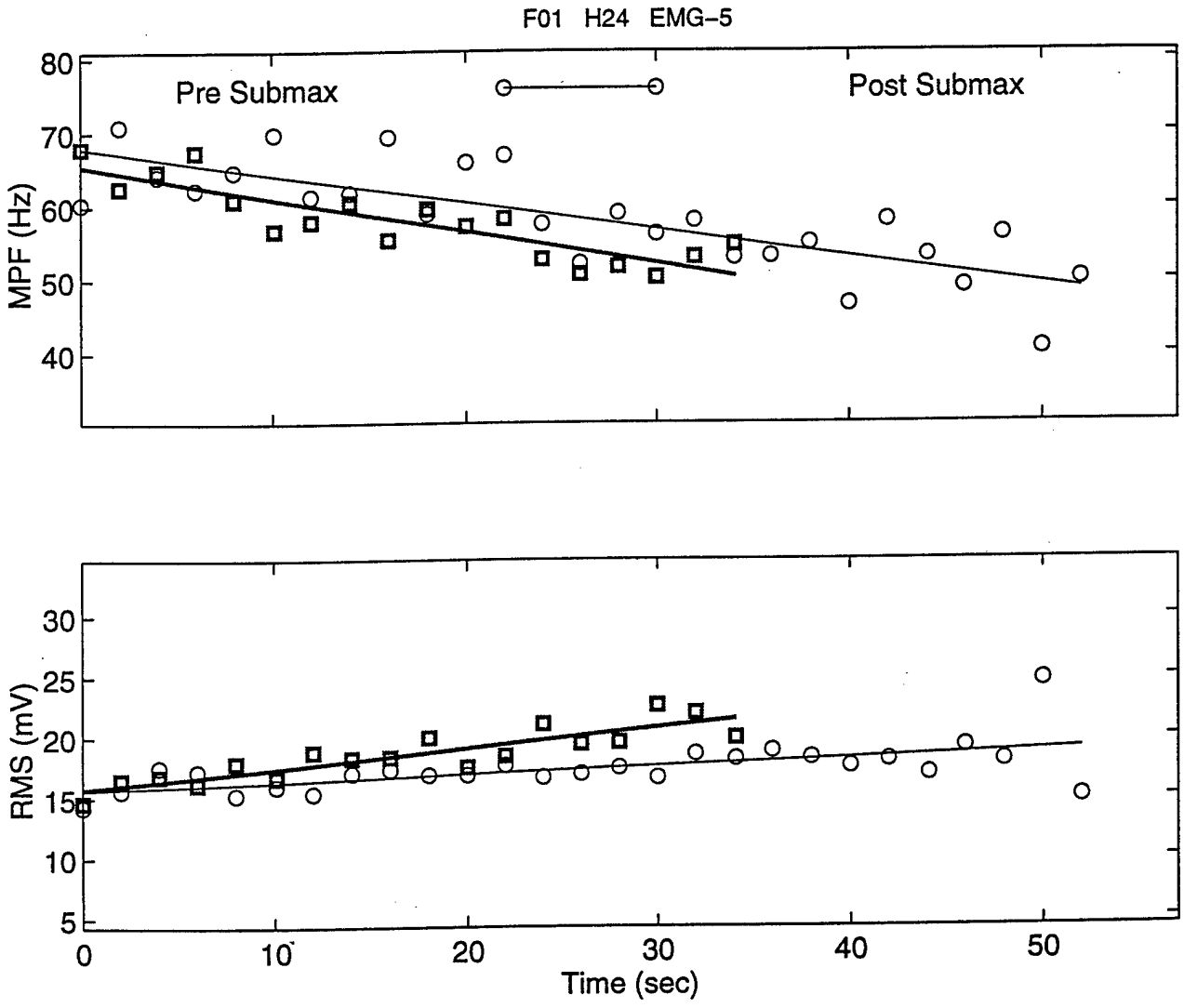

Figure E-15. Mean power frequency (MPF) and root mean squared (RMS) of EMG-5 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H22.

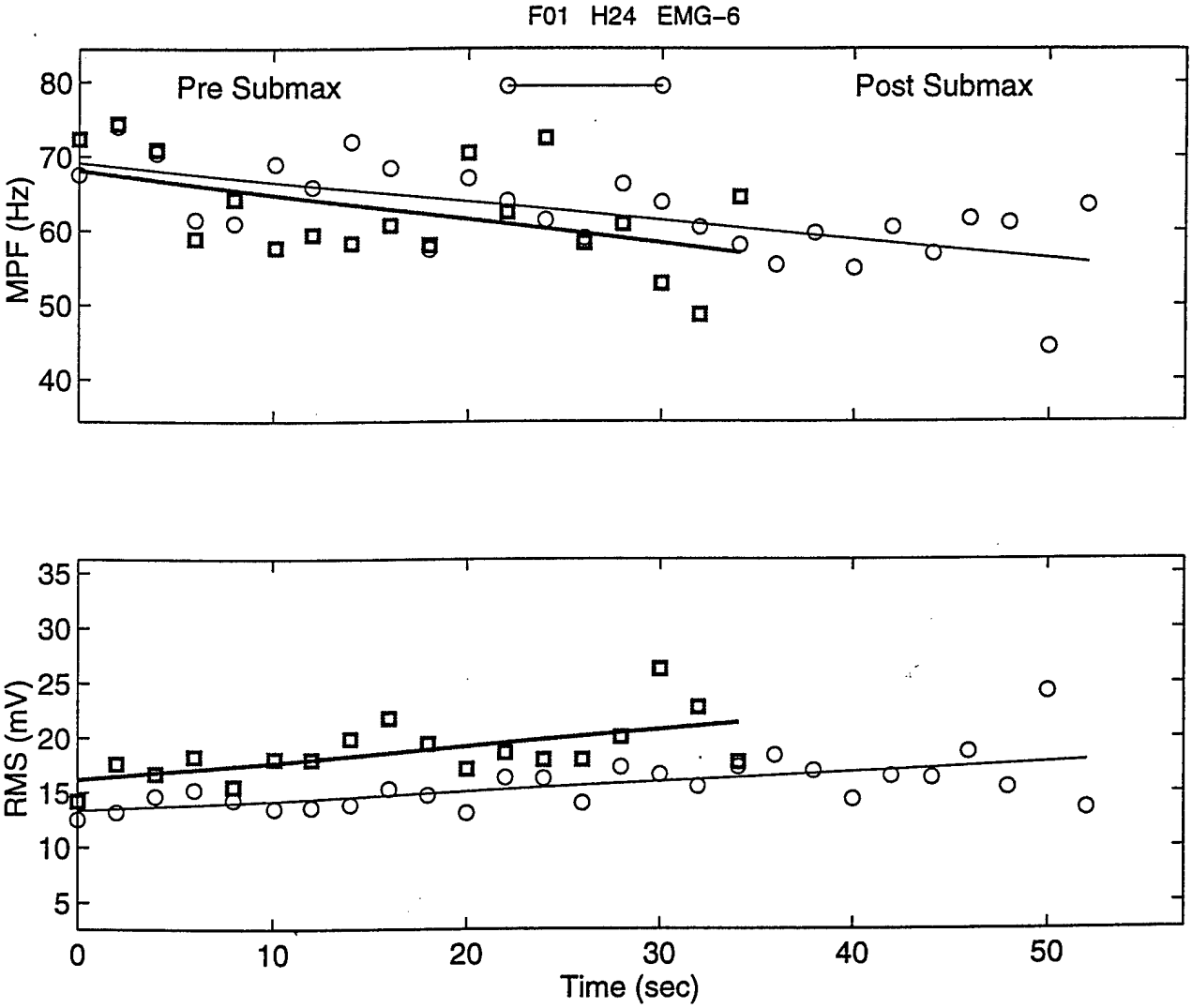

Figure E-16. Mean power frequency (MPF) and root mean squared (RMS) of EMG-6 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H22.

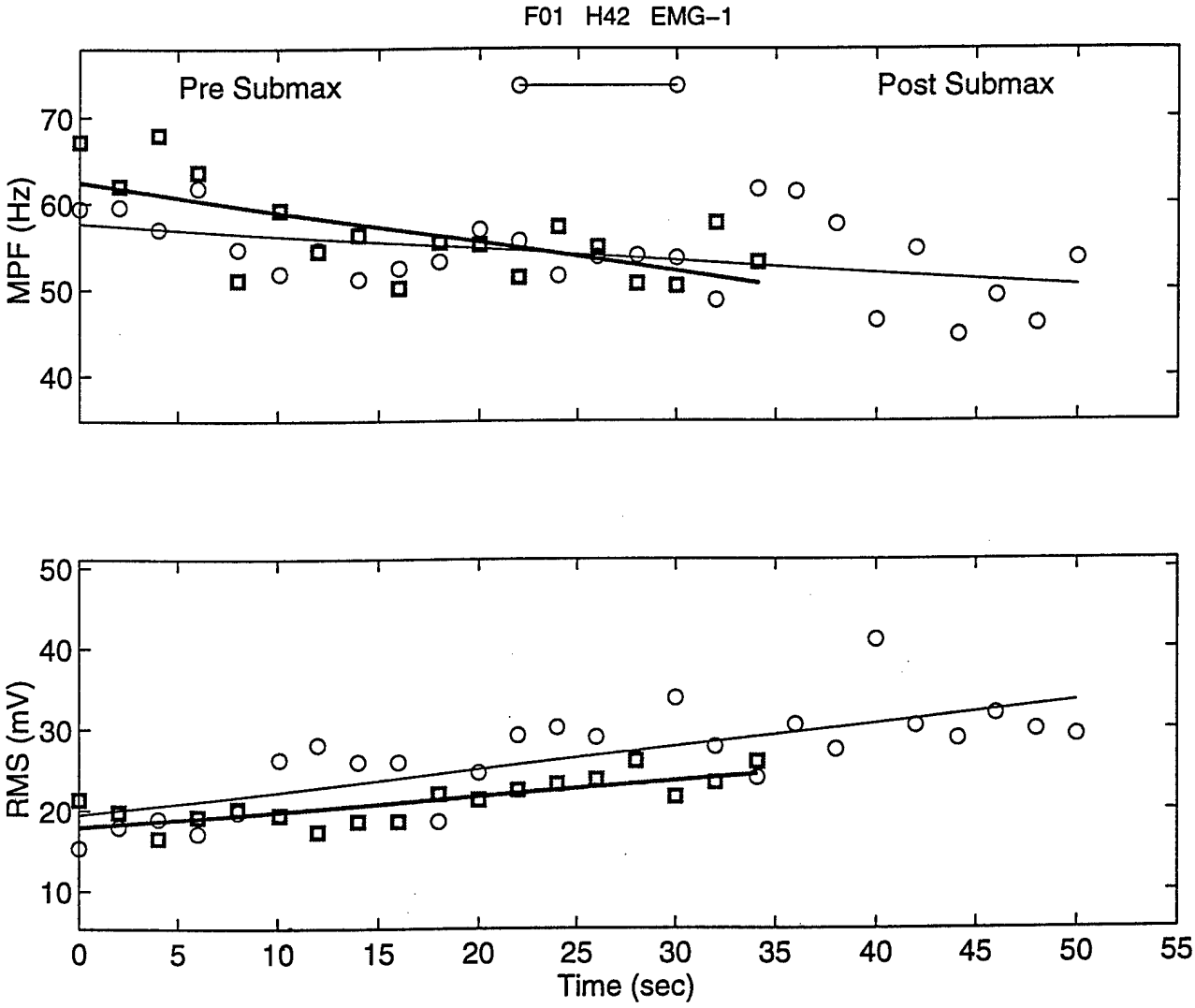

Figure E-17. Mean power frequency (MPF) and root mean squared (RMS) of EMG-1 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H42.

