Spring 2003

Effects of diabetes and aging on posture and acceleration thresholds during lateral translations

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EFFECTS OF DIABETES AND AGING ON POSTURE AND ACCELERATION THRESHOLDS DURING LATERAL TRANSLATIONS

By

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in Biomedical Engineering

COLLEGE OF ENGINEERING
LOUISIANA TECH UNIVERSITY

May 2003

UMI Number: 3082021

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THE GRADUATE SCHOOL

April 24, 2003
Date

We hereby recommend that the thesis/dissertation prepared under our supervision by Samantha Richerson

entitled Effects of Diabetes and Aging on Posture and Acceleration Thresholds During Lateral Translations

be accepted in partial fulfillment of the requirements for the Degree of Ph.D. in Biomedical Engineering

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Recommendation concurred in:

Advisory Committee

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Director of Graduate Studies

Approved:
Dean of the Graduate School

Dean of the College

GS Form 13
(4/02)

ABSTRACT

Research Objectives: One source of falls in the elderly may be an inability to sufficiently adjust to transient postural perturbations or slips. Identifying useful predictors of fall potential, as well as factors that affect the ability of an individual to detect a movement of the standing support surface may provide insight into postural stability and methods to increase stability in elders. To do this, acceleration thresholds to short, precise, lateral platform translations and the resultant psychophysical responses of adults with early Type 2 diabetes to age-matched controls and young adults were measured.

Methods: Using an innovative SLIP-FALLS platform, short (1, 2, 4, 8,and 16mm) lateral perturbations were presented to 21 individuals — 9 young adults, 6 neurologically intact elder adults, and 6 elders with diabetes using a two-alternative forced choice (2AFC) protocol. All subjects underwent lower-limb nerve conduction velocity determination, air conduction velocity testing, Semmes-Weinstein monofilament thresholds, the Mini Mental Status Exam, and reaction time tests to touch, tone and high acceleration, 4mm super-threshold perturbations.

Results: All three groups had significantly different thresholds at all small (< 4mm) movement lengths, with the diabetic neuropathy group having a markedly higher acceleration threshold ($P<0.001$); the healthy elderly, which, in turn, had markedly higher thresholds than young adults. Patients with neuropathy had significantly higher reaction times to platform

movements and touches to the plantar sole, but not for auditory tones. Both elderly groups had a significantly higher reaction time to superthreshold platform movement than did young adults. Sensory tests revealed slower nerve conduction velocities, higher air conduction velocities, and lower cognitive ability in the diabetic group.

Conclusions: A marked decrease in perception of very small moves due to aging and diabetic neuropathy could well have a detrimental effect on postural control mechanisms. The higher prevalence of falls in the elderly and elderly diabetics may be due to decreased perceptual ability, slower nerve conduction velocities, and slowing reaction times compounded by larger amounts of imparted energy needed for detection of a slipping event.

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ACKNOWLEDGEMENTS

I have great appreciation for all those people who have helped me achieve the completion of my dissertation. It is impossible to mention everyone who has played a role in this long-term goal of mine, but a few people have stood out in their efforts to assist me in this enterprise.

Of course, my mentor, and the man who started this long term project that I was so fortunate to be a part of, Dr. Charles J. Robinson. Thank you for allowing me the freedom to pursue my work unhindered, while granting me responsibilities few graduate students have undertaken. Through your help, I have gotten a better education not only in the classroom, but in the workplace, and everyday life.

Thanks also to Scott Morstatt. Without you Scott, I would have given up long ago. Although our challenges were many, and oftentimes overwhelming, you helped me work through them and see that there was indeed a light at the end of the tunnel.

Also, great thanks goes to the members of my committee, Dr. Stan Napper, Dr. Paul Hale, Dr. Mesut Sahin, Dr. Ed Goshorn, and Dr. Anne Hollister. Your continued support and guidance has made this experience an enjoyable as well as memorable one.

To the graduate students at Louisiana Tech, including Dan Hoven, Kimberlyn Gray, Marcia Pool, Patrick Grant, Quincy Brown, and a myriad of others who helped in many ways, whether it be emotional support, lab and classroom guidance, proofreading

of this dissertation, help in preparing for comprehensive exams, and critiquing my dissertation defense. Without all of you this task would have been insurmountable.

To the individuals at the Overton Brooks VA Medical Center in Shreveport, LA including Charlotte Eichelberger, Duanne Redman, Dorothy Jarzabeck, and Linda Ritmo, this research study went smoothly because of your hard work and support. Thanks.

To my subjects, without your help, this endeavor would have been impossible.

To my family and friends, who have been staunch supports throughout my life. The guidance you have given me has allowed me to accomplish this lofty goal.

To Robert Paul Kitchell, you were right... we are stardust; we are golden.

NOMENCLATURE

2AFC	Two alternative forced choice
ANOVA	Analysis of variance
AP	Anterior–posterior
BMB	Backwards moving backwards
BMF	Backwards moving forwards
BMI	Body Mass Index
COG	Center of Gravity
COM	Center of mass
COP	Center of pressure
DB	Decibel
DM	Diabetes Mellitus
EOM	End of Movement
EMG	Electromyograph
FMB	Forward moving backward
FMF	Forward moving forward
GS	Gastrocnemis soleus muscle
HP	Horse power
HZ	Hertz
IRB	Institutional review board
K-W	Kruskall- Wallis
LML	Left moving left
LMR	Left moving right
mJ	milli-Joule
ML	Medial–lateral
MMSE	Mini–mental status examination
MOM	Middle of Movment
NI	Neurologically intact
PEST	Parameter estimation by sequential testing
PMAC	Programmable multi–axis controller
PN	Peripheral neuropathy
Psi	Pounds per square Inch
RML	Right moving left
RMR	Right moving right
RMS	Root mean square
ROC	Receiver operating characteristic
SLIP–FALLS	Sliding linear investigative platform for analyzing lower limb stability

SOM	Start of Movement
TA	Tibialis anterior muscle
VAMC	Veterans Administration Medical Center
VI	Virtual instrument
WAIS	Wechsler adult intelligence scale
YA	Young Adult

CHAPTER 1

INTRODUCTION/LITERATURE REVIEW

1.1 Balance and Balance Testing

1.1.1 Balance

Balance is the ability to maintain the body's center of gravity (COG) over the base of support.[1,22] This seemingly simple task requires awareness of the body's location in space (through the visual, vestibular, and somatosensory systems) and the ability to make an appropriate musculoskeletal response within the biomechanical restraints of the body and the physical constraints of the environment.[47]

The ability to maintain postural control is critical to avoid falls and successfully perform activities of daily life. Balance has three basic dimensions: maintenance of the position, stabilization for voluntary movements, and reaction to external disturbances.[13] To maintain one's position and stabilize voluntary motion, visual, vestibular, proprioceptive, kinesthetic, and somatic senses are used. However, no single sense is able to directly measure the position of the body in space. These senses must be used in an integrated fashion to receive accurate information about body position. The visual sense relays information about body location in relation to surrounding objects while the

vestibular sense provides a gravitational reference and information about accelerations in three nearly orthogonal axes.[81] The three somatic senses proprioceptive, kinesthetic, and somatosensory) arise from the limbs. The proprioceptive sense informs us on the limb angles about our joints, and provides the basis for us to know where our limbs are oriented in space. The kinesthetic sense yields subtle information about how much effort is being expended by each of the muscles about a joint and the direction of movement of our limbs in space. Through a variety of different receptors, the somatosensory sense encodes contact, pressure over an area, shear and stretch of soft tissue, slippage, and tactile pain.[10] Utilizing these inputs requires more than simply combining them, because at times there may be inaccuracies in one or more of the inputs. Sensory conflicts require the brain to select the accurate inputs while disregarding the inaccurate ones.[81] On the other hand, the redundancy of the information provided via the inputs allows one to stand and walk without the use of vision, on unstable surfaces, and even without vestibular input.[81]

Reactions to external stimuli (e.g. a slip or fall) require the process to detect and control motion changes. The normal human being uses a variety of motion detection stimuli and various compensation strategies to prevent falls. Current thought on standing balance is that it uses both open and closed loop controls.[21]

The visual and vestibular systems are factors in setting muscle tension in the feed-forward control system of standing balance, but the quickest changes occur from the feedback of the neuro-muscular system, with the alpha motor neuron loop through segmental stretch reflexes. Of all the muscle groups active during "static" standing, the

gastroc-soleus combination, a postural muscle pair, is already pre-stretched and would most likely be the most sensitive to velocity or acceleration changes.[94,109]

1.1.2 Balance Tests

Balance and fall–initiation testing can range from simple clinical tests to completely instrumented tests that quantitatively assess complex postural responses. The quantitative assessment of postural stability can be divided into static and dynamic tests. In static tests spontaneous movement of the subject (commonly termed "sway") is measured during quiet standing. On the other hand, dynamic tests have been designed to both observe voluntary movements as well as produce external perturbations to which a subject responds. Postural sway and balance testing is commonly assessed experimentally using force plate or force mat systems. Attributes of sway, balance, and stability are then inferred from these measures.

1.1.2.1 Static Tests Static balance studies have been either clinical in nature (e.g. The Rhomberg Test and its variants,[11] the Functional Reach Test,[28] etc.) or have been developed to use a force platform as the primary measurement tool.[92] The Rhomberg test, first recorded in 1853, was originally considered to be a test of the kinesthetic pathways with a positive result meaning damage to the posterior columns of the spinal cord.[97] The test required patients to stand upright with feet together and hands at their sides. Subjects then close their eyes and if the subject's sway is more than the examiner believes to be normal, the result is positive. A Sharpened Rhomberg test developed by Graybie and Fregly[41] assessed sway with the toe of the dominant foot placed against the heel of the non-dominant foot, again with the eyes closed. In a group of over 100 healthy, non

institutionalized elderly, Heitmann et al. used the Sharpened Rhomberg test to determine that non-fallers were able to maintain postural control longer than fallers.[45] A method of changing the Rhomberg test from primarily a peripheral kinesthetic test to a test of the vestibular system is by changing the standing surface from a firm level base to a compliant or rocking base. A piece of foam, two to four inches thick, is the most common standing surface used when the kinesthetic sensation around the ankle is dismissed.[14,33,63]

Beside the subjective clinical assessment techniques, many instrumented techniques that use some modification of a force platform have been promulgulated to quantify postural stability.[92] A force platform may be considered to be a flat surface that can detect changes in the application of a force over an area. A single axis force platform can be made up of an array of force transducers, or can be a plate attached to a single or multiple force transducers.[27,136] If a single transducer is used, the moments caused by off-axis force must be taken into account, while if the force transducers are near the edge of a platform and buckling does not occur, then the total force as well as position of the force can be determined. The most common commercial force platforms are able to record the force and moments in three planes and around three axes (e.g. the Balance Master™ produced by NeuroCom™).[55,92]

Sway has also been quantitatively evaluated by a variety of techniques, the most common of which is through the measurement of the variations of the Center-of-Pressure of the subject. The Center of Pressure (COP) is the point location of the vertical ground reaction force vector at the ground.[136] It represents a weighted average of all the pressures over the surface of the area in contact with the ground and is generally determined by an instrumented force plate or platform.[68,77,120] In quiet standing, the location of COP is

related directly to the Center of Mass (COM) of the body. Center of pressure should not be confused with the position of the COM or the intersection of the vertical line of force through the center of mass to the standing surface. The location of the COP under each foot reflects the neural control of the ankle muscles. Increasing plantarflexor activity (or decreasing dorsiflexor activity) moves the COP anteriorly, while increasing activity of ankle invertors moves the COP laterally. COP is expressed in length units. The rate of change of COP is usually referred to as sway and has velocity units.[136]

There are four different common stance positions of the feet for which COP can be analyzed: 1) side–by–side, 2) step, 3) tandem (heel–to–toe), and 4) one–legged. Goldie, et al.,[39] in a large–scale reliability study of these different stances concluded that the COP is a reliable discriminating measure only in the side–by–side stance.

In most posture and balance studies, electromyographic (EMG) readings are performed using surface electrodes to record muscle activity. Surface electrodes allow for a larger area of muscle to be recorded. Therefore, is more than likely that a motor event will be recorded. The problem with surface EMG recordings is cross-talk from one muscle group to another; therefore, care must be taken to correctly place the EMG sensors. EMG transducers are commonly made of silver-silver oxide metal layers and use a highly conductive gel between the metal and the skin. The transducers are then amplified prior to recording and then modified by rectification and / or some type of filtering to reduce biological or line noise. While two sensors and leads can be used to pick up EMG signals, any extraneous signals on the same frequencies will also be recorded. However, if three electrodes and a differential amplifier are used; common noise across both active lines can be rejected. Thus, only the EMG signal is being

transmitted from the electrodes. Since there is little change in EMG activity unless a perturbation is provided, EMG is rarely recorded during postural or "static" standing tests.[44,117,135,136]

Reflective or emittive marker systems are useful for determining limb or whole body linear and rotational displacements, velocities, and derived accelerations. These systems have progressed from stroboscopic pictures, to video of reflective markers, to computer analysis of infrared markers or reflective markers seen through charge-coupled devices. Once the markers are identified a computer model can be built to generate stick figures or movement data.[50,92,136]

The amount of subject sway has been correlated with clinical neurological findings. Sway tends to increase with a decrease in joint position sense, tactile sensitivity, vibration sense, or visual acuity.[63] Other factors that positively correlate with the amount of sway are age, strength and reaction time.[14,77,142] Sway seems to be greater for those elderly individuals who fell without warning than for those who occasionally tripped and fell.[61,85] However, a recent study has called into question the proposition that increased sway always correlates positively with increased falls. Wolf et al. found one group of elder adults (Tai Chi practitioners) who displayed lesser stability in static sway tests and lesser falls than two other treatment groups.[139]

The limitations of clinical tests are that they are not vigorous enough in their application and they are only sensitive enough to find moderate to severe deficits. The problems with static standing tests performed on a balance platform is that they only measure parameters when the body is static. Most of the events that occur in every day living are not static. These tests do not stress the balance system and therefore may

produce invalid findings for dynamic balance problems. This is apparent in a study by Panzer,[86] which showed that although there was a change in postural control strategy used in the elderly during quiet standing, there was no evidence of postural instability concurrent with aging.[86] This finding seems contrary because it is a well-known fact that elderly patients have a higher incidence of slips and falls. Therefore the altered control strategy seen in the elders may be less effective when balance is suddenly or severely compromised, but that deficit can not be seen in the quiet standing data.

1.1.2.2 Dynamic Tests Dynamic postural stability tests measure the response of a subject when a perturbation is applied. The perturbation can be externally applied to the feet or ankles by translating or rotating a platform[68] that the subject stands on, or by applying an external load to the subject.[142] Most of these tests impart a high acceleration or velocity perturbation or use a very large perturbation that produces near-falling events. Dynamic perturbations can also be internally generated by having the subject perform a reaching[28] or a weight-shifting task.[26,77] Tests of dynamic postural stability are often used to examine some aspect of the complex postural mechanisms, although some tests are beginning to be used clinically.[23,27,79,91,133] Two clinical tests have been developed to assess balance during functional movement — the Functional Reach [28] and Functional Standing[125,142] Tests. Of these designs, the Functional Standing test is probably a more natural test as it requires concentration on a task rather than balance. Commercial products that test dynamic stability also exist. The Equi-test™ manufactured by NeuroCom™ measures mechanical responses to sudden rotations or translations of the ankle and/or the visual field.

Many different measures have been used to evaluate dynamic stability tests. Center-of-Pressure,[26,73] body segment movement,[142] and patterns of muscle activation as measured by electromyographic techniques[79] have all been used to quantify the response to various perturbations. Interpretation of the measurements obtained with dynamic postural stability testing range from simple scoring of observed movement of body segments[133] to stability analysis of biomechanical models.[68] Basic muscle synergies have been proposed to account for the observed "normal" and pathological muscle activation patterns.[79,133]

A number of theories concerning how postural control is achieved have come from laboratories using commercial and/or custom test fixtures. As an example, Nashner and co-workers have proposed that control strategies may differ depending on the collective initial status of the appropriate muscles (See 142). They postulate that within certain well defined regions (i.e., groups of muscle states), one strategy alone prevails to control recovery from small perturbations. But, if the perturbation crosses a regional boundary, or begins within another region, then a different strategy will be used. For instance, an upright, neurologically normal individual will attempt to compensate for small translational or rotational perturbations by using distal musculature first (i.e., muscles about the ankle) and in a characteristic way. If recovery cannot be made with only the ankle muscles, then knee and eventually hip muscles will be activated.[47] But if the individual enters the perturbation while in a posture other than upright, other characteristic strategies might be adopted. Therefore care must be taken during data collection to induce external perturbations in similar postures when testing balance reactions. This has not always been controlled or considered in previous studies, leading

to a possible flaw and uncertainty in evaluation and modeling of what a "normal" recovery strategy would entail.

Ring, et al.,[104] argued that while the measurement of postural sway is reliable in detecting fallers, such a measurement is somewhat artificial. They have championed the use of a rapid movement of the visual field ("visual push") as a sensitive indicator of balance function, especially when it is conducted with the subject standing on a compliant surface (like foam). In this paradigm, non- fallers had less sway than fallers.

The few somatosensory studies related to falling have concentrated on single joint motion.[95,115] Detection thresholds for angular displacements have shown that proprioceptive performance at the hip, knee, and ankle, were superior to that of the toe.[95] It is notable that it is this joint, however, that is the principle one at which proprioceptive sense is evaluated in clinical examinations. However, it as also notable that these thresholds were determined while the joints were unloaded. Therefore, thresholds as well as performance may be different in loaded situations (i.e. during standing and walking).

Even fewer studies have considered the standing person as the system being measured. In a study by Fitzpatrick and McCloskey,[35] a rotational perturbation was presented to harnessed subjects. This harnessing may have provided tactile cues which skews the threshold results obtained. Brown et al.[17] showed that translational displacements using varied acceleration profiles at two different peak velocities cause varied postural reactions. This indicates that the movement parameters used to test are very important, and the lack of standardization or reporting of testing protocols may be the factor in influencing postural reaction results from group to group.

As a fall predictive tool, assessing balance by using these large perturbations may lead to some specific complications. The first is due to compensation strategies used by the subjects to protect themselves. These compensations may also change from the initial run.[71] The second is that these perturbations may maintain or increase a subject's fear of falling.[69]

1.1.3 Balance in the Elderly

Falls are incurred by one third of the elderly population and are a common source of morbidity and mortality. The risk of falls increases with age beyond the age of 65.[82,124] Many falls in the elderly occur due to the inability of posture control mechanisms to correct for unexpected displacements of the body.[63] In all these studies, healthy adults were used to determine normal sway characteristics.

Aging has been associated with the increase in sway as seen by center-of-pressure or -of-gravity (COP, COG), or head and hip variability.[86,142] Although no age related changes have been found in the rms distance of the AP COP, changes in both mean velocity and range of anterior-posterior (AP) and medial-lateral (ML) COP have been seen, with stronger changes in the former.[8,9,70,92] In many studies, an increase in velocity and range of COP in the AP and ML direction was seen with eyes closed for both healthy young and older adults.[8,70,86,92] Increases in ML COP excursions correlate with fall incidence, and may help predict future fall potential of elderly individuals.[70]

Not all elderly fall, have postural instabilities, or are even at a risk for falling. However, there are various subsets of elders who are at known risk for falling, including, but not limited to, those with a history of stroke or hip replacement,[128] those with

peripheral neuropathies,[19,99,116,117] those with low visual acuity (including visual neuropathies),[63] and those with vestibular dysfunction.[72] As age increases, sensory inputs may become slowed and dulled; reaction times, diminished; and muscles used for control, slowed and weakened.[62] Yet while decreased sensory acuity, reaction or activation times, or muscle strength might correlate with the increased risk of falling, none of these measures are predictive or necessarily causal, since individuals over time can often learn or adopt various coping strategies that vary the weighting among inputs and readjust the output activation patterns accordingly. Speers et al.[114] has hypothesized that increases in sway amplitude seen in the elderly are due to the inability to tune the postural feedback because of sensory "noise" or decreased ability to detect small platform motions. Environmental modifications, like increased lighting and the removal of obstacles, are other important strategies.

1.1.4 Balance in those with Diabetes

Diabetes Mellitus (DM) is a metabolic disorder in which the body does not produce or properly use insulin. The most common form of this disease is Type 2, or adult-onset, diabetes which accounts for 90 to 95 percent of all diabetes cases.[2] Nearly 16 million Americans (5.9 percent) have diabetes with another 5.5 million having undiagnosed adult–onset diabetes.

One of the more prevalent side effects of diabetes is peripheral neuropathy (PN). Sixty to 70 percent of people with diabetes have mild to severe forms of peripheral nerve damage. Peripheral neuropathy is the damage or impairment of sensory or motor axons (nerve cells) in the peripheral nervous system. This damage results in slowing of the

conduction speed of the signals in the nerves.[10] Well known clinical neurophysiological tests called nerve conduction tests can be used to quantify the extent of any peripheral neuropathy. Long–term diabetes can result in a variety of subtle cerebral disorders. Individuals with diabetes have repeatedly been reported to have lower reaction times, cognition, vascular dementia and a higher incidence of fall than their age–matched cohorts.[40,63,118]

Some diabetes literature from perturbation tests[98] and quiet standing tests show there is no significant difference in balance measures between persons with diabetes mellitus and aged-matched elders. However, other studies show significant differences between persons with diabetes and peripheral neuropathy and those with DM or the healthy elder subject groups.[24,117,128] Yamamato et al.[144] as well as others[46,89], have shown that diabetics have larger sway areas and sway velocities than control subjects. Other factors shown to be associated with increased falls in the diabetic elderly are the severeness of the peripheral neuropathy and the body mass index (BMI) of the subject.[98] Simmons et al.[116] recently used perturbation measures to investigate balance control. Their findings match the static / quiet standing testing literature which separated the diabetes population into two sub-groups, those with and without cutaneous sensory deficits at the feet related to diabetic peripheral neuropathy. Groups with PN showed variability in stretch-reflex responses which was determined to be a factor in the increased postural sway seen in that group.[116] Due to the potential for ulceration, a related aspect is the amount and location of force being applied to the plantar surface of the diabetic foot (i.e. the center-of-pressure under each foot). Poor cutaneous sensation leads to a greater chance of ulcers occurring.[18,19] Bohannon and Kelly[18] found that persons with

diabetes had a greater variance in the amount of force they apply during partial weight-bearing specified by the percentages of full body weight when compared to age-matched subjects.

Adults with peripheral neuropathies and other impairments have been shown to have different sway patterns.[144] Those with peripheral neuropathy have an increased threshold of sensation to ankle inversion and eversion when compared to age matched controls.[131] This increase in threshold indicates a decrease in sensitivity of the somatosensory system which leads to an increase in reaction time because the body is forced to rely more on the slower visual and vestibular senses. This leaves less time for recovery from an impending fall.[131] Robinson's group has shown that much higher accelerations are needed for elderly with peripheral neuropathy to determine a motion has occurred than for normal elderly (see Previous Studies).[4,5,6,109]

1.2 Cognitive Evaluation

Examination of mental state is essential in evaluating the ability of subjects to follow instructions. The mental state of a person can affect the ability of a person to listen to instructions, remember them for a short duration, and react in a manner that they have been instructed. Some elderly subjects, particularly those with delirium or dementia syndromes, diabetes, or depression cooperate well only for short periods.[64,110,111,119]

There are many batteries of tests that can be performed to evaluate the cognitive status of a person. A standard Withers and Hinton's test comprised of 33 questions and requires about 30 minutes to administer and score. Other elaborate tests like the Wechsler Adult Intelligence Scale (WAIS) take an even longer time to administer. Folstein, et al.[36]

proposed a cognitive mental status examination, Mini–mental state examination (MMSE), that was thorough in cognitive aspects of mental functions. This test however excludes questions concerning mood, abnormal mental experiences, and the form of thinking. It requires about 5 to 10 minutes to administer.

1.3 Nerve Conduction Studies

Nerve signals are transmitted by action potentials, which are propagating rapid change in the membrane potential. Each action potential begins with a sudden change from the normal resting, internally negative potential to a positive membrane potential, and then ends with an almost equally rapid change back to the negative potential. To conduct a nerve signal, the action potential moves along the nerve fiber until it comes to the fiber's end.

In myelinated axons, the action potentials can occur only at the nodes of Ranvier.[10] The action potentials are conducted from node to node by a process called salutatory conduction. That is, electrical current flows through the surrounding extracellular fluids outside the myelin sheath, as well as through the axoplasm from node–to–node exciting successive nodes one after another. Thus, the nerve impulse jumps down the fiber.

Salutatory conduction is of value for two reasons. First, by causing the depolarization process to jump long intervals along the axis of the nerve fiber, this mechanism increases the velocity of nerve transmission in myelinated fibers as much as 5 to 50 – fold. Second, salutatory conduction conserves energy for the axon because only the nodes depoloarize, allowing perhaps a hundred times smaller loss of ions than would

otherwise be necessary and therefore requiring little metabolism for reestablishing the sodium and potassium concentration differences across the membrane after a series of nerve impulses.[10]

Any factor that causes sodium ions to begin to diffuse inward through the membrane in sufficient numbers will set off the automatic regenerative opening of the sodium channels. This can result from simple mechanical disturbance of the membrane, chemical effects on the membrane, or passage of electricity through the membrane. All these are used at different points in the body to elicit nerve or muscle action potentials: Mechanical pressure to excite sensory nerve endings in the skin, chemical neuro–transmitters to transmit signals from one neuron to the next in the brain, and the electrical current to transmit signals between muscle cells in the heart and intestine.

The usual means for exciting a nerve or muscle in the experimental laboratory is to apply electricity at the nerve or muscle surface through small electrodes, one of which is negatively charged and the other positively charged. When this is done, one finds that the excitable membrane becomes stimulated at the negative electrode.

The velocity of conduction in nerve fibers varies from as little as 0.25 m/s in very small unmyelinated fibers to as high as 100 m/s in very large myelinated fibers. The velocity increases approximately with the fiber diameter in myelinated nerve fibers and approximately with the square root of fiber diameter in unmyelinated fibers.

The energy used during propagation of a nerve impulse is derived from the potential energy stored in the form of concentration differences across the ions in the membranes. A high concentration of potassium inside the fiber and low concentration of sodium outside the fiber constitute a type of energy storage. Likewise, a high

concentration of sodium on the outside of the membrane and a low concentration on the inside represent another storage of energy.

Conduction velocity in a peripheral nerve is measured by stimulating the nerve at two points at a known distance apart along its course. Subtraction of the shorter latency from the longer latency gives the conduction time along the segment of nerve between the stimulating electrodes. Knowing the separation distance, the conduction velocity of the nerve can be determined. This velocity has clinical importance because the conduction velocity in a regenerating nerve fiber slows following nerve injury. Although field potentials from nerves are of much smaller amplitude than extracellular potentials from surrounding excitable muscle fibers, such potentials can be recorded with either concentric needle electrodes or surface electrodes. Nerve field potentials can be evoked by applying stimuli to "mixed" nerves that contain both motor and sensory components (such as the ulnar nerve of the arm), in which case the resultant field potentials are derived from both types of active fibers.

