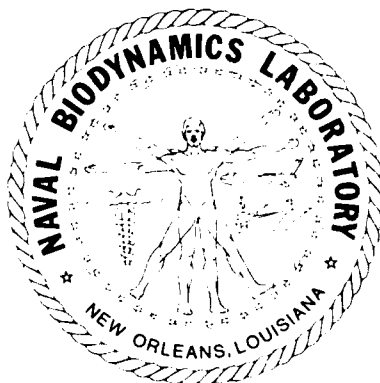# HUMAN SHORT-LATENCY SOMATOSENSORY EVOKED POTENTIALS IN IMPACT ACCELERATION RESEARCH:

EQUIPMENT, PROCEDURES AND TECHNIQUES

DAVID L. MATSON, Ph.D.

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Technical Report

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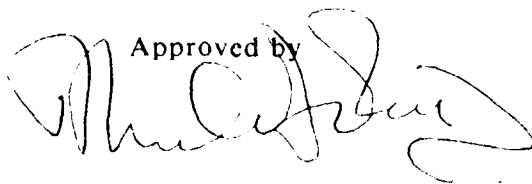NAVAL BIODYNAMICS LABORATORY
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13. ABSTRACT (Maximum 200 words)

The Naval Biodynamics Laboratory has been investigating the neurophysiological effects of impact acceleration on humans. The goal of this research program is to establish impact injury thresholds for properly restrained personnel. This report summarizes the techniques and equipment configurations developed for neuro-physiological impact research and offers suggestions for future research. Our efforts have focused on the use of somatosensory evoked potentials to assess the integrity of the central nervous system of humans undergoing impact acceleration. In our experiments we have exposed human research volunteers to impact accelerations ranging from three to fifteen times the force of gravity (3 to 15 g's) in various directions. These experiments provide data to help determine thresholds of injury to cervico-cortical neural pathways during impact events and indicate that the potential for injury may be reduced if these injury thresholds are taken into consideration in the designs of cockpits and emergency aircraft egress and recovery systems.

14. SUBJECT TERMS

Evoked potentials; somatosensory; impact; human techniques.

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HUMAN SHORT-LATENCY SOMATOSENSORY EVOKED POTENTIALS IN IMPACT ACCELERATION RESEARCH:

EQUIPMENT, PROCEDURES AND TECHNIQUES

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1. INTRODUCTION

The Naval Biodynamics Laboratory (NAVBIODYNLAB) has been investigating the neurophysiological effects of impact acceleration on rhesus monkeys and human research volunteers (HRVs). This report focuses on our use of somatosensory evoked potentials (SEPs) to assess the integrity of the central nervous system of HRVs undergoing impact acceleration. It is meant to document current techniques and rationales involving short-latency somatosensory evoked potentials as used in impact acceleration research.

This document will serve as a guide to future researchers at NAVBIODYNLAB and can be disseminated to contractors and collaborators as a technical reference. It can also be used as a resource for others conducting similar evoked potential research in advers environments.

One short-term objective of this research is to compare human neurophysiological data [1] with monkey neurophysiological data [2]. The long-term goal is to establish impact injury thresholds for properly restrained personnel. These thresholds will enable engineers to design safer cockpits, emergency egress and recovery systems.

In these experiments, HRVs are exposed to impact accelerations ranging from 3 to 15 times the force of gravity in various vector directions. These studies provide data to help determine whether the integrity of cervico-cortical neural pathways are compromised by such impact events.

The following three sections describe subject parameters, current equipment, techniques and procedures, along with notes on previous techniques and justifications for the changes. The methods section deals with experimental techniques and equipment. Section 3, "Signal Processing," details procedures and the hardware involved in our data analysis system. Recommendations for further improvements are included in Section 4, "Discussion."

2. METHODS

2.1 SUBJECTS

The human subjects are Navy enlisted men, ages 17 to 30 years, who have volunteered to be experimental subjects. Subjects are medically evaluated for cardiovascular, dental, psychological, pulmonary and skeletal contraindications for NAVBIODYNLAB impact experiments [3] before they qualify as HRVs.

Alcohol and several commonly used medications cause variations in SEPs. HRVs must report the use of any of these drugs during the three-week period preceding an experiment. The use of these drugs disqualifies them from participating as scheduled.

Prior to each experiment, the HRV's vital signs are recorded. A physician attends all impact experiments and emergency medical care facilities are immediately available.

The recommended clinical procedure for recording SEPs [4] is to have the subject supine on a bed with pillows at the head to minimize neck muscle tone. The room is kept quiet and a mild hypnotic, such as chloral hydrate, is usually administered. By contrast, subjects on the

NAVBIODYNLAB accelerators are strapped into a chair with no neck support (see Figure 1). The environment is acoustically and electrically noisy, and the subject is tense. Therefore, the recommended procedure is inappropriate for this research, and we have developed and continue to develop innovations to cope with this unique environment. A description of our equipment, procedures and techniques follows.
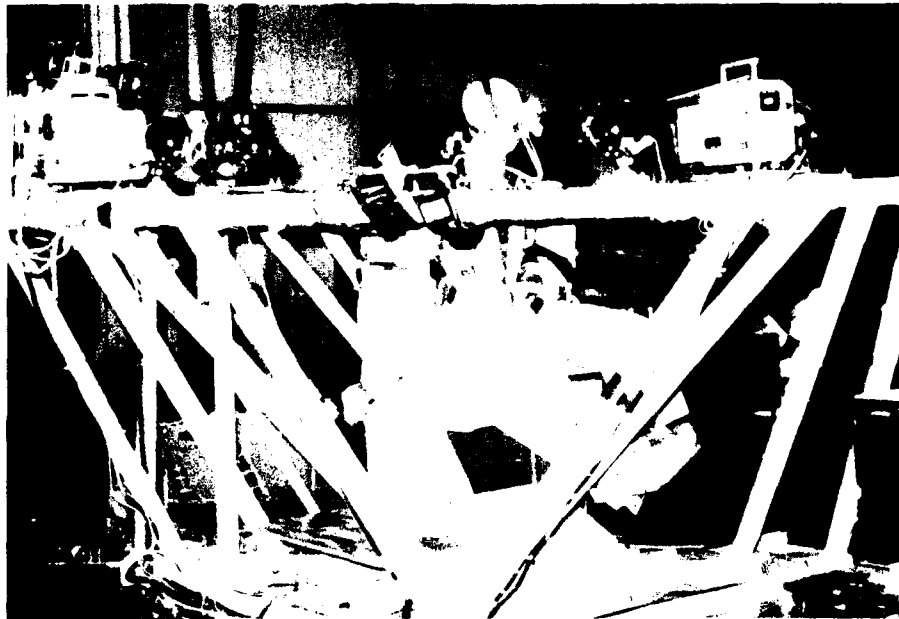
Figure 1. Fully Instrumented Subject