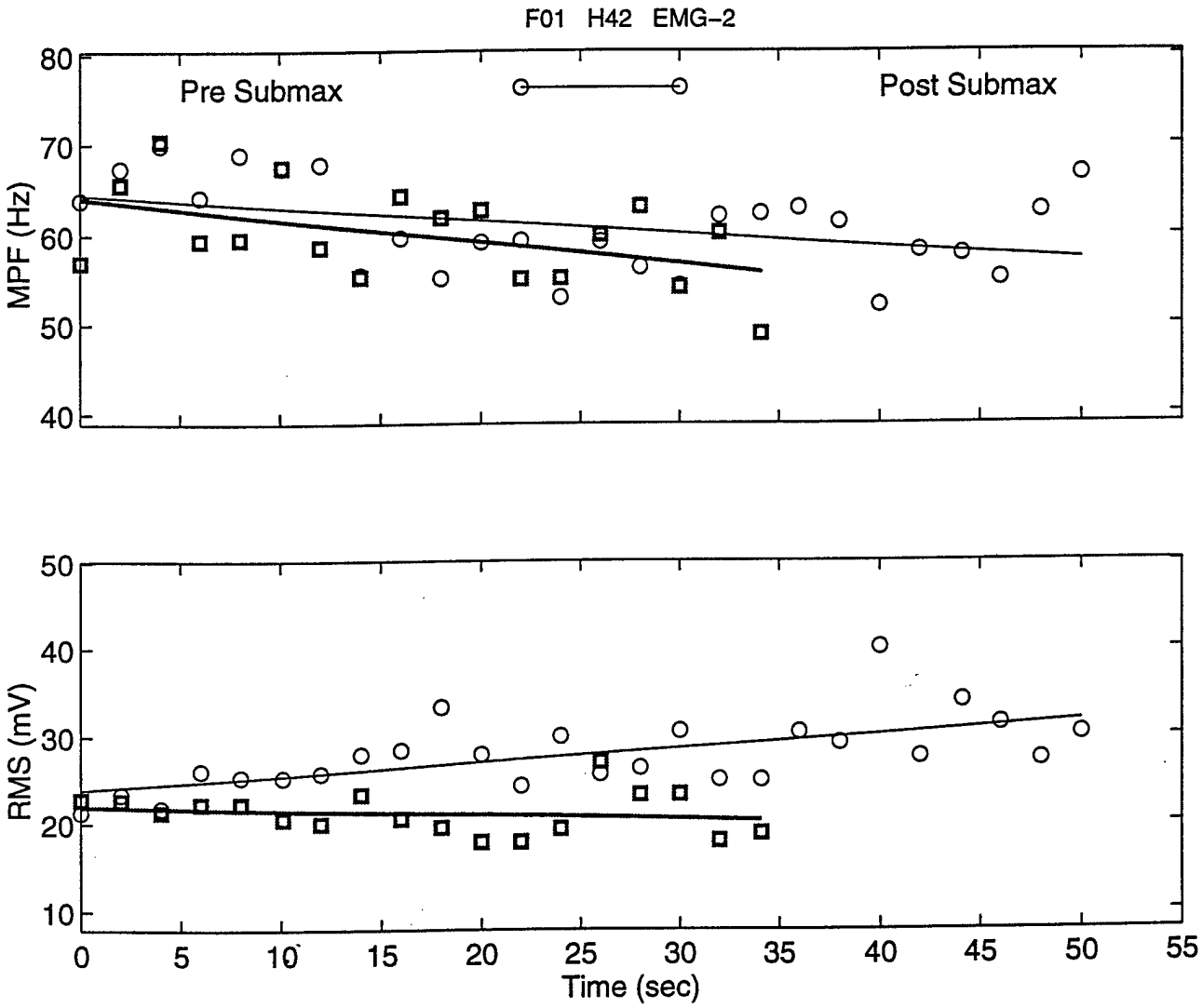

Figure E-18. Mean power frequency (MPF) and root mean squared (RMS) of EMG-2 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H42.

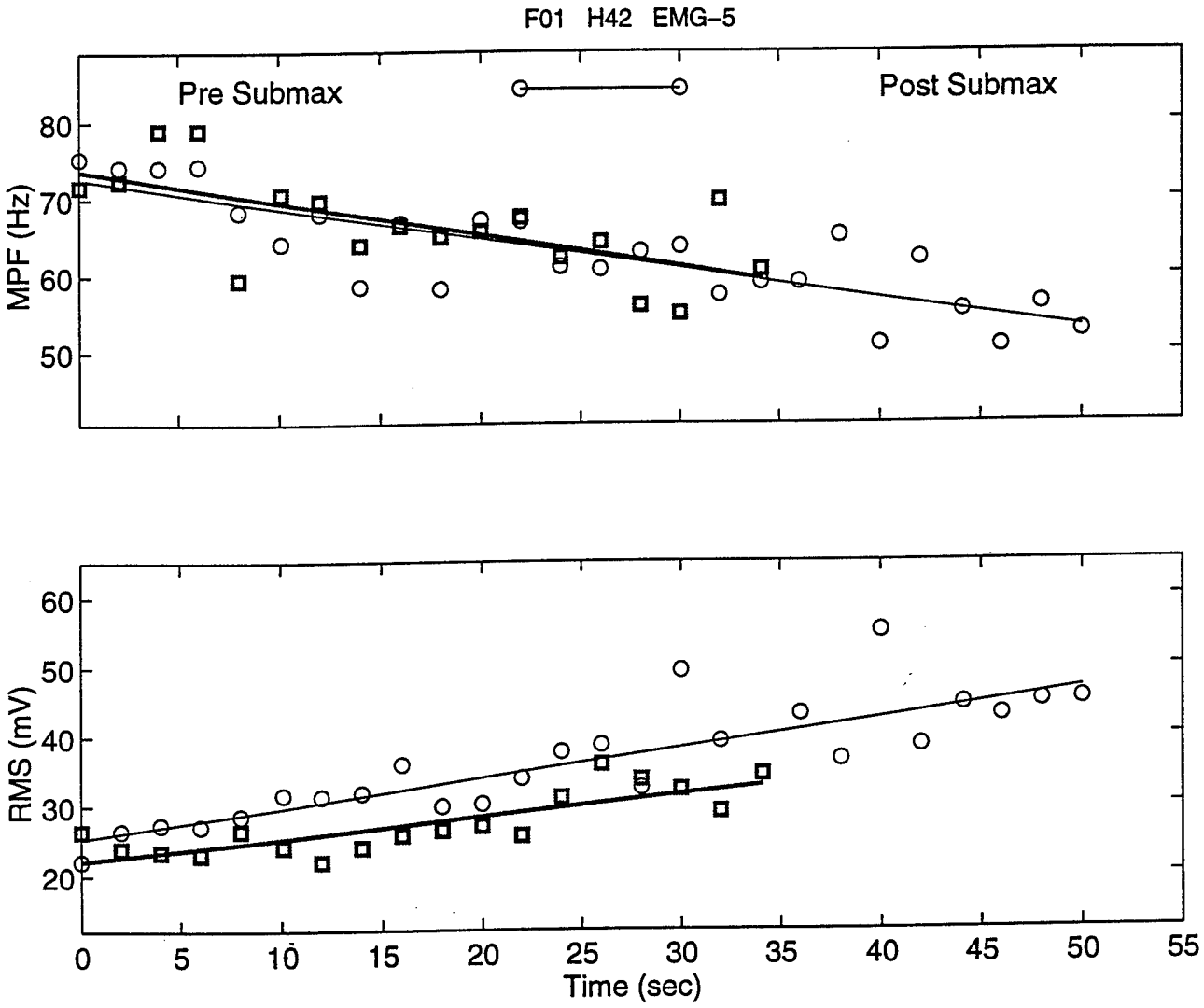

Figure E-19. Mean power frequency (MPF) and root mean squared (RMS) of EMG-5 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H42.

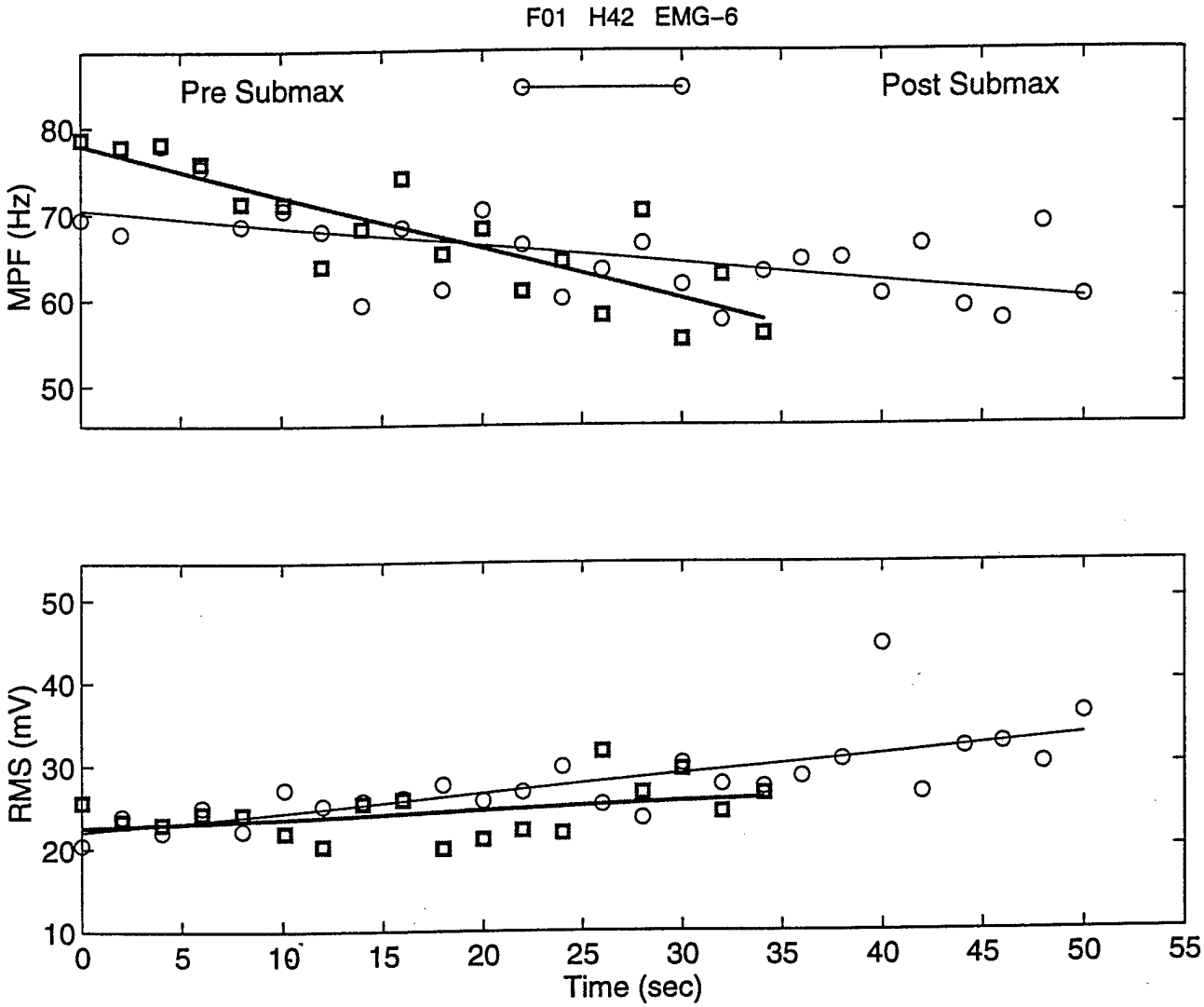

Figure E-20. Mean power frequency (MPF) and root mean squared (RMS) of EMG-6 versus exertion time ,measured during endurance tests before and after exposure of subject F01 to helmet H42