Nerve field potentials can also be elicited from a purely sensory nerve or from sensory components of a mixed nerve, in which the simulation is applied in a manner that does not excite the motor components of the nerve.[10]

Several disorders can cause damage to the nerves. In the peripheral nervous system, peripheral neuropathy is the most common and consists of degenerative changes in peripheral nerves, causing sensory loss and motor weakness.[10] Distal portions of the nerves are affected first, with symptoms in the hands and feet. There are multiple causes of peripheral neuropathy including nutritional deficits, toxins of various kinds, and metabolic disorders such as diabetes.[10]

1.4 Psychophysics and Threshold Testing

Psychophysics is the field of physiological psychology that quantifies a subjective response to a quantifiable stimulus property.[60] Detection thresholds, discrimination thresholds, and just–noticeable–difference thresholds, stimulus scaling, and magnitude estimation are typical psychophysical variables. Many psychophysical theories describe the ability of the observer to detect or discriminate a signal in a background of noise.[123]

Psychophysical responses are greatly influenced by the instructions given to a subject. Subjects only rewarded for detection (and not punished for misses) quickly realize they should always indicate that they detected the event and never indicate non–detect. Subjects asked to be always certain (i.e., conservative) will signal few if any detectable events. A more liberal instruction (i.e., signal if you even think that an event occurred), without any fear of punishments, will produce the opposite effect. Considerations of this type have given rise to the receiver–operating characteristic (ROC) curve in engineering and statistics. In psychophysics, it is referred to as psychometric curve. As indicated, the determination of an absolute detection threshold is difficult when the subject is presented with a "Yes / No" (Present / Absent) question because one is never certain of the liberal/conservative judgment criteria adopted by the subject.

To circumvent this drawback, a two alternate forced choice (2AFC) paradigm can be used. This paradigm forces the subject to pick one alternative from two available choices presented sequentially. Most sensory modalities have a power law (log–log) relationship between the stimulus magnitude and the response magnitude.[123]

In dealing with determinations of threshold, a first stimulus that is too large can bias the results. Thus the choice of the first stimulus magnitude and how later stimuli are modified are important considerations. Ideally one would like to have a strategy where all perturbations are near threshold or at least rapidly converge towards a threshold value.

To address these issues, a special psychophysical testing technique, called the parameter estimation by sequential testing (PEST) method, was introduced by Taylor and Creelman[122] and later modified by Findlay[32]. PEST is one of a class of adaptive psychophysical methods in which the task difficulty is changed dynamically to arrive at a desired level of performance. This technique reduces the number of measurements needed to converge to the "threshold" of an experiment.

Adaptive psychometric procedures estimate points on the psychophysical function by making use of the subject's previous responses to select new stimuli for testing. Adaptive testing procedures offer many advantages over conventional procedures, including higher efficiency, greater flexibility, and less reliance on restrictive assumptions. Although higher efficiency (and hence greater precision for a fixed number of observations) is often thought of as the major advantage of adaptive procedures, the latter advantages may well be of greater practical importance. Special problems also occur with small samples. Many of the theorems showing maximum efficiency or maximum rates of convergence are only asymptotically true, and testing procedures based on these results may be inferior in experiments of limited size.[60,65,123]

PEST by itself is not a psychophysical procedure. It is a set of rules for changing the difficulty level of an embedded psychophysical procedure, coupled with rules for determining the difficulty level corresponding to a desired level of performance. It can

essentially be viewed as an adaptive digital algorithm, where the selection of the next test stimulus level depends on the response (Correct/ Incorrect) given to the previous two or three stimuli. Threshold in PEST is assumed to have reached wherever the value of the stimulus increment falls below a certain percentage of the absolute stimulus level. The increments by which the stimulus is either increased or decreased are referred to as steps. They are categorized into two mutually exclusive groups, termed the UP group and the DOWN group, respectively.

The rule for controlling the stimulus level is analogous to the simple up–down rule, except that the stimulus level is changed only after a sequence of observations belonging to either the UP or DOWN groups is obtained. The stimulus level is not changed until such a sequence is obtained. Levitt presented the probability of positive response at convergence for the different sequence of Up–Down criteria used.[60] For example, according to Entry 4 in Table 1 (staircase 71), the stimulus level would be increased after a negative response and decreased after two consecutive trials yielding correct responses. As the test progresses, one or other of these sequences must be obtained.

The optimum strategy for increasing or decreasing step size depends on the type and the extent of the changes that are likely to occur during a test, and the maximum number of trials that are desired in a given test sequence. These factors are usually difficult to identify *a priori*. Since all subject responses are forced (i.e., via the 2AFC paradigm), some false–positive detection and some misses are statistically possible. However as the intensity of the stimulus increases, a decrease in these false positives and misses and an increase in true detection will occur. The importance of this study lies in

determining the true thresholds, not the supra–threshold limits presented when all responses are correct. For this reason, the PEST target probability is set at a level of change rather than a percentage of "correct" responses.

Psychophysical studies of the perception of whole–body motion stimuli are a means of investigating the characteristics of the vestibular sensory system. However, care should be taken to exclude visual and auditory cues to minimize differential movement of body segments and to distribute applied forces over the surface of the body. If these steps are taken, the detection of dynamic motion stimuli of minimal intensity is primarily determined by the integrity of the subject's vestibular apparatus.

Table 1: Response Groupings for Transformed Up–Uown Strategies and Probability of Positive Response at Convergence[60]

Entry	UP Group Increase Level After	DOWN Group Decrease Level After	Probability of Positive Response At Convergence
1	− − − −	− − − + or − − + or − + or +	0.159
2	− −	− + or +	0.293
3	−	+	0.500
4	+ − or −	+ +	0.707
5	+ + − or + − or −	+ + +	0.795
6	+ + + − or + + − or + − or −	+ + + +	0.841

In one of the few combined psychophysical tests, Fitzpatrick and McCloskey[35] studied subjective proprioceptive, visual and vestibular "thresholds" (either singularly or paired) for the perception of sway during standing in neurologically intact standing subjects. The body was either rotated with ankles fixed (i.e., a rigid rotation or their so-called "vestibular" stimulation), a "room" was moved around the subject ("visual" stimulation), or the subjects balanced a load equal to their body weight ("proprioceptive" stimulation). The thresholds for the perception of sway during standing were very small, typically 0.003 radians (~0.2°) at a velocity of 0.001 rad/s (0.6°/s), and even smaller movements were perceived as the mean velocity of the sway increased up to 0.003 rad/s. The visual thresholds for perceiving movement were higher than the proprioceptive thresholds at slower velocities of movement, but not at higher velocities. The vestibular thresholds were an order of magnitude greater than the visual or proprioceptive thresholds and above the largest sway movements that were recorded during normal standing. However, criteria for "detection" were not forced and therefore the judgment criteria adapted by the subjects is not known and can vary between subjects. Vestibular stimulation also produced somatosensory changes within the ankle fixation apparatus, which may have affected thresholds.

Horak, et al.[51] and others have tried to separate the results of head accelerations from those of body accelerations, but found that vestibular stimulation (via head rotation) was a weaker elicitor of lower limb EMG activity. Peterka and Benolken[90] looked at the role of somatosensory and vestibular cues in attenuating visually induced human postural sway, but they used the EquiTest platform, which produces excess vibration to the subject (see section 1.5). Pavard and Berthoz[87] studied the effect of a linear vestibular

stimulation on the velocity perception of a moving scene, and found that the intensity of this effect was complexly related to the amplitude of the cart acceleration, image velocity, spatial frequency of the visual stimulus, and the angle between the directions of cart and image movement.

1.5 Novel Approach using SLIP-FALLS

A new approach to study to balance, slips, falls, and the perception of motion was designed. This method attempts to minimize the deficits found in the previous balance studies.

It was proposed that a level of perturbation stimulus exists which would elicit dynamic responses from a subject, but would not be strong enough to elicit significant compensation to the movements, or a fear reaction. This level of perturbation stimulus would have to be near or slightly above the perception threshold. Therefore, thresholds of perceptions to small perturbations were used to study balance and postural control. In order to determine the perception thresholds to movement, psychophysical methods were used. Because these methods are extremely sensitive to environmental cues, extraneous cues such as vibration and motor sounds have to be removed. The current balance testing platforms were not adequate when looking at minimizing the vibration of the platform. Perhaps the greatest rationale for designing a new platform, the Sliding Linear Investigative Platform for Assessing Lower Limb Stability (SLIP-FALLS) lies in its comparison with the currently most common commercial balance test device, the EquiTest systems (Figure 1).[108] For a 0.15 m/s linear translation at 4 m/s^2, SLIP-FALLS produces far less vibration than the worm-driven EqiTest devices. In fact, the EqiTest

(and its neurological version, the NeuroTest) produce a maximum peak-to-peak z-axis vibration of greater than 1g, almost obviating any possibility of a valid quantitative measurement, especially in the psychophysical measurement domain.

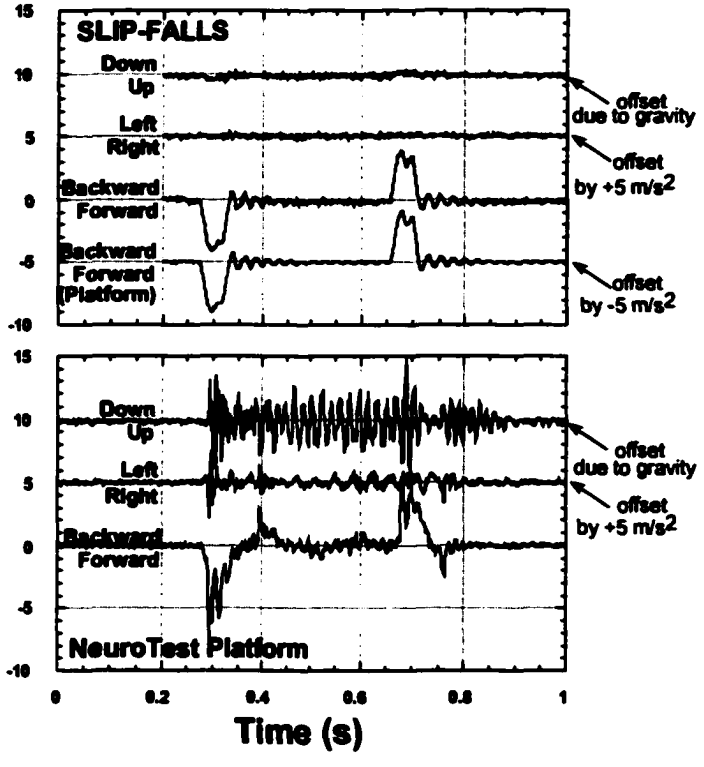


Figure 1: A Comparison of Tri-Axial Acceleration Measures of a 57 mm (2.25 in) Horizontal Translation Poduced in 400 ms by SLIP-FALLS (top) and the EqiTest or NeuroTest® Platform (Bottom). Acceleration Values for the Left/Right Plane have been Offset by +5 m/s^2 for Clarity, and the Additionally Measured Platform Accelerometer Values by -5 m/s^2. The Signs of the Acceleration Profiles Have Also Been Reversed, Again for Clarity, with Actual Directions Indicated (i.e., Down/Up, Left/Right, Backward/ Forward). Note the Marked Z-Axis (Vertical) Vibration Seen on the NeuroTest® Platform as Compared to the Almost Negligible Vibration Seen with SLIP-FALLS.(Adapted from Ref 108)

Design steps were also taken to eliminate or minimize tactile cues to the world other than the standing platform. This was performed to reduce the chance of a reduction

in sway through tactile cues.[55] Subject fatigue was an additional factor that had to be considered. The best psychophysical method had to be determined in order to minimize the number of tests needed to reach a threshold with a reasonable resolution and subject consistency.

Besides the work from Robinsons' group, there are very few who have studied the detection thresholds or reaction times to small displacements, standing or otherwise. Benson, et al.[12] determined the acceleration detection threshold of a seated subject along the three body axes. However the study was performed on a rail bearing, which by itself could be providing a high vibration that could cue the subject of the perturbation.

1.6 SLIP–FALLS System

The design and characterization of SLIP-FALLS have been presented in conference[30,93,94,105,106,107,113] and published[108] forms. The system involves a core structure, its controller, a master computer, and other peripheral instrumentation. The core structure involves a force plate with four load cells mounted on a rail floating on air bearings. This force plate is referred to as the platform (for specifications see the methods section).

A commercial multi–axis motion controller (DMM–2004, Dover Instrument Corporation) was custom configured to control the sliding platform which was also manufactured by Dover. This controller's principal component is a commercially available single–board programmable multiple–axis controller (PMAC™, Delta Tau Systems), which determines nearly all aspects of SLIP performance. PMAC controls motor #1 (the linear motor) and uses output #2 to assist in the sinusoidal commutation of motor #1.[93] A master computer interfaces to PMAC via a serial link. A data acquisition

board (National Instruments, Austin, TX) is also used for collecting the inputs (data) from the other peripheral instruments. LabVIEW™ (National Instruments, Austin, TX) software was used for the entire instrumentation.

By design, SLIP-FALLS[108]:

- Reduces or eliminates the inertial, viscous (damping) and elastic (stiffness) components resisting movement in one direction while maintaining stability in other directions.
- Precisely controls platform displacement, velocity, and acceleration, with peak ranges up to 0.27 m, 0.4 m/s, and 3 m/s^2, respectively.
- Reduces or eliminates vibrations produced by a movement.
- Has a tunable control system where stiffness and damping could be adjusted to provide instantaneous control of platform dynamics, so that the platform could be held fixed (stiff), be free-moving (compliant), or have dynamics between these two extremes. In its compliant state, the platform moves freely (open-loop) in response to the sway pattern of a subject standing on it.
- Measures the normal force on the platform in a way that minimizes the cross-axis effect of the shear forces produced by movement.

This system was first built at the joint Rehabilitation Neuroscience Lab of the University of Pittsburgh and the Pittsburgh Highland Drive Veterans Administration Medical Center (VAMC). The SLIP–FALLS system was moved from the Highland Drive VAMC, Pittsburgh, PA, to the Overton Brooks VAMC, Shreveport, LA, in January 1999.

The assembly and integration of the system and update was performed at this new lab as described in the methods section.

1.7 Previous Studies Using SLIP-FALLS

The first study undertaken was to determine the stopping criteria and create the modified PEST method used in testing. This study determined the criteria that reduced the number of trials while maintaining a low false detection threshold outcome. The maximum number of trials was set to 30, while a combination of staircase 71 and staircase 79 (see Entry 4 and 5 in Table 1) was used in determining threshold.[31]

This study also used a group of 11 young adults to show for displacements less than normal sway, acceleration is used to detect motion, but at displacements greater than normal sway, velocity is used. Detection of movement only occurred when the mean velocity or acceleration was exceeded during that movement.[30,31,105,106]

Next, a group of four subjects were tested under a latin-squares design to look at the factors that influence perception of motion underfoot. Two different perturbation lengths (4 and 20 mm), were presented in two directions (forward and backward) and with two different acceleration profiles (smooth and jerk). For the perturbations employed in this study, detection of motion was dependent upon the magnitude the acceleration, but it was independent of the acceleration profile or movement direction.[101]

Using a second group of subjects, clinical peak acceleration thresholds were psychophysically determined for detecting anterior horizontal translations (1, 4, and 16 mm), with the acceleration profile 100% smoothed to reduce jerk.[4,5,6,109] Subjects were 14 veterans over 50 years old (range 50 to 80 years) —six who had a clinical diagnosis of

Type II diabetes (Group D) and eight who did not (NDs). The Ds were otherwise healthy, and were all functional walkers, without a history of falls and with correctable vision. Clinical sensorimotor nerve conduction studies revealed peripheral neuropathies (Group PN) in all 6 diabetics and one ND who was dropped from the study. The remaining 7 were classified as Neurologically Intact (NI). The 1 and 4 mm translations were smaller than that of the root mean square (RMS) sway (~5 mm) seen for the NI older group. The 16 mm value was chosen because it is near the maximum sway range seen in this group. We compared the acceleration threshold results to those previously obtained from testing a different group of 11 healthy younger adults (YA, age < 35 years) under the same protocol. Reaction times to foot touch, auditory tones, suprathreshold platform displacements (25 mm at 50 mm/s^2), and near-threshold displacements were also determined. Mini-Mental tests showed no gross cognitive difference between PN and NI groups.

For all three groups, the acceleration threshold profile had a negative power law relationship with distance moved (Figure 2). The acceleration thresholds at each displacement for each group were all significantly different (via repeated-measures ANOVA). The NI group had significantly lower threshold profiles than the NP group, and the YA group had significantly lower threshold profiles than either older group. Older adults (PN and NI) need a high acceleration (100 mm/s^2) to detect small 1mm perturbations. Neurologically intact individuals, whether old or young (NI or YA), detect longer translations (16 mm) at a much lower acceleration threshold (10 mm/s^2) than do the PN group (50 mm/s^2); although the confidence of the NI group appears to be less than the YAs in making that detection (Figure 3). Reaction times to touch and tone also

differed between the three groups, but the response latency to supra-threshold translations was the same in older adults (PN & NI), and almost triple that seen for the Ya's (Figure 4). The YAs had essentially the same reaction times to all three supra-threshold test modalities. These data indicate that our protocols are sensitive indicators of balance control, and detect age and neuropathic effects.[6]

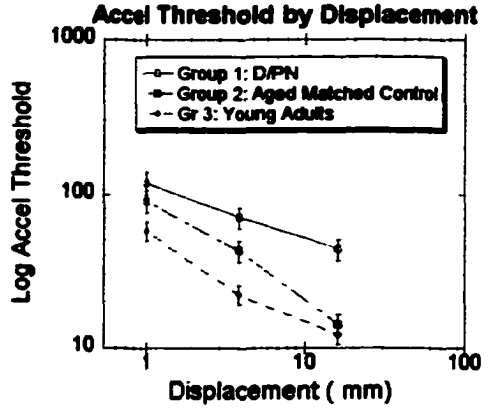


Figure 2: Psychophysically Determined Acceleration Threshold versus Displacement (1, 4 and 16 mm) Separated by Group (Diabetic/ Peripheral Neuropathic Elder Adult (PN), Neurologically Intact Elder Adult (NI), Younger Adult (YA).[6]

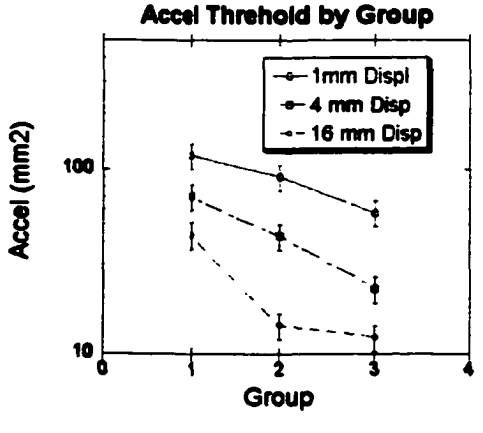


Figure 3: Psychophysically Determined Acceleration Threshold Verses Group Separated by Displacements. Same Data as in Figure 2 Plotted Differently.[6]

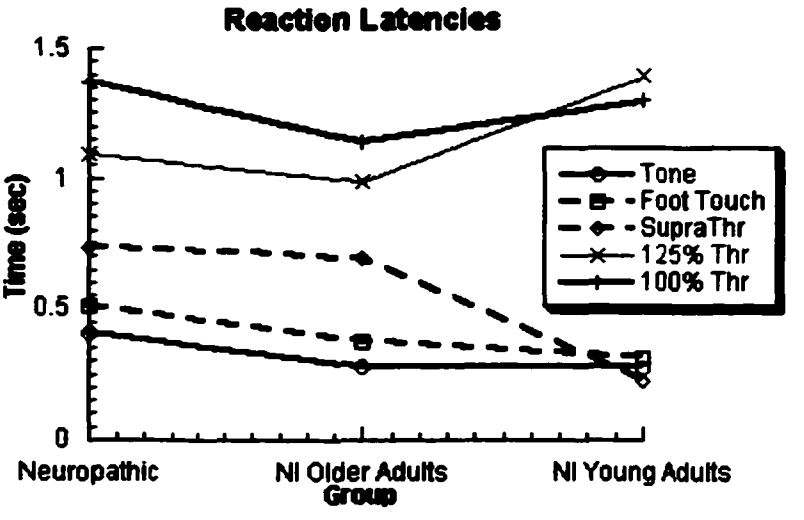


Figure 4: Reaction Time Latencies to Auditory Tone, Foot Sole Touch, and Suprathreshold Platform Translation.[6]

Figures 2 through 4 reveal remarkable differences in the three groups tested. They suggest a simple influence of age itself on certain findings, such as the threshold to short translations made at the higher levels of acceleration (100 mm/ s^2) or the (un)certainty of detection of long translations (25 mm) at a slightly lower acceleration (50 mm/ s^2) when detection is not forced by choice. Yet, those with exceedingly mild diabetes, and mild sensory (but not motor) peripheral neuropathy require accelerations 5 times larger than that of the neurologically intact elderly or young adults to detect moderate distance (16 mm) translations during the 2-AFC PEST tests (where detection choice is forced, and hence cues used for perception much subtler). Because of the crossed relationship between age and peripheral neuropathic effects on these findings, multiple underlying etiologies, including interactive ones, must be simultaneously occurring.[6]

Using the acceleration detection thresholds for anterior perturbations of 1, 4, and 16 mm from the previous study, the threshold value for acceleration from the 2AFC method, and 125% of that threshold, latencies from the start of a platform move to movement detection were determined for all 3 displacements. Latencies and percent-correct detections were compared among groups. Lower acceleration values (over longer moves) required longer latencies for motion detection. While no significant differences among groups existed in latencies at 100 or 125% of threshold, a group difference in latency was seen to a super-maximal acceleration (>500% of threshold). The percent-correct detections showed that latency testing was a less sensitive indicator of acceleration thresholds that those determined by the 2AFC test.[132]

For this investigation into human sensitivity to movement during relaxed standing, we decided to look at the threshold obtained during lateral translations. Medial-lateral (ML) COP is postulated to be under the control of the hip abductors/adductors and have little contribution to net COP.[137,138] Previous studies have shown that lateral sway, as measured during quiet standing, was found to be the best single predictor of future falling risk in the elderly.[70] This study will look at the detection thresholds for young adults, healthy elderly, and elderly with peripheral neuropathy (diabetes). Studies into center-of-pressure excursions, EMG activity, and reaction times will also be conducted.

CHAPTER 2

MATERIALS AND METHODS

2.1 SLIP–FALLS System

As previously determined, a new type of platform that minimizes vibratory cues has been designed to study the psychophysics of balance. This SLIP-FALLS platform and all the components involved with measurement and testing will be described here. A general descriptive diagram of the SLIP–FALLS system is provided in Figure 5.[108]

2.1.1 Enclosure Construction and Subject Safety

For the combination of postural sway analysis investigations, a top plate with dimensions of 60.96 cm length x 53.34 cm width provides the target area allowing subjects to stand quietly in the center of the four load cells. The top plate slides under a 183 cm length x 122 cm width x 0.64 cm thick aluminum plate that covers the remaining structural elements of the sliding platform, limiting the exposure of the slide and air bearing components to dust particles and other impurities. The aluminum plate is supported by 1.91 cm thick cabinet grade wood around the periphery of the device and extending outward to beams spanning between the steel Unistrut P1000/P1001 posts and frame approximately 30 cm above ground level (See Figure 6).

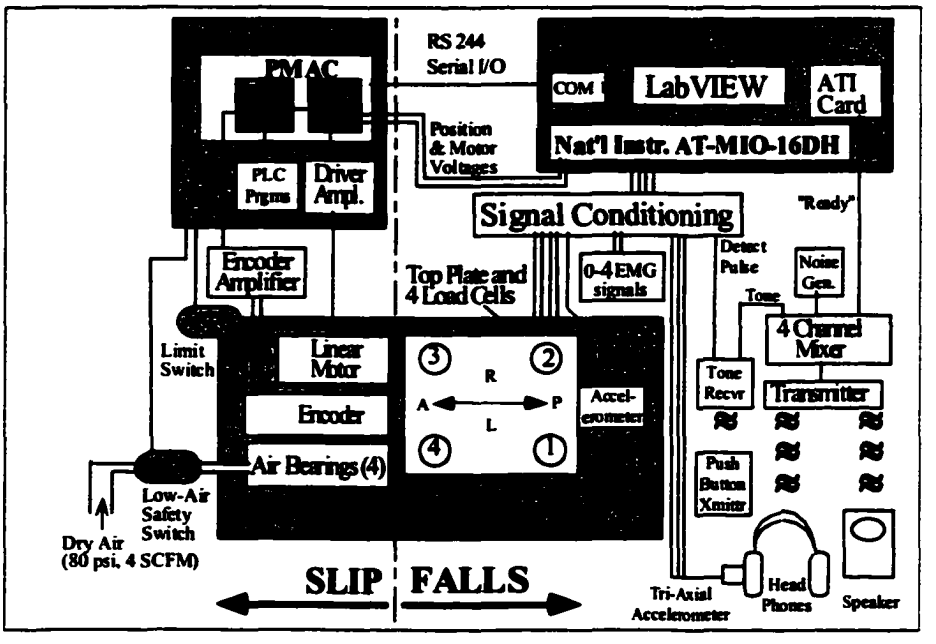


Figure 5. Diagrammatic Description of the SLIP–FALLS System[108]

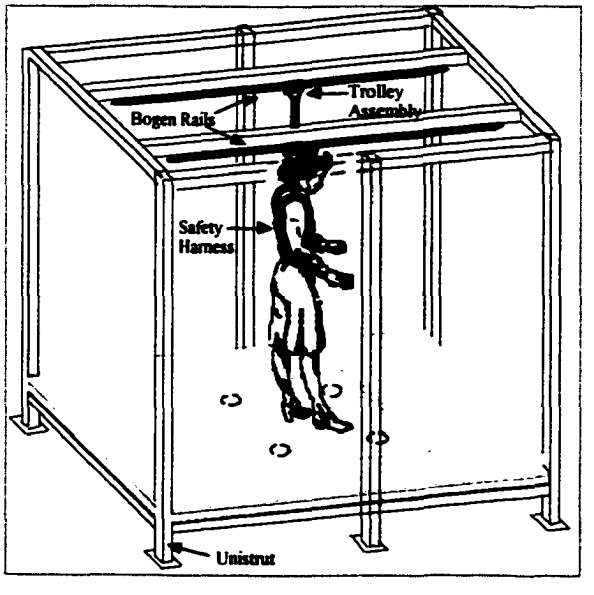


Figure 6: A Descriptive Sketch of the SLIP–FALLS System[108]

An opening in the cover plate of 48.26 cm along the direction of travel and 53.66 cm wide allows maximum travel of 15 to 20 cm with the subject standing on the top plate before contact is made with the cover plate. With the subject centered on the top plate and the top plate centered within the cover plate opening, the travel of +/- 7 cm is sufficient for postural sway testing.[93,94]

Subject safety in SLIP-FALLS was initially achieved through the combination of a sliding safety harness and supporting steel Unistrut structure. Double strength overhead beams were used to support point loads of up to 800 pounds. A chest harness with additional groin support could be used to encompass subjects during testing. The load of the subject was supported through two vertical attachments from the shoulders up and away from the midline of the subject's body. If significant instability occurred during perturbation, a complete fall by the subject could be prevented by the harness and frame. An enclosure around the sliding platform provides additional safety by preventing subjects from stepping between the air bearing rails during a fall. When perturbations are slight (as in this study), the chest harness was not necessary and may have incidentally caused a skewing of results if used, therefore in these situations, a human spotter was used to control aberrant postural changes. A slight perturbation was defined as a linear perturbation of less than 0.3 m/s^2 acceleration, 0.1 m/sec peak velocity, and 0.07 m displacement length. This level was under half of the speed seen to cause asymmetric step responses in approximately 20 percent of young adults.[67]

2.1.2 Air Flow System

An essential component for running the SLIP–FALLS system is a constant supply of compressed, ultra–dry air at a pressure greater than 70 pounds per square inch (psi) and a flow rate of greater than 3.8 scfm. Since the air bearings gam is so small (10 um), their ability to glide smoothly would be irreversibly affected by the presence of moisture or oil in the compressed air supply. Thus, a single–stroke, oil–free air compressor with a large reservoir tank (30 gal) provides a buffered compressed air source. Atmospheric moisture is absorbed in a pneumatic desiccant air dryer (O'Keefe). The two chambers in the dryer are alternatively used for a span of 30 seconds. This continual switching regenerates the desiccant but also adds pulsations to the air output of the dryer. To eliminate this pulsed flow problem, a secondary 3-gallon storage tank, Granger model 1Z782F, with additional micro-filtration on its output is used. The compressor motor is loud and would cause vibration on the lab surface that would affect the working of SLIP–FALLS. Hence the compressor is located in an environmentally conditioned room 30 feet from the room where SLIP–FALLS is located.