2.2 ELECTROENCEPHALOGRAPHY (EEG) DATA ACQUISITION

2.2.1 Electrode Recording Sites

Our minimal montage, which is based on Chiappa [4], contains the following recording sites: C4', Cz', Fz and REF (see Figure 2). C4' and Cz' are just posterior to C4 and Cz respectively (i.e., over the primary somasthetic cortex).

The ideal non-cephalic reference site for recording far-field potentials is CVII linked to the manubrium via a potentiometer. However, the constraints involved in the impact experiments make CIV the best possible substitute for upper limb studies, and Kc the best substitute for lower limb studies. Other sites which have been tried on impact experiments include the hip, shoulder and CII [1, 5].
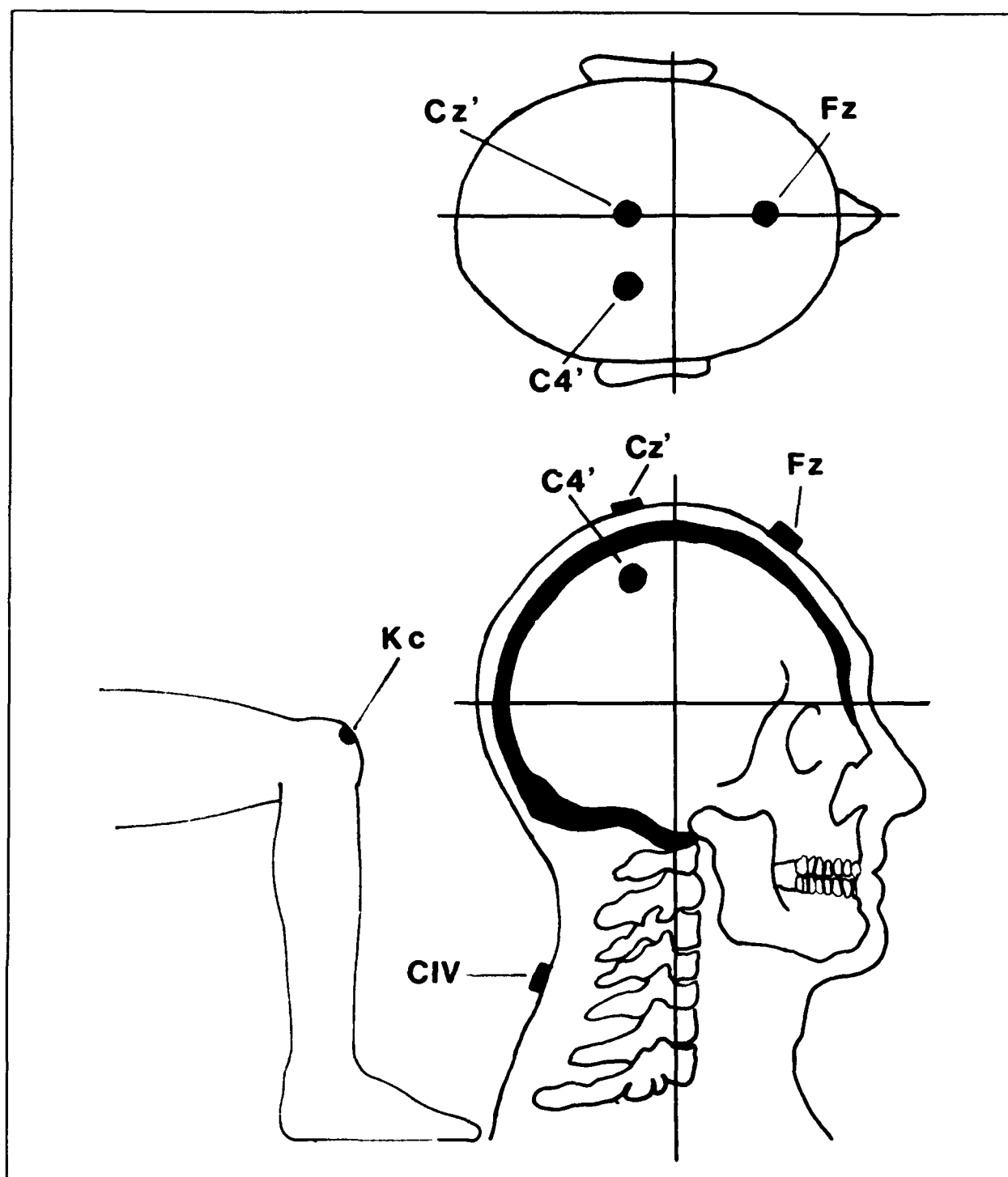
Figure 2. Electrode Configuration

2.2.2 EEG Electrode Harness

The harnesses containing the electroencephalographic (EEG) leads and electrodes are fabricated at the NAVBIODYNLAB. Two active electrodes and one reference electrode are used. The lead wire used is National Cable Molding Corporation™ part number 2390-72. A snap-on electrocardiographic (ECG) electrode connector is fastened at one end of the lead wire, the other end is left unterminated. For the reference electrode, the lead wire is used without modification. For the two active electrodes we remove the molded snap-on connectors and replace them with Grass™ Instruments E5S silver cup electrodes. Skin surfaces are cleaned with cotton-tipped swabs dipped in acetone and abraded by rubbing with the untipped end of the wooden swab; then Synapse™ electrode cream is applied. An Ace™ bandage wrapped around the HRV's head is sufficient to maintain electrode contact throughout the session.