APPENDIX F

Sample Head Accelerations from Bite Bar

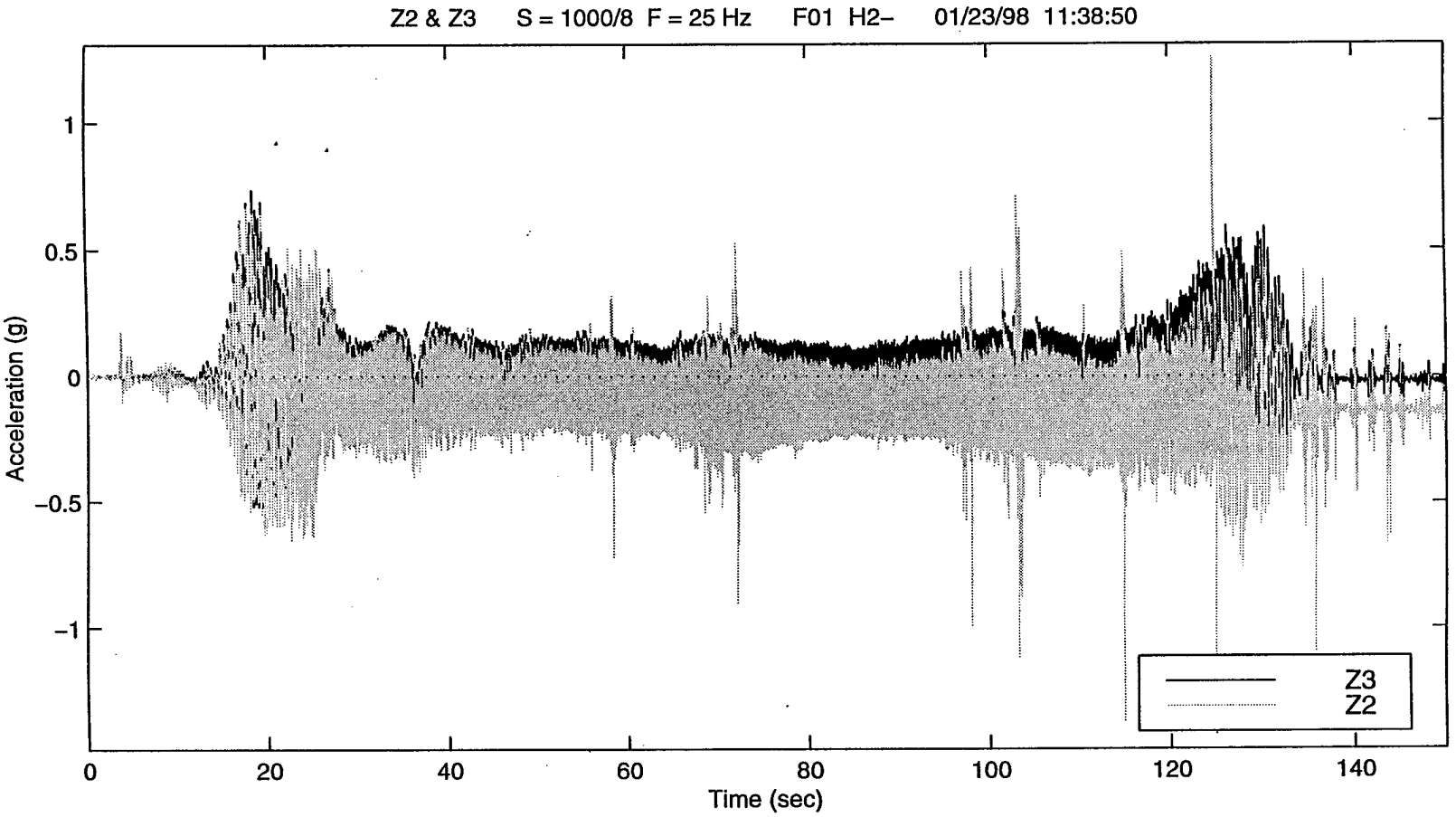

Figure F-1. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 2-.

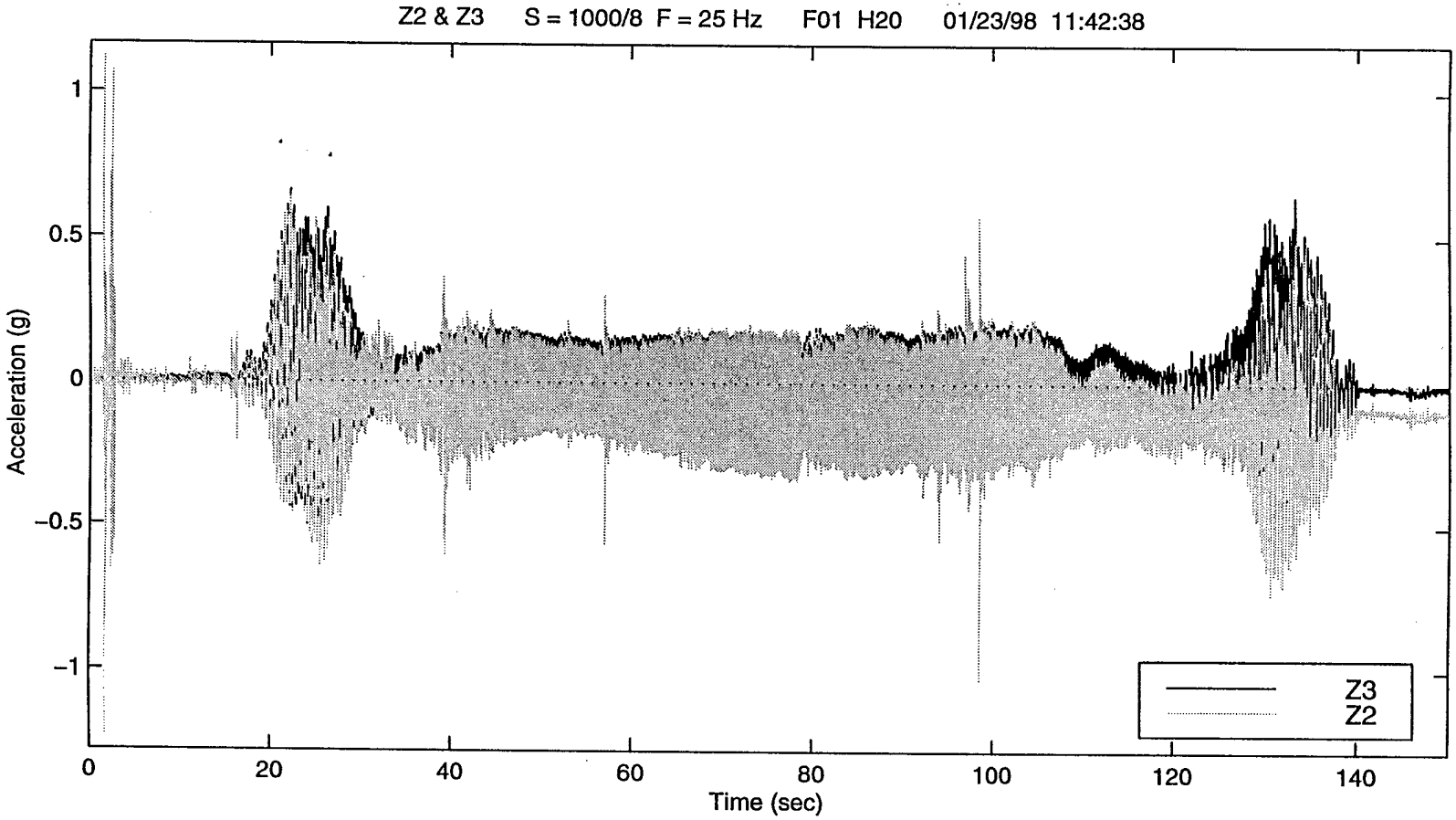

Figure F-2. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 20.

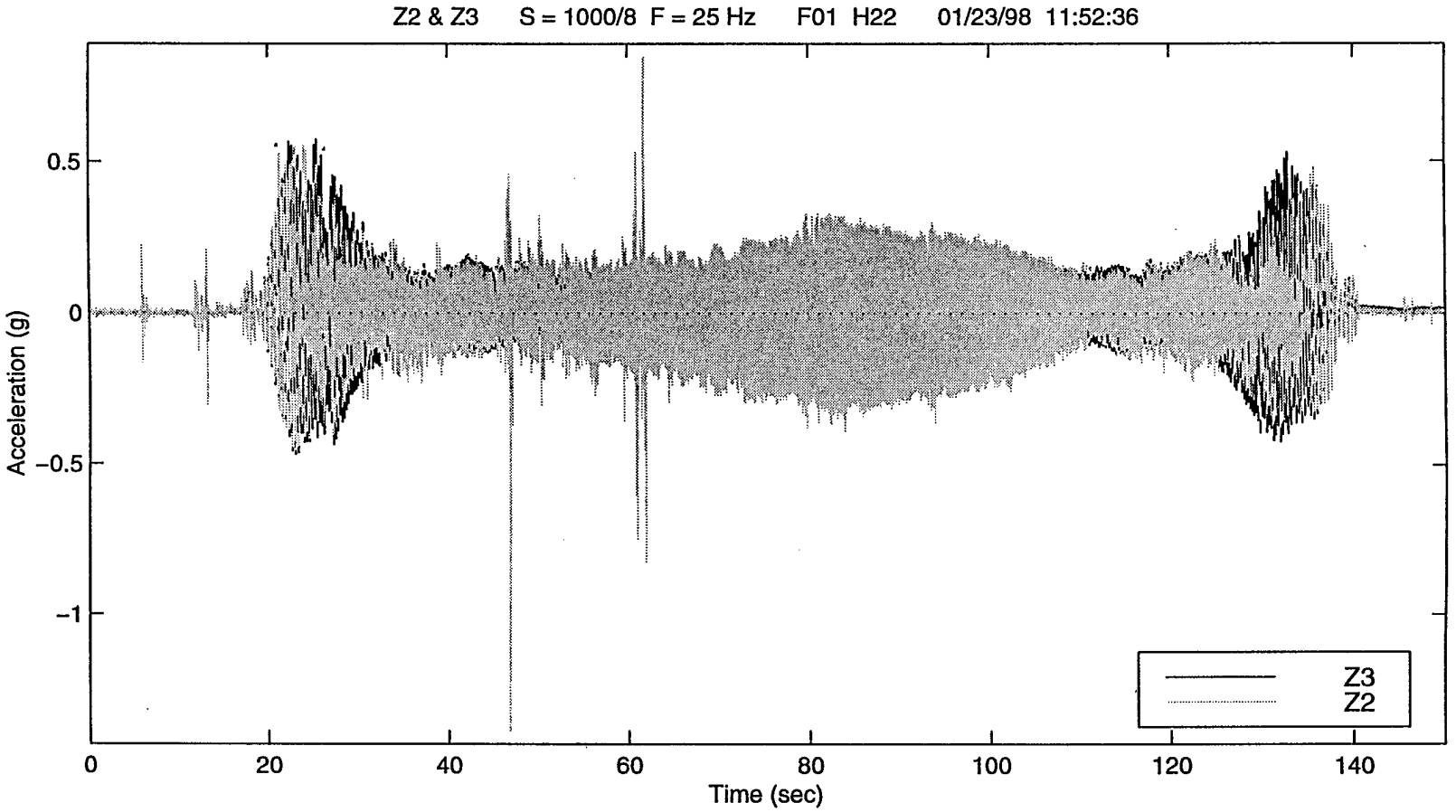

Figure F-3. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 22.