Crossover plumbing in the compressor room allows supply from the primary compressor or its backup. Copper pipe (5/8") transmits compressed air to the lab. The desiccant dryer is located in the lab. Quarter inch, non–moisture–absorbing tubing (Granger) transmits the dried compressed air between the dryer and the secondary reservoir tank, and from the tank 25 feet to the bearing inlets. Shut off valves and pressure gauges are mounted at the compressor reservoir tank, at the inlet to the dryer, at the output of the secondary reservoir tank and at the inlet to the bearing.

Additionally, a flow meter is mounted next to the pressure gauge at the inlet to the bearings to monitor the availability of the required 3.8 scfm airflow. Bleed-off water drains are located on the compressors, at their outlet, at the inlet tube in the lab, and on the small storage reservoir.

The air compressor operates at its rated level of 120 psi. To avoid a large pressure loss on the supply line and, hence, insufficient pressure and flow at the air bearings, a newer and more powerful compressor motor (10 HP) with a larger reservoir tank having a capacity of 30 Gallons and a displacement of 21.2 scfm (Sears, IL) was installed. A newer desiccant dryer, O'Keefe Model OCK-141C, with higher throughput of up to 9 scfm was installed. The engineering services at Overton Brooks VAMC provided materials and manpower to execute this setup.

2.1.3 LabVIEW™ Interface

2.1.3.1 LabVIEW™ and PMAC™ Controller The SLIP is controlled by a DMM-2004 multi-axis motion controller (Dover Instrument Corporation), custom configured to control the sliding platform manufactured at the same site. The principal component of the controller is a commercial single-board Programmable Multi-Axis Controller (PMAC from Delta Tau Systems), which controls nearly all aspects of SLIP performance. PMAC controls motor #1 and uses output #2 to assist in the sinusoidal commutation of motor #1.[93,94]

LabVIEW™ is a program development application that uses "G", a graphical programming language, to create programs in block diagram form. LabVIEW™ programs are called virtual instruments (VIs) because their execution, operation and

appearance simulate actual laboratory instruments. The VI user interface is termed the front panel, with various controllers, indicators, graphs, etc. accessible via knobs, buttons, and other simulated instrument controls. The VI receives its operating instructions from block diagrams, which are constructed in G. VIs are hierarchical and modular; the same VI can be used as the top-level program or as a subprogram (subVI) within other programs.[78]

PMAC commands to control the SLIP-FALLS motion events were determined and executed from LabVIEW VIs through an RS-232 interface with communication speeds of up to 64000 bits per second. To decrease the delay between a VI commanded action and the actual movement, the full PMAC command was often sent in 2 parts, an initialization character string, and an execute character string. Whenever possible, the execute string was minimized to two ascii characters "/r" = [return].

2.3.1.2 LabView™ Data Collection Data acquisition, display and analysis were performed primarily in LabVIEW™. An initialization VI starts PMAC, sets the platform zero position and defines the analog input gains. It then moves the platform to the zero (Home) position. Calibration VI's obtain initial values of the SLIP inputs before subject use and stores these reference voltages, enabling near real-time acquisition and analysis of the actual input signals in other VIs. Other program VIs send platform control commands, provide for data acquisition and store the raw values in a spreadsheet file for further analysis. Most data collection is performed with a digital memory buffer to allow for concurrent use of dynamic links such as the use of *.wav files for auditory commands and cues during data collection.

2.1.4 Platform Generated Sounds

During platform movement, it was noted that sounds of up to 70 decibels (DB) as measured by a portable sound level meter (Realistic / Radio Shack, Catalog No. 33-2050) were being produced. In order to mask this potential movement cue while allowing the subject to clearly hear commands and auditory cues needed for the psychophyisical testing, a system of external noise dampening and auditory cue presentation was developed. The following are components of this system.

2.1.4.1 ATI™ Commands and Cues An ATI™ 32 bit sound card was chosen as the auditory output from the computer since it required only a single computer interrupt identification and provided stereo output for all necessary *.wav files. The *.wav files used for this dissertation include a preparatory speech before testing commenced, start and end of trial cues, cues as to when a testing interval was occurring, and an end of testing speech. The actual text of the commands and cues are as follows:

1. Preparatory for quiet standing: "Please stand still for 20 seconds."
2. Preparatory for perturbation tests: "Prepare for testing, Press the button after the cue word decide."
3. Data collection begins: "Ready"
4. Start of interval 1: "One"
5. Start of interval 2: "Two"
6. End of trial: "Decide"
7. End of experiment block of trials: "Testing completed. Please remove blindfold and headphones."

After being patched through the sound mixer to the wireless headphones, the auditory commands and cues were presented to the subjects at a measured level of 78 DB inside the headphones.

2.1.4.2 Random Frequency (White) Noise In order to mask the platform motor noise, a white noise waveform generator was approximated by the speaker output of an AM radio set to a frequency which produced a wide band noise after the antenna was removed. This simulated white noise measured to be 70 DB at the headphone speakers was delivered to subject after passing though the sound mixer and headphone amplifier.

2.1.4.3 Wireless Door Bell Detection Indication A wireless door chime from Radio Shack™, catalog number: 63-874 was used to provide a hand-held wireless detection switch and an auditory tone signifying detection. The tone generator of the receiver was identified and was wired to one of the data collection inputs while the speaker output of the receiver was routed through the sound mixer to the wireless headphones for subject confirmation that he or she appropriately pressed the signal detection switch.

The tone generation relay state was collected via LabVIEW. The two states were 0 V during the open switch position or 4 V when the wireless doorbell switch was closed. The change in state was determined to take approximately 3 ms. A change in voltage of 0.5 V was counted as a switch closure. The amount of change from 0 V takes less than 1 ms.

With data collected at 250 samples/s, the single axis force sensor was pressed against the wireless doorbell switch. Over a series of ten tests, the average delay between then onset of a force applied to the wireless doorbell switch and a change of

0.5 V in the doorbell tone relay output was 47 ms. This time is taken into account when the doorbell was used for reaction time testing.

2.1.4.4 Sound Mixer A 4 channel sound mixer from Radio Shack (Optimus, model number SSM-1750) was used to mix and amplify the auditory commands and cues, the simulated white noise, and the signal detection doorbell sound. These sounds were sent to the wireless transmitter for the headphones and external speaker.

2.1.4.5 Wireless Speakers and Headphones A single wireless sound system transmitter, from RCA® was used to transmit the mixer output to the subject via a set of wireless headphones, and to the experimenter for confirmation, via a wireless speaker, model: RCA® WSP150. The wireless speaker was also placed in such a manner to partially overlay the platform sounds during movement and provide cues to the subject if the headphones failed during a test.

2.1.5 Data Collection Transducers

Specific transducers were chosen to provide relevant position, velocity and acceleration data for the horizontally translating platform and during the subject's center of pressure changes. Other equipment was integrated into SLIP-FALLS to record lower leg muscle activity, head acceleration, reaction time to various stimuli, and to signal when the subject thought the platform had been displaced.

2.1.5.1 Load Cells for Center of Pressure Vertical loads cell voltages were recorded from Four 90 kg Eaton Lebow load cells (part #3173-200) installed under the top plate of the SLIP-FALLS device centered over the four air bearings. Each load cell is placed 27.28 cm diagonally from the center of the top plate. This arrangement makes

for a rectangle 69.85 cm width x 83.82 cm length. The calibrated load cell voltages were digitally low pass filtered at 20 Hz then used as inputs to a VI (COPcalcD.VI), a center-of-pressure (CoP) algorithm.[11] From this algorithm resolutions of 0.08 Kg total weight and 0.4 mm CoP distances were obtained.[11] The voltage-to-distance conversions were calibrated to be 20.95 cm/V for Anterior-Posterior (A/P) displacements and 17.46 cm/V for right-left (R/L) displacements.

2.1.5.2 Platform Position and Acceleration Platform displacement in counts (20000 counts/mm) from the optical position encoder was converted to a voltage by a PMAC subroutine and output through channel 3 of the PMAC D/A. Platform acceleration was determined from the Endevco 7290A-30 accelerometer attached to the top plate.

2.1.5.3 Motor Current for Platform Shear Force Shear force was estimated during static platform tests by reading the motor current provided to the DC linear motor and multiplying by a conversion factor to have voltage output on D.A channel 4 proportional to newtons since motor current has been found to be proportional to horizontal force applied to the top plate while the top plate was being held stable by PMAC.[85] The conversion factor is part of a PMAC routine and can be adjusted for a range of values by specifying the maximum value (P302) to the PMAC routine prior to data collection.

2.1.6 Electromyographic Potentials and Representations

Four channels of muscle potential were captured by 4 tri-surface electrodes (with a single ground electrodes) which were doubly differentiated at the electrode head

to reduce cross talk, amplified by a Delsys™ EMG amplifier, then modified in LabView™ by filtering at 20-400 Hz and taking the RMS value during 25 ms windows as recommended by De Luca.[25] These electrodes were placed over the muscle bellies of the subject's Tibialis Anterior and just distal to the transition between the gastrocnemious muscle and achilles tendon in order to receive signals from the soleus muscle as well.

2.1.7 Tri-Axial Head Accelerometer

A triaxial accelerometer was purchased from NGT Technology to provide a +/- 1.33 G acceleration range with 1.5 Volt per G conversion. From testing during protocol development, it was noted that most detections occurred during platform accelerations above 50 mm/s^2 and current literature noted that pure vestibular detection occurred at approximately 60 mm/s^2.[12] Therefore the triaxial head accelerometer TAA-31013-20 was specified to have a root mean square (rms) noise floor of approximately 25 mm/s^2. The head accelerometer was placed on the left headphone ear-piece roughly in line with the horizon while the head was held in a zero degree tilt position. The three acceleration lines of force that were collected were related to the head with "X" perpendicular to the frontal plane, "Y" perpendicular to the sagittal plane, and "Z" perpendicular to the longitudinal plane.

2.1.8 Tactile Reaction Time Probe

The single axis force sensor was used during reaction time tests for tactile sensation at the foot and for an auditory stimulus produced by a wireless doorbell. Since the unloaded force may vary over time or with a change in the position of the sensor, the single axis force sensor is calibrated to a zero state prior to each reaction time test series. A change of approximately 10 times the sensor's resolution (0.1 N) or greater was determined to be the trigger for a detection event. Demarcation of a switch in the state of the force sensor by more than 0.01 N was counted as the start time marker in the tactile reaction time tests, or the end time marker in the auditory reaction time tests.

2.2 Modifications and Upgrades to SLIP-FALLS Platform

The following modifications to the SLIP-FALLS platform and associated peripherals were undertaken during this research.

2.2.1 Air Flow System

After the completion epsilon group testing was undertaken, a new Atlas oil free scroll compressor (model #SF4) was installed to provide 4 bars of pressure. An additional air dryer was added as an integrated accessory to the air dryer. The model only produces 59dB of sound pressure, which is much less than the 10HP 30 Gallon Sears Compressor. The Sears compressor was retained in series with the new scroll motor for backup in case of malfunction.

Because this compressor has no tank for accumulating a reserve of air, a 30 gallon tank was attached to the output of the Atlas compressor to serve as an accumulator to alleviate constant cycling on and off of the compressor.

2.2.2 PMAC

A new upgraded Firmware chip (v1.16H) was installed into the PMAC after the completion of testing of the Epsilon group. This chip allowed the lab to upgrade to the new PEWIN32 software, which allows a windows interface to the PMAC controller. With the addition of the new chip, a new configuration file for the PMAC had to be created. Within in this new configuration, a new tuning of the platform had to be undertaken. Changes in the configuration occurred at the following variables: Motor 1 PID proportional gain (I130) was set to 50,000; Motor 1 PID Derivative gain (I131) was set to 250; Motor 1PID Velocity Feedforward gain (I132) was set to 0; Motor 1 PID Integral gain (I133) was set to 10,000; and Motor 1 PID Acceleration Feedforward gain (I135) was set to 0. These changes in PID coefficients tuned the platform such that the system is critically damped. This is imperative because any vibration due to overshoot and rebounding of the platform to reach its steady state position can be an extra cue to the subject that a movement has occurred. This tuning allows the platform to perform without giving any extra vibratory cues to the subject.

2.2.3 Platform Calibration

Upon installation of the new compressor and after the new tuning characteristics of the PMAC were determined, a calibration of the load cells was undertaken. First,

individual load cells were calibrated by placing increments of weights (~40 Kg at a time up to 80kg) in the individual load cells. Voltages were then recorded and individual regression lines determined. Table 2, below, shows the output voltages for each load cell at the given weights. Individual regression lines for each load cells are also given. R^2 values for each the individual force cell regression lines was approximately 1, indicating that over the range of testing, the data collected was linear.

Table 2: Voltage output and calibration curve for each of the four load cells

Weight (kg)	Force Cell 1 (V)	Force Cell 2 (V)	Force Cell 3 (V)	Force Cell 4 (V)
0	-0.0732	-0.0806	-0.0928	0.1172
40	-0.3174	-0.3345	-0.3271	-0.1294
80	-0.5664	-0.5811	-0.5762	-0.3638
Regression Equation	Weight = -0.0062 * Voltage – 0.724	Weight = -0.0063 * Voltage – 0.0818	Weight = -0.0060 * Voltage – 0.0903	Weight = -0.0060* Voltage +0.1152
R^2 Value of Regression Equation	1	0.9999	0.997	0.998

After individual load cells were calibrated, the platform top plate was bolted to the four load cells in a manner that roughly balanced the load between the four cells. To calculate the entire system, weights were placed in the center of the platform and outputs of the four force cells were taken. This positioning equates to a AP and ML position of zero. The weights were then placed at a point on the plate that was 104.775 mm in the AP direction and 88.1 mm in the ML direction. Voltage outputs were then taken (force cell 1 = -0.1343 V, force cell 2 = -0.952 V, force cell 3 = -0.1538 V, force cell 4 = -0.0439 V). Using the calibration curves in Figure 2, the weight on each of the load cells was calculated (force cell 1 = 9.98 kg, force cell 2 = 2.13 kg, force cell 3 =

10.58 kg, force cell 4 = 26.51 kg). To calculate the AP COP calibration value, the following equation was used:

*AP COP position (mm) = AP COP Calibration [mm/kg] * ((Force cell 1[kg]+Force Cell 4[kg] – Force Cell 2[kg] – Force Cell 3[kg]) / Σ Force Cells* (1)

Because we measured the AP COP position of the weights to be 104.775, and the weights from each load cell were calculated, the AP COP Calibration value was calculated to be 216.9 [mm/kg]. The ML COP calibration value was calculated much the same way, except the equation to calculate ML COP is as follows:

*ML COP position (mm) = MLCOP Calibration [mm/kg] * ((Force cell 3[kg]+Force Cell 4[kg] – Force Cell 1[kg] – Force Cell 2[kg]) / Σ Force Cells* (2)

The ML COP Calibration value was calculated to be 173.5. These values are not significantly different from the calibration values from the previous calibration testing a year prior. This indicates that the system has remained stable over time.

2.2.4 LabVIEW

After completion of the Epsilon group, the addition of two new moves were added to the protocol (2 and 8 mm). To facilitate the inclusion of these two new movements, several LabVIEW programs had to be upgraded. For the new movement lengths, the several additional commands in LabView were added. To control movement length, new jog commands have to be sent to the PMAC (J = 40000 and J=160000 for a 2 mm and 8 mm movement respectively). Additional movements were

added to the front panel for easy selection of these movements during the test, and the outputs were manipulated such that files for these new movements were additive to the current files instead of writing over existing files. All changes were made and saved to filenames with a new version number (V.7). The current version of the *vi's used for testing each individual was saved with each data set such that the method by which each data set is recorded is saved.

2.3 Subject and Data Collection Protocols

Each test subject was screened for medical history and underwent a neuromuscular and anthropometric screening. If the subject was still appropriate for the study, the initial screening was followed by multiple blocks of data collection with a platform displacement preceded by a period of quiet standing. All platform displacement tests used a two-alternative-forced-choice (2AFC) protocol. The stimulus level for the different displacement accelerations within each test block were derived according to Staircase-71, Staircase-79, and PEST rules for determining the stimulus levels for presentation and the final threshold. After two or three threshold determination blocks were run, or after all threshold tests were performed, reaction times were collected.

2.3.1 Initial Subject Recruitment, Selection and Screening

The protocol for testing and the informed consent document were reviewed and approved by institutional review board (IRB) of the Overton Brooks VAMC and Louisiana State University Health Science Center, Shreveport (see appendix A). In the

middle of the study, the IRB had to be reapproved for an additional year. The renewed IRB consent form, which has minor wording modifications, can be seen in Appendix B. An IRB–approved flyer was posted on the premises of the Overton Brooks VAMC to request volunteers in the 50 to 80 year old age group (see appendix C). Elder subjects were also recruited by word–of–mouth from throughout the Shreveport/Bossier and Ruston city area. The Social Service Department at Overton Brooks VAMC helped identify and recruit veterans, although volunteer subjects were not limited to veterans. Young adults were recruited from Louisiana Tech University through word-of-mouth.

All participating subjects were compensated at $25 per four–hour session attended. Subjects were initially screened by phone to ensure that they met the age criteria and did not have any exclusionary criteria. They were also informed about the nature of the study and what would be expected of them during the course of the study. Directions to the testing facility and a testing date and time were given to prospective subjects at the end of the phone interview.

2.3.2 Pre-Testing Protocol

For the purpose of uniformity, a standard protocol has been developed over a period of time for the Rehabilitation Neuroscience Laboratory. This protocol has been modified for the testing of the Epsilon and Gamma groups of subjects (see Appendix D).

The lab and the various testing equipment are checked and setup before the arrival of the subject. The wireless headphones are charged for at least 12 hours before an experiment. The platform (force plate where the subject steps on) is disinfected

using ethanol before and after any testing. A heating blanket is laid over the top plate to make sure the platform is warm when the subject steps on it. This would eliminate any decreased tactile sensation in the feet due to the cold surface. The heating blanket is placed over the platform between tests to ensure that the platform remains at approximately the same temperature throughout the testing. The protocol forms and IRB consent forms for the subject are previously filled out and placed in readiness. A five digit, unique alphanumeric code is assigned for each subject. The code has the subject's gender, age, group, and order in that group. For instance, a 64–year old male subject being tested second in the epsilon group would have a unique code as "M64EB."

The ON switches on the Daytronic signal conditioners (load cells), Gould signal conditioners (accelerometers), master computer, Delsys® EMG box, headphone transmitter, and mixers are checked. The air compressor is turned on. The moisture in the line and primary reservoir tank are blown out at a low pressure of 20 and 40 psi respectively. All the check valves are opened and the line checked for leaks. Operating pressure and flow at platform is checked (> 70 psi and 3.6 scfm). All the electrical connections are manually checked.

NIDAQ data acquisition software (National Instruments, TX) is run to check if the individual sensors were working properly. Channels 0 to 3 receive the output from load cell strain gauge conditioners 1 to 4 respectively. Channel 5 receives the acceleration signal of the platform. Channel 4 receives the platform position signal at selectable resolution from the DMM 2004 controller that also outputs a signal proportional to motor voltage that is input to channel 6. The motor voltage is

proportional to the horizontal sheer force in the quiescent state. Channel 7 receives input from the single axis force sensor DC output. Channels 8 to 11 receive EMG signals amplified and conditioned by the Delsys® front end. Channels 12, 13, and 15 acquire zero–nulled voltages representing the acceleration in the X–, Y–, and Z–axes of the triaxial head accelerometer. Channel 15 receives the 0 v or 4 v output of the doorbell receiver gate signal.

The white noise generator, wireless headphones and speakers are then turned on. A VI, "Get_sound.VI," is then run to transmit a test signal (voice command in "wav" format) that is overlaid with the white noise with the mixed signal heard on the headphones/speakers, and the volumes are adjusted and mixed accordingly. The doorbell transmitter is pressed to check if the doorbell feedback is audible in the mixed auditory input. A VI, "5_Randoms.VI," is then run to ascertain the order of the displacement (1, 4, and 16 mm for epsilon group and 1, 2, 4, 8, and 16 mm for gamma group) sequence.

Next, the VI's that are used during experimentation are opened. These VI's are, "VDA Initialize and Home.VI, 5Jog.VI, FC Learning7F.VI, EMG_CoP Calibrate.VI, Forced Choice VDA7F.VI, Latencies VDA7F.VI, and Reaction VDA7.VI" (see Appendix A for these programs). To ensure that the entire testing is performed in the shortest duration, a time log of the start and end of each activity during the test are maintained. This time log helps ascertain when unnecessary down times occur during testing and helps rectify that for future testing. By doing this, length of testing is minimized while providing maximum comfort to the subject.

2.3.3 Testing Protocol

Once the subjects arrive, they are introduced again to the nature and scope of the study. The subjects are then shown what a typical displacement is like (using the VI, "5jog.VI"). After these explanations, they are read the IRB approved, informed consent form that explains the scope and nature of the study and their rights (see appendix A,B). Any questions they might have are answered.

The testing is performed in three different parts. The first part is the clinical and cognitive evaluation; the next part, the threshold and reaction determination; and the last part, the nerve conduction study (nerve conduction studies are only undertaken for the elderly population, young adult subjects did not undergo this testing). The actual testing of the subjects is not necessarily in that order. Some subjects have their nerve conduction study performed on a different date than the other two due to the scheduling constraints of the Neurology Service at Overton Brooks, VAMC. However, all testing on a given subject is performed within a window of fourteen days' time.

From the time log of the first three subjects, it was apparent that the optimum schedule of test sequencing that maximized subject comfort and minimized test time was to interlace the clinical and cognition evaluation with threshold testing. Thus, an evaluation questionnaire was followed by threshold testing for a given displacement criterion.

2.3.3.1 – Part 1 – Clinical and Cognitive Evaluaion A detailed screening of the patient's medical history (cardiac, neurological, and orthopaedic) is performed using a pertinent standardized questionnaire developed by us and approved by the IRB (see appendix E). Individuals with one or more of the exclusion criteria are excused from

participating further in the study. Vestibular stability, vision, myotactic reflex activation, joint acuity, and tactile threshold using calibrated Semms–Weinstein Monofilaments (Stoeliting Inc.) applied to the foot sole are tested. General anthropometric measures were taken and recorded.

A short, standardized Mini–Mental status examination (MMSE) questionnaire evaluating the cognitive mental state of the subjects is administered. It concentrates only on the cognitive aspects of mental functioning and excludes questions concerning mood, abnormal mental experiences, and the form of thinking. The MMSE has two sections – the first requires vocal responses only and covers orientation, memory, and attention (see appendix F). The maximum score possible in this section is 21. The second part tests the subjects ability to name, follow verbal and written commands, write a sentence spontaneously, and copy a complex polygon similar to a Bender–Gestalt figure. The maximum score possible in this section is 9. Thus, the maximum total score is 30. The test is not timed. However, it takes an average of 10 minutes to administer.

2.3.3.2 Part II – Threshold Detection on SLIP–FALLS System After the initial screening, subjects changed into shorts and took off their shoes and socks. To keep their feet warm between testing, subjects wore a pair of disposable operating theater slip–on boots. The two alternative forced choice (2AFC) protocol was then explained to the subject. Since the actual instructions given have an effect on the subject performance, a standardized instruction script was used, and any questions that the subject may have are addressed.

"With this doorbell transmitter, you will be able to tell me when you feel the platform move. For this test, you will be asked to step on the platform, place the headphones over your ears, and cover your eyes with the blindfold. From your headphones you will be hearing a constant 'masking white noise,' and four verbal cues: 'Ready,' 'One,' 'Two,' and 'Decide.' If you think that the platform moved between the words 'One' and 'Two,' press the button once; if between the words 'Two' and 'Decide,' press the button two times. All decisions should be made as quickly as possible after the word 'Decide.' Go ahead and try the button with your left hand to make sure you are comfortable with it. It may take several pushes to get the second doorbell chime."

Tri–electrode EMG electrodes are placed on the medial segment of the gastrocnemious soleus (GS) and tibialis anterior (TA) muscle groups bilaterally with the help of a double–sided tape. To test the integrity of the EMG recordings, subjects practice toe and heel stands for at least 20 seconds without holding any object for support. Once they are comfortable with this technique, they step barefooted on the platform of SLIP–FALLS and position their feet in a designated area.

The electrodes and load cells are then calibrated using the routine, "EMG_COP_Calibrate.VI." During the execution of this routine, the subject is asked to stand on the platform with eyes open and feet side–by–side. A sequence of toe stands, heel stands, and quiet standing for 20 seconds each is recorded. Subjects are then asked to slowly step down from the platform and take a seat without entangling themselves on the EMG leads.