Resistance readings between pairs of recording electrodes are usually under 5,000 ohms. Readings of over 10,000 ohms as measured with a multimeter are unacceptable and the preparation procedure is repeated until readings are acceptable.

The EEG harness is fastened to a connector at shoulder height on the side of the subject's chair on the accelerator. The connector is part of a test box used to check resistances between pairs of electrodes. A toggle switch selects the RUN mode, in which the electrodes are connected to the EEG amplifiers, or the TEST mode, in which the electrodes are connected to pin jacks located on the test box. The switch is set to the test position to check the electrode resistances at the pin jacks with a multimeter. This makes it possible to take pre- and post-impact resistance readings. The pin jacks are labeled Fz, C4' or Cz', and REF which correspond to the Fz, C4' or Cz', and reference electrodes. The remaining free ends of the leads are terminated by a Bendix™ PT06CE-12-10S circular connector with the following pin-outs:

PIN	LEAD	SITE
A	ACTIVE #1	Fz
B	ACTIVE #2	C4' or Cz'
C	REFERENCE	CIV or Kc
J	GROUND	

2.2.3 Card Cage EEG Recording

Four EEG amplifiers are mounted on a single circuit card located in the card cage (slot J12) on the sled (see Figure 3). Each amplifier uses a differential input stage with programmable gain, a fixed gain (x2.5) second stage, and a programmable gain output stage. They also include programmable high pass and low pass filters. Gains and filter parameters are chosen using plug-in resistors and capacitors of selected values. Lotz [6] provides details including circuit schematics and gain/filter resistor/capacitor selection criteria.

For HRV EEG recordings the gain and filter settings of the amplifiers are set to the following values (although the gain levels are being re-evaluated):

CHANNEL	BANDPASS (Hz)	GAIN
Fz to CIV	10 to 1500	100,000
C4' to CIV	10 to 1500	100,000
Fz to C4'	10 to 1500	100,000
Fz to Cz'	10 to 1500	100,000
Cz' to Kc	10 to 1500	100,000

4
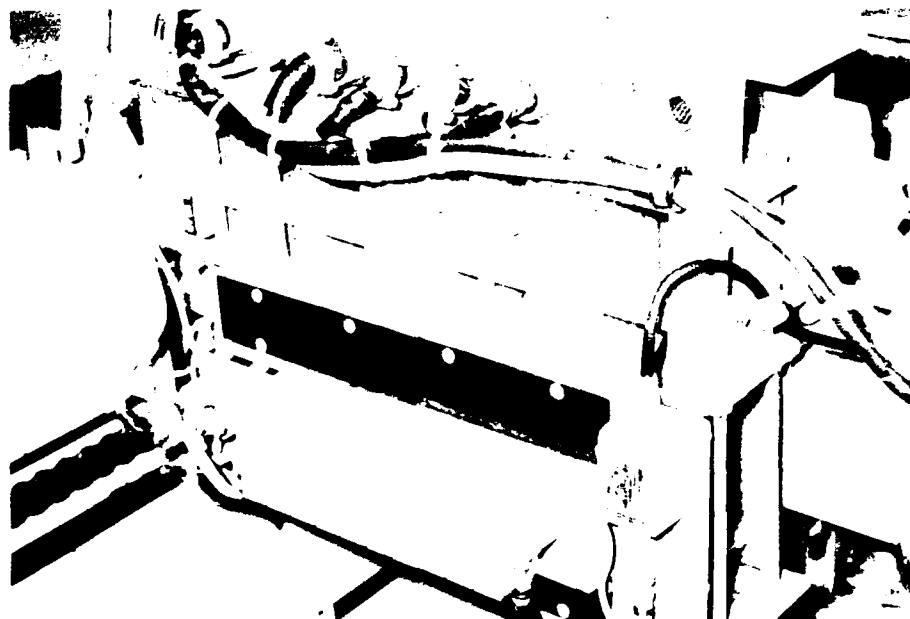
Figure 3. Card Cage on Sled

The narrow bandpasses recommended by Chiappa [4] are utilized. In this particular example only three of the seven available DC-1500 Hz channels allocated for EEG are used. The available channels include one wide-band channel (110 kHz ± 36 kHz) for the stimulus monitor and seven DC-1500 Hz channels (-3.0 dB) — one of which is used for the trigger.

The EEG input program card is located (slot J10) in the card cage [6] and routes signals from the EEG electrodes to the EEG amplifiers. Wire jumpers on the card are used to route the signals. The EEG output program card (located in slot J14 of the card cage) is used to route the amplifier outputs to the VCO/Transmitter for multiplexing and transmission to the control room.

EEG signals are generally routed to a multiplexer (MUX 2) as follows:

AMPLIFIER OUTPUT	MUX 2 CHANNEL NUMBER	CHANNEL CENTER FREQUENCY (Hz)
1	1	25,000
2	2	40,000
3	3	55,000
4	4	70,000

MUX 2 is used because it has a wide bandwidth (DC-1500 Hz). The stimulus trigger is routed to MUX 2 (channel 5, 85 kHz ± 4 kHz) via the output program card (J15). The stimulus voltage/current monitor signal passes through the same output program card to MUX 1 (channel 9, 110 kHz ± 36 kHz). In this particular example, only five of the seven available DC-1500 Hz (-3.0 dB) channels allocated for EEG are used. Eight DC-170 Hz channels (-3.0 dB) are also available and may be used for temperature monitoring, vector ECG, and/or electromyography. Lotz [6] describes the complete physiological package wiring for a typical experi-

mental series. All multiplexed signals are then transmitted to the control room.