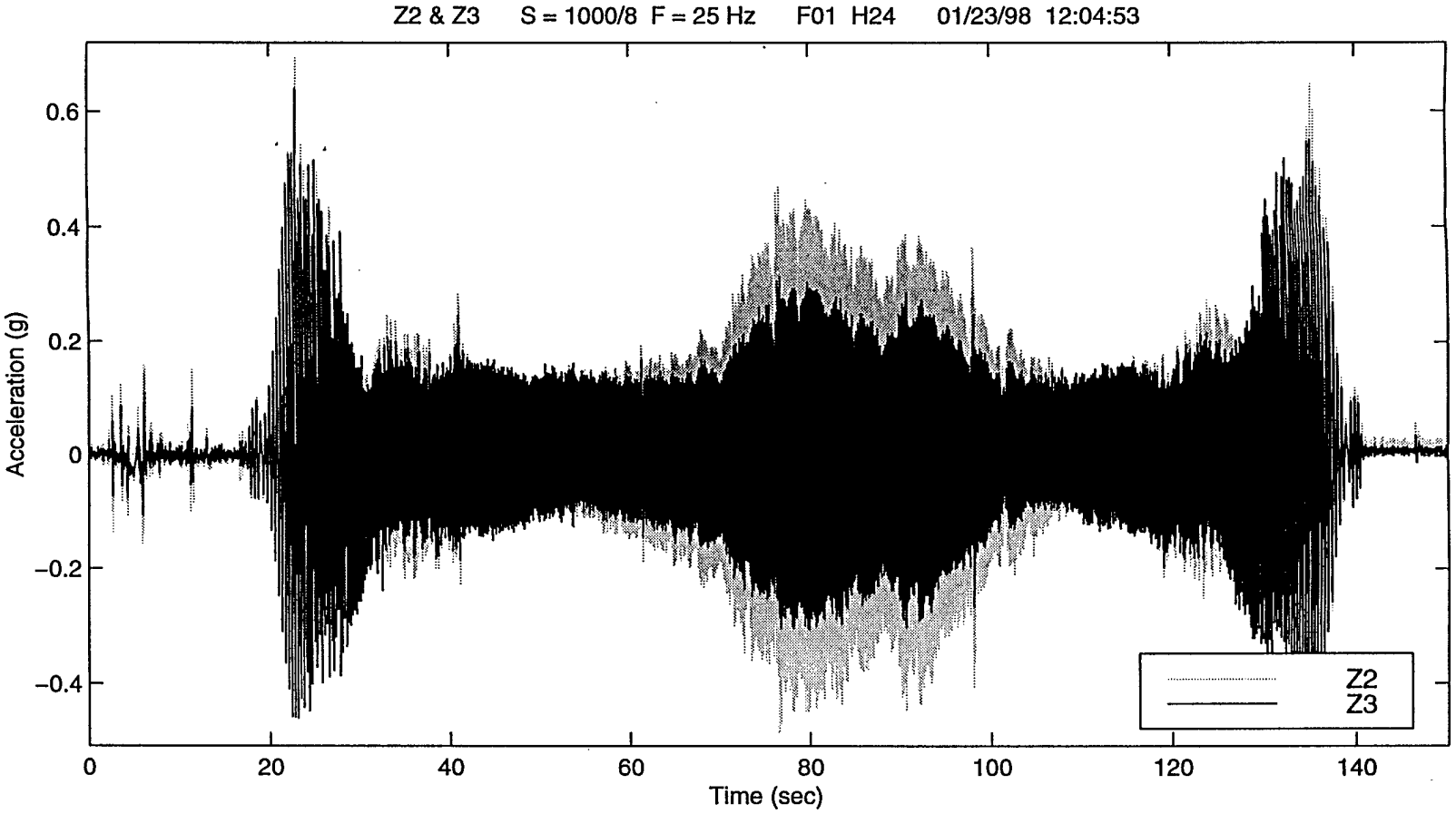

Figure F-4. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 24.

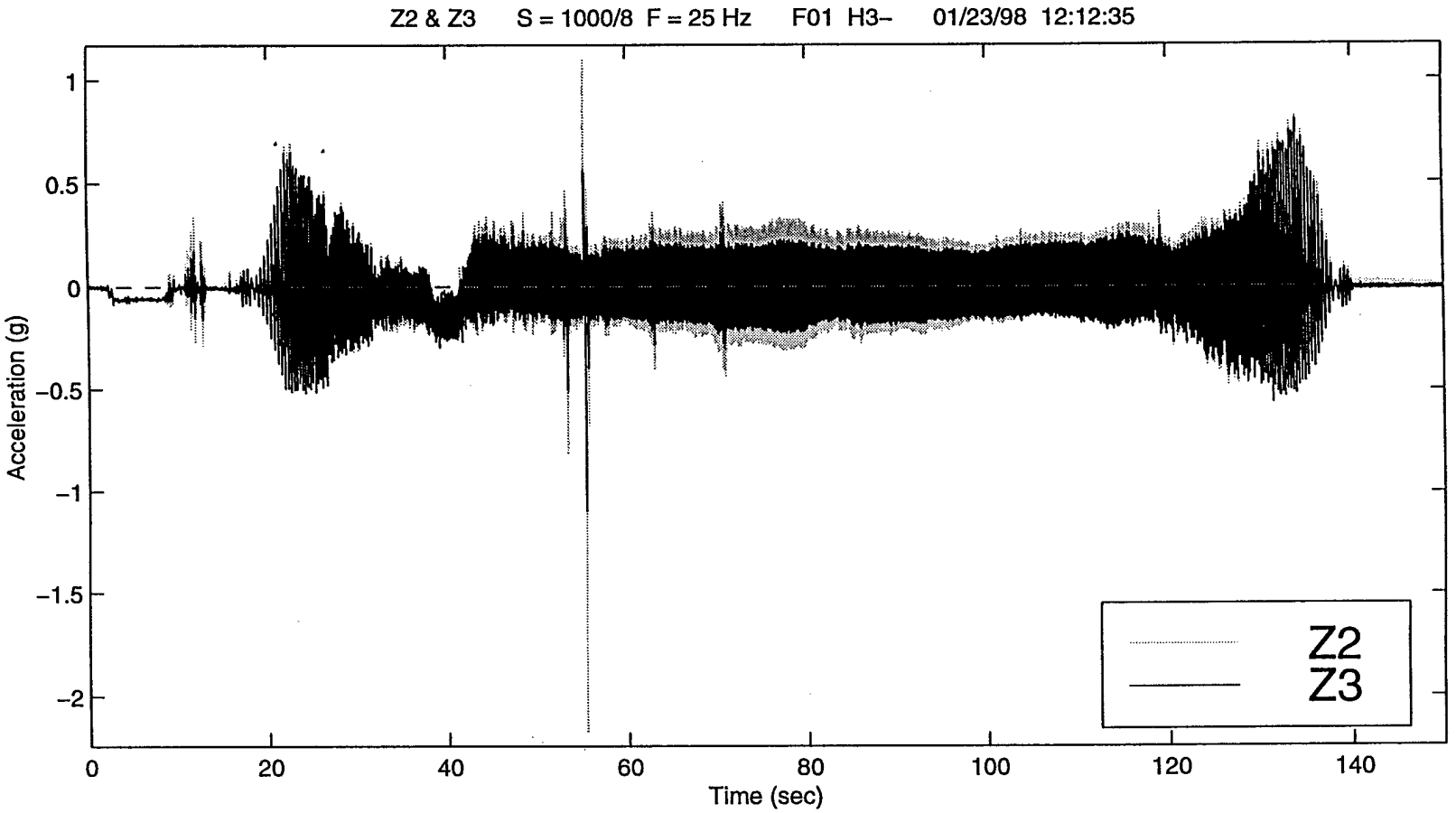

Figure F-5. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 3-.

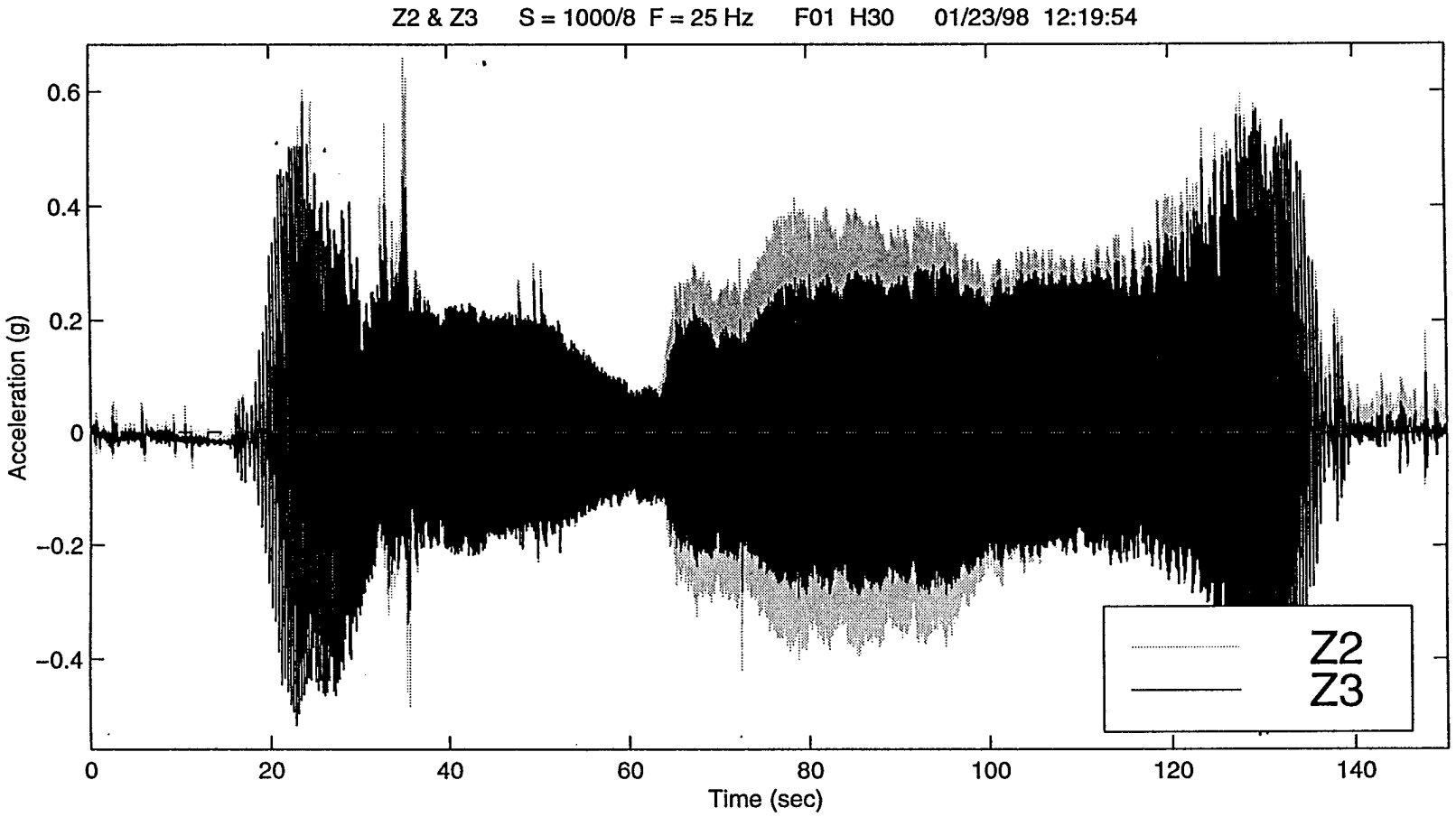

Figure F-6. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 30.