The subject receives a second explanation of the 2AFC protocol. They are then asked to step on the platform to receive a practice run ("FC_Learning.VI") for the movement criteria to be tested based on the predetermined sequence for the subject. The practice trials are at a constant acceleration of 50 mm/s^2 for all displacement criteria and are not adaptive. For safety, a human spotter is used at all times to control aberrant postural changes. A slight perturbation is defined as a linear perturbation of less than 0.3 m/s^2 acceleration, 0.1 m/s peak velocity, and 70 mm displacement length. Typically there are 10 practice trials in which the subject has 4 or 5 trials with eyes open and the remaining with eyes closed. During these trials they are given a feedback via the headphones as to the interval in which movement occurred. After the completion of the practice trials, the subjects step down from the platform and relax by sitting on a chair. The subjects also get to warm their feet with the heating blanket if they feel their feet are getting cold. In order to move on from this point, the subject had to have correctly detected six out of the ten motions. If this did not occur, another training session would be given. For all subjects in this protocol, one training session was sufficient for every subject.

The routine "Forced_Choice_VDA.VI" is then run to determine the subjects acceleration threshold. This routine uses an adaptive psychophysical methodology (PEST) performed on a 2AFC protocol to determine the threshold. Subjects step on the platform and wear a blindfold (to cut off any visual cues). The EMG leads are taped to the platform so that they do not touch the legs (and hence provide an unwanted additional cue that a movement occurred). The head accelerometer is placed via Velcro fixture on the left headphone earpiece. The accelerometers X–axis is set horizontal

with the help of a fixed spirit level while the head was held in a zero degree tilt position. Thus, the three orthogonal acceleration values that are collected are related to the head with "X" perpendicular to the frontal plane, "Y" perpendicular to the saggital plane, and "Z" perpendicular to the longitudinal plane (see Figure 7). The test routine first collects data for 20 seconds of quiet standing. During this interval the patient is asked to stand still (via the headphones using a standard instruction), with eyes blindfolded and there are no perturbations involved. Signals are sampled at 1000 Hz.

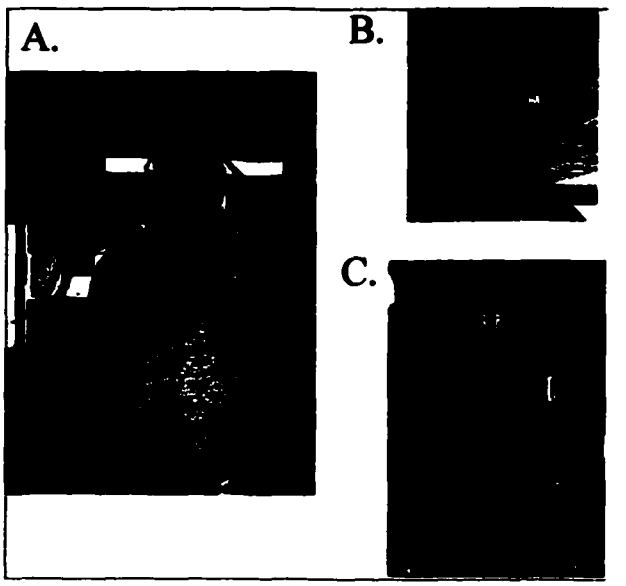


Figure 7. Psychophysical Testing on SLIP–FALLS. A. Young Adult Subject Being Tested. Note Headphones, Blindfold and Button Transmitter (in Left Hand). Spotter's Arm is Shown Coming in from Left Side to the Mid–Back Region of the Subject (but Not Touching It). B. Earphones with Tri–Axial Accelerometer and Small Spirit Levels Attached Along Two Axes. C. Foot Placement on Platform and Location of TA EMG Electrodes. Note that the Sliding Portion of SLIP is Completely Surrounded by the Aluminum Cover.

The initial acceleration value is set to be about 150% of the expected threshold. Further acceleration values are then determined using the modified PEST criteria for the given displacement. The test runs for a maximum of 30 trials. The routine is stopped if

threshold is achieved before the maximum, or if the subject wishes to stop for any reason. The subject then steps down and takes a seat to relax.

After a threshold is identified, its validity is checked by a second sequence of fixed stimuli tests called peri–threshold trials. This is done using the program "Latencies V7.vi". Five trials at threshold and five trials at 125% of threshold are performed. In these trials, the perturbation occurs any time after the cue "READY." The subject has to buzz the doorbell transmitter as soon as they feel the perturbation. To make sure the patient was not buzzing at random, two control trials (no movement of platform) are also provided.

The subject is asked on what grounds they judged that a perturbation occurred. Their responses are recorded. The heating blanket is replaced on top of the platform to warm it again. After a few minutes, the subject undergoes the practice and threshold detection routine for the next movement distance. This process is repeated until all of movement distances are tested.

Finally, using the program "ReactionsVDA7with 100scurve.vi", the reaction times to various stimuli are tested: 1) to platform perturbation under supra–threshold acceleration, 2) to foot touch, and 3) to auditory input. Supra–threshold acceleration was a large displacement of 4 mm at a constant acceleration of 100 mm/s^2. Reaction time was measured as the latency to respond (buzz) after being perturbed. The latency to respond to a touch by the single axis force sensor to the sole of the foot (greater toe), and the latency to respond to an auditory stimulus in the form of doorbell were recorded.

2.3.3.3 Part III – Nerve Conduction and Audiology Study Using a Nicolet Viking IV (Nicolet Biomedical Inc), nerve conduction studies of the lower extremity are performed at the Neurology Service of the Overton Brooks VAMC by a technician under the supervision of a neurologist. Motor (peroneal and tibial nerve) and sensory nerves (sural nerve) are tested bilaterally. F– and M– latency tests that test the entire lower motor loop (sensory nerve –> vertebrae –> motor nerve) were initially performed to ascertain any problems in the Sherrington's final common pathway. However, the first two subjects expressed severe discomfort in undergoing that part of study. Hence the F– and M– latency tests were optional to subsequent subjects.

The institutional standards for normal nerve conduction values are provided in the Tables 3 and 4 that follow.

Table 3. Overton Brooks VAMC institutional standards for motor nerve conduction study

Nerve	Recording Site	Minimum Velocity (m/s)	Max Distal Latency (ms)	Amplitude (mV)	Max F-Wave Latency (ms)
Median	Thenar (7 cm)	>=49	<=4.4	>=4.0	<=31
Ulnar	Hypothenar (7 cm)	>=49	<=3.3	>=6.0	<=32
Peroneal	EDB (9 cm)	>=44	<=6.5	>=2.0	<=56
Tibial	Abd Hall (9 cm)	>=41	<=5.8	>=4.0	<=56
Tibial	ADQ (10 cm)	>=41	<=6.3	>=3.0	N/A

Table 4. Overton Brooks VAMC institutional standards for sensory nerve conduction study

Nerve	Max Peak Latency (ms)	Amplitude (mV)
Median	<=3.5 (13 cm)	>=20
Ulnar	<=3.1 (11 cm)	>=17
Radial	<=2.9 (10 cm)	>=15
Sup. Peroneal	<=4.4 (14 cm)	>=6
Sural	<=4.4 (14 cm)	>=6

Auditory air conduction testing was also undertaken through the Audiology Department at the Overton Brooks VA Medical Center. Pure-tone thresholds were measured at 1k, 2k, 4k, and 8k Hz by an audiologist. Normal scale of hearing impairment states that if threshold levels are less than 25 db, hearing is normal. A mild hearing loss is seen between 26 and 40 db, and manifests itself as difficultly hearing distant or faint speech. A moderate hearing loss is between 41 and 55 db, and allows only conversational speech at a close distance. A severe hearing loss is between 56 and 70 dB, and allows for only loud conversational speech. Profound hearing loss is over 71 db, and allows for no hearing of conversational speech.[57] Pure-tone thresholds obtained solely by air conduction have limited value for diagnostic purposes, but certain patterns of impairment across frequency are often noted clinically. The aging process in people gradually reduces the ability to hear the higher frequency sounds, to the extent that by the age of 70, most people lose usable hearing above 6 kHz.[57]

2.4 Data Analysis Methods

2.4.1 Analysis of Quiet Standing Data

Data analysis for the quiet standing data used the equations provided by Prieto.[92] For consistency, a low-pass, fourth-order, zero-phase Butterworth filter with a 5 Hertz (Hz) cutoff frequency was used to smooth the static standing data. Not all metrics presented in the Prieto paper were analyzed since the authors found that only a few metrics proved to statistically differentiate between the young and elder subjects. The only differences between the Preito et al. 1996 protocols and those presented here

are the reduction in the number of metrics, the use of a 16 s observation window from 20 s of data.

Analysis of quiet standing metrics was performed to compare the findings from this dissertation to previously known findings, and to serve as a basis of comparison to COP metrics found from the perturbation tests. The center of pressure metrics which were analyzed for this dissertation were:

1) mean of resultant distance (mm)
2) rms distance (mm)
3) rms distance - A/P (mm)
4) rms distance –M/L (mm)
5) range (mm)
6) range - A/P (mm)
7) range - R/L (mm)
8) mean velocity (mm/s)
9) mean velocity - A/P (mm/s)
10) mean velocity – M/L (mm/s)

Two-Way Analysis of Variance (ANOVA) will be used to determine differences in trials and between groups.

2.4.2 Threshold Analysis

Acceleration thresholds determined for each subject at each displacement was done through the use of a two-alternative-forced choice paradigm. These thresholds will be compared using a two-way ANOVA to determine if there are differences in

thresholds between groups or among displacements. Post-hoc tests will provide the exact combinations of variables that are significantly different.

2.4.3 Detection Percentage

The number of correct and incorrect responses for each subject during each displacement will be determined. This data will then be compared between groups and among displacements to determine if there is any difference in the amount of trials detected throughout the test. A two-way ANOVA will be the statistic used to measure this parameter.

2.4.4 Clinical Measurements

Several clinical measurements were recorded during the testing procedure. These tests will be compared between groups to determine differences.

2.4.4.1 Semmes-Weinstein Monofilaments The Semmes-Weinstein Monofilament test was performed on the right and left base metatarsal as well as the right and left base of digit 5 on the bottom of the feet of each subject. The results will be compared using a non-parametric ANOVA to determine if there are group differences in plantar sensation. Non-parametric statistics are used in this case because the monofilaments are not continuous, instead the values are discrete with non-equal intervals.

2.4.4.2 Height and Weight Height and weight of each of the subjects was measured and will be compared using a one-way ANOVA to determine if there are group differences that may affect the results.

2.4.4.3 MMSE The results of the thirty point Mini-Mental Examination will be compared using a non-parametric ANOVA to determine if there are between group differences in cognition. Non-parametric statistics are used in this case because the maximum possible score is 30 and the minimum score is 21 (below 21 subjects are rejected for this study), skewing the distribution of scores.

2.4.4.4 Nerve Conduction The speed of the sensory nerves, as tested in the Nerve Conduction Study will be compared between the healthy elderly and the elderly with diabetes or peripheral neuropathy. A one-way ANOVA will be used to determine if the conduction velocity of diabetics is significantly different than that of healthy elderly adults.

2.4.4.5 Audiology Testing Air Conduction thresholds at 1, 2, 4 and 8 kHz, as tested by the Audiology Department at the Overton Brooks VA Medical center, can compared between elderly groups as well as across frequencies using a Two-Way ANOVA to determine if diabetes has any effect on air conduction velocities.

2.4.5 Sway (COP Phase Plane) Analysis

The plot of COP displacement verses COP velocity was reviewed, to determine if detection of platform movement is based on a person's position or velocity at the start, middle, or end of the move.

2.4.6 EMG Analysis

EMG activity was analyzed to determine if there is a correlation between sway in either the AP or ML direction and the activity of the muscles recorded. Detect and

non-detected trials will also be compared to determine if EMG activity affects detection of platform movement

2.4.7 Latency and Reaction Time Analysis

Latencies at threshold, super-threshold, and supra-threshold platform movements will be compared to see if these three different types of movement have an effect on latency within or across groups. Supra-threshold movements will also be compared to the reaction times to touch and tone to determine differences between modalities as well as between groups.

CHAPTER 3

HYPOTHESES

The following hypotheses were formulated based on research in the postural control field. Hypotheses are broken down into three categories: Psychophysical, Clinical, and Comparative. Psychophysical hypotheses deal with measured parameters taken during the psychophysical portion of the test. Clinical hypotheses deal with parameters measured during the clinical portion of the test. Comparative hypotheses deal with comparisons between the ML perturbations taken here and AP perturbations measured previously.

3.1 Psychophysical Hypotheses

3.1.1 Quiet Standing Hypothesis

- Quiet standing metrics calculated from the 20 second interval taken before testing will show that for healthy subjects with their eyes closed, sway increases significantly with age.[66,96,92]
- Mean velocity of COP and COP range should be significantly different between healthy young adults and healthy elderly adults.[8,9,92,138]
- Sway will be larger in women than men for healthy adults of all ages.[85,86]

- Sway will be larger in diabetic elderly adults than in healthy elderly adults.[14,20,24,84]

3.1.2 Threshold Hypothesis

- Acceleration thresholds will have a negative power-law relationship with the distance moved.[4,6,7,30,31,101,109]
- Thresholds will be significantly different between all three groups (young adult, healthy elderly adult, and elderly adult with peripheral neuropathy) and across displacements (1, 2, 4, 8, and 16 mm).[4,6,30,31,66,109]

3.1.3 Detection Percentage Hypothesis

- There will be no significant differences in the percentage of correctly detected trials among groups or across displacements.[6]

3.1.4 Sway Hypothesis

- Position and velocity of the center of pressure at the beginning, middle, and end of the perturbation, will have a significant effect on the detection of the trial (i.e., if a subject's sway is to the left of center at the beginning of the trial, with a trajectory moving more left throughout the perturbation, and the perturbation is to the right, a higher percentage of these trials will be detected).[6,103]
- Correctly detected trials will positively correlate with large deterministic COP movements across groups and among displacements.[102]

3.1.5 EMG Hypothesis

- EMG patterns will be causally related to the changes in AP COP position (i.e. tibalis anterior pulls the body forward of center while gastrocnemius/soleus activity pulls the body back).[102]

3.1.6 Latency and Reaction Time Hypothesis

- Latencies for threshold, superthreshold, and suprathreshold platform perturbations will be significantly different between groups.[4,6,132]
- Reaction times to touch and tone will differ significantly between groups, with the peripheral neuropathy groups having higher reaction times than healthy elderly and young adults. [4,6,109]

3.2 Clinical Hypotheses

3.2.1 Semms-Weinstein Monofilament Hypothesis

- Monofilament measurements will be significantly different between groups. Diabetic elderly adults will have a significantly higher perception threshold than healthy young or elderly adults due to the peripheral neuropathy that is a side affect of diabetes.[3,14,38,63,131]

3.2.2 Height and Weight Hypothesis

- Height and weight measurements will not differ between groups because any differences in height and weight may effect the COP sway of individuals, skewing the results.[6]

3.2.3 Mini-Mental Examination Hypothesis

- By experimental design, no differences in Mini-Mental State Exam scores will be seen between groups. All individuals recruited for this test had to score above 21 to be considered candidates.[36]
- Non-significant trends will show that diabetic elderly adults will score lower than healthy young or elderly adults due to cognitive impairment that is often seen in association with diabetes.[58,64,111,118,119]

3.2.4 Nerve Conduction Hypothesis

- Nerve conduction latencies will be significantly longer for elderly diabetic patients than healthy elderly patients.[6,99]

3.2.5 Air Conduction Velocity Testing Hypothesis

- Air Conduction velocities will not significantly differ between elderly groups.
- Aging effects higher frequency hearing, and therefore, air conduction thresholds at higher frequencies will show mild hearing loss.[57]

3.3 Comparative Hypotheses

3.3.1 AP vs ML Perturbation Comparison Hypothesis

- **Acceleration thresholds for AP perturbations will be significantly higher than ML perturbations at all perturbation lengths among all groups.**
- **Reaction times to all testing modalities will not differ between AP and ML moves in any group.**

CHAPTER 4

ADDITIONAL ANALYSIS OF PREVIOUS ANTERIOR PERTURBATION TESTING

4.1 Factors That Influence Reaction Times to Small Anterior Perturbations

4.1.1 Introduction

Frequently, falls in elders result from an accidental slip or trip associated with unsteady gait.[22] This lack of a stable gait may be due to the inability to correct for short, unexpected displacements of the body[63] by posture control mechanisms. Normally, when instability in body position occurs, it is sensed and consciously and/or unconsciously corrected. However, aging slows both the sensory input and the ability to make a correction.[16,112] Thus, a longer failure-to-recover interval occurs before the potential loss of balance is detected and corrected, which might lead to a fall.

Past studies have used measures of quiet standing sway,[8,70,86] head and hip variability,[142] fitness levels,[141] and the presence of other risk factors for falling including, but not limited to, individuals with peripheral neuropathy,[19,99,117] low visual acuity,[63] and those with vestibular dysfunction.[72] Yet, these measures do not address the common

factor of all falls – failure of recovery to transient perturbations. Given this commonality, perhaps a better measure of relative stability is the response to transient perturbations. Pavol et al.[88] has recently looked at the effects of age on sit-to-stand slips and found that older adults are more likely to fall upon exposure to an unexpected perturbation; but upon repeated exposure, learning occurs. However, the perturbations presented were very large translations (24 cm) that were easily sensed, with easy adaptation. Response to a smaller, less discernable perturbation presented in a standing paradigm may be a better measure of overall stability and lead to further insights as to why elders might fail to recover from slips.

Identifying useful predictors of fall potential requires determining which factors affect the ability of an individual to detect a differential movement of the standing support surface. We have used two-alternative-forced-choice (2AFC) psychophysical protocols[4,5,101] to determine the peak acceleration thresholds (minimum peak acceleration needed) at which anterior moves of varying lengths (1, 4, 16 mm) could be detected by young adults and elders with and without diabetic peripheral neuropathy. Acceleration thresholds had a negative power-law relationship with movement length – meaning short movements needed higher accelerations – while long movements required much smaller accelerations for detection of the movement.[4,5,101] Threshold values were significantly higher for elders when compared to young adults; and individuals with peripheral neuropathy had much higher thresholds than healthy elderly for all movement lengths.[4,5]

Factors such as age, neurological status (healthy elderly verses elderly with peripheral neuropathy), perturbation displacement, and acceleration were addressed to determine influences on reaction times. A new metric, imparted peak energy, was introduced to

better analyze the combined effects of the displacement and acceleration of the perturbation on reaction times of the subjects.

4.1.2 Methods

4.1.2.1. Subjects - Subjects included 13 elder adults between 50 and 80 yrs of age. Six had a clinical diagnosis of type II diabetes (group D, mean = 55 yrs) and 7 did not (group ND, mean =59.6 yrs). Clinical sensorimotor nerve conduction studies demonstrated peripheral neuropathies in all 6 diabetics while the remaining subjects were classified as neurologically intact. Responses from the elderly were compared to a young adult group (age <35, N=11, mean =24.8 yrs).

All subjects read and signed an approved IRB consent from. Subjects were screened for history of falls, neurological, visual, vestibular, somatosensory, and musculoskeletal disorders. Sensory threshold testing was conducted using Semms-Weinstein Monofilaments to ensure subjects had either no sensory loss (in the case of healthy subjects) or mild loss (seen in diabetic subjects).

4.1.2.2 Equipment and Previous 2AFC Threshold Determination - The minimum acceleration needed for a subject to detect a perturbation at a given length (1, 4, or 16 mm) was found using the Sliding Linear Investigative Platform for Assessing Lower Limb Stability (SLIP-FALLS).[108] Subjects were blindfolded to eliminate visual cues and received verbal instructions via headphones that also provided white noise to mask auditory cues to movement. A Parameter Estimation by Sequential Testing (PEST)[59,123] paradigm adaptively iterated the next acceleration value to be presented, based on the correctness of previous responses. Responses were acquired using a two-alternative

forced choice (2AFC) method in which platform perturbations were presented in one of two possible intervals. Subjects signaled their choice of interval via pushbutton. Using this method, it was possible to increase measurement precision while minimizing the number of trials required estimating a threshold. Further detail about threshold determination can be found in Richerson et al.[101] The acceleration thresholds for the subjects tested can be seen in Table 5.

Table 5: Geometric Average Peak Acceleration Thresholds Previously Determined by 2AFC Method. Range is Given in [min, max]

Perturbation Length	Diabetic/PN (mm/s^2)	Non-Diabetic (mm/s^2)	Young Adults (mm/s^2)
1 mm	116.7 [85.8 ,200.0]	88.7 [46.4 ,164.9]	57.5 [33.0 ,126.5]
4 mm	63.4 [34.8 ,100.0]	45.9 [25.9 ,89.4]	22.3 [8.1 ,48.5]
16 mm	38.5 [16.0 ,88.0]	14 [5.8 ,40.1]	12.2 [6.4 ,24.3]

4.1.2.3 Reaction Time Protocol - After an acceleration threshold was identified for each subject using the 2AFC method, 10 additional trials were presented to the subject, with the first 5 at his/her threshold acceleration (T), and the last 5 at a suprathreshold (ST) of 125% (1.25T). In these trials, the move started within a random one to four second period after a cue word "Ready". Subjects were instructed to press the button "when" they felt the platform move. We purposely did not use the terms "as soon as" or "when certain that" since either of these terms bias the psychometric response. Reaction time was defined as the time between the start of the platform move and the button press.

To determine the response time of individuals to a movement well above the detection threshold, superthreshold (SST) reaction times were also measured. This series

of 10 trials was not based on individual thresholds; instead a consistent 4 mm move at 100mm/s^2 was used for all groups. Again, the platform was moved randomly 1 to 4 seconds after the cue word "Ready".

4.1.2.4 Imparted Peak Energy Our study revealed that in order to establish a true detection, either sufficient acceleration is needed during fixed displacements, or conversely; sufficient displacement is necessary with a fixed acceleration in order to establish a true detection (testing on the latter is the subject of a separate, just completed study). Additionally, since the collected data failed to meet the criteria of statistical normality, non-parametric statistical procedures do not make available information on multiple interactions. Therefore, constrained to the use of one-way ANOVA's with nonparametric procedures, we have found that the *interaction* of displacement and acceleration can be analyzed through the calculated quantity of energy or work imparted on a subject. We choose the convention where work equals the effort consumed, and energy equals the effort supplied. Thus, energy imparted on the subject is due to the perturbation of the SLIP/FALLS platform onto the subject is defined as effort applied. Imparted peak energy (IPE) was calculated as the product of the following three factors: mass of the subject (kg), displacement of the move (m), and the peak acceleration during the move (m/s^2). For instance, a 100 kg individual moved 1 mm at a peak acceleration of 100 mm/s^2 would have a peak energy of 10 mJ.

4.1.3 Results

To analyze the effect of each of the factors on the average detection reaction time, a Spearman Rank Order Correlation was performed. To aid in this correlation, factors had

to be binned to achieve a correlation coefficient. Subject sex (coded "0" for Male and "1" for Female), was not significantly related ($p = 0.090$) to average latency. Also unrelated to detection reaction time was group ($p = .894$, coded as "–1" for young adults, "0" for neurologically intact elder adults, and "1" for elder adults with peripheral neuropathy, see Table 6) and age ($p = 0.174$). Factors that do relate to detection reaction time include size of the displacement of the perturbation (correlation coefficient = 0.278, $p < 0.001$), and perturbation type (threshold coded "0", suprathreshold,"1", and superthreshold, "2"; with a correlation coefficient = -0.288, $p < 0.001$).

Table 6: Average Detection Latencies for Young Adult, Healthy Elderly, and Diabetic Elderly Groups for each Displacement Length (1, 4, and 16 mm) and Test Type (T = Threshold, ST = Suprathrehold, STT = Superthreshold).

Displacement (mm)	Test Type	Young Adults (ms)	Healthy Elderly (ms)	Neuropathic Elderly (ms)
1	T	1031 ± 399	1133 ± 500	879 ± 142
4	T	1283 ± 356	1033 ± 499	1370 ± 473
16	T	1309 ±886	1835 ± 579	1382 ± 537
1	ST	1122 ± 533	1012 ± 692	1092 ± 549
4	ST	1530 ± 552	1259 ± 500	1045 ± 269
16	ST	1688 ± 725	1978 ± 987	1407 ± 793
4	SST	492 ± 107	653 ± 402	715 ± 138

The peak acceleration values were also correlated to detection reaction time. To facilitate this analysis, acceleration values of threshold and suprathreshold trials were binned into categories based on the mean of all trials (58 ± 51 mm/s^2). Six acceleration bins were created and labeled as follows: very low (VL, coded "-3"), low (L, "-2"), medium (M, "-1"), medium high (MH, "1"), high (H, "2"), and very high (VH, "3"). The bins were designed to put the mean value in the center of the middle bin "M" (see Table 7). The

Spearman Rank Order Correlation coefficient between acceleration bins and detection latency showed a significant relation (correlation coefficient = -0.404, $p < 0.001$).

To further investigate the relationships found, additional Kruskall-Wallis One Way ANOVAs were performed on those factors found significant. Median reaction times for 1mm movements (959 ms), were not different than 4 mm movements (985 ms), although 16 mm movement RT's were significantly higher (1498 ms, $p < 0.001$) than both other displacements.

Median reaction times for threshold (T) trials (1110 ms) were not significantly different than suprathreshold (ST) trials (1274 ms), but superthrehsold (SST) trials had significantly shorter latencies (559 ms, $p < 0.001$) than either of the other two testing protocols. Both threshold and suprathreshold trials were at or around the perceptual detection of the subject, while superthreshold trials were well above the ability to detect the motion.

Significant differences ($p<0.001$) between latency values were seen between acceleration bins (see Table 3). Very Low (VL), and Low (L) bins all had longer latencies than the High (H) and Very High (VH) bins. It is apparent that those individuals in the M to VH acceleration bins were more capable of identifying a movement (as seen through the lower reaction times) than were those in the either the VL or L bins.

Table 7: Median Detection Reaction Times at Peak Acceleration Groups For Threshold and Suprathreshold Movements

Bins	Acceleration (mm/s^2)	Median RT (ms)
VL	0 – 25.99	1612
L	26 – 50.99	1169
M	51 – 75.99	963
MH	76 – 100.99	935
H	101 – 150.99	837
VH	> 151	780

Next, the average peak energy imparted within a group was compared across groups (see Table 8). With no significant difference in reaction times between groups, this measure allows us to compare peak energy across groups, while not having to complicate the analysis with measures of displacement and acceleration (both of which were significant factors, and measures of platform dynamics). This measure also allows a correlation of the interactions of mass, displacement, and acceleration, which until this point was not possible with only non-parametric One-Way ANOVAs analysis available.

Table 8: Average Energy Imparted to the Three Groups at Each Displacement and Acceleration Paradigm.