2.2.4 Control Room

The signals from the subject are sent to the control room as shown in Figure 4. The EEG multiplexed signals and the voltage/current monitor signal are routed via the patch panels to an Ampex™ FR2000 tape recorder. An IRIG B modulated time code signal is recorded on track 4 of the Ampex™ FR2000 tape recorder. The multiplexed signals are also patched over to the real time physiological discriminator input. This connection demultiplexes the signals and allows real time monitoring of the EEG signals. From the discriminator outputs the EEG signals and the stimulus trigger are routed to a Beckman™ Type R 12-channel chart recorder, an oscilloscope and EEG monitor lines. A second oscilloscope is used to view the stimulus voltage/current monitor signal.

Connections to the EEG monitor lines at the patch panel route the EEG signals to a junction box attached to the rear panel of the Beckman™ Type R chart recorder. The EEG signals are connected to a Nicolet™ 1170 Signal Averager located on a table adjacent to the Beckman™ chart recorder.

2.3 STIMULUS

For an upper limb site, the medial phalange of the index finger and middle finger [7] of the left hand are stimulated percutaneously. The stimulus level for each session is approximately four times the detection threshold (in tenths of a milliampere), which is determined prior to each session for each HRV. Bilateral stimuli would also be useful for some experiments, but can't be utilized because the HRV needs to hold an abort switch in his right hand. Anodes are placed distally using two pairs of TECA™ digital ring electrodes in parallel (see Figure 5). For lower limb peripheral nerve stimulation, Chiappa [4] recommends an electrode placed midway between C3' and C4' (see Figure 3). The ankle is a conventional site for the stimulation of the posterior tibial nerve, and has been used to assess the effects of diseases and injury [8, 9], as well as normal functioning [10, 11]. A braided, tin-plated copper shielding strap is fitted just proximal to the stimulation site. This eliminates most of the stimulus artifact contaminating the first few milliseconds of recordings. Previous attempts using a cup electrode or single wire ground were unsatisfactory. The surface of the skin is prepared as for electrode placement. The possibility of using a biphasic stimulus was investigated, to reduce stimulus artifacts, but this did not significantly improve the recordings.

The stimulator (Figure 6) is capable of providing isolated constant current rectangular stimulus pulses of adjustable width and repetition rate. (Currently pulses are of 0.2 ms duration and the repetition rate is 5 Hz.) An adjustable current output from zero to 26.5 mA and a trigger output that is time-locked to the stimulus are used. A stimulus voltage/current monitor signal output is also provided. The stimulus battery is checked before each run because small decrements in the battery voltage can have dramatic consequences in the stimulus.