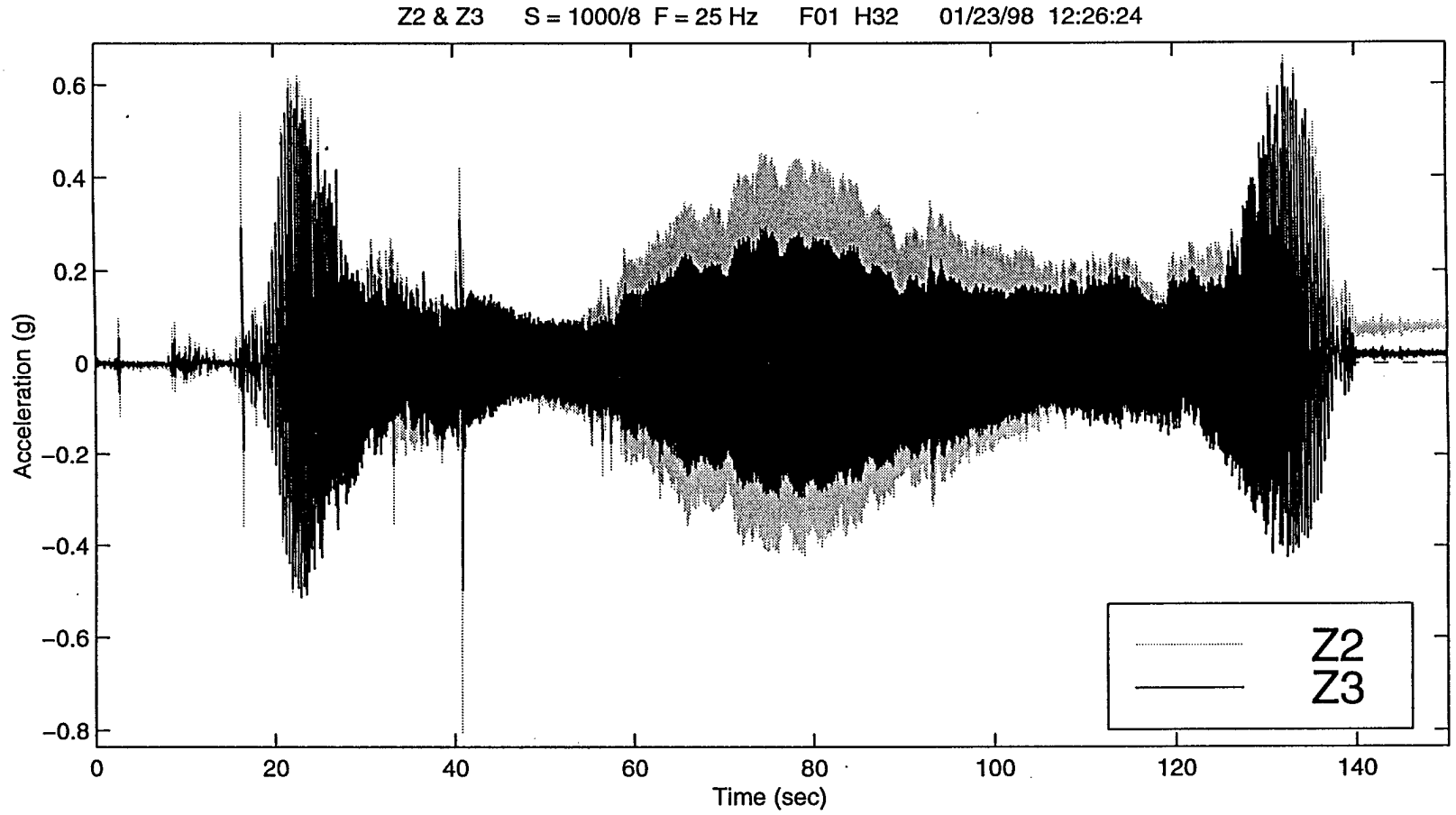

Figure F-7. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 32.

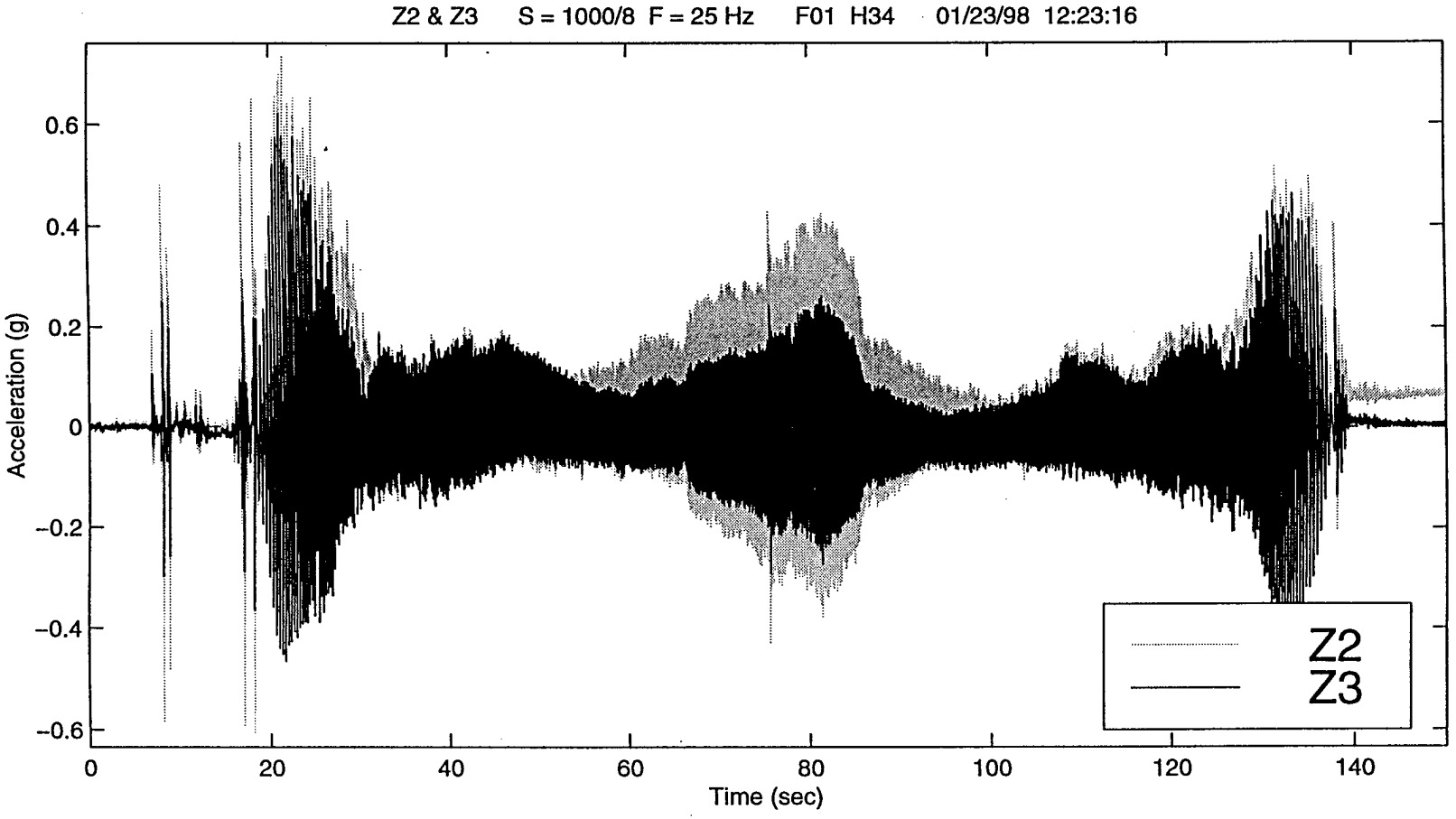

Figure F-8. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 34.

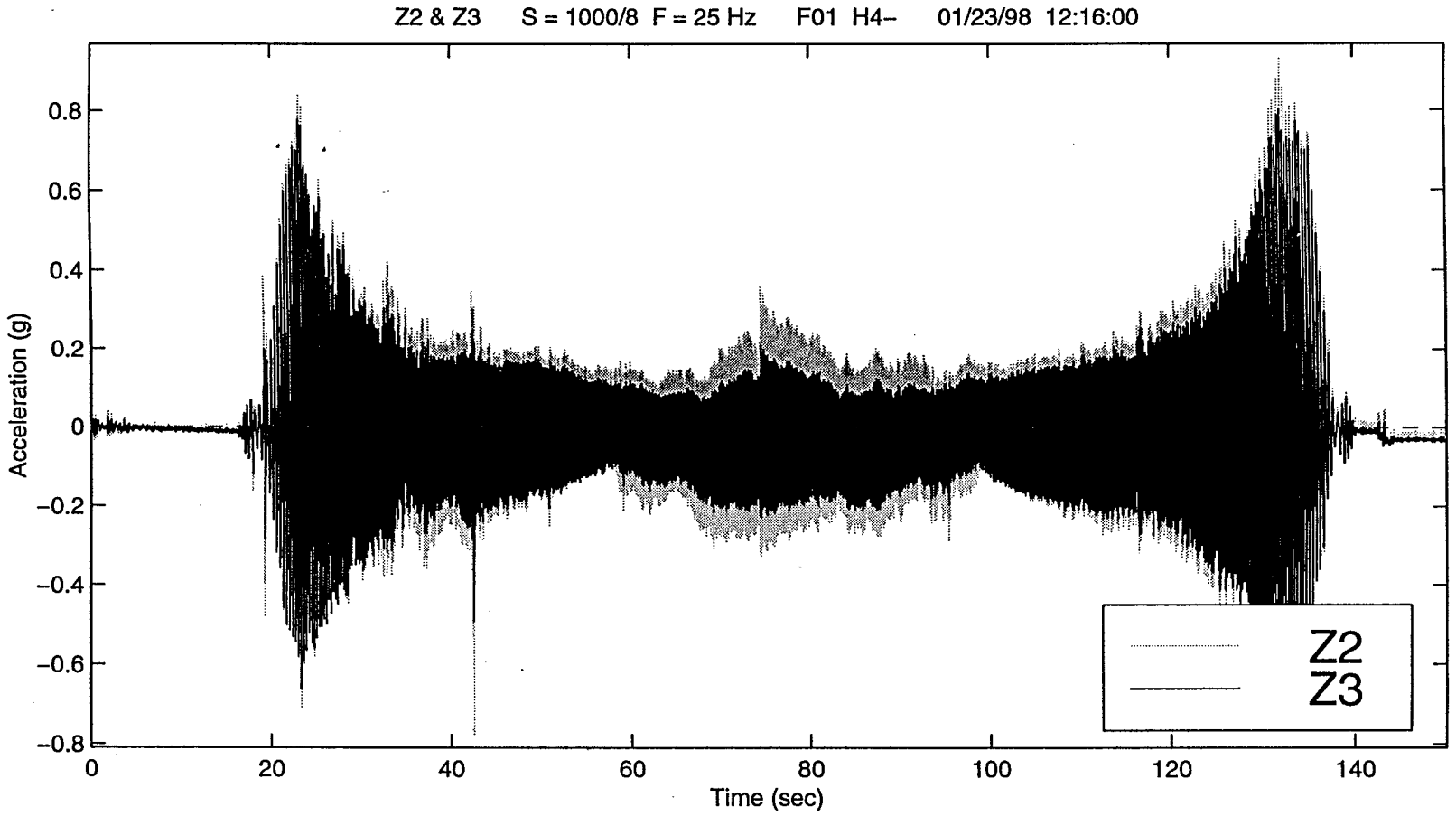

Figure F-9. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 4-.