Displacement (mm)	Test Type	Young Adults (mJ)	Healthy Elderly (mJ)	Neuropathic Elderly (mJ)
1	T	7.57± 7.50	6.27 ±1.79	12.08 ± 6.55
4	T	8.20 ± 3.47	14.52 ± 6.56	27.83 ± 10.56
16	T	16.77 ± 7.92	21.42 ± 15.43	75.26 ± 53.07
1	ST	6.91 ± 4.05	9.05 ± 3.61	15.11 ± 8.19
4	ST	10.25 ± 4.34	17.21 ± 7.93	34.79± 13.20
16	ST	18.3 ± 7.90	26.78 ± 19.28	94.07 ± 66.33
4	SST	32.16 ± 5.28	30.04 ± 5.39	35.92 ± 4.86

A significant difference in groups can be seen from Table 8. The IPE/ reaction time spearman rank correlation coefficient was significant ($p = 0.002$) at a value of –0.245. Of

course, the amount of energy imparted increases as both the displacement and acceleration increased, because the energy is defined as the linear combination of these variables, energy also increases among the groups. A Kruskall – Wallis One Way Anova shows a significant ($p<0.001$) difference between the diabetic elderly (median energy = 30.458 mJ) and the healthy elderly (median = 14.229 mJ) and young adults (median = 11.122 mJ). No difference was seen between the young adults and healthy elderly.

4.1.4 Discussion

Across amplitudes (threshold, suprathreshold, and superthreshold), reaction times were expected to decrease since it would be easier to pick out the signal from the background noise. The threshold and suprathreshold tests had a smaller signal-to-noise ratio and therefore should have needed a longer reaction time from the subjects. The 2AFC protocol forces subjects to make decisions near threshold (defined as at least 75% correct) where the SNR ratio is low.[75] In contrast, the superthreshold acceleration was well above the sensory perception level of all subjects and have a higher signal-to-noise ratio — allowing less indecision about the movement; and hence yielding a shorter latency. Comparing latencies across modalities showed that the shortest latency for the all groups were indeed in the superthreshold reaction time tests. As expected, the reaction times to platform movement increased with age or peripheral neuropathy for the very strong *superthreshold* move that was fixed in magnitude for all subjects. But, the *threshold* and *suprathreshold* acceleration values used were individualized to each subject, so it might be realistic to expect that no group differences in reaction time should be seen (and none were), since the thresholds themselves already had group differences.

For threshold and suprathreshold movements, the amount of variability seen in the reaction time measurements generally increased as the displacement length increased. Also, young adults and diabetics had generally less variability than the healthy elderly group, although the difference is not significant. This may reflect on the heterogeneous nature of unspecified elderly. Some elderly fall and others of the same age do not, and this study did not include questions about other risk factors. Hultsch et al.[53] did find a significant difference in reaction time variability between young and old, although the reaction times tested there were not postural, instead they focused on cognitive functioning and generally visual in nature. Another possibility might be that the increased variability seen in tests may be due to the testing paradigm, and the fact that these tests were done at or near perceptual threshold. Superthreshold tests did show a much smaller variability than either of the other two testing paradigms.

Reaction times did decrease as platform acceleration increased (or length decreased) in all cases. This was an expected result since the VL accelerations tended to be associated with the larger 16 mm platform motions, which took longer to execute. This was also seen in the fact that reaction times to 16 mm trials were significantly longer than both the 1 mm and 4 mm trials. To look at the combined effects of displacement and acceleration on reaction times, the amount of peak energy imparted to the subject for each trial was used. The average amount of energy needed to produce approximately the same reaction times (reaction times were not significantly different among groups) was significantly different among groups. Although only a slight increase from the young adult baseline was necessary for the healthy elder adults to perform the same, a dramatic increase of greater than twice the baseline energy was needed by the neuropathic elderly.

What this indicates is that in order for elderly and especially neuropathic elderly to be consciously aware of a perturbation (whether it be a forced perturbation as in this experiment, or a slip seen in everyday life), either the distance traveled or the peak acceleration of the move has to be increased. This may be a factor that contributes to the higher prevalence of falls in the elderly and elderly adults with diabetes. The slips that are experienced may either be below the threshold level of detection or the energy of the slip may be so low that the reaction time may be severely delayed, not allowing a proper recovery from the slip, leading to a fall.

Because the same energy is used at superthreshold in all three groups, this makes the last line in Table 8 very important. It is clear that that the elderly adults with diabetes require more time for the detection of the same amount of energy. It is quite possible that different detection mechanisms are stimulated with different levels of stimulation, but an additional overall decline in the elderly adults with diabetes is seen, although the mechanism, be it a central or peripheral nervous system deficit, is not known.

4.1.5 Summary for Chapter 4

In this chapter, the reaction times to anterior perturbations of 1, 4, and 16 mm were analyzed at threshold, suprathreshold, and superthrehsold movements from a set of previously tested subjects. A new measure, imparted peak energy, was introduced to compare displacements and accelerations to reaction times. To achieve the same reaction times, it was shown that elderly adults with diabetes need twice as much energy as the healthy elderly, or almost four times as much energy as the young adults.

CHAPTER 5

LATERAL PERTURBATION PILOT STUDY AND CONCLUSIONS

The epsilon group was a small trial group tested to determine if the same protocols used in the previous testing of the delta group could be used. This group consisted of three young adults (group YA, aged 20, 22, and 30), three healthy elderly adults (group NI, aged 54,59, and 64) and one elderly adult with peripheral neuropathy (group PN, aged 55). Thresholds were obtained at three movement lengths, 1, 4, and 16 mm. For the statistical tests performed here, only the young adults and healthy elderly were compared.

5.1 Quiet Standing Metrics

The twenty second period of quiet standing that was measured before the start of each movement trial was analyzed to determine differences between trials and between groups. Quiet standing metrics set forth in Prieto[92] were calculated using the Matlab program seen in Appendix G. Analysis was done using a two way ANOVA that determined if there were any differences between groups or between trials. Table 9 shows the metrics for each group.

Table 9: Quiet Standing Metrics for Epsilon Group

Group	Mean Resultant Distance (mm)	Standard Deviation Resultant Distance (mm)	Mean RMS Distance (mm)	RMS Distance – AP (mm)	RMS Distance – ML (mm)	Range (mm)	Range - AP (mm)	Range - ML (mm)	Mean Velocity (mm/s)	Mean Velocity – AP (mm/s)	Mean Velocity – ML (mm/s)
YA	4.190± 2.825	3.056± 1.873	5.201± 3.365	4.779± 3.048	2.015 ± 1.486	15.728 ±8.655	25.792± 14.808	10.936 ±8.414	0.539 ± 0.874	0.441 ± 0.684	0.223 ± 0.497
NI	3.095± 0.723	1.963± 0.626	3.669± 0.942	3.514± 0.880	1.026 ± 0.429	9.285 ±3.690	17.052 ±6.136	5.185 ±2.086	0.194 ± 0.178	0.190 ± 0.175	0.013 ± 0.012

5.1.1 Mean and standard deviation of resultant distance (mm)

The resultant distance is defined as the vector distance from the mean COP to each pair of points in the AP and ML direction. The mean and standard deviation of these measures for each group can be seen in Table 5. No significant group effect was seen for either the mean ($F_{1,17,0.05}$>1.156, p=0.303) or the standard deviation ($F_{1,17,0.05}$>2.327, p=0.153) of the resultant distance. The trial effect (mean: $F_{2,17,0.05}$>0.791, p=0.475; standard deviation: $F_{2,17,0.05}$>0.647, p=0.541) and the interaction term (mean: $F_{2,17,0.05}$>0.486, p=0.627; standard deviation: $F_{2,17,0.05}$>0.0923, p=0.913) was also not significant.

5.1.2 RMS distance (mm)

The RMS distance is defined as the RMS value of the resultant distance time series. The mean for each of the groups can be found in Table 5. No significant group effect ($F_{1,17,0.05}$>1.514, p=0.242), trial effect ($F_{2,7,0.05}$>0.686, p=0.522), or interaction ($F_{2,17,0.05}$>0.313, p=0.737) was found.

5.1.3 RMS distance - A/P (mm)

The RMS distance – AP is the RMS distance from the mean COP to the COP time series in the AP direction. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>1.239, p=0.288), trial effect ($F_{2,17,0.05}$>0.643, p=0.543), or interaction ($F_{2,17,0.05}$>0.309, p=0.740) was found.

5.1.4 RMS distance –M/L (mm)

The RMS distance – ML is the RMS distance from the mean COP to the COP time series in the ML direction. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>3.334, p=0.093), trial effect ($F_{2,17,0.05}$>0.862, p=0.447), or interaction ($F_{2,17,0.05}$>0.375, p=0.695) was found.

5.1.5 Range (mm)

The range is the maximum resultant COP minus the minimum resultant COP. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>3.533, p=0.085), trial effect ($F_{2,17,0.05}$>0.697, p=0.517), or interaction ($F_{2,17,0.05}$>0.0112, p=0.989) was found.

5.1.6 Range - A/P (mm)

The range is the maximum resultant COP in the AP direction minus the minimum resultant COP in the AP direction. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>2.354, p=0.151), trial effect ($F_{2,17,0.05}$>0.952, p=0.413), or interaction ($F_{2,17,0.05}$>0.0852, p=0.919) was found.

5.1.7 Range - M/L (mm)

The range is the maximum resultant COP in the ML direction minus the minimum resultant COP in the ML direction. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>3.430, p=0.089), trial effect ($F_{2,17,0.05}$>0.721, p=0.506), or interaction ($F_{2,17,0.05}$>0.210, p=0.813) was found.

5.1.8 Mean velocity (mm/s)

The mean velocity is the average velocity of the COP. Metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>1.449, p=0.252), trial effect ($F_{2,17,0.05}$>1.541, p=0.254), or interaction ($F_{2,17,0.05}$>1.084, p=0.369) was found.

5.1.9 Mean velocity - A/P (mm/s)

The mean velocity - AP is the average velocity of the COP in the AP direction. The metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>1.279, p=0.280), trial effect ($F_{2,17,0.05}$>1.814, p=0.205), or interaction ($F_{2,17,0.05}$>1.191, p=0.337) was found.

5.1.10 Mean velocity – M/L (mm/s)

The mean velocity –ML is the average velocity of the COP in the ML direction. The metrics can be seen in Table 5. No significant group effect ($F_{1,17,0.05}$>1.533, p=0.239), trial effect ($F_{2,17,0.05}$>0.829, p=0.460), or interaction ($F_{2,17,0.05}$>0.800, p=0.472) was found.

5.1.11 Summary

There were no significant differences between groups, trials, or the interactions in any of the quiet standing data. Prieto[92] and Maki[70] found age related changes in mean velocity-AP and range- AP. In addition Prieto[92] also saw differences in mean frequency – AP, but none of these differences were seen here. This may be due to our small sample size or differences in methodology. No between trial differences were found and this indicates that no fatigue occurred in the testing procedure. The interactions were also not significant.

5.2 Threshold Analysis

The acceleration threshold determined for each displacement distance through the two-alternative-forced choice protocol is presented here. Thresholds for each subject at each displacement length can be seen in Table 10.

Table 10: Acceleration Thresholds for Epsilon Subjects at Three Different Movement Lengths. Accelerations are Given in mm/s^2

	1mm	4mm	16mm
YA			
M20ea	110.28	3.23	15.66
F30ec	8.15	7.35	5.00
M22ef	29.02	7.35	7.00
NI			
M64eb	200.00	6.47	22.80
M54ed	200.00	4.56	2.00
M59eg	191.22	11.77	19.04
PN			
M50ee	200.00	9.12	19.04

Acceleration threshold plots that show the individual subject's thresholds can be seen in Figures 8 and 9. Figure 10 shows the mean thresholds of the YA and NI groups along with the threshold for the single PN subject so that group differences can be seen.

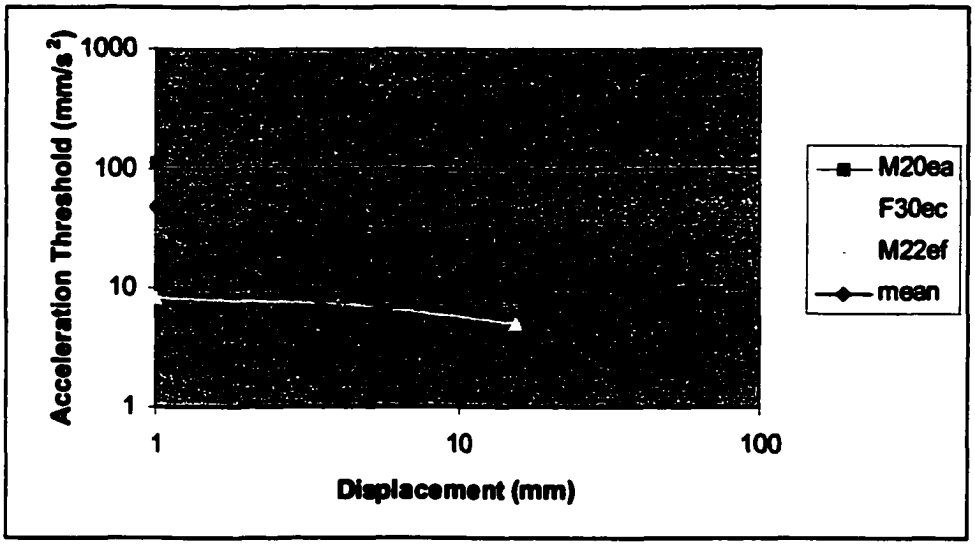


Figure 8: Plot Acceleration Threshold of Young Adults. Each Individual's Thresholds as well as the Mean is Plotted on a Log-Log Scale.

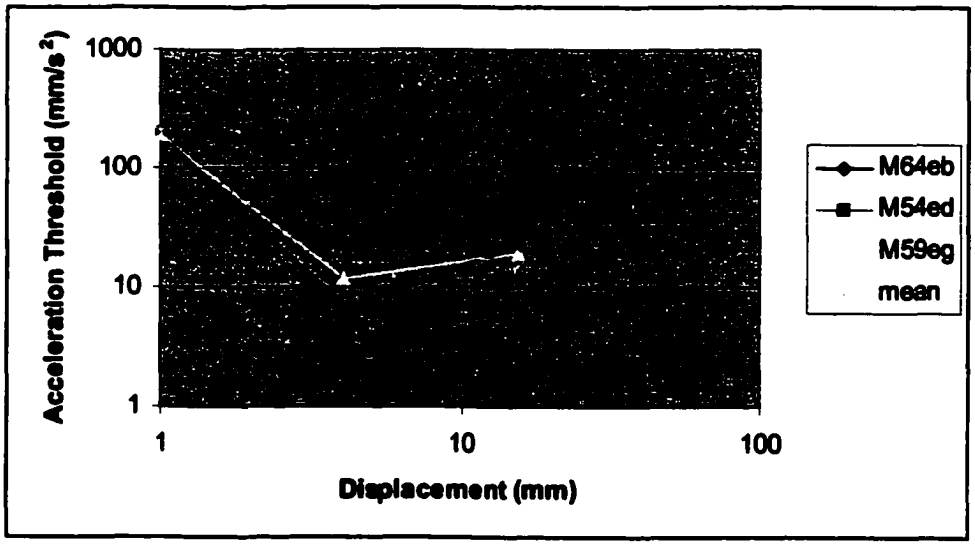


Figure 9: Plot Acceleration Threshold of Healthy Elderly Adults. Each Individual's Thresholds as Well as the Mean is Plotted on a Log-Log Scale.

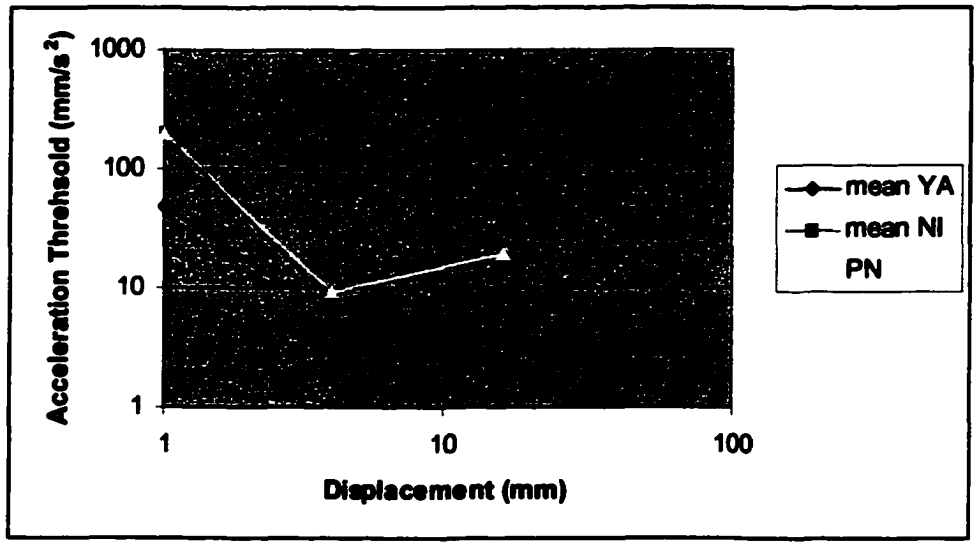


Figure 10: Plot Acceleration Threshold of Group. The Mean of the YA and NI Groups are Plotted Against the One Observation for the PN Group.

A two-way ANOVA was performed to determine the differences in threshold between groups (only young adult and healthy elderly were compared) and displacements. The ANOVA table can be seen in Table 11.

Table 11: ANOVA Table for Two-Way ANOVA Comparing Acceleration Thresholds for Groups and Displacements

Source of Variation	DF	SS	MS	F	P
Group	1	12002.17	12002.17	23.141	<0.001
Disp	2	51843.07	25921.54	49.978	<0.001
Group x Disp	2	20866.6	10433.3	20.116	<0.001
Residual	12	6223.917	518.66		
Total	17	90935.76	5349.162		

A post-hoc Tukey test was used for the pairwise multiple comparison method to determine what groups and displacements differ significantly.

The results of the multiple comparison procedure shows that acceleration thresholds differ significantly between young adults and healthy elderly adults only at the

1 mm movement. At all other movements, displacements between groups are not significantly different. This test also showed that within the young adult group, there were no significant differences in thresholds between displacements. Conversely, in healthy elderly adults, acceleration thresholds at 1mm were significantly higher than those at 4 and 16mm, but thresholds at 4 and 16 mm did not differ significantly.

5.3 Detection Percentage Analysis

The number of detects and non-detects for each subject at each displacement distance was counted and divided by the total number of trials to yield the detection percentages seen in Table 12.

Table 12: Detection Percentages for Each Subject for Each Movement Length.

	1 mm		4mm		16mm	
	Detect	Non-Detect	Detect	Non-Detect	Detect	Non-Detect
YA						
M20EA	73.33%	20.00%	84.62%	15.38%	80.00%	20.00%
F30EC	86.67%	13.33%	76.92%	23.08%	83.33%	16.67%
M22EF	91.67%	8.33%	83.33%	20.00%	94.74%	5.26%
NI						
M64EB	53.33%	46.66%	66.67%	33.33%	75.00%	25.00%
M54ED	63.33%	36.66%	80.00%	20.00%	86.96%	13.04%
M50EG	80.00%	20.00%	56.25%	43.75%	92.00%	8.00%
PN						
M50EE	56.67%	43.33%	95.00%	5.00%	66.67%	33.33%

A two way ANOVA was then used to determine if there was any group or displacement length effect on detection percentage. There was a significant difference between groups ($F_{1,17,0.05}$<6.014, p=0.030), while there was no significant difference between

displacement lengths ($F_{2,17,0.05}$<2,410, p=0.132) or the interaction between group and displacement ($F_{2,17,0.05}$< 1.234, p=0.325). Tukey's test was then run to determine within what displacements the groups differed. The only significant difference was between groups at the 1 mm displacement (p=0.039). The detection percentage between groups at 4 mm (p=0.103) and 16 mm (p=0.866) were not significant. This shows that young adults detected a significantly larger percentage of trials at the 1mm movement only. Because this is the smallest displacement used in testing, this might be an indicator that as aging occurs, one loses the ability to detect very small motions.

5.4 Clinical Measurements

Analyses of clinical measurements were done to determine if any of these measures could differentiate between groups.

5.4.1 Analysis of Semmes Weinstein Monofilament Measurements

Semmes-Weinstein monofilament measurements were taken to determine tactile sensory perception thresholds at the base of the metatarsal and digit IV. The threshold values can be seen in Table 13.

Table 13: Semmes-Wienstein Monofilament Thresholds for Epsilon Group

	Right Base Meta Tarsal	Left Base Meta Tarsal	Right Base Digit IV	Left Base Digit IV
YA				
M20EA	3.84	4.08	2.83	2.83
F30EC	3.22	3.61	2.83	2.83
M22EF	2.83	2.83	3.61	3.84
NI				
M54ED	4.17	4.17	4.17	4.31
M64EB	2.83	3.22	4.08	4.08
M59EG	4.17	4.31	3.61	3.84
PN				
M50EE	4.17	4.17	3.84	4.08

A non-parametric Mann-Whitney Rank sum test was performed for each target to determine if there were differences between the young adults and healthy elderly subjects. Non-parametric statistics were used because the grading of the monofilaments was discrete, not continuos. Results show that there is no significant difference between groups at any of the testing positions (right base metatarsal: $T_{1,5,0.05} = 8.50$, $p=0.400$; left base metatrsal: $T_{1,5,0.05} = 8.00$, $p=0.400$; right base digit IV: $T_{1,5,0.05} = 6.50$, $p=0.100$; left base digit IV: $T_{1,5,0.05} = 6.50$, $p=0.100$). Significant results were not expected in this case because both groups were neurologically intact. Upon inclusion of the diabetic/peripheral neuropathy subjects, a significant difference between groups is expected.

5.4.2 Height and Weight Measurement Analysis

Height and weight were measured for each individual during the clinical portion of the testing. Analysis was done to make sure that there are no differences between groups that might skew the data. Height and weight metrics can be found in Table 14.

Table 14: Height and Weight Metrics for Epsilon Group

	Weight (kgs)	Height (cm)
YA		
M20EA	78.93	173.99
F30EC	57.61	168.91
M22EF	83.46	180.34
NI		
M54ED	78.93	170.18
M64EB	80.74	165.1
M59EG	97.07	177.8
PN		
M50EE	89.36	172.72

A One-Way ANOVA was used to test for differences between groups. Neither height ($F_{1,5,0.05} < 0.467$, $p=0.532$) or weight ($F_{1,5,0.05} < 1.549$, $p=0.281$) were significantly different between groups. This proves that height and weight are not influencing factors, whose differences may contribute to differences seen in other testing measures.

5.4.3 MMSE Exam Score Analysis

The cognitive evaluation used the Mini-Mental Status Examination to check for cognitive impairment. None of the subjects showed cognitive impairment (i.e., a score below 21). This implies that subjects clearly understood the instructions given to them. There was also no short-term memory loss, which may have affected the subjects ability to remember to respond to the stimuli at the appropriate time. Cognitive MMSE scores can be seen in Table 15.

Table 15: Cognitive evaluation MMSE Scores for Epsilon Group

Group	MMSE
YA	
M20EA	30
F30EC	30
M22EF	30
NI	
M54ED	30
M64EB	30
M59EG	29
PN	
M50EE	30

Clearly, there is no significant difference between groups, and through this test both groups exhibited awareness to place and time, the ability to remember short term instructions, and follow instructions.

5.5 Latency and Reaction Time Analysis

5.5.1 Latency Analysis

The latency, or time between the move and response by the subject, via bell push, was determined at both threshold and 125% of threshold (termed superthrehsold). Using the Matlab program seen in Appendix H, latencies were then compared between groups and across displacements using a Kruskall-Wallis (K-W) ANOVA. Non-parametric statistics were used because the data here failed the normality test. There was no significant difference across groups (including the PN group), ($H = 2.353$, 2 degrees of freedom, $p = 0.308$). However, there was a significant difference across displacements (H

= 14.848, 2 degrees of freedom, $p < 0.001$). A multiple comparison method (Dunn's Method) was used to determine that the latencies at 1 and 16 mm were the only two to differ significantly. The average latency at 1mm was 709 ms, at 4 mm was 1239 ms, and 16mm was 1505 ms. This difference indicated that at larger lengths, it took an increased time for subjects to determine that they were moving.

The velocities and accelerations of the move were then looked at to determine if the dynamics of the movement has an effect on detection latency. Velocity was binned into the following categories: 0 – 5 mm/s = VL (very low); 6 – 10 mm/s = L (low); 11 – 15 mm/s = M (medium); 16 – 20 mm/s = H (high); and >20 mm/s = VH (very high). Median latencies for VL, L, M, H, and VH velocities are 1668 ms, 1447 ms, 738 ms, 792 ms, and 1941 ms respectively. Looking at these values, it can be seen that, at the extremes (VL and VH accelerations), latencies are almost twice as long as M and H velocities. A Kruskall-Wallis ANOVA was used to determine that there was a significant difference ($H = 19.764$, 4 degrees of freedom, $p < 0.001$) between the latencies for each acceleration bin. Dunn's multiple comparison method determined that the only significant differences occurred between the VL and M bins.

Accelerations were binned into the following categories: : 0 – 25 mm/s^2 = VL (very low); 26 – 50 mm/s^2 = L (low); 51 – 75 mm/s^2 = M (medium); 76 – 100 mm/s^2 = MH (medium-high); 101 – 150 mm/s^2 = H (high);and >150 mm/s^2 = VH (very high). All accelerations fell into the VL, L, or VH categories. Average latency for the VL groups was 1424 ms, while L velocities averaged 1552 ms, and VH velocities averaged 523 ms. A Kruskall-Wallis One Way ANOVA was used to determine that the latencies at these acceleration bins were significantly different ($H = 22.256$, 2 degrees of freedom, $p <$

0.001). Dunn's method for multiple comparison determined that latencies at VH acceleratrations were significantly different from both VL and L accelerations, but the latencies for the VL and L velocities were not significantly different. This indicates that the higher the acceleration, the easier it is to determine that a movement has occurred.

Further analysis will be undertaken in a larger group study to determine if there is a direct connection between groups, displacements, velocities, accelerations, and latency to threshold and superthrehsold movements.

5.5.2 Reaction Time Analysis

The reaction time, or response time, to platform movement, touch, and auditory stimuli were identified using the Matlab program seen in Appendix I. All these measures involve the function of the cranial nerve VIII. A decline in the reaction time may indicate the existence of central neuropathy. The reaction time for suprathreshold perturbations (4 mm at 100 mm/s^2) of the platform, touch, and tone can be seen in Table 16 and Figure 11.