2.4 AVERAGER

The Nicolet™ 1170 signal averager is used to recover EEG data that are time-locked to the stimulus pulse. The display scale may vary for each HRV. Generally, a setting of 16 K gives
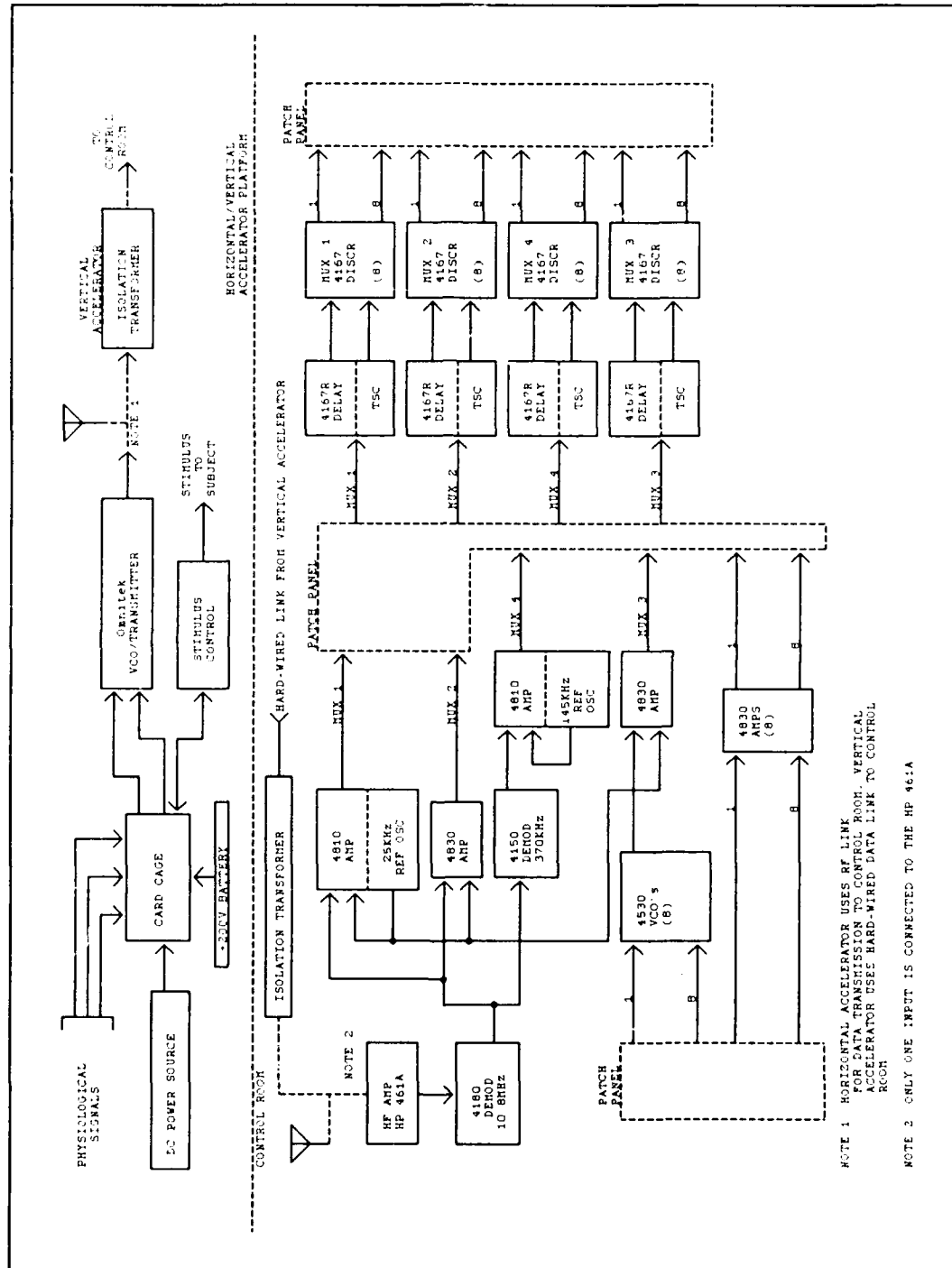
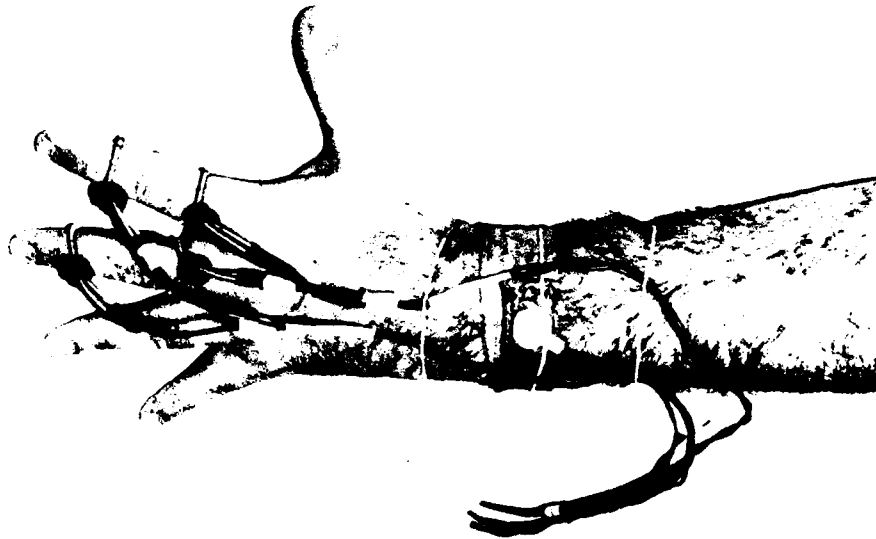**Figure 4.** Block Diagram of Physiology Data Acquisition System
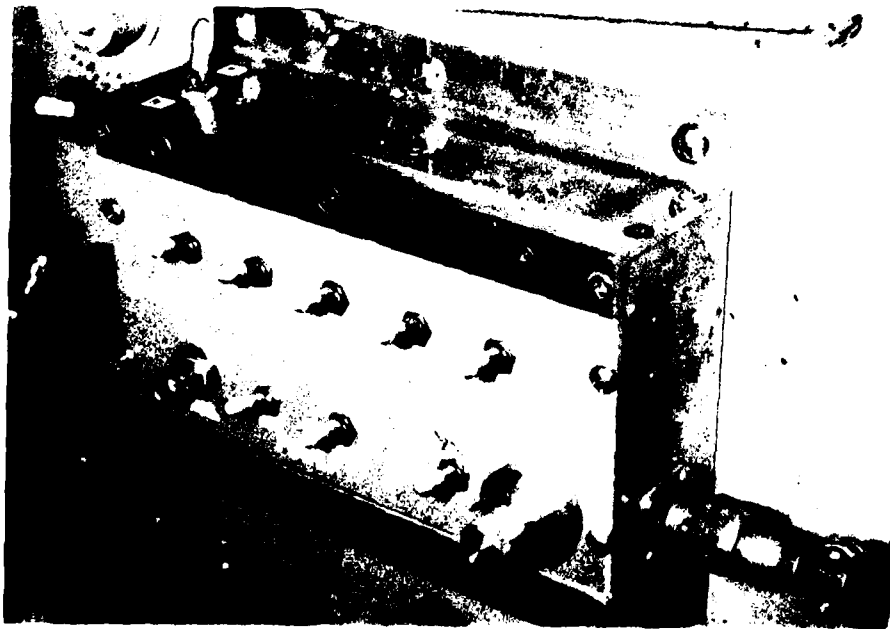
Figure 5. Stimulating Electrodes

Figure 6. Stimulator

good display resolution for most subjects. Figure 7 shows a typical evoked subject response and settings for the averager. Photographs are taken of the pre-impact and first post-impact averages with a Tektronix™ C-5 oscilloscope camera to document each run.

2.5 EVOKED POTENTIALS

Techniques to record evoked potentials from intact, healthy subject populations [12, 8], as well as injured and diseased populations [13, 14] are well documented. Our procedures include averaging a calibration pulse on all EEG channels prior to and when required after each experiment. The pulse is a 5 μV rectangular pulse which lasts 2 ms. The EEG signals are recorded on FM tape and later digitized with an analog-to-digital (A/D) sampling rate of up to 25000 Hz (6250 Hz per channel) with a 12-bit resolution (see Section 3.1, "Digitization," for more details). Stimuli are presented at five per second.

Each averaged SEP samples approximately one minute of EEG. The number of stimulus presentations per averaged SEP range from 210 to 300. This range was chosen as a compromise between the need to improve peak resolution and the need to restrict the amount of time sampled by each averaged SEP so that transient changes could be detected. This number of presentations provides accurate peak identification and good data for assessing the variability of latencies.

The four upper limb SEP components which are most useful for monitoring cervical spine integrity are N11 (P11), N13 (cervical), P14 and N20 (arrival at the primary cortical receiving area). We derive latency, amplitude and conduction time for all components using a customized evoked potential analysis software package (REPANL) on a Data General Eclipse™ computer (see Section 3.2, "Data Analysis").

2.6 ACCELERATORS

On the horizontal accelerator, the sled is accelerated along a 213 m horizontal track with a Bendix™ 12-in (30.48 cm) HYGE system capable of generating 996,750 N of thrust. An environmentally controlled housing surrounds the track. The sled is decelerated by friction forces ranging from 2 to 4 m/s/s (meters per second squared).