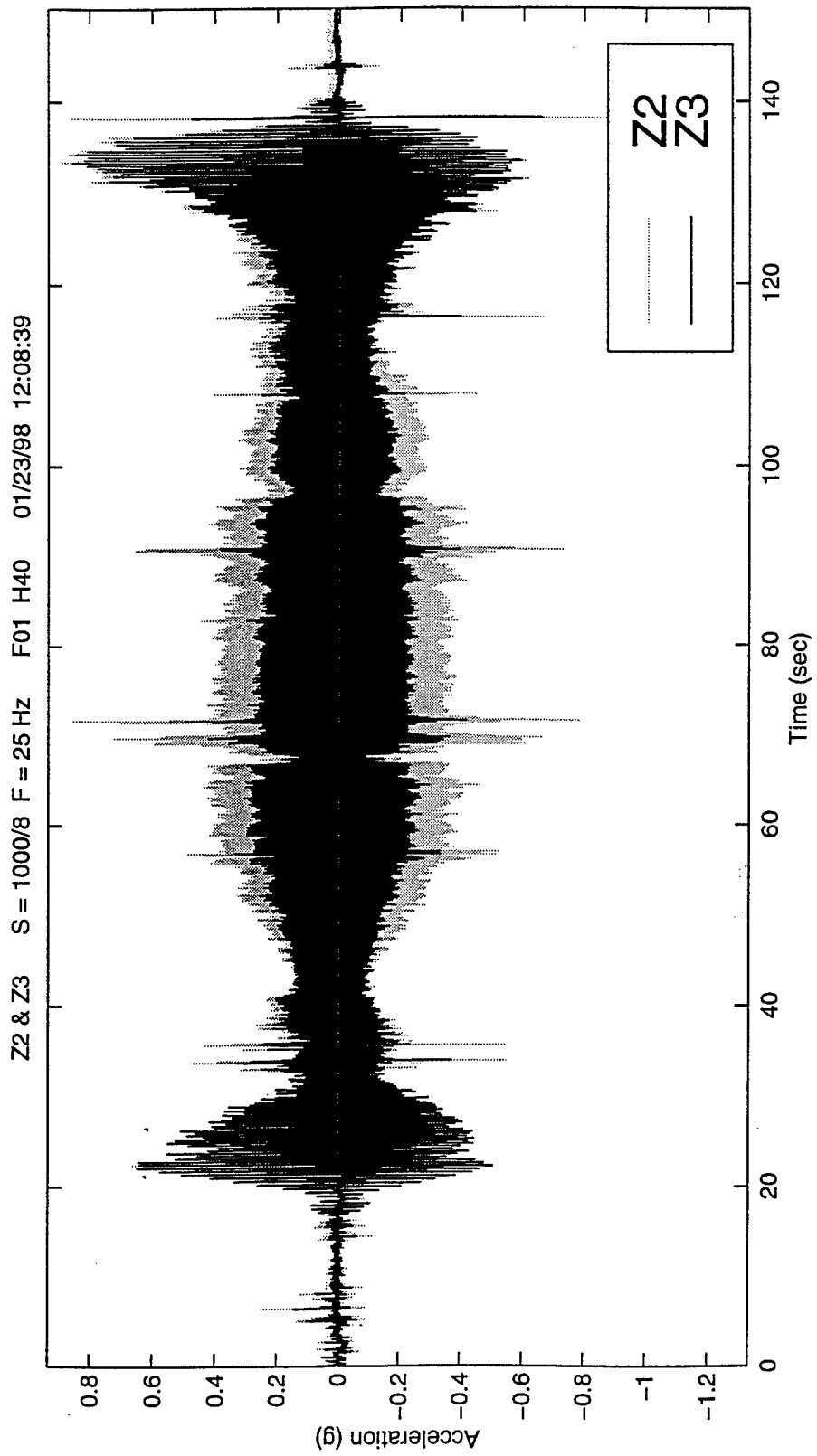

Figure F-10. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 40.

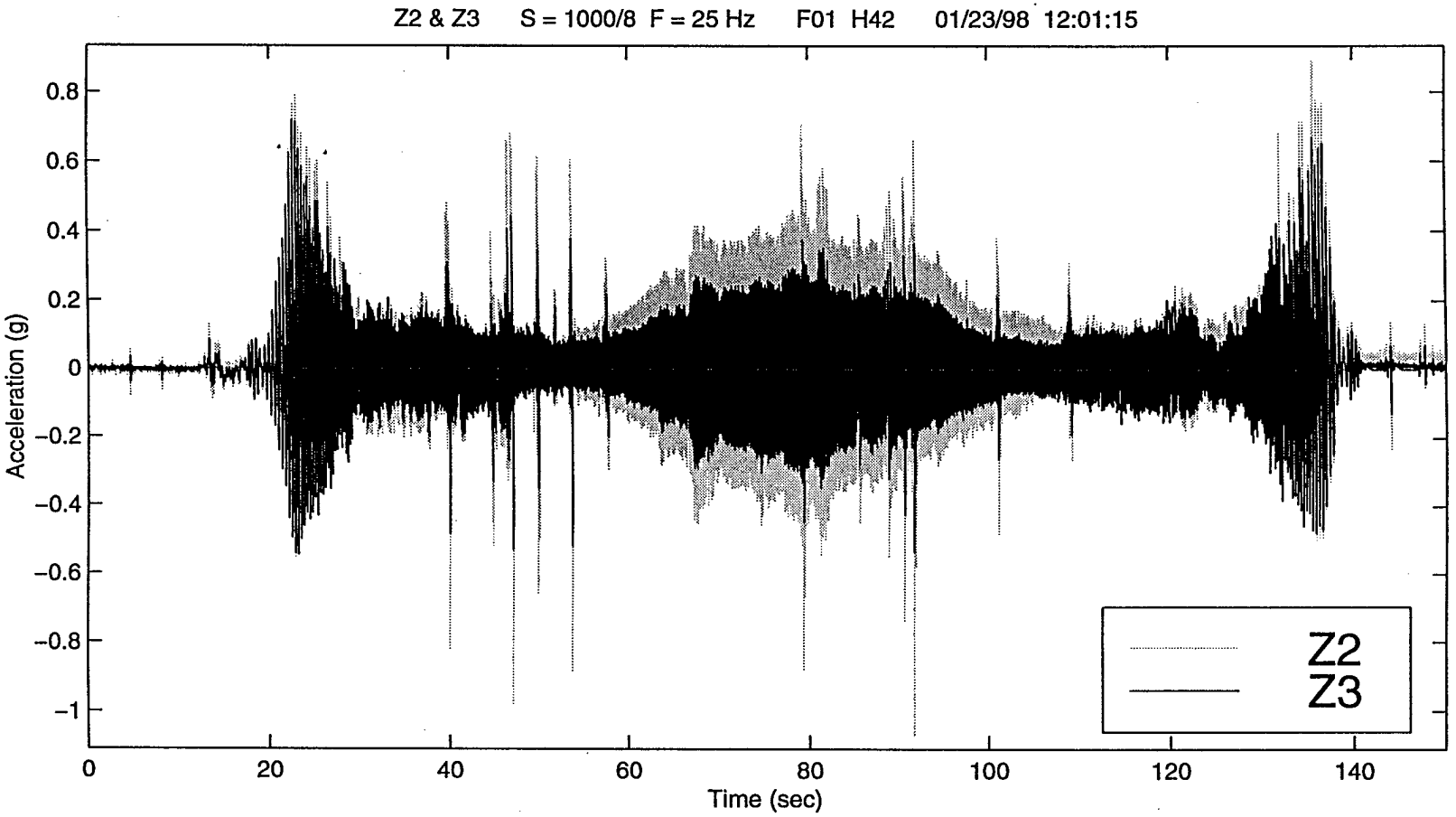

Figure F-11. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 42.

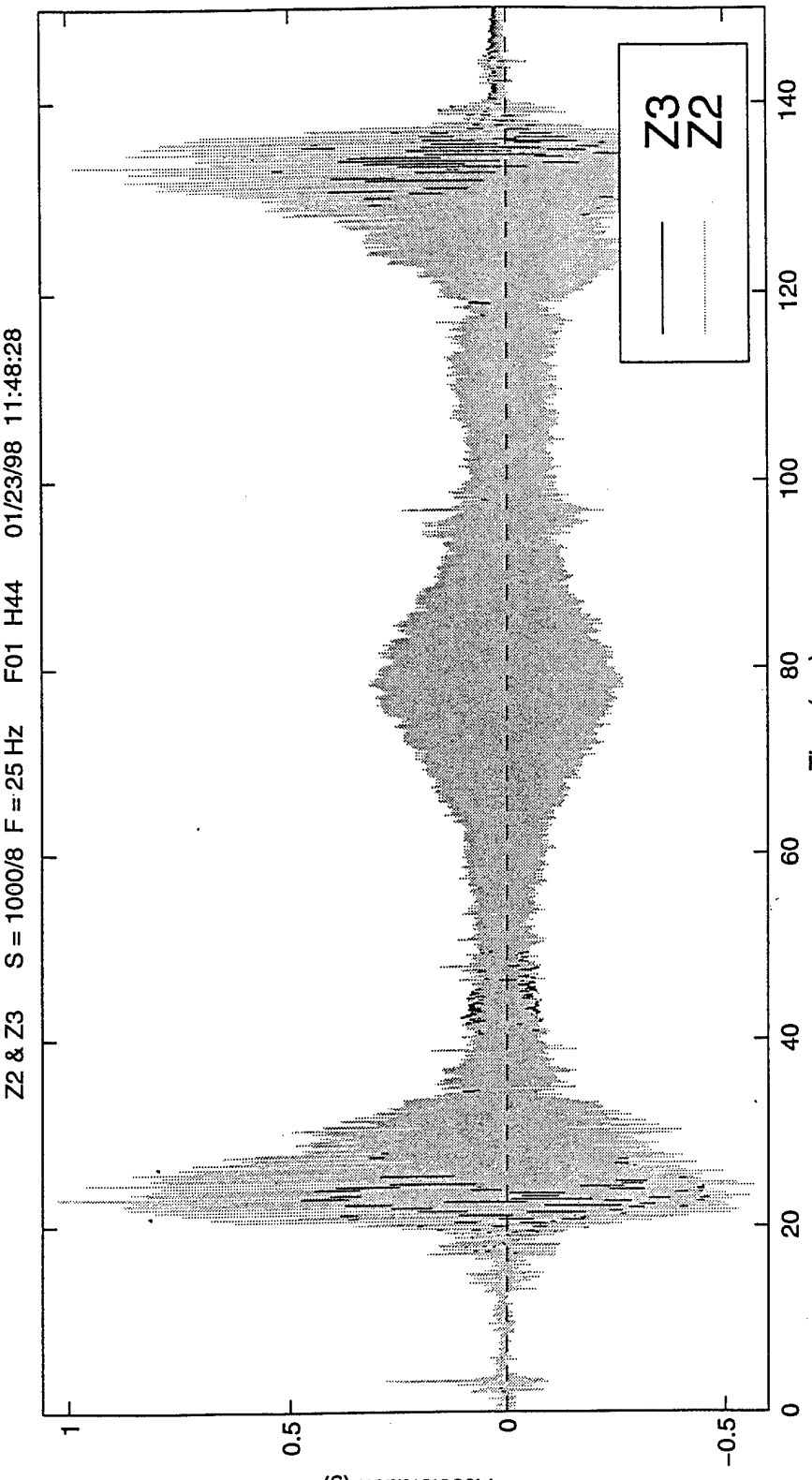

Figure F-12. Bite bar acceleration for accelerometers 2 and 3 in the z-direction during swept sine vibration for subject 01 wearing helmet 44.