Table 16: Reaction Time to Stimuli by Epsilon Group (ms)

Modality	YA	NI	PN
Platform	320.52 ± 82.54	488.96 ± 138.88	632.3 ± 325.68
Touch	265.70 ± 43.41	278.13 ± 57.86	263.00 ± 123.57
Tone	240.00 ± 154.88	252.93 ± 110.53	143.25 ± 31.07

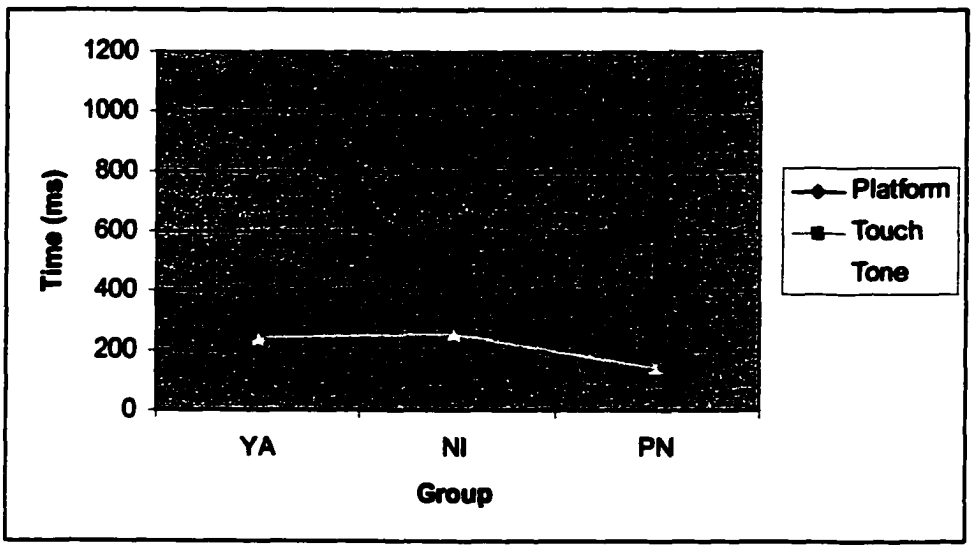


Figure 11: Reaction Time by Group for SuperThreshold Platform Perturbation, Touch, and Tone for the Epsilon Group.

A Two-Way ANOVA was used to determine the statistical differences in the platform reaction time measures between all three groups. The testing for platform reaction times was done using both forward and backward movements for all three groups. No significant difference was seen between reaction times for forward and backward movements, so measures were pooled. The reaction times can be seen in Table 17, and the corresponding ANOVA table can be seen in Table 18.

Table 17: Platform Reaction Time Metrics for Epsilon Group

Group Name	N	Mean	Std Dev
YA	26	320.52	82.54
NI	27	488.96	138.88
PN	10	632.3	325.68

Table 18: Two-Way ANOVA Table Showing Results of Platform Reaction Time Between Groups and Direction.

Source of Variation	DF	SS	MS	F	P
Group	2	830331.960	415165.980	15.509	<0.001
Direction	1	69572.350	69572.350	2.599	0.112
Group x Direction	2	43584.071	21792.036	0.814	0.448
Residual	58	1552594.339	26768.868		
Total	63	2453213.359	38939.895		

Results indicate reaction times do not depend on the direction of movement; although a significant difference was found between groups. A pairwise multiple comparison procedure (Tukey Test) was performed to determine which groups were significantly different.

Results indicate that reaction times differ significantly between all groups. Young adults had the lowest reaction times, followed by the healthy elderly, and elderly adults with diabetes. This may indicate that suprathreshold perturbations may be a good metric to determine differences in groups.

A One-Way ANOVA was used to determine differences in groups for the touch reaction time test. Table 19 shows the metrics for all three groups while Table 20 shows the corresponding ANOVA table.

Table 19: Touch Reaction Times for Epsilon Group

Group Name	N	Mean	Std Dev
YA	10	265.700	43.408
NI	8	278.125	61.851
PN	4	263.000	123.566

Table 20: One-Way ANOVA Table for Touch Reaction Times for Epsilon Group

Source of Variation	DF	SS	MS	F	P
Between Groups	2	907.389	453.694	0.0963	0.909
Residual	19	89542.975	4712.788		
Total	21	90450.364			

Results indicate that there are no significant differences between groups in the touch reaction time test. This is not surprising considering that no significant differences were found in the Semmes-Weinstein Monofilament test either.

A One-Way ANOVA was used to determine differences in groups for the tone reaction time test. Table 21 shows the metrics while Table 22 shows the ANOVA table.

Table 21: Metrics for the Tone Reaction Times for the Epsilon Group

Group Name	N	Mean	Std Dev
NI	14	252.929	114.701
YA	10	240.000	154.876
PN	5	139.600	31.069

Table 22: ANOVA Table for Tone Reaction Time test for Epsilon Group

Source of Variation	DF	SS	MS	F	P
Between Groups	2	49187.733	24593.867	1.636	0.214
Residual	26	390772.129	15029.697		
Total	28	439959.862			

Results indicate that there are no significant differences between groups during the tone reaction time test, indicating that any hearing loss by the elderly subjects had no effect on the results of the test.

Finally, all the data from the reaction time test was compiled into the following chart (see Table 23) and a two way, Repeated Measures ANOVA was performed to determine if there were any differences between groups across modalities (e.g. if reaction times to touch and tone differed between groups, see Table 24).

Table 23: Data from Reaction Time Tests for Epsilon Group

Subject	Group	Modality	Reaction Time
M20EA	YA	Touch	NA
M20EA	YA	Tone	NA
M20EA	YA	Platform	308.4
M22EF	YA	Touch	261.4
M22EF	YA	Tone	289.4
M22EF	YA	Platform	346.6
F30EC	YA	Touch	270.0
F30EC	YA	Tone	190.6
F30EC	YA	Platform	306.6
M64EB	NI	Touch	NA
M64EB	NI	Tone	306.2
M64EB	NI	Platform	627.9
M50EG	NI	Touch	265.3
M50EG	NI	Tone	251.3
M50EG	NI	Platform	421.0
M54ED	NI	Touch	291.0
M54ED	NI	Tone	201.0
M54ED	NI	Platform	441.0
M50EE	PN	Touch	263.0
M50EE	PN	Tone	143.5
M50EE	PN	Platform	623.3

Table 24: Repeated Measures ANOVA for Reaction Time Tests for Epsilon Group

Source of Variation	DF	SS	MS	F	P
Group	2	21562.819	10781.410	1.470	0.334
Subject (Group)	4	28615.825	7153.956		
Modality	2	190954.200	95477.100	51.691	< 0.001
Group x Modality	4	56796.890	14199.222	7.687	0.023
Residual	5	9235.431	1847.086		
Total	17	293540.275	17267.075		

The reasoning behind a Repeated Measures ANOVA is that this test increases the power of performed a test, and it shows differences across modalities between groups.

This RM ANOVA shows that there is a significant difference between modalities as well as a significant interaction between groups and modalities. The interaction was tested, using Tukey's test, to determine the significant interaction. The only significantly different reaction time occurred between the PN and YA group for the Platform modality.

This indicates that reaction times for the Touch and Tone modalities were not significantly different from each other, or between groups. But looking at the reaction times to the platform movement, YA group averaged 320.5 ms, the NI group averaged 496.6 ms, and the PN group averaged 623.3 ms. It is obvious that as aging occurs, the reaction time to the platform movement increases, although not significantly. Also, as a subject loses peripheral feeling (PN group), the reaction times to platform movement increase significantly. This will be further investigated in the larger study where data will be available.

5.6 Summary for Chapter 5

This small pilot study was used to determine if perturbations at 1, 4, and 16 mm were appropriate for determining acceleration thresholds for small lateral movements. As seen, the thresholds were significantly different between young and healthy elderly, but when observing Figure 10, the plot is non-linear on a log-log scale. This result was not expected. Results from psychophysical tests are usually found to be linear on log-log scales, which was not the case here. Also, the "dip" in acceleration threshold is seen in all groups at the 4 mm displacement. This "dip" may represent a sensitivity to the movement at that length, or just because the accelerations at that distance were not significantly different from accelerations at the 16 mm displacement, the "dip" may be an artifact due to the small sample size.

To further investigate the non-linearity and the "dip" in acceleration thresholds, additional displacements of 2 mm and 8 mm were added to the subsequent testing protocol. These additional displacements would allow for additional points for the non-

linear regression analysis. For the larger study, additional subjects with peripheral neuropathy will also be tested to determine more accurately the effects of disease state on acceleration threshold. Additional subjects in all groups will also strengthen the power of many of the previously performed tests.

CHAPTER 6

LATERAL PERTURBATION DATA AND ANALYSIS FOR COMPLETE STUDY

The gamma group was the group that received all five perturbation lengths (1, 2, 4, 8, and 16 mm), as was deemed to be necessary after the initial pilot study. Subjects included 9 healthy young adults (mean = 23 yrs), 6 neurologically intact elder adults (mean = 56.5 yrs), and 7 elder adults with diabetes (mean = 60.3 yrs). The method of analysis and type of statistics used for each measure are given in each individual section.

6.1 Quiet Standing Metrics

The twenty-second quiet standing period that occurs before each perturbation test was analyzed to determine differences between trials and between groups. Quiet standing metrics set forth in Prieto[92] were calculated using the LabVIEW program seen in Appendix J. Analysis was done using a two way ANOVA that determined if there were any differences between groups or between trials. Table 25 shows the metrics for each group.

Table 25: Gamma Group Metrics for Quiet Standing Measures

Group	Mean Resultant Distance (mm)	Mean RMS Distance (mm)	RMS Distance – AP (mm)	RMS Distance – ML (mm)	Range (mm)	Range - AP (mm)	Range - ML (mm)	Mean Velocity (mm/s)	Mean Velocity – AP (mm/s)	Mean Velocity – ML (mm/s)
YA	3.78 ± 1.50	4.50 ± 1.78	4.02 ± 1.69	1.87 ± 0.98	22.74 ± 8.88	19.47 ± 7.42	10.76 ± 6.82	9.70 ± 2.52	7.76 ± 1.84	4.24 ± 1.60
NI	5.19 ± 3.18	6.35 ± 3.87	5.22 ± 2.58	3.31 ± 3.24	34.20 ± 24.11	27.56 ± 16.17	18.51 ± 19.73	13.14 ± 6.50	10.43 ± 4.51	5.82 ± 4.12
PN	7.53 ± 8.44	8.84 ± 9.37	7.69 ± 8.03	4.15 ±5.02	43.25 ± 41.14	37.27 ± 35.77	20.66 ± 21.66	21.86 ± 31.97	18.56 ± 28.41	8.16 ± 9.71

6.1.1 Mean of resultant distance (mm)

The resultant distance is defined as the vector distance from the mean COP to each pair of points in the AP and ML direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was run to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 5.427$, $p=0.006$) of the resultant distance. The trial effect ($F_{4,104,0.05} = 1.260$, $p=0.292$) and the interaction term (mean: $F_{8,104,0.05} = 1.427$, $p=0.196$) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 3.78 mm) differed significantly from the peripheral neuropathy elders (mean = 7.53 mm), with a probability $p = 0.004$ ($q = 4.653$). Young adults and neurologically intact elders (mean = 5.19 mm) did not differ significantly ($p = 0.153$), nor did neurologically intact elders when compared to elderly adults with diabetes ($p = 0.432$).

6.1.2 RMS distance (mm)

The RMS distance is defined as the RMS value of the resultant distance time series. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 5.722$, $p=0.005$) of the RMS distance. The trial effect ($F_{4,104,0.05} = 1.157$, $p=0.335$) and the interaction term (mean: $F_{8,104,0.05} = 1.450$, $p=0.187$) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 4.50 mm) differed significantly from the peripheral neuropathy elders (mean = 8.84 mm), with a probability p = 0.0 3 (q = 4.782). Young adults and neurologically intact elders (mean = 6.35 mm) did not differ significantly (p = 0.185), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.325).

6.1.3 RMS distance – A/P (mm)

The RMS distance - AP is defined as the RMS distance from the mean COP to the COP time series in the AP direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 5.732$, $p=0.005$) of the RMS distance in the AP direction. The trial effect ($F_{4,104,0.05} = 1.139$, $p=0.344$) and the interaction term (mean: $F_{8,104,0.05} = 1.146$, $p=0.341$) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which

groups differed. Young adults (mean = 4.02 mm) differed significantly from the peripheral neuropathy elders (mean = 7.69 mm), with a probability p = 0.003 (q = 4.773). Young adults and neurologically intact elders (mean = 5.22 mm) did not differ significantly (p = 0.102), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.513).

6.1.4 RMS distance – M/L (mm)

The RMS distance - ML is defined as the RMS distance from the mean COP to the COP time series in the ML direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 5.113$, p=0.008) of the RMS distance in the ML direction. The trial effect ($F_{4,104,0.05} = 1.293$, p=0.279) and the interaction term (mean: $F_{8,104,0.05} = 1.146$, p=0.341) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 1.87 mm) differed significantly from the peripheral neuropathy elders (mean = 4.15 mm), with a probability p = 0.007 (q = 4.384). Young adults and neurologically intact elders (mean = 3.31 mm) did not differ significantly (p = 0.128), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.553).

6.1.5 Range (mm)

The range is the maximum resultant COP minus the minimum resultant COP. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 5.899$, p=0.004) of the range. The trial effect ($F_{4,104,0.05} = 0.862$, p=0.490) and the interaction term (mean: $F_{8,104,0.05} = 1.506$, p=0.166) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 22.74 mm) differed significantly from the peripheral neuropathy elders (mean = 43.25 mm), with a probability p = 0.003 (q = 4.787). Young adults and neurologically intact elders (mean = 34.20 mm) did not differ significantly (p = 0.147), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.365).

6.1.6 Range – A/P (mm)

The range - AP is the maximum resultant COP in the AP direction minus the minimum resultant COP in the AP direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 6.312$, p=0.003) of the range. The trial effect ($F_{4,104,0.05} = 1.082$, p=0.370) and the interaction term ($F_{8,104,0.05} = 1.262$, p=0.273) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed.

Young adults (mean = 19.47 mm) differed significantly from the peripheral neuropathy elders (mean = 37.27 mm), with a probability p = 0.002 (q = 5.016). Young adults and neurologically intact elders (mean = 27.56 mm) did not differ significantly (p = 0.246), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.187).

6.1.7 Range – M/L (mm)

The range - ML is the maximum resultant COP in the ML direction minus the minimum resultant COP in the ML direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 4.144$, p=0.019) of the range in the ML direction. The trial effect ($F_{4,104,0.05} = 0.631$, p=0.642) and the interaction term ($F_{8,104,0.05} = 1.952$, p=0.062) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 10.76 mm) differed significantly from the peripheral neuropathy elders (mean = 20.67 mm), with a probability p = 0.025 (q = 3.756). Young adults and neurologically intact elders (mean = 18.52 mm) did not differ significantly (p = 0.100), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.859).

6.1.8 Mean Velocity (mm/s)

The mean velocity is the average velocity of the COP. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05}$ = 4.480, p=0.014) of the velocity of the COP. The trial effect ($F_{4,104,0.05}$ = 1.047, p=0.388) and the interaction term ($F_{8,104,0.05}$ = 1.224, p=0.295) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 9.70 mm/s) differed significantly from the peripheral neuropathy elders (mean = 21.86 mm/s), with a probability p = 0.011 (q = 4.199). Young adults and neurologically intact elders (mean = 13.14 mm/s) did not differ significantly (p = 0.679), nor did neurologically intact elders when compared to elderly adults with diabetes (p = 0.133).

6.1.9 Mean Velocity – A/P (mm/s)

The mean velocity - AP is the average velocity of the COP in the AP direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05}$ = 4.612, p=0.012) of the velocity of the COP. The trial effect ($F_{4,104,0.05}$ = 1.087, p=0.368) and the interaction term ($F_{8,104,0.05}$ = 1.233, p=0.289) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 7.76 mm/s) differed

significantly from the peripheral neuropathy elders (mean = 18.56 mm/s), with a probability p = 0.010 (q = 4.237). Young adults and neurologically intact elders (mean = 10.44 mm/s) did not differ significantly (p = 0.739), nor did neurologically intact elders when compared to elder adults with diabetes (p = 0.105).

6.1.10 Mean Velocity – M/L (mm/s)

The mean velocity - ML is the average velocity of the COP in the ML direction. The mean of this measure for all five trials from each subject in each group can be seen in Table 25. A Two-Way ANOVA was performed to determine if there was a group difference, or if the metric changed over the five trials. A significant group effect was seen for the mean ($F_{2,104,0.05} = 4.260$, p=0.017) of the ML velocity of the COP. The trial effect ($F_{4,104,0.05} = 0.899$, p=0.468) and the interaction term ($F_{8,104,0.05} = 1.199$, p=0.309) were not significant. A pairwise multiple comparison procedure (Tukey's Test) was run on the groups to determine which groups differed. Young adults (mean = 4.24 mm/s) differed significantly from the peripheral neuropathy elders (mean = 8.16 mm/s), with a probability p = 0.012 (q = 4.128). Young adults and neurologically intact elders (mean = 5.82 mm/s) did not differ significantly (p = 0.470), nor did neurologically intact elders when compared to elder adults with diabetes (p = 0.256).

6.1.11 Summary

All quiet standing measures were significantly different between young adults and elder adults with diabtetes. Young adults consistently had significantly smaller metrics than the diabetic elderly Metrics for healthy elders were not significantly different than

metrics from either two groups, but metric values fell in-between young adults and diabetic elderly. Also, in all cases, measures in the medial-lateral plane were smaller than their counterparts in the anterior-posterior plane for all groups.

6.2 Threshold Analysis

The acceleration threshold determined for all five displacements through the use of the PEST method in conjunction with the two-alternative forced choice protocol for each subject can be seen in Table 26. The overall group averages can be seen in Table 27.

Table 26: Acceleration Thresholds for Gamma Subjects at Five Different Movement Lengths. Accelerations are Given in mm/s^2.

Subject	Group	Displacement (mm)				
		1	2	4	8	16
f22gc	YA	14.3	11.08	12.07	8.5	13.02
f23gd	YA	175.84	6.03	21.04	21.59	20.57
m23ge	YA	40	9.43	5.14	24.04	25.92
m25gf	YA	22.43	8.45	15.3	7.68	1
m24gg	YA	112.47	11.41	21.94	8.5	13.47
m22gh	YA	31.215	14.715	10	8.5	19.04
f224gi	YA	46.59	7.64	26.68	26.4	22.05
m22gj	YA	40	15.29	2.93	20	3.23
f21gl	YA	64.158	9.43	6.023	7.68	4.01
m53ga	NI	164.86	55.51	11.77	34.68	3.12
f54gn	NI	16.59	20	24.14	21.59	16.03
m66go	NI	92.71	25.29	18.83	20.77	20
f58gq	NI	145.42	8.02	7.35	11.36	19.32
m58gr	NI	100	20	10	8.5	14.81
m50gt	NI	97.1	59.64	38	26	31.08
f61gb	PN	59.44	56.99	16.19	7.61	13.31
m65gk	PN	170.9	160.05	59.49	8.5	25.06
m67gm	PN	200	125.7	97.35	5.23	31.08
m75gp	PN	97.1	59.64	38	26	31.08
f51gs	PN	200	35.52	11.33	15	11.89
f53gu	PN	200	200	20.61	20.61	16.59

Table 27: Acceleration Threshold Averages for Gamma Group Given in mm/s^2

Group	1 mm	2 mm	4 mm	8 mm	16 mm
YA	60.78 ± 51.83	10.39 ± 3.09	13.46 ± 8.34	14.78 ± 8.01	13.59± 9.08
NI	117.36 ± 61.04	33.61 ± 24.96	15.45 ± 6.67	18.90 ± 9.28	15.42 ± 6.37
PN	154.57 ± 61.34	106.32 ± 65.82	40.46 ± 32.97	13.83 ± 8.20	21.50 ± 8.72

A plot showing the average acceleration thresholds for each group can be seen in Figure 12.

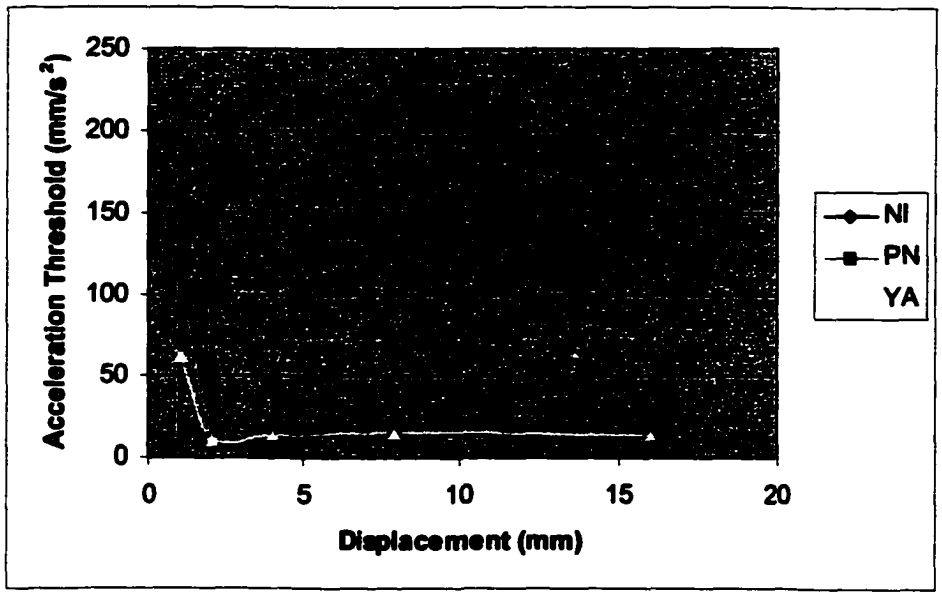


Figure 12: Plot of Average Acceleration Thresholds by Group for Gamma Group

A Repeated Measures Two Way ANOVA was used to determine if there were differences in acceleration thresholds across groups or among displacements. The ANOVA table, seen in Table 28, shows there is a significant difference in acceleration thresholds between groups, as well as among displacements. The interaction of group and displacement was also significant, therefore pairwise multiple comparison procedures (Tukey's Test) was run to determine where the differences lie.

Table 28: ANOVA table for Two Way Repeated Measures ANOVA comparing acceleration thresholds across groups and among displacements

Source of Variation	DF	SS	MS	F	P
Group	2	36043.198	18021.599	11.391	<0.001
Subject(Group)	18	28478.013	1582.112		
Disp	4	131186.303	32796.576	36.870	<0.001
Group x Disp	8	34587.155	4323.394	4.860	<0.001
Residual	72	64046.219	889.531		
Total	104	280019.189	2692.492		

Results from the Tukey test show that at 1 mm displacements, the acceleration thresholds of young adults are significantly smaller ($p < 0.05$) than the acceleration threshold of both elder groups. However, the acceleration threshold of the healthy elderly did not differ significantly from the diabetic elderly. At 2mm displacements, diabetic elderly had a significantly higher acceleration threshold ($p < 0.05$) than both healthy elders and young adults. However, young adult thresholds and healthy elderly thresholds did not differ significantly. At the 4, 8, and 16 mm displacements, no significant differences in acceleration thresholds were seen among groups.

As can be seen in Table 27, as well as Figure 12, all groups start with a large acceleration threshold at small displacements, then at some larger displacement, a minimum in acceleration threshold occurs, followed by a plateau effect at displacements larger than the minimum. For example, young adults have a high acceleration threshold at 1mm, a minimum at 2mm (where threshold is the smallest over all displacements), and after 2mm (at 4, 8, and 16 mm) all acceleration thresholds are approximately the same. The minimum or "dip" in acceleration threshold occurs at 2 mm for young adults, 4 mm for healthy elderly, and 8 mm for diabetic elderly. Plateau acceleration thresholds for each group are approximately the same.

An additional Kruskall - Wallis One Way ANOVA on Ranks was performed to determine if the random pattern of displacements had an effect on the acceleration threshold. Results indicate that there was no significant difference in acceleration threshold ($H_{4,104,0.05} = 2.393$, $p = 0.664$) depending on the order the displacements were presented to the subjects. This indicates that fatigue did unduly influence the values of acceleration thresholds.

A One-Way ANOVA was used to determine if there were any differences in threshold between trials that did and did not reach step criteria. Those trials that did reach step criteria (came to a distinct threshold within the PEST criteria, mean = 32.68 mm/s^2) were not significantly different ($F_{1,104,0.05} = 2.706$, $p = 0.103$) from those trials in which a 75% rule was used to determine threshold because at the end of the 30 trials, step criteria was not met (mean = 46.13 mm/s^2). Although those trials that did not reach threshold were slightly higher, this difference was not significant. This metric needs to be continually monitored to ensure that thresholds determined by the investigator do not significantly differ from those determined via the PEST method.

Finally, a Two-Way ANOVA was used to determine if there were any differences in acceleration threshold between sexes, and among groups. Acceleration thresholds were not significantly different between males and females in any group ($F_{1,104,0.05} = 0.799$, $p = 0.373$), nor was there any interaction between groups and sex ($F_{2,0.4,0.05} = 0.696$, $p = 0.501$), indicating that sex played no part in unduly influencing acceleration thresholds.

6.3 Detection Percentage Analysis

The number of detected trials for each displacement for each subject was recorded and divided by the total number of trials run to determine the detection percentage seen in Table 29. The average detection percentages for each group can be seen in Table 30. Note that these data were collected across a complete 2AFC PEST test run, and hence contain stimuli that are sub–threshold, peri–threshold, and supra–threshold. Since the PEST methodology is an adaptive, iterative method, many, if not most, stimuli will be below threshold. At or above threshold, at least 79% detection is theoretically expected by the definition of the staircase 79 formulations. Subjects either asymptotically approached threshold or oscillated around it.

Table 29: Detection Percentages for Gamma Group for all Displacements.