On the vertical accelerator, the carriage is accelerated along an 11 m vertical tower with a Bendix™ 6-in (15.24 cm) HYGE system capable of generating 177,920 N of thrust. The vertical accelerator facility is located entirely within an environmentally controlled building. The carriage is decelerated by gravity and friction forces of 5 m/s/s.

2.7 PHYSIOLOGY DATA BASE

Data for each human experimental run are entered into a physiology data base consisting of three pages. The first page is a parameter page. The example in Figure 8 is a page with defaults in place. The second page is a field for noting any clinical signs after the test run, such as "headache" or "stiff neck" (see Figure 9). The third page is a field for entering any remarks about the run, such as "Fz electrode pulled off at impact" (see Figure 10). "RUNID" designates the device used (LX for the horizontal accelerator and LZ for the vertical accelerator) and the sequential run number. The entry is restricted so that the first two characters are letters and the remaining four characters are numbers. The help text is "Run

EVOKED POTENTIAL INSTRUMENTATION DATA SHEET

Run Number __LZ0397__   Date __14 AUG 90__
Subject Number __H-224__   (day - mo. - yr)
        g-level __9__   Vector __+Z__

Device (circle one): horizontal accel. / vert. accel. / shaker / SMS

Tape #: __MPH 215__
Physiology channel data:
    CH 1. __FZ+ ---> CZ-__   __10-1600__   Hz   Gain: __100K__
    CH 2. __CZ+ ---> REF__   __10-1600__   Hz   Gain: __100K__
    CH 3. __FZ+ ---> REF__   __10-1600__   Hz   Gain: __100K__
    CH 4. __FZ+ ---> CZ-__   __10-1600__   Hz   Gain: __100K__
Stimulus: __5.0__ Hz, __0.2__ ms
Stimulus threshold: __4.1__ mA; sensation [X] twitch [ ]
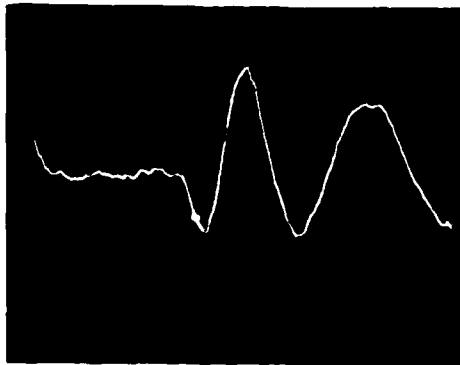Stimulus level used: _____ mA.
Stimulus site: __ANKLE__
Averager: Vertical display scale: __65K__   Number of sweeps: __1024__
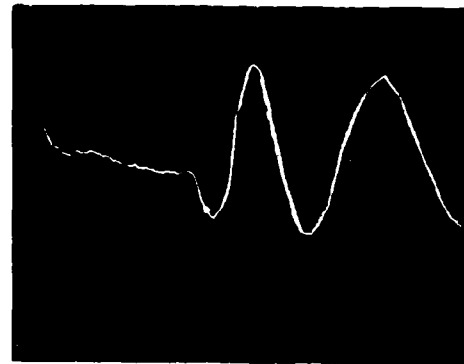   Time base: __100ms__ Full scale volts: _____ Input filter: __1KHz__

COMMENTS: Channel 1 only for photo.

[X] Pre-impact average (photo)   [X] Post-impact average (photo)

Signature

Figure 7. Evoked Potential Instrumentation Data Sheet

*****HUMAN PHYSIOLOGY SCREEN*****

Please Read First

To move from one field to the next, press the RETURN key. To find out how to Insert, Update, Delete, and Query records press the CLEAR DSPLY key. You may display the meaning of the function keys anytime with ESC k.

RUNID:_____   Subject Number:_____   Date:_____

G-Levels:_____   Time of First Motion:_____:_____:_____._____

Age:_____   Sex: <u>M</u>   Weight:_____   Temp:_____

BP:_____   Pulse Rate:_____   Resp. Rate:_____

ELECTRODES   **STIMULUS**

Channel 1: <u>None</u>   Threshold Type: <u>Sensation</u>

Channel 2: <u>Fz, REF</u>   Level: _____

Channel 3: <u>C4', REF</u>   Used: _____

Channel 4: <u>Fz, C4'</u>   Rate: ___5___

                                        Site: <u>Index & Middle Finger — Lt Hand</u>

Figure 8. Human Physiology Screen One

Number."

When the RUNID number is entered, the following are automatically retrieved from the engineering data base:

> **Subject Number:** Refers to a sequential number designating entry into the HRV population, preceded by the letter 'H' for human. We are currently up to approximately H240.
> **Date:** Refers to the date of the experimental run, expressed as the Julian date plus the two digit year.
> **G-Level:** Refers to the peak sled acceleration.
> **Time of First Motion:** Refers to the time in hours, minutes, seconds and ten-thousandths of a second at which the sensors first detected motion of the sled on that run.

The following are entered directly into the physiology database:

CLINICAL SIGNS:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Figure 9. Human Physiology Screen Two

REMARKS:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Figure 10. Human Physiology Screen Three

Age: The age of the subject, in whole years, restricted to a number from 17 to 40. The help text is "Enter the age of the subject. Range is 17 to 40."

Gender: The gender of the subject is a forced choice 'M' or 'F.' The help text is "Enter gender of the subject. Must be either 'F' (female) or 'M' (male)."

The following are automatically retrieved from the medical table database:

Weight: The subject's weight, in kilograms, restricted to a number between 40 and 125.

Temp.: The subject's core temperature, Fahrenheit, restricted to a number between 96 and 100.

BP: The subject's blood pressure, with systolic restricted to a number between 90 and 150 and diastolic restricted to a number between 50 and 90.

Pulse Rate: The subject's pulse rate, per minute, restricted to a number between 20 and 200.

Resp. Rate: The subject's respiratory rate, per minute, restricted to a number between 5 and 30.

The following are entered directly into the physiology database:

Electrode Channel 1: Electrode sites are chosen from the 10-20 electrode montage. The help message is "Enter electrode pair for Channel 1 (using the 10-20 Electrode Placement System)."
Electrode Channels 2, 3, 4 are similar to Electrode Channel 1.