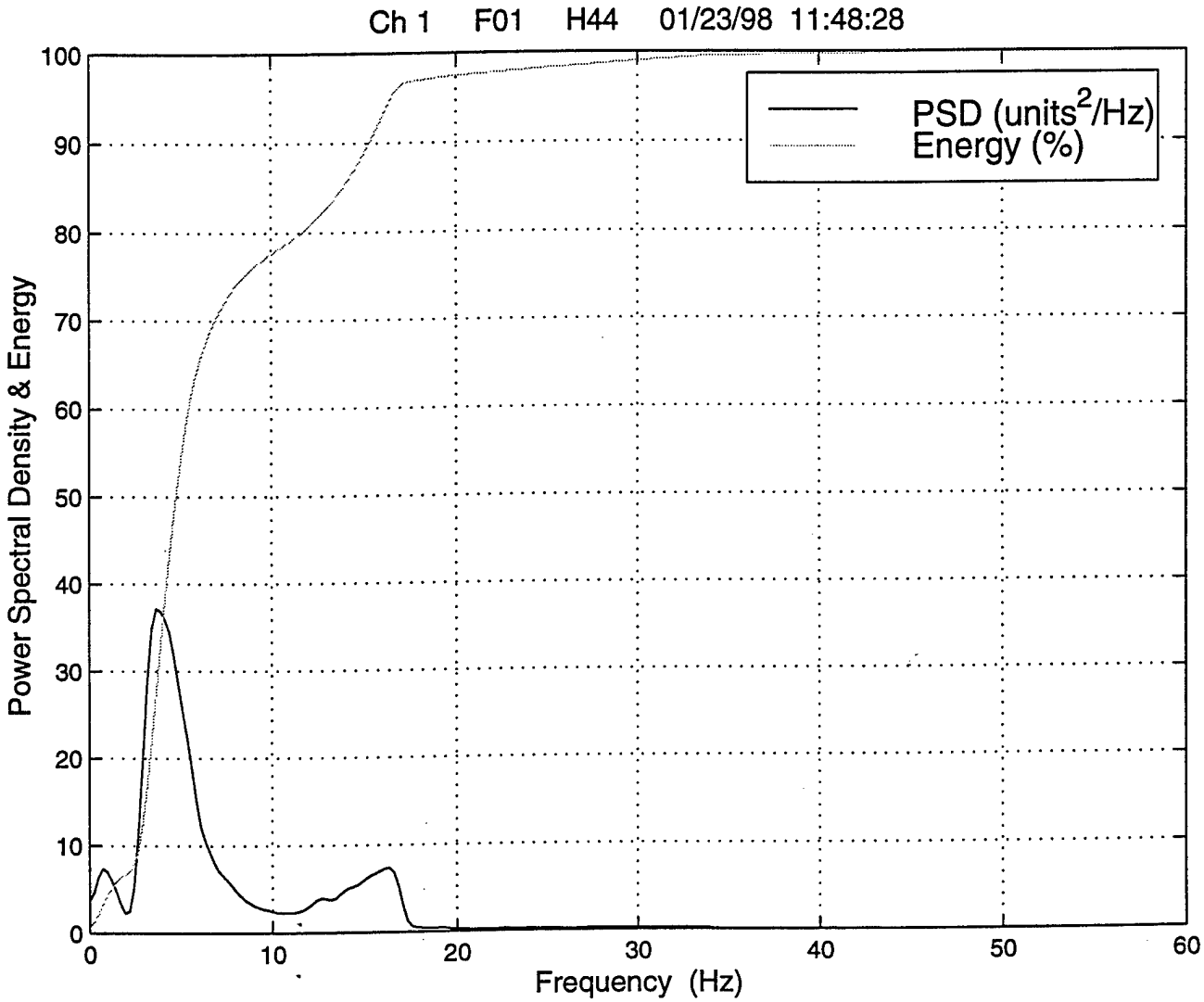

Figure F-13. Power spectral density (PSD) and energy for bite-bar acceleration channel 1 (X1), from swept-sine test of subject F01, helmet H44.

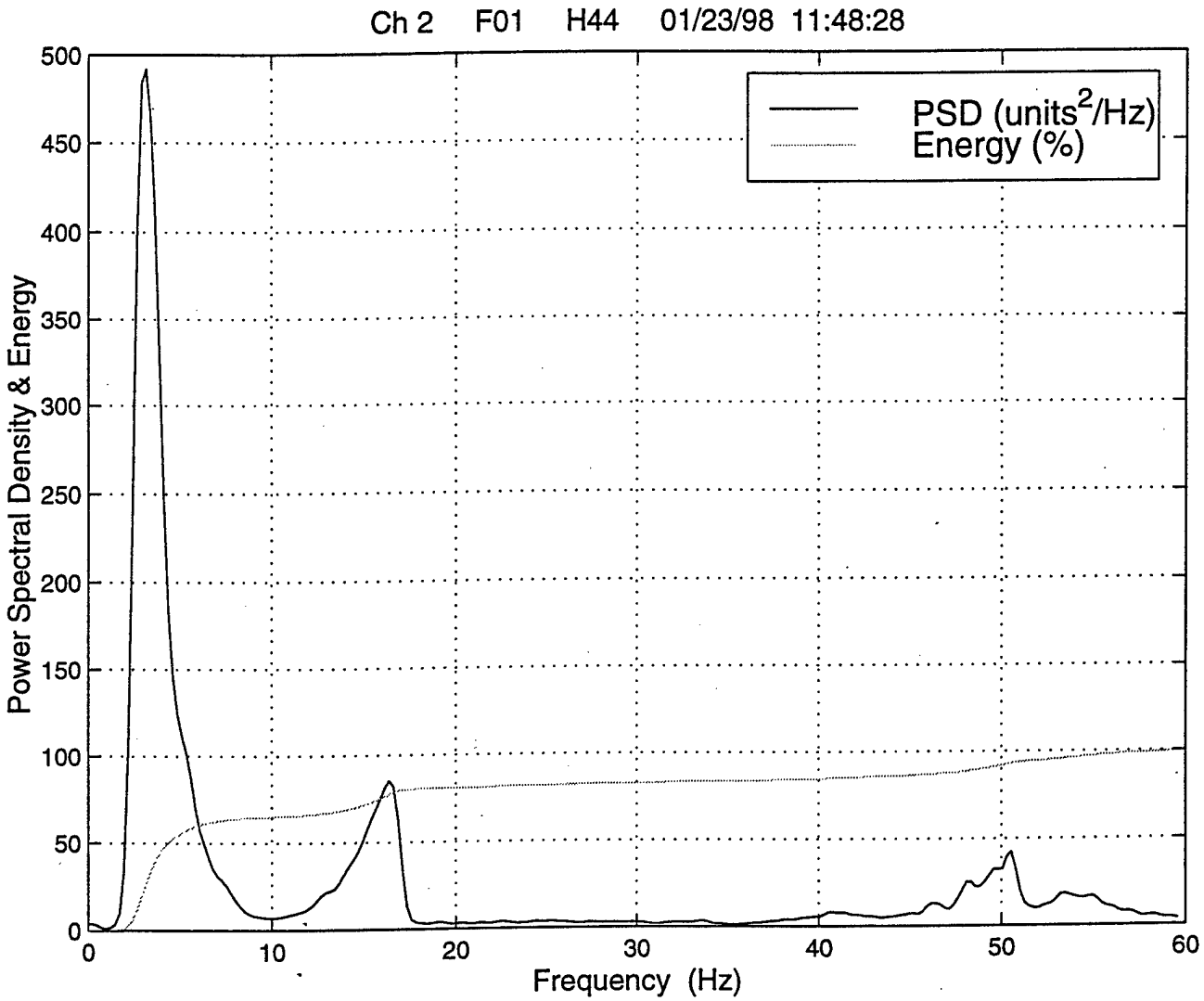

Figure F-14. Power spectral density (PSD) and energy for bite-bar acceleration channel 2 (Z2), from swept-sine test of subject F01, helmet H44.

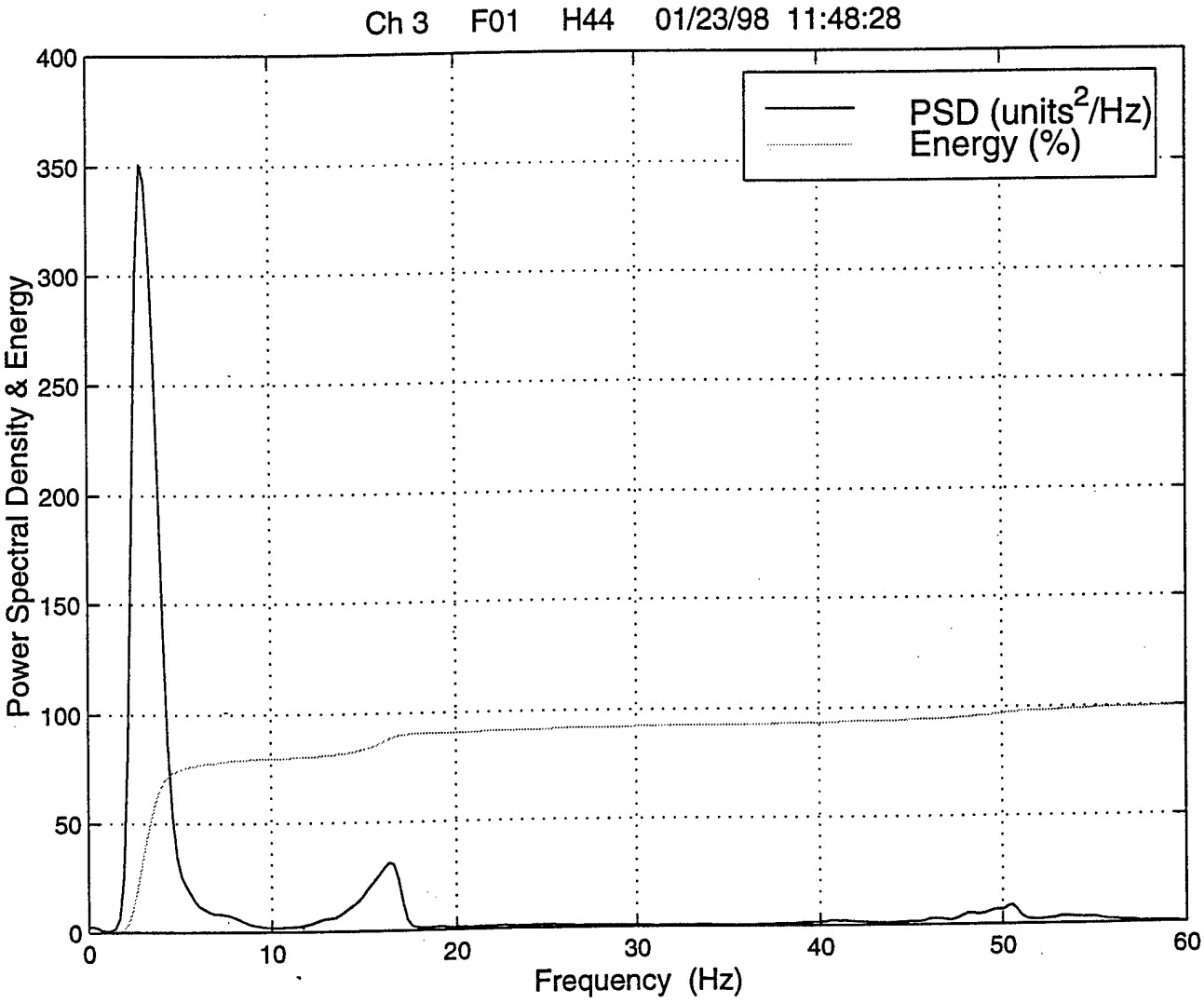

Figure F-15. Power spectral density (PSD) and energy for bite-bar acceleration channel 3 (Z3), from swept-sine test of subject F01, helmet H44.