Subject	Group	1 mm	2 mm	4 mm	8 mm	16 mm
f22gc	YA	85.7	73.8	80	71.4	85
f23gd	YA	73.3	85	76.7	76.7	73.3
m23ge	YA	76.7	76.7	72.2	80	73.3
m25gf	YA	66.7	83.3	86.7	76.7	90
m24gg	YA	82.6	73.7	80	73.3	76.7
m22gh	YA	83.3	70.6	73.3	79.2	66.7
f24gi	YA	66.7	80	77.8	76	76.7
m22gj	YA	83.3	76.7	73.3	88	80
f21gl	YA	66.7	83.3	77.8	66.7	76.7
m53ga	NI	66.6	76	73.1	70	78.2
f54gn	NI	66.6	76.7	66.6	63.3	60
m66go	NI	60	63.3	66.7	61.5	50
f58gq	NI	63.3	73.9	78.6	76.9	82.8
m58gr	NI	70	70	70	70	72.2
m51gt	NI	63.3	70	73.3	81.8	85.1
f61gb	PN	73.3	73.3	80	73.3	73.3
m65gk	PN	63.3	70	73.3	61.1	86.7
m67gm	PN	60	76.7	74	76.7	70
m75gp	PN	69.2	66.7	53.3	83.3	66.7
f51gs	PN	60	70	51.6	63.3	82
f53gu	PN	47	53.3	80	80	70

Table 30: Average Percent Detection for Gamma Groups

Group	1 mm	2 mm	4 mm	8 mm	16 mm
YA	76.11 ± 8.00	78.12 ± 5.04	77.53 ± 4.49	76.44 ± 5.96	77.60 ± 6.82
NI	64.97 ± 3.49	71.65 ± 4.99	71.38 ± 4.59	70.58 ± 7.77	71.38 ± 13.80
PN	62.13 ± 9.10	68.33 ± 8.11	68.70 ± 12.92	72.95 ± 9.00	74.78 ± 7.84

Because percentage values were used, non-parametic statistics were used to analyze the data. A Kruskall-Wallis One Way ANOVA was used to determine a significant difference ($H_{2,104,0.05}$ =20.304, $p< 0.001$) in detection percentage among groups. A multiple comparison procedure (Dunn's Method) was used to determine that young adults detected a significantly ($p < 0.05$) higher percentage of trials than both elder groups. However, the percentage of detects was not significantly different between healthy elderly and elderly adults with diabetes. Also, no significant difference ($H_{4,104,0.05}$ = 7.088, $p = 0.131$) was seen in the percentage of correctly detected trials across displacement lengths.

6.4 Clinical Measures

6.4.1 Analysis of Semmes Weinstein Monofilament Measurements

Tactile force perception thresholds were determined using graded Semmes-Weinstein monofilaments applied to the base of the metatarsal, the base of digit IV and the big toe bilaterally. Threshold was determined using the graded monofilaments that, upon bending, exerted a known force on the sole of the foot. Stimuli were presented three times, and if two of the three trials were detected, a positive result was indicated. Threshold was then defines as the smallest force in which two of the three trials were

detected. Thresholds were determined for all subjects bilaterally, and measurements can be seen in Table 31. Group averages can be seen in Table 32.

Table 31: Graded Semmes-Weinstein Monofilament Measurements for Gamma Group

Subject	Group	Right Base Meta Tarsal	Left Base Meta Tarsal	Right Base Digit IV	Left Base Digit IV	Right Big Toe	Left Big Toe
f22gc	YA	2.36	2.36	2.36	2.36	2.83	3.22
f23gd	YA	1.65	1.65	1.65	2.36	1.65	1.65
m23ge	YA	1.65	1.65	2.36	2.36	2.44	2.36
m25gf	YA	2.83	2.36	2.36	2.36	2.36	2.36
m24gg	YA	3.22	3.22	2.83	3.22	3.22	3.61
m22gh	YA	3.61	3.61	3.61	3.61	3.61	3.84
f24gi	YA	3.61	3.61	3.61	3.61	3.84	3.22
m22gj	YA	2.36	2.83	2.36	2.83	2.83	2.83
f21gl	YA	3.61	2.83	3.61	2.83	3.22	3.22
m53ga	NI	3.61	2.44	3.84	4.17	*	*
f54gn	NI	3.84	3.84	3.84	3.22	3.61	3.84
m66go	NI	4.17	4.17	3.84	3.61	3.84	3.84
f58gq	NI	3.84	3.61	3.84	4.08	3.61	3.61
m58gr	NI	4.08	4.08	4.08	4.17	3.84	4.17
m50gt	NI	4.31	4.31	4.31	4.31	4.31	4.31
f61gb	PN	3.22	3.22	4.17	4.31	*	*
m65gk	PN	4.17	4.08	4.17	4.31	3.84	3.84
m67gm	PN	4.56	4.56	4.74	4.56	4.74	4.56
m75gp	PN	5.18	4.56	4.93	4.56	4.17	4.31
f51gs	PN	3.61	3.84	4.08	4.56	3.61	3.22
f53gu	PN	3.84	3.84	4.08	3.84	3.84	3.84

*Subjects not tested

Table 32: Group Averages for Graded Semmes-Weinstein Monofilaments

Group	Right Base Meta Tarsal	Left Base Meta Tarsal	Right Base Digit IV	Left Base Digit IV	Right Big Toe	Left Big Toe
YA	2.77 ± 0.80	2.68 ± 0.74	2.75 ± 0.71	2.84 ± 0.53	2.89 ± 0.68	2.92 ± 0.69
NI	3.98 ± 0.26	3.74 ± 0.68	3.96 ± 0.20	3.93 ± 0.42	3.84 ± 0.29	3.95 ± 0.28
PN	4.10 ± 0.70	4.02 ± 0.51	4.36 ± 0.37	4.36 ± 0.28	4.04 ± 0.44	3.95 ± 0.51

The above tables measure tactile threshold using the evaluator sizes provided. This is not a direct measure of force, and evaluators are ordered in an ordinal manner. Therefore, the average calculated in Table 32 is not very meaningful. The evaluator sizes were

converted to forces in Newtons to obtain some more information. Tactile threshold in Newtons can be seen in Table 33, and the group averages can be seen in Table 34.

Table 33: Converted Semmes-Weinstein Evaluator Size to Force Measurements (N)

Subject	Group	Right Base Meta Tarsal	Left Base Meta Tarsal	Right Base Digit IV	Left Base Digit IV	Right Big Toe	Left Big Toe
f22gc	YA	0.02	0.02	0.02	0.02	0.07	0.16
f23gd	YA	0.008	0.008	0.008	0.02	0.008	0.008
m23ge	YA	0.008	0.008	0.02	0.02	0.04	0.02
m25gf	YA	0.07	0.02	0.02	0.02	0.02	0.02
m24gg	YA	0.16	0.16	0.07	0.16	0.16	0.4
m22gh	YA	0.4	0.4	0.4	0.4	0.4	0.6
f24gi	YA	0.4	0.4	0.4	0.4	0.6	0.16
m22gj	YA	0.02	0.07	0.02	0.07	0.07	0.07
f21gl	YA	0.1	0.07	0.4	0.07	0.16	0.16
m53ga	NI	0.4	0.04	0.6	1.4	*	*
f54gn	NI	0.6	0.6	0.6	0.16	0.4	0.6
m66go	NI	1.4	1.4	0.6	0.4	0.6	0.6
f58gq	NI	0.6	0.4	0.6	1	0.4	0.4
m58gr	NI	1	1	1	1.4	0.6	1.4
m50gt	NI	2	2	2	2	2	2
f61gb	PN	0.16	0.16	1.4	2	*	*
m65gk	PN	1.4	1	1.4	2	0.6	0.6
m67gm	PN	4	4	6	4	6	4
m75gp	PN	15	4	8	4	1.4	2
f51gs	PN	0.4	0.6	1	4	0.4	0.16
f53gu	PN	0.6	0.6	1	0.6	0.6	0.6

* Subject Not Tested

Table 34: Average Gamma Group Force Measurements for Semmes-Weinstein Monofilament Testing in Newtons

Group	Right Base Meta Tarsal	Left Base Meta Tarsal	Right Base Digit IV	Left Base Digit IV	Right Big Toe	Left Big Toe
YA	0.13 ± 0.16	0.13 ± 0.16	0.15 ± 0.16	0.13 ± 0.16	0.17 ± 0.20	0.18 ± 0.20
NI	1.00 ± 0.61	0.91 ± 0.71	0.90 ± 0.69	1.06 ±0.69	0.80 ± 0.68	1.00 ± 0.68
PN	3.59 ± 5.76	1.73 ± 1.78	2.77 ± 1.44	2.77 ± 1.44	1.80 ± 2.38	1.47 ± 1.57

Although force is a ratio metric, the measurement of force here is still an ordinal type of data. Therefore, non-parametric statistics were used to both compare tactile

thresholds between right and left legs as well as compare among groups. Using a Mann-Whitney Rank Sum test, no significant differences were found in thresholds between right and left legs for the metatarsal (T = 461, p = 0.821), the base of digit IV (T = 442.5, p = 0.831), or the big toe (T = 364.5, p = 0.872). Data from the right and left legs were then pooled and a Kruskall- Wallis One Way ANOVA was used to determine differences in tactile threshold among groups. Figure 13 shows average group metrics.

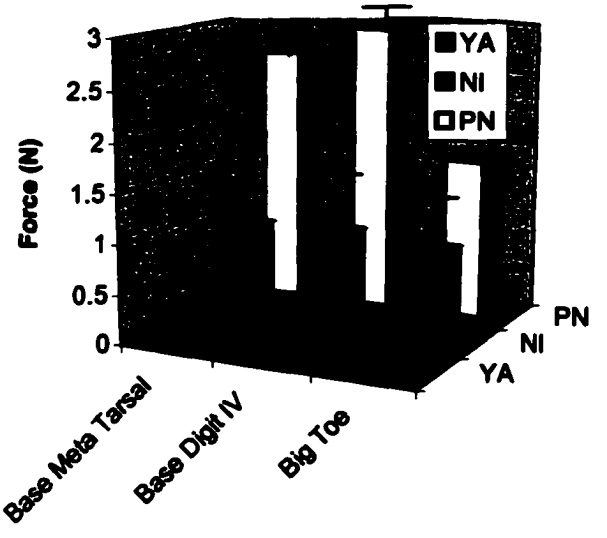


Figure 13: Average Tactile Threshold for Gamma Groups

For the metatarsal, young adults had significantly lower (median = 0.07; $H_{2,42,0.05}$ = 23.708, p =< 0.001) tactile thresholds than both elder groups. Healthy elders (median = 0.80) did not differ significantly from elders with diabetes (median = 0.08). For the base of digit IV, young adults had significantly lower (median = 0.045; $H_{2,42,0.05}$ = 31.166, p =< 0.001) tactile thresholds than both elder groups. Healthy elders (median = 0.80) did not differ significantly from elders with diabetes (median = 2.0). For the big toe, young adults had significantly lower (median = 0.115; $H_{2,42,0.05}$ = 20.803, p =< 0.001) tactile

thresholds than both elder groups. Healthy elders (median = 0.60) did not differ significantly from elders with diabetes (median = 0.60).

6.4.2 Height and Weight Measurements

Height and weight measurements were taken from all subjects for use in modeling measures. Metrics for each subject can be seen in Table 35.

Table 35: Height and Weight Measurements for Gamma Group

Subject	Group	Weight (kgs)	Height (cm)
f22gc	YA	62.73	160.02
f23gd	YA	52.73	162.56
m23ge	YA	80.45	176.53
m25gf	YA	72.73	175.26
m24gg	YA	74.09	177.80
m22gh	YA	82.73	166.37
f24gi	YA	100.00	157.48
m22gj	YA	77.27	175.26
f21gl	YA	69.09	167.64
m53ga	NI	99.09	177.80
f54gn	NI	63.64	158.75
m66go	NI	80.45	171.45
m58gr	NI	100.91	177.80
f58gq	NI	71.36	162.56
m50gt	NI	101.36	166.37
f61gb	PN	95.45	173.99
m65gk	PN	101.82	182.88
m67gm	PN	84.55	177.80
m75gp	PN	85.00	187.96
f51gs	PN	92.27	154.94
f53gu	PN	124.10	176.53

A One Way ANOVA comparing weight among groups showed that elderly adults with diabtetes had a significantly higher weight (mean = 97.20 ± 14.70; $F_{2,20,0.05} = 4.330$, $p = 0.029$) than young adults (mean = 74.65 ± 13.26), however, it was not significantly higher than healthy elderly (mean = 86.14 ± 16.58). Young adults and healthy elderly did

not differ significantly either. A One Way ANOVA comparing height among groups found no significant difference ($F_{2,20,0.05} = 1.240$, $p = 0.313$) among groups.

6.4.3 MMSE Exam Score Analysis

The Mini-Mental Status Examination was used to determine if subjects had the ability to follow directions and had adequate short-term memory to complete the test. All subjects had to score 24 out of a possible 30 to be eligible for the study. Examination scores for each subject can be seen in Table 36.

Table 36: MMSE Scores for Gamma Group

Subject	Group	Score
f22gc	YA	30
f23gd	YA	30
m23ge	YA	30
m25gf	YA	30
m24gg	YA	30
m22gh	YA	30
f24gi	YA	30
m22gj	YA	30
f21gl	YA	30
m53ga	NI	29
f54gn	NI	30
m66go	NI	29
f58gq	NI	30
m58gr	NI	29
m50gt	NI	30
f61gb	PN	30
m65gk	PN	29
m67gm	PN	29
m75gp	PN	29
f51gs	PN	28
f53gu	PN	29

Because statistical analysis is difficult due to the nature of the data (ordinal data with lower and upper limits), only anecdotal comparisons will be made here. There were no

young adults that scored less than a perfect 30 on the test. In the healthy elderly group half, or three of the six, subjects scored below a 30. Five of the six diabetic elders scored below 30. This trend indicates that there is some cognitive decline in elders with diabetes, but the exact nature and amount of decline was not determinable though this test. All subjects tested did score above 24, indicating they were fit to complete the study.

6.4.4 Nerve Conduction Analysis

Nerve conduction studies were done by a trained technician under the supervision of a Neurologist at the Overton Brooks VA Medical Center. Peroneal and Tibial Motor nerve conduction velocities were measured bilaterally and can be seen in Table 37.

Table 37: Motor Nerve Conduction Velocities in m/s for Gamma Group

Subject	Group	Left Peroneal Nerve	Left Tibial Nerve	Right Peroneal Nerve	Right Tibial Nerve
m53ga	NI	49	45	49	42
f54gn	NI	49	47	*	*
m66go	NI	*	*	50	38
f58gq	NI	50	**	50	45
m58gr	NI	45	50	49	50
m50gt	NI	44	38	40	38
f61gb	PN	51	41	42	40
m65gk	PN	39	40	40	39
m67gm	PN	43	43	40	36
m75gp	PN	29	28	**	30
f51gs	PN	47	39	46	44
f53gu	PN	40	36	36	41

*Subject preferred nerve conduction testing on one leg only.
**Response was not recordable

According to standards set forth by the VA Medical center, normal motor nerve conduction studies have velocities greater than 44 m/s for the peroneal nerve and greater than 41 m/s for the tibial nerve. Because of the missing data from the subjects who

preferred testing on only one leg, and those individuals whose responses were too small to record via surface stimulation, the data has been processed using non-parametric statistics. Mann-Whitney Rank Sum T-tests determined no differences in the conduction velocities between the two legs for both the peroneal nerve (T = 107.5, p = 0.888) and the tibial nerve (T = 114.0, p = 0.805). The data was pooled, and further Mann-Whitney Rank Sum Tests determined significantly slower conduction velocities for the peroneal nerves of the diabetic group (T = 145.5, p = 0.014) and a trend to slower conduction velocities in the tibial nerves of the diabetic groups (T=127, p = 0.051). This indicates that in the diabetic group there are significant motor nerve deficit present.

Additionally, F Wave studies were conduced to determine the M Latencies and F Latencies of all subjects. Data on latency values can be seen in Table 38.

Table 38: F Wave Studies to determine M and F Latencies in ms.

		M Latency				F Latency			
Subject	Group	Left Peroneal Nerve	Left Tibia Nerve	Right Peroneal Nerve	Right Tibia Nerve	Left Peroneal Nerve	Left Tibia Nerve	Right Peroneal Nerve	Left Peroneal Nerve
m53ga	NI	4.7	4.8	4.2	5.2	52.4	55.4	50.2	54.4
f54gn	NI	*	*	*	*	*	*	*	**
m66go	NI	*	*	*	*	*	*	*	**
f58gq	NI	2.8	3.8	3.5	4.9	45.8	50.6	44.9	51.2
m58gr	NI	4.2	4.8	4.5	4.4	55.4	2.3	50	53.6
m50gt	NI	4.6	4.7	6.6	5	49.7	53.7	54.1	54.6
f61gb	PN	11.5	4.7	5.1	4.1	52.7	62.8	51.9	62.2
m65gk	PN	4.7	4.4	5.3	5.2	63.9	60.5	60.8	59.3
m67gm	PN	4.2	5.6	5.4	4.3	56.5	59.3	59.5	55.5
m75gp	PN	5.6	13.4	**	6.6	65.5	**	**	**
f51gs	PN	4.6	6.4	5	4.8	42.1	53.9	46.9	52.6
f53gu	PN	4.3	4.5	4.4	5.9	66.1	74.2	61.4	75.5

*Subject preferred not to undergo this portion of the study
**Response was not recordable

Normal standards for peroneal nerve M latencies are less than 6.5 msec, while the tibial nerve M latencies are less than 5.8ms. F-Wave latencies less than 56ms are normal for

both the peroneal and tibial nerves. Because two subjects declined to participate in this portion of the study, and one individual's responses were too small to record, non-parametric statistics were again used for analysis. A Mann-Whitney Rank Sum test determined that there was no difference in latencies between legs for both the M Latency Peroneal nerve studies ($T = 97.0$, $p = 0.596$) and the M Latency Tibial studies ($T = 100.5$, $p = 0.762$). No significant differences in latencies were seen between legs for the F Wave Peroneal nerve studies ($T = 83$, $p = 0.596$) and the F Wave Tibial Studies ($T = 83.5$, $p = 0.965$). Data from the right and left legs were then pooled and differences in M and F latencies were determined via Mann-Whitney Rank Sum Tests. No significant differences were seen between groups in the M latencies of either the peroneal nerve($T = 58$, $p = 0.076$) or the tibial nerve ($T=72.5$, $p = 0.396$), but F latencies of the diabetic group were significantly higher than the healthy elderly in both the peroneal nerve ($T=55.0$, $p = 0.043$) and the tibial nerve ($T=44.0$, $p=0.005$).

The final part of the nerve conduction testing determined the velocity of the sural sensory nerve. Conduction velocities for each subject can be seen in Table 39.

Table 39: Sensory Nerve Conduction Velocities in m/s for Gamma Group

Subject	Group	Right Sural Nerve	Left Sural Nerve
m53ga	NI	50	45
f54gn	NI	*	*
m66go	NI	44	*
f58gq	NI	45	47
m58gr	NI	53	52
m50gt	NI	48	46
f61gb	PN	**	**
m65gk	PN	42	37
m67gm	PN	41	40
m75gp	PN	**	**
f51gs	PN	35	46
f53gu	PN	**	**

*Subject preferred nerve conduction testing on one leg only.
**Response was not recordable

According to VA Medical Center standards, conduction velocities of sural nerves greater than 34 m/s is normal. Because several subjects had readings too small to be recordable, and others declined this part of the testing procedure, non-parametric statistics were used in analysis. A Mann-Whitney Rank Sum test was used to determine that there were no differences in conduction velocities between legs ($T = 56.5$, $p = 0.955$). Data for the left and right leg were then pooled and a Mann-Whitney Rank Sum test was used to determine a significantly lower conduction velocity in subjects with diabtes ($T=24.5$, $p = 0.007$).

These tests have shown that subjects with diabetes do have significantly slower motor and sensory nerve conduction velocities, as expected from the peripheral neuropathy associated with diabetes. Also, as expected, sensory nerve conduction velocities are slower than motor nerve conduction velocities, which validate the data.

6.4.5 Auditory Testing

An audiologist at the Overton Brooks VA Medical Center completed air Conduction Testing. Both elderly groups underwent testing at 1k, 2k, 4k, and 8k Hz in both ears. Average threshold level was recorded in decibels and can be seen in Figure 40. Using a One Way ANOVA, the threshold in each ear was compared to determine any differences in threshold. No significant differences were found ($F_{1,79,0.05} = 0.336$, $p = 0.564$), allowing the pooling of the data. Averages for each group at each frequency with the lumped right and left ear can be seen in Table 41 and Figure 14.

Figure 40: Air Conduction Testing. Average Threshold Level Measured in db was Measured for Each Subject at 1k, 2k, 4k, and 8k Hz for Both Ears.

		Right				Left			
Subject	Group	1000 Hz	2000 Hz	4000 Hz	8000 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
m53ga	NI	*	*	*	*	*	*	*	*
f54gn	NI	10	15	15	20	10	15	5	15
m66go	NI	10	10	25	45	15	10	30	45
f58gq	NI	10	5	25	50	5	5	15	30
m58gr	NI	15	15	20	40	15	25	20	50
m50gt	NI	20	10	35	30	25	15	25	35
f61gb	PN	*	*	*	*	*	*	*	*
m65gk	PN	20	15	50	95	45	35	60	85
m67gm	PN	25	45	70	70	20	55	65	70
m75gp	PN	25	25	45	75	40	45	55	60
f51gs	PN	5	5	5	10	5	5	0	15
f53gu	PN	20	15	25	35	20	25	25	40

*Subject Not Tested

Table 41: Group Average Air Conduction Thresholds in dB for Each Frequency

Group	1000 Hz	2000 Hz	4000 Hz	8000 Hz
NI	13.5	12.5	21.5	36
PN	22.5	27	40	55.5

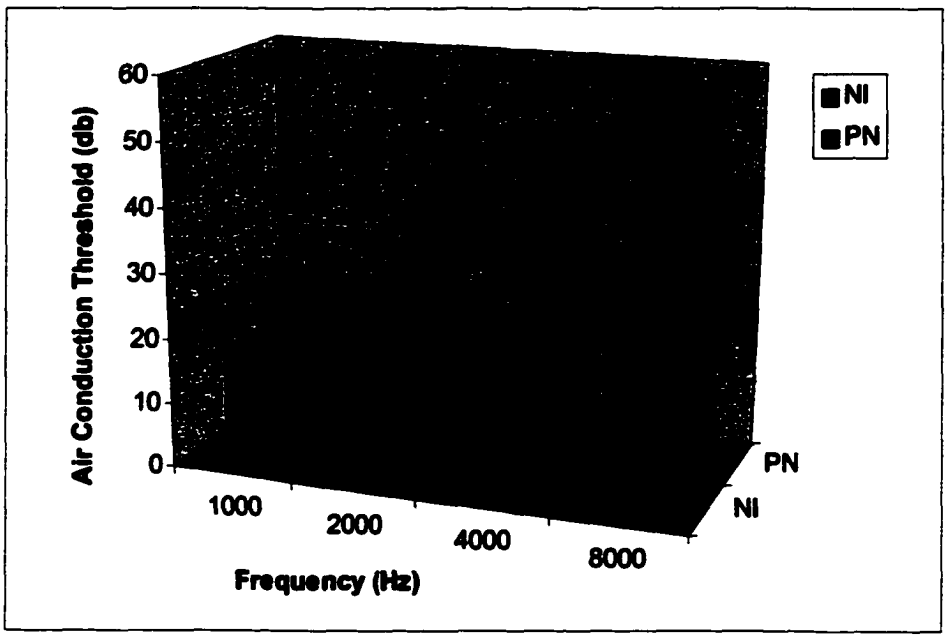


Figure 14: Air Conduction Thresholds in dB for Each Group at Varying Frequencies.

A Two-Way ANOVA was then run to determine differences in thresholds between groups and among frequencies. Significant differences were found between groups ($F_{1,79,0.05} = 15.592$, $p < 0.001$) and among frequencies ($F_{3,79,0.05} = 10.713$, $p < 0.001$), but no interaction between group and frequency was found ($F_{3,79,0.05} = 0.347$, $p = 0.791$). A post hoc Tukey test was run to determine at what frequencies thresholds differed. Results show that thresholds at 8k Hz were significantly higher ($p < 0.05$) than all other frequencies, but thresholds at all other frequencies were not significantly different than each other.

6.5 Sway (COP Phase Plane) Analysis

Center-of-pressure analysis was done using the Matlab program seen in Appendix K. COP phase planes relate the position of the COP to the velocity of the COP at the

same instant. For correctly detected trials, position and velocity of the AP and ML sway was taken at the start of the platform movement (SOM), the middle of the platform movement (MOM), and the end of the platform movement (EOM). Using the Matlab program seen in Appendix L, positions and velocities for AP and ML motion were binned into four categories based on COP position and velocity at that instant. For AP motion, these categories are 1. COP motion forward of center, COP velocity moving forward (FMF); 2. COP motion forward of center, COP velocity moving backward (FMB); 3. COP motion backward of center, COP velocity moving forward (BMF); and 4. COP motion backward of center, COP velocity moving backward (BMB). For ML motion, backwards and forwards does not properly describe the motion, so the bins were revised for left and right motion. The four categories for ML motion are 1. COP motion left of center, COP velocity moving left (LML); 2. COP motion left of center, COP velocity moving right (LMR); 3. COP motion right of center, COP velocity moving left (RML); and 4. COP motion right of center, COP velocity moving right (RMR). The percentage of trials that fall into each bin for each subject in AP trials can be seen in Table 42, and the ML trials can be seen in Table 43.

Table 42: Percentage of Correctly Detected Trials for each COP Bin (BMB = Backwards Moving Backwards, BMF = Backwards Moving Forwards, FMB = Forwards Moving Backwards, FMF = Forwards Moving Forwards) in the AP direction, at Each Position of the Movement (SOM = Start of Movement, MOM = Middle of Movement, EOM = End of Movement)

Subject	Group	Portion of Movement	BMB	BMF	FMB	FMF
f21gl	YA	SOM	20.37	20.37	35.19	24.07
f22gc	YA	SOM	31.03	15.52	25.86	27.59
f23gd	YA	SOM	25.68	32.43	18.92	22.97
f24gi	YA	SOM	18.29	36.59	24.39	20.73
m22gh	YA	SOM	25.64	29.49	16.67	28.21
m22gj	YA	SOM	28.24	29.41	23.53	18.82
m23ge	YA	SOM	24.14	33.33	24.14	18.39
m24gg	YA	SOM	26.15	20.00	33.85	20.00
m25gf	YA	SOM	21.13	23.94	28.17	26.76
f21gl	YA	MOM	31.48	20.37	27.78	20.37
f22gc	YA	MOM	22.41	29.31	17.24	31.03
f23gd	YA	MOM	22.97	25.68	21.62	29.73
f24gi	YA	MOM	30.49	25.61	24.39	19.51
m22gh	YA	MOM	16.67	26.92	23.08	33.33
m22gj	YA	MOM	28.24	21.18	27.06	23.53
m23ge	YA	MOM	14.94	40.23	25.29	19.54
m24gg	YA	MOM	24.62	21.54	20.00	33.85
m25gf	YA	MOM	35.21	23.94	21.13	19.72
f21gl	YA	EOM	25.93	24.07	29.63	20.37
f22gc	YA	EOM	29.31	27.59	22.41	20.69
f23gd	YA	EOM	24.32	27.03	29.73	18.92
f24gi	YA	EOM	20.73	20.73	28.05	30.49
m22gh	YA	EOM	23.08	15.38	32.05	29.49
m22gj	YA	EOM	15.29	28.24	29.41	27.06
m23ge	YA	EOM	17.24	22.99	33.33	26.44
m24gg	YA	EOM	23.08	27.69	23.08	26.15
m25gf	YA	EOM	15.49	22.54	30.99	30.99
f51gs	PN	SOM	27.69	23.08	29.23	20.00
f53gu	PN	SOM	27.27	14.55	34.55	23.64
f61gb	PN	SOM	22.50	22.50	26.25	28.75
m65gk	PN	SOM	26.97	25.84	25.84	21.35
m67gm	PN	SOM	29.41	20.00	29.41	21.18
m75gp	PN	SOM	16.67	30.56	29.17	23.61
f51gs	PN	MOM	29.23	32.31	18.46	20.00
f53gu	PN	MOM	30.91	23.64	18.18	27.27
f61gb	PN	MOM	17.50	32.50	22.50	27.50
m65gk	PN	MOM	29.21	28.09	16.85	25.84
m67gm	PN	MOM	28.24	31.76	18.82	21.18
m75gp	PN	MOM	20.83	29.17	25.00	25.00
f51gs	PN	EOM	15.38	30.77	29.23	24.62
f53gu	PN	EOM	21.82	34.55	23.64	20.00
f61gb	PN	EOM	30.00	23.75	21.25	25.00
m65gk	PN	EOM	24.72	28.09	25.84	21.35
m67gm	PN	EOM	24.71	18.82	29.41	27.06

m75gp	PN	EOM	27.78	27.78	18.06	26.39
f54gn	NI	SOM	15.91	36.36	21.59	26.14
f58gq	NI	SOM	17.14	24.29	30.00	28.57
m50gt	NI	SOM	24.36	19.23	33.33	23.08
m53ga	NI	SOM	20.00	28.33	30.00	21.67
m58gr	NI	SOM	19.18	27.40	17.81	35.62
m66go	NI	SOM	25.42	33.90	22.03	18.64
f54gn	NI	MOM	19.32	35.23	26.14	19.32
f58gq	NI	MOM	27.14	30.00	17.14	25.71
m50gt	NI	MOM	28.21	23.08	25.64	23.08
m53ga	NI	MOM	31.67	26.67	20.00	21.67
m58gr	NI	MOM	27.40	19.18	24.66	28.77
m66go	NI	MOM	16.95	40.68	15.25	27.12
f54gn	NI	EOM	29.55	27.27	23.86	19.32
f58gq	NI	EOM	28.57	21.43	24.29	25.71
m50gt	NI	EOM	30.77	26.92	21.79	20.51
m53ga	NI	EOM	21.67	25.00	25.00	28.33
m58gr	NI	EOM	31.51	28.77	23.29	16.44
m66go	NI	EOM	18.64	37.29	25.42	18.64

Table 43: Percentage of Correctly Detected Trials for each COP Bin (LML = Left Moving Left, LMR = Left Moving Right, RMR = Right Moving Right, RML = Right Moving Left,) in the ML Direction, at Each Position of the Movement (SOM = Start of Movement, MOM = Middle of Movement, EOM = End of Movement)

Subject	Group	Portion of Movement	LML	LMR	RML	RMR
f21gl	YA	SOM	27.78	11.11	38.89	22.22
f22gc	YA	SOM	20.69	25.86	27.59	25.86
f23gd	YA	SOM	24.32	33.78	22.97	18.92
f24gi	YA	SOM	20.73	26.83	29.27	23.17
m22gh	YA	SOM	19.23	26.92	23.08	30.77
m22gj	YA	SOM	21.18	21.18	29.41	28.24
m23ge	YA	SOM	27.59	20.69	22.99	28.74
m24gg	YA	SOM	32.31	23.08	20.00	24.62
m25gf	YA	SOM	16.90	30.99	26.76	25.35
f21gl	YA	MOM	33.33	24.07	20.37	22.22
f22gc	YA	MOM	34.48	27.59	25.86	12.07
f23gd	YA	MOM	28.38	18.92	27.03	25.68
f24gi	YA	MOM	28.05	30.49	20.73	20.73
m22gh	YA	MOM	33.33	32.05	20.51	14.10
m22gj	YA	MOM	27.06	22.35	27.06	23.53
m23ge	YA	MOM	31.03	22.99	24.14	21.84
m24gg	YA	MOM	29.23	27.69	29.23	13.85
m25gf	YA	MOM	28.17	28.17	22.54	21.13
f21gl	YA	EOM	24.07	33.33	20.37	22.22
f22gc	YA	EOM	18.97	22.41	22.41	36.21
f23gd	YA	EOM	21.62	14.86	28.38	35.14
f24gi	YA	EOM	21.95	23.17	23.17	31.71
m22gh	YA	EOM	26.92	28.21	23.08	21.79
m22gj	YA	EOM	40.00	24.71	18.82	16.47
m23ge	YA	EOM	19.54	24.14	29.89	26.44

m24gg	YA	EOM	20.00	35.38	15.38	29.23
m25gf	YA	EOM	23.94	32.39	19.72	23.94
f51gs	PN	SOM	24.62	27.69	18.46	29.23
f53gu	PN	SOM	27.27	27.27	21.82	23.64
f61gb	PN	SOM	13.75	12.50	22.50	51.25
m65gk	PN	SOM	24.72	30.34	16.85	28.09
m67gm	PN	SOM	22.35	14.12	30.59	32.94
m75gp	PN	SOM	29.17	29.17	20.83	20.83
f51gs	PN	MOM	27.69	29.23	24.62	18.46
f53gu	PN	MOM	18.18	32.73	29.09	20.00
f61gb	PN	MOM	46.25	18.75	21.25	13.75
m65gk	PN	MOM	33.71	14.61	24.72	26.97
m67gm	PN	MOM	28.24	17.65	35.29	18.82
m75gp	PN	MOM	30.56	23.61	26.39	19.44
f51gs	PN	EOM	20.00	16.92	30.77	32.31
f53gu	PN	EOM	16.36	25.45	23.64	34.55
f61gb	PN	EOM	30.00	45.00	13.75	11.25
m65gk	PN	EOM	19.10	21.35	29.21	30.34
m67gm	PN	EOM	27.06	34.12	17.65	21.18
m75gp	PN	EOM	20.83	27.78	15.28	36.11
f54gn	NI	SOM	25.00	26.14	25.00	23.86
f58gq	NI	SOM	20.00	28.57	24.29	27.14
m50gt	NI	SOM	20.51	23.08	20.51	35.90
m53ga	NI	SOM	33.33	30.00	15.00	21.67
m58gr	NI	SOM	24.66	28.77	19.18	27.40
m66go	NI	SOM	22.03	23.73	22.03	32.20
f54gn	NI	MOM	20.45	20.45	29.55	29.55
f58gq	NI	MOM	38.57	27.14	17.14	17.14
m50gt	NI	MOM	25.64	26.92	17.95	29.49
m53ga	NI	MOM	30.00	28.33	30.00	11.67
m58gr	NI	MOM	31.51	15.07	27.40	26.03
m66go	NI	MOM	22.03	28.81	25.42	23.73
f54gn	NI	EOM	35.23	32.95	15.91	15.91
f58gq	NI	EOM	27.14	14.29	31.43	27.14
m50gt	NI	EOM	29.49	17.95	25.64	26.92
m53ga	NI	EOM	26.67	30.00	18.33	25.00
m58gr	NI	EOM	23.29	34.25	20.55	21.92
m66go	NI	EOM	25.42	15.25	22.03	37.29

Statistical analysis used non-parametric tests because percentages were used. From analysis, it was determined that there were no significant differences in the percentage of COP phase plane position and velocity between groups in either AP or ML data. No significant differences were found in location of the COP phase plane for detection in either AP or ML data at any point in the move. From this analysis, it can be seen that for both AP and ML data, for all groups, percentages were approximately

equally spread between bins with averages between 24 and 25 percent for each bin. This shows that position and velocity of COP motion at the start, middle, and end of the move have no effect on detection of the motion. This may be true due to the fact that some finite time needs to pass before reaction to the move occurs and changes in COP data are seen.

To look at the response time, and actual magnitude of the COP response to the perturbation, a model was constructed to match the data taken. For this analysis only ML sway was analyzed, because it was easier to pick out the response to the perturbation from the background sway. An inverted pendulum model was used, because for small movements, it has been found that the body acts as an inverted pendulum instead of a double stance support system. Friction was neglected in the analysis, because the motion of the plate on the air bearings negates any friction in the system. The system was first broken down into two components, the motion of the plate and the motion of the body. The two free body diagrams of the system can be seen in Figure 15.

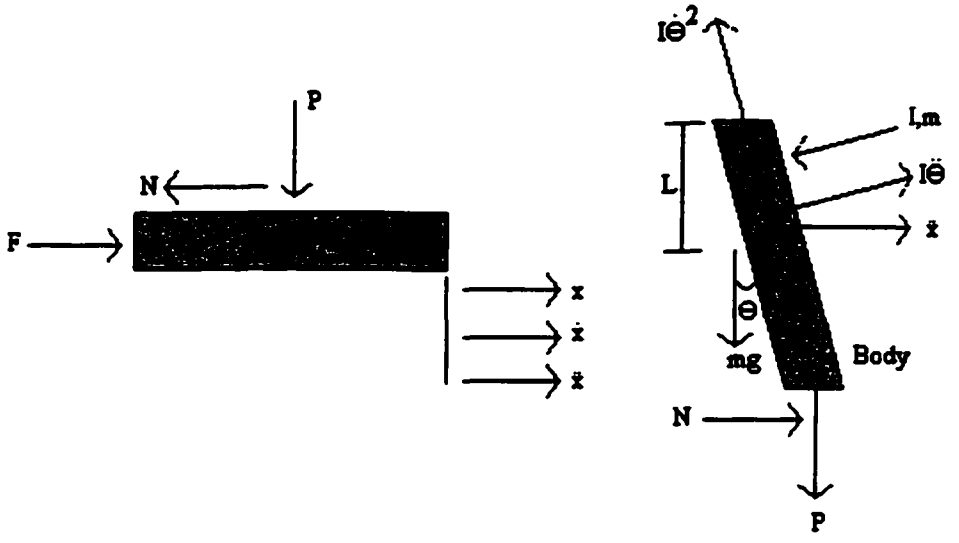


Figure 15: Free Body Diagrams of Slide and Body for Sway Model. M = Mass of Slide, m = Mass of Body, L = Length to the Center of Mass, I = Inertia of Pendulum, F = Force Applied, and θ is the Pendulum Angle from Vertical.

The final transfer function is as follows:

$$\frac{\Phi(s)}{U(s)} := \frac{-6 \cdot m \cdot L}{\left(-9 \cdot m \cdot I - 9M \cdot I - 2 \cdot M \cdot m \cdot l^2\right) \cdot s^2 + 6 \cdot m^2 \cdot g \cdot L + 6 \cdot m \cdot g \cdot M \cdot I} \qquad (3)$$

The derivation of this transfer function can be seen in Appendix M. In this analysis, only 8 mm motions from all subjects are analyzed. This length was chosen because all acceleration thresholds for the groups were not significantly different, and COP responses to the movement are easily seen. To be able to compare between groups, these motions were further reduced to those whose imparted peak energy fell between 5 mJ and 15 mJ, so that the amplitude and frequency of the COP response can be adequately compared across groups. A Matlab program was written (see Appendix N), to analyze the COP response. The output from this program can be seen in Figure 16. Then, using the Matlab program seen in Appendix O, a PID controller was added to transfer function of the

system, and the proportional and differential coefficients were changed manually until the response of the model was the similar as the response of the individual.

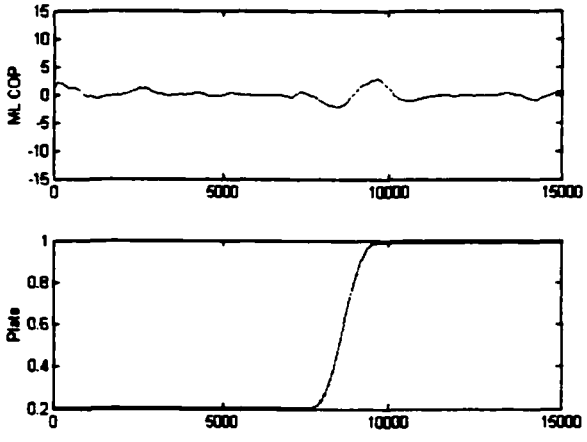


Figure 16: Output from sub_COP_det_move.m Matlab File to Look at ML COP Responses of the Perturbations. This Data is Taken from f22gc5as3rf25.raw

Comparisons of the model and the ML sway were done side by side to attain the proper coefficients. One comparison from each group can be seen below. Figure 17 is the young adult comparison, figure 18 is the healthy elderly comparison, and figure 19 is the elderly adult with diabetes comparison.

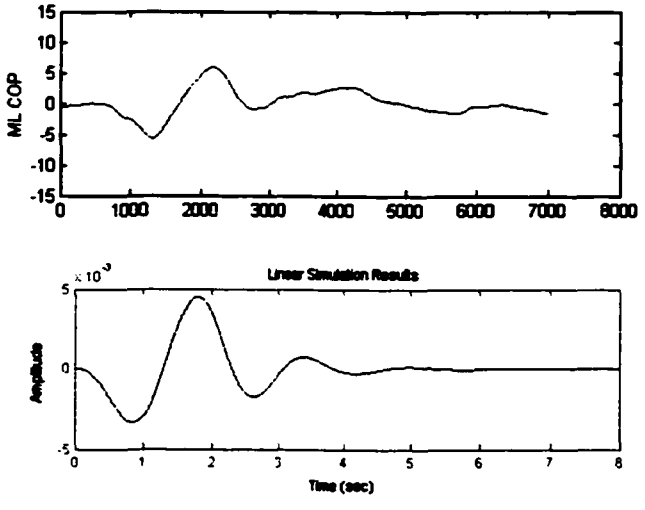


Figure 17: Comparison of Sway Data to Modeled Data for Young Adult File m23ge1as3rf26.raw

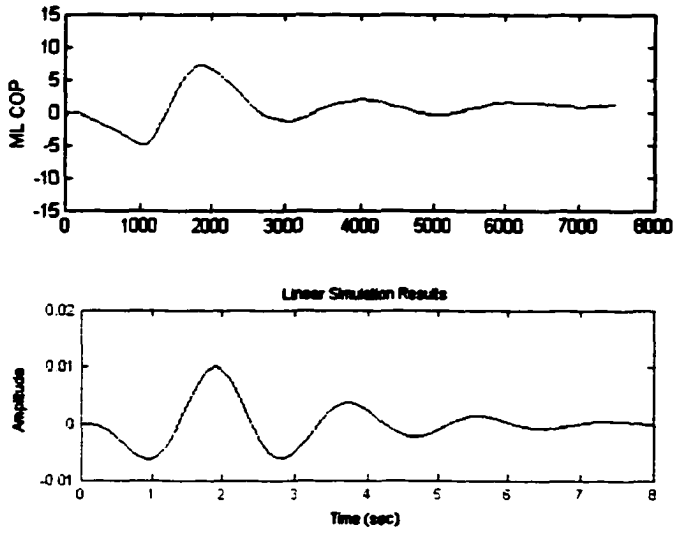


Figure 18: Comparison of Sway Data to Modeled Data for Healthy Elderly Adult File f58gq4as3rf4.raw

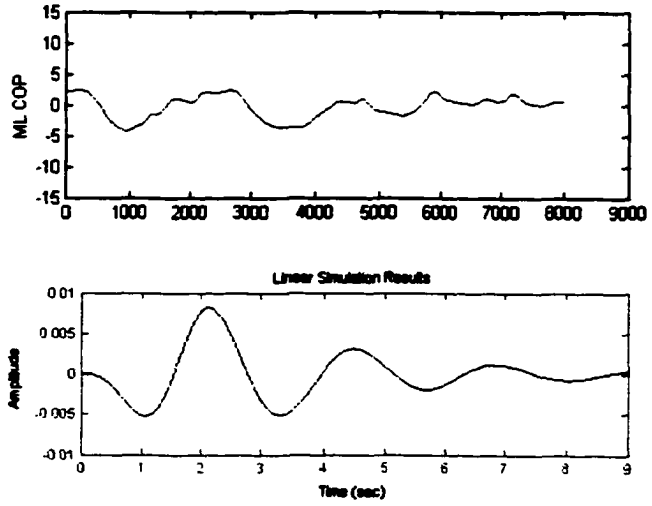


Figure 19: Comparison of Sway Data to Modeled Data for Elderly Adult with Diabetes File f53gu4as3rf1.raw

The closed loop system was then broken down into its natural frequency and damping coefficients. These parameters can be seen in Table 44 and were then compared between groups to determine differences in the ability to control responses to these perturbations.

Table 44: Natural Frequency and Damping Coefficients Determined for Each Subject Though COP Modeling

Subject	Group	Natural Frequency Wn (Hz)	Damping Coefficient Z
f22gc	YA	5.06	0.40
m23ge	YA	4.16	0.27
f23gd	YA	5.03	0.27
m25gf	YA	3.68	0.40
m24gg	YA	2.46	0.52
m22gh	YA	1.88	0.49
m22gj	YA	3.18	0.29
f21gl	YA	1.90	0.28
m53ga	NI	1.67	0.30
f54gn	NI	4.63	0.17
m66go	NI	4.70	0.20
m58gr	NI	1.38	0.26
f58gq	NI	3.47	0.15
m50gt	NI	3.67	0.18
f61gb	PN	2.23	0.29
m65gk	PN	2.55	0.23
m65gm	PN	4.49	0.16
m75gp	PN	2.88	0.19
f51gs	PN	1.87	0.19
f53gu	PN	2.69	0.15

A One – Way ANOVA was shows no significant difference ($F_{2,19,0.05} = 0.468$, $p = 0.634$) in the natural frequency among groups. However, the mean for the young adult group (3.418 ± 1.285) is slightly higher than the healthy elderly mean (3.253 ± 1.429), which is also higher than the elderly adult with diabetes mean (2.784 ± 0.910). Even though the difference between groups is not significant, this trend in the mean of the undamped natural frequency can be seen in the sway data. The damping coefficient was significantly different ($F_{2,19,0.05} = 10.374$, $p = 0.001$) between groups. Young adults had significantly larger damping coefficients (mean = 0.366 ± 0.1) than both healthy elderly (mean = 0.210 ± 0.0565) and diabetic elder (mean = 0.202 ± 0.0528) groups. Elder groups did not differ significantly.

6.6 EMG Analysis

EMG data was taken bilaterally from the gastroc-soleus and tibialis anterior. Each of the four EMG's for each trial for each subject were compared with the AP COP to determine if any EMG activity was correlated with sway using the Matlab program seen in Appendix P. An example from each group can be seen below. Figure 20 represents typical young adult data, Figure 21 represents typical healthy elder data, and Figure 22 represents diabetic elderly data.

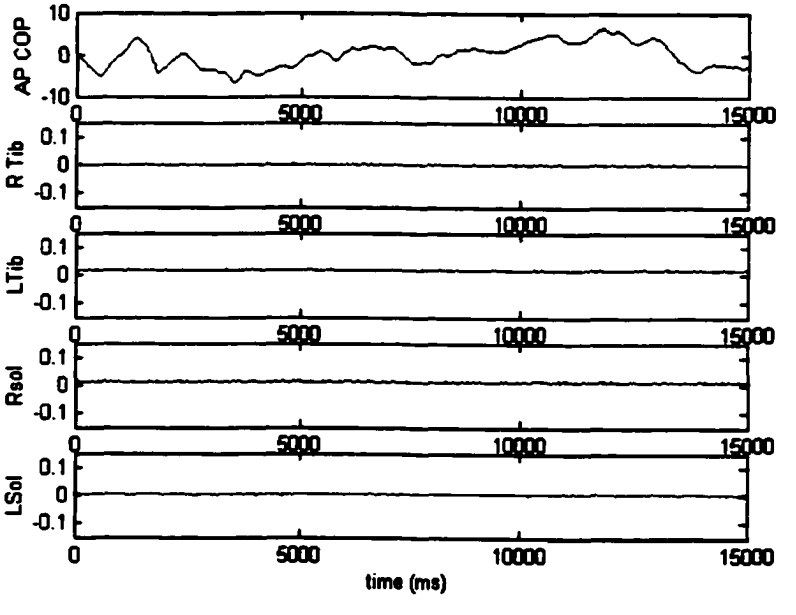


Figure 20: EMG Plot from f23gd5as3rf4.raw

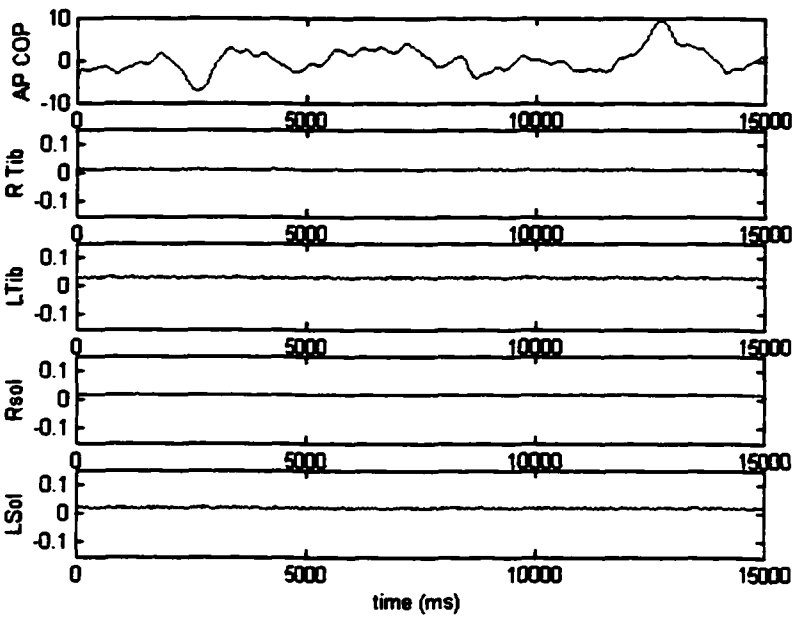


Figure 21: EMG Plot from f58gq2as0rf5.raw

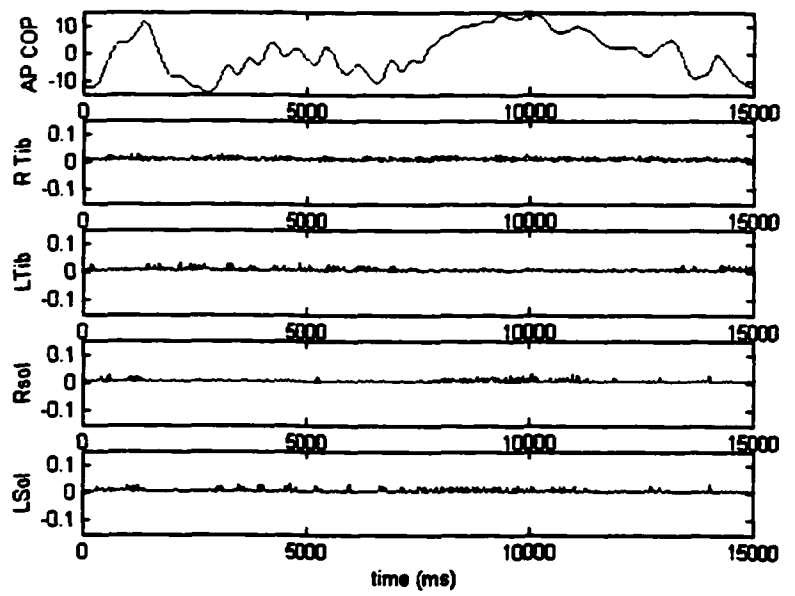


Figure 22: EMG Plot from m65gkn3as0rf2.raw

As can be seen in the previous two figures, AP COP does not correlate with any of the four EMGs measured. Instead of a turning on of tibialis when gastroc-soleus muscles turned off, a constant activation level is seen in both muscles. This is unlike a normal quiet standing EMG where little or no activity is recorded. It is also unlike the EMG responses seen in maximal contractions, because no burst patterns are seen. Instead, these EMGs show a typical anticipatory response to the testing paradigm. During testing, all muscles are tensed with no increase or decrease in amplitude based on changes in COP. In looking at all the data, it can be stated that all subjects elicited this anticipatory response, although not all did it in exactly the same way. Some subjects only tensed gastroc muscles, while others tensed muscles on one side of the body. There was no consistent pattern between groups of subjects as to what anticipatory posture was taken. With the anticipatory EMG data seen here, one would hypothesize that responses to perturbations were done through trunk composition, although no kinematic data was available to prove this hypothesis. This anticipatory EMG activity, though, allows a much quicker and accurate response of the body because the muscles are already tensed, awaiting execution of some postural correction. If EMG data had exhibited quiet standing, or random patterns, a longer time to recover from a postural perturbation would most likely be necessary.

6.7 Latency and Reaction Time Analysis

6.7.1 Latency Analysis

Latency tests were run after the 2AFC tests to determine if the threshold obtained in that test were accurate. Five trials were presented at the same threshold (T) as obtained

through the 2AFC test, and five trials were presented at 125% of that threshold (termed suprathreshold, ST). For detected trials, the time between the start of the platform movement and the signal from the bell indicating the subject felt the platform move was calculated for all moves. For each displacement, the average time (in milliseconds) for each group at threshold and suprathreshold trials to detect the motion is presented in Table 45.

Table 45: Latency Times for Each Displacement in Milliseconds for Each Gamma Group at Threshold and Suprathreshold Trials.

Group	Modality	1 mm	2 mm	4 mm	8 mm	16 mm
YA	T	933.78 ± 413.83	1652.78 ± 528.48	1528.78 ± 483.92	1873.15 ± 987.97	2237.89 ± 1163.23
	ST	878.15 ± 447.14	1270.48 ± 328.02	1628.20 ± 592.25	1479.35 ± 706.43	2106.82 ± 1602.84
NI	T	877.20 ± 258.33	1858.75 ± 1320.76	1938.86 ± 1167.45	1907.08 ± 843.40	2377.85 ± 1049.94
	ST	906.33 ± 450.59	1348.39 ± 407.47	1897.16 ± 832.85	1481.52 ± 574.21	2273.05 ± 1309.32
PN	T	1516.56 ± 729.88	991.07 ± 374.51	1450.82 ± 363.34	2141.97 ± 702.12	1795.03 ± 519.72
	ST	11.27.07 ± 473.52	1004.31 ± 383.41	1713.51 ± 295.04	1907.55 ± 489.36	1769.22 ± 514.28

A Three-Way ANOVA comparing groups, threshold verses suprathreshold trials, and displacements was attempted, but this comparison failed the normality test. Non-parametric Kruskall-Wallis One Way ANOVA's were then used to determine that there was no significant difference in latency times between groups ($H_{2,208,0.05} = 0.668$, $p = 0.716$). No difference was expected because thresholds already showed significant group differences, and metrics here were taken at those thresholds. A Mann-Whitney Rank Sum test showed no significant difference in latency times between threshold and suprathreshold trials($T = 10205.5$, $p = 0