Thresh.: Refers to stimulus threshold, in milliamperes, with a forced choice of 'sensation' or 'twitch,' and a number between 0.1 and 26.5. The help texts are "Enter either 'SENSATION' or 'TWITCH'" and "Enter value for threshold (milliamperes)."

Used: Refers to the stimulus level used during the run, and is restricted to a number between 0.1 and 26.5. The help text is "Enter value for stimulus used (milliamperes), e.g., 24.6."

Rate: The stimulus presentation rate in Hertz, with a forced choice '5' or '10.' The help text is "Enter value for stimulus rate in Hertz (either 5 or 10)."

Site: This is the site of the stimulating electrodes. The help text is "Enter the site of the stimulating electrodes."

3. SIGNAL PROCESSING

The following section details the methods used to convert raw EEG data into evoked potentials. The evoked potentials are then processed to produce our results.

3.1 DIGITIZATION

The EEG data are recorded on analog tape. The analog tape must provide a stimulus signal and the IRIG B time code with a resolution of .1 ms for correct operation of the digitization process.

The NAVBIODYNLAB-developed evoked potential software allows the user to specify different A/D sampling rates up to 20,000 Hz during different segments of the response.

A maximum of eight sampling epochs are available. Currently three epochs are used: 40 ms pre-stimulus to stimulus (dwell time = 0.4 ms); stimulus to 30 ms post-stimulus (dwell time = 0.05 ms); and 30 ms post-stimulus to 40 ms (dwell time = 0.2 ms).

The A/D system is an 80286-based AT-type microcomputer hosting a Data Translation, Inc., DT-2821 analog to digital converter and digital to analog converter capable of processing 150,000 samples per second. Other hardware incorporated in the system includes an IRIG B

time measurement expansion board and a locally designed and fabricated expansion board which contains an external clock circuit for precise control of the DT-2821 and a circuit for detection of the stimulus trigger signal. Digitized data are output to a Qualstar NineTrack nine-track tape system at 1600 BPI.

Prior to using the digitization program, the user prepares a disk file containing the program parameters for the particular run. The program allows user-generated interrupts via the keyboard to perform such functions as terminating the conversion process. The program begins digitization when it obtains a match between the IRIG time from the analog tape and the requested start time from the parameter input file.

The trigger signal is sent to an analog comparator, with the triggering threshold determined by the set-up parameters. Upon initiation of the digitizing process, the pre-stimulus data are sent to a sample and hold amplifier and sampled by the A/D converter at a rate determined by the sampling parameters, and are always the first epoch. If the trigger occurs before the buffer is full, a status bit and indices of the first and last points are saved, and written to magnetic tape.

When the stimulus threshold is detected and triggering is initiated, the variable sampling schemes are enabled for post-stimulus data, and are designed to correspond with the expected frequency content during various time frames. Seven remaining epochs (the first being used for pre-stimulus data) are available. Multiple I/O buffers are used so that data can be acquired and written to magnetic tape concurrently.

The data associated with a single stimulus are entered on magnetic tape as a logical record and logical data are packed into a physical record whose length is part of the setup parameters. Multiple tape reels may be used, and the number of physical records per reel is also part of the setup parameters.

Each logical record contains the IRIG B time of trigger and time of the last data point. A status word is written, indicating the detection of errors such as tape error, missed stimulus and incomplete pre-stimulus data. Partial information from the header is also included as part of each logical record.

A brief run summary is sent to a printer upon completion of the digitization process, providing the operator with information on the number of logical records acquired and recorded, and a general overview of system performance during the run.

A NAVBIODYNLAB-developed utility program (EPPLOT) can provide a plot on a Tektronix™ 4010 Graphics Terminal of user-selected logical records from the EAI magnetic tape (or tapes) as a verification of system performance.

The Principal Investigator or Experimenter [15] establishes a four-letter prefix for the experimental series. This prefix, along with the run number, uniquely identifies the EEG/EP data. Prefixes for human data that have been used to date are ZRUN and MXHH. The analog (FM) tapes are assigned a number by the electronics engineer in charge of neurophysiology data acquisition.

Low-density to high-density conversion is accomplished by executing a program call WRITETAPE on the Data General Eclipse™ computer equipped with two tape drives and hard disks.

Once the digitized data tapes are converted to high density format (1600 BPI), the FM tape and low-density (800 BPI) digital tapes are archived by a computer assistant.

3.2 DATA ANALYSIS

The raw EEG data and time codes on the high-density back-up tape are processed using a customized evoked potential analysis program package called REPANL (Revised Evoked Potential Analysis system). REPANL is resident on the Data General Eclipse™ computer.

The first step in the analysis is to compute the averaged evoked potentials. These are written to tape, along with corresponding standard deviations. Superaverages are also computed for

pre-impact, post-impact and combined evoked potentials.

REPANL currently has two other functions: Maxpeak and Crosscor. Maxpeak finds the maximum (or minimum) value for each evoked potential within a given window. The output tape created by Maxpeak contains the amplitude and latency of this point for each evoked potential. Crosscor performs an auto-correlation for a template (a given peak or set of peaks chosen from the pre-impact superaverage) within a user-specified window. Crosscor outputs a tape containing the correlation coefficient and latency offsets for each evoked potential. The latency offsets of the component are then plotted against time to illustrate the effect of impact on that EP component during a run [16].

A human volunteer has never been run at impact levels that would cause latency shifts, so for illustration purposes Figure 11 shows the latency offset plots of anesthetized monkeys. The two vertical lines represent the impact event. As shown in the figure, there is some normal variability prior to impact. After impact the latencies are prolonged and gradually recover toward the individual's pre-impact baseline. Note that the prolongation is greater at higher impact levels.