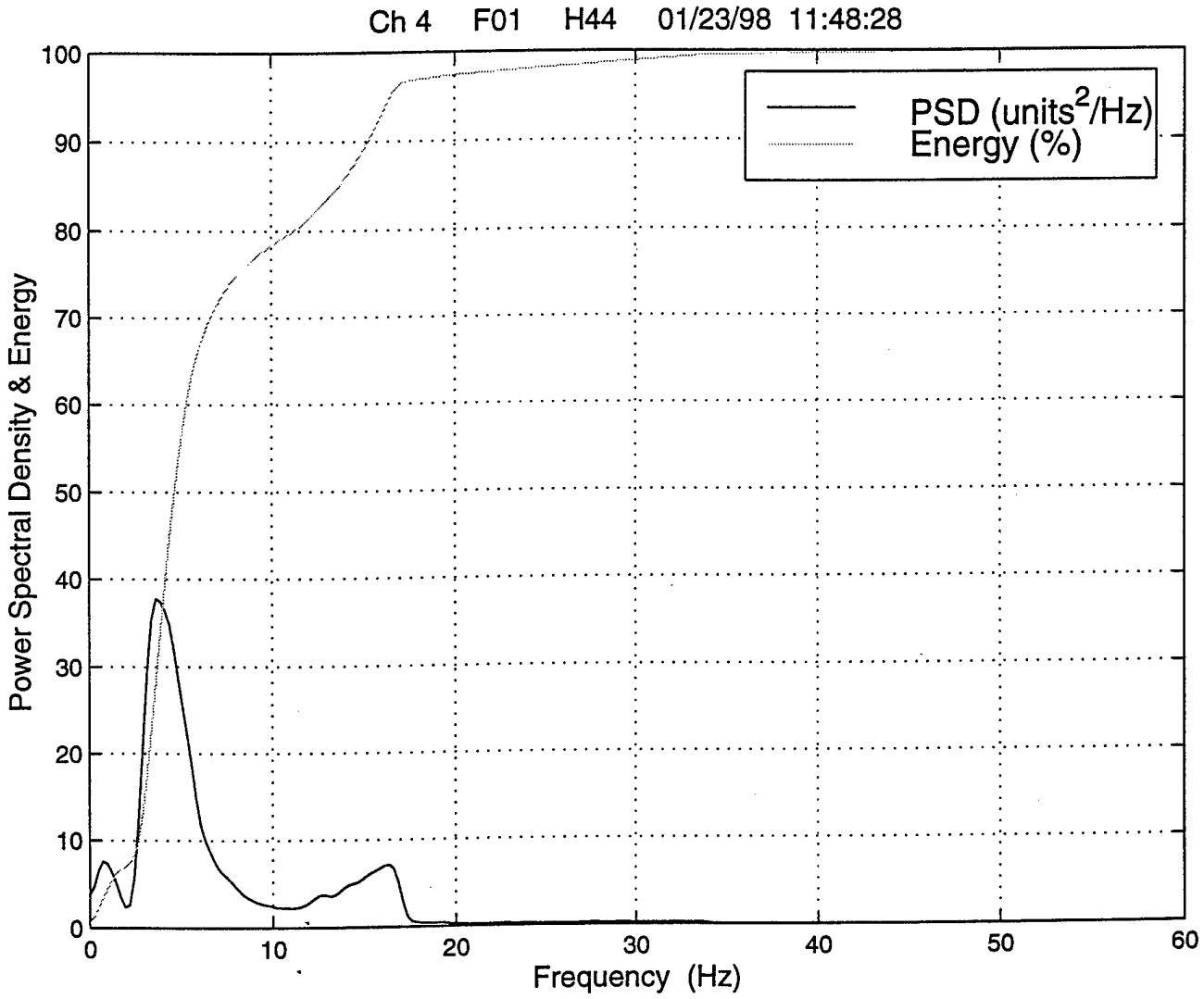

Figure F-16. Power spectral density (PSD) and energy for bite-bar acceleration channel 4 (X4), from swept-sine test of subject F01, helmet H44.

Table F-1. Summary of spectral analysis of bite-bar accelerations. By retaining the highest frequency (58.3 Hz), we are guaranteed to keep all frequency components that make up 99 percent of the energy in any signal.

FFT Length = 4096
FFT Window = Blackman
Overlap (%) = 12.5
Detrending = Linear

Power Frequency (Hz)

	90 percent				95 percent				99 percent			
	ch-1	ch-2	ch-3	ch-4	ch-1	ch-2	ch-3	ch-4	ch-1	ch-2	ch-3	ch-4
H2-	8.3	31.7	15.1	8.1	11.0	49.6	16.8	10.5	17.3	54.9	50.0	16.8
H20	12.0	19.8	15.4	11.5	15.1	48.3	16.6	14.9	17.3	53.0	49.6	17.1
H22	13.2	27.3	15.9	12.7	15.6	47.4	16.8	15.4	17.8	52.2	48.3	17.3
H24	15.4	40.3	16.6	15.4	16.4	48.1	17.3	16.4	23.2	52.5	48.8	22.5
H3-	15.6	31.2	15.6	15.6	16.6	48.1	16.8	16.6	27.8	51.0	48.8	24.2
H30	15.9	18.1	15.6	15.9	16.6	46.4	16.6	16.6	29.3	50.8	47.6	28.1
H32	15.9	47.9	16.6	15.9	16.6	49.6	39.3	16.6	29.1	50.8	49.8	27.6
H34	16.1	37.4	16.6	16.1	16.8	48.8	20.3	16.8	30.8	56.2	49.6	30.3
H4-	16.6	40.5	15.4	16.8	25.1	44.4	29.8	26.4	49.3	53.5	45.7	50.8
H40	16.4	22.5	16.1	16.4	16.8	44.4	16.8	16.8	30.0	51.0	48.3	28.8
H42	16.4	33.0	16.6	16.4	16.8	46.9	26.6	16.8	27.8	53.0	48.3	27.8
H44	15.4	49.1	17.1	15.4	16.6	52.7	47.4	16.6	30.3	58.3	54.7	30.8
Avg	14.8	33.2	16.1	14.7	16.7	47.9	23.4	16.7	27.5	53.1	49.1	26.8
min	8.3	18.1	15.1	8.1	11.0	44.4	16.6	10.5	17.3	50.8	45.7	16.8
max	16.6	49.1	17.1	16.8	25.1	52.7	47.4	26.4	49.3	58.3	54.7	50.8

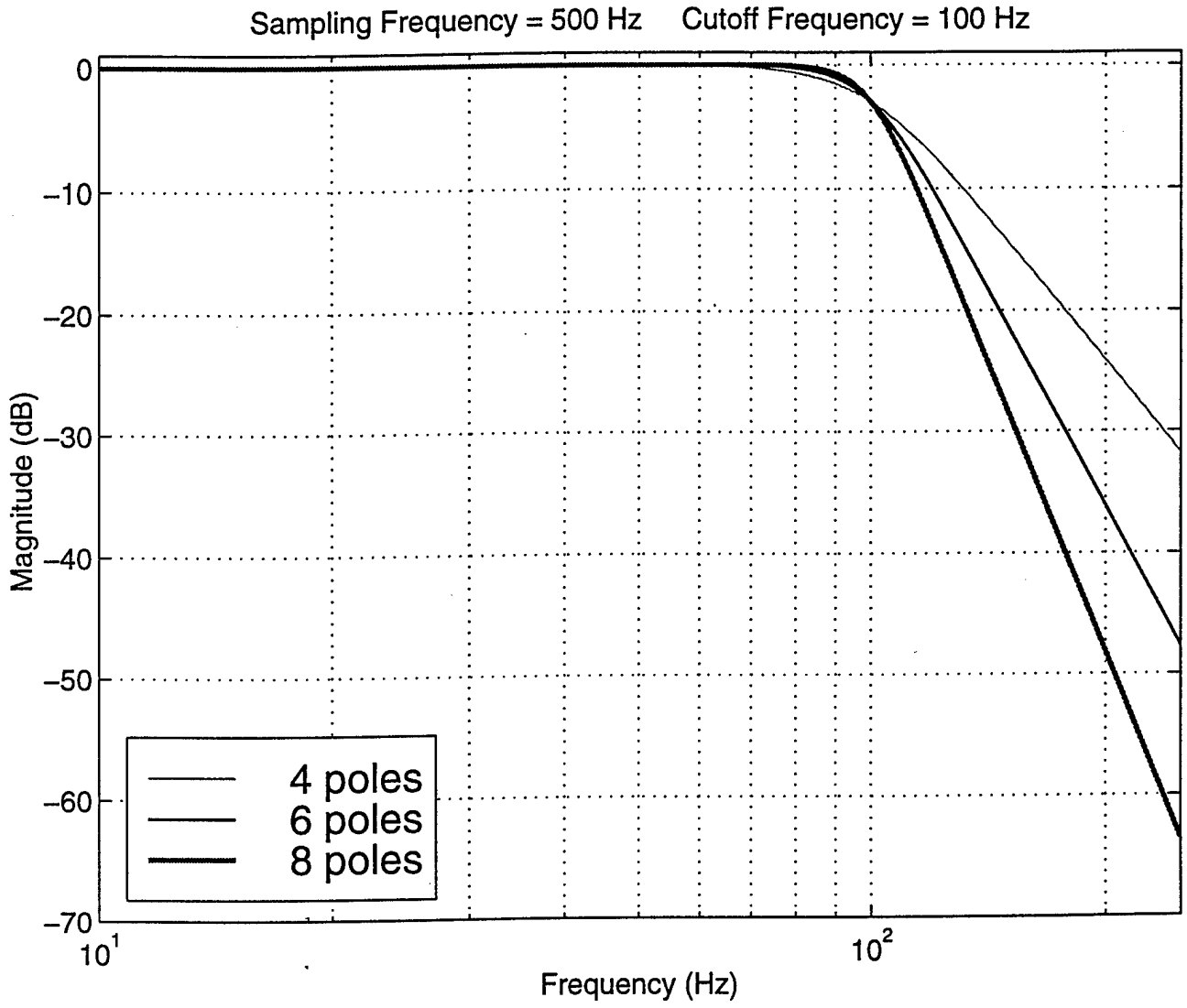

Figure F-17. Frequency response of 100-Hz anti-alias filters that may be used with bite-bar accelerometers. By selecting a 6-pole, 100-Hz filter, sampling rate can be reduced to 500 samples/second.