4. DISCUSSION

REPANL requires additional facilities, the most important of which are digital filtering and pattern-matched filters. This should reduce the current disparity between averaged SEPs from monkeys (one every two seconds) and averaged SEPs from humans (one every one or two minutes). Implementing a moving average is a poor second choice. We should also have the facility to output difference waves (subtracting one wave from another), across channels and between files. The option to output difference waves from either single waveforms (e.g., pre-impact averages) or series (e.g., sweep-for-sweep or average-for-average) should be included. Using (sine x)/x interpolation or quadratic interpolation instead of linear interpolation might also prove useful because the implicit assumption that inter-point data are linear is naive at best.

Besides the above mentioned improvements, two new areas for consideration are descending (motor) pathways and the investigation of cognitive processes.

We are interested in assessing descending pathways for the following reasons: Motor function is critical during impact situations (e.g., ability to escape); the sensorimotor system is only assessed partially by concentrating on ascending pathways; and, evidence [17] implies that some motor impairment occurs commensurate with ventral bruising of the brain stem, and that these motor effects precede sensory impairment under $-G_x$ acceleration.

To assess descending pathways, we could monitor the voluntary movement of the HRV to permit opisthochronic averaging on the electrophysiological data [18]. This could be accomplished by reconfiguring the current equipment. Alternatively, transcortical stimulation techniques such as neuromagnetic stimulation would permit assessment of descending pathways.

Recording locations such as the vertex (for the N100 SEP component) may prove to be more sensitive to central nervous system impairment than the locations currently used. Vertex potentials are also more prominent and capable of recordings with only a few trials, which would be a great improvement over the time resolution possible with averages for short-latency components.

Adding more EEG channels would enable us to use a spatiotemporal mapping approach [19], which might be sensitive to transient disruptions of neural pathways due to impact.

Cognitive processes may prove to be a more sensitive index of impact effects than simple conduction parameters. One possibility involves the addition of a second stimulating electrode and a method to record HRV behavioral responses. This technique would enable recording of cortical SEPs. For example, the stimuli could be presented randomly to the two sites, with one site being five to ten times more likely to receive a stimulus than the other site. The HRV's task would be to count the infrequent stimuli. Alternatively, a single stimulus could be used, with two stimulus lengths or intensity values. Pre-rolandic C3′ and C4′ electrode placements could be added if the N60 component is to be investigated [20].
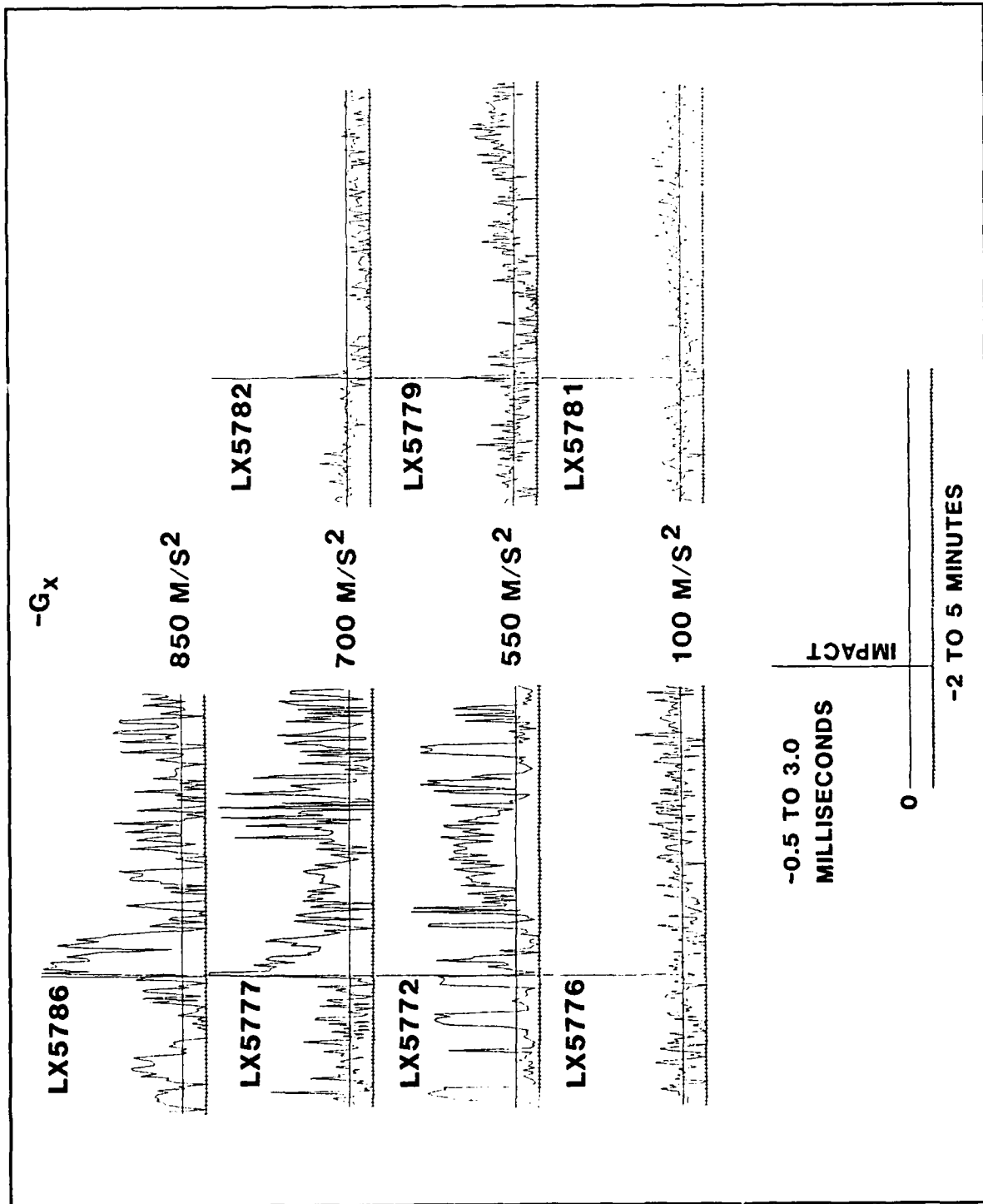
Figure 11. Latency Offset Plots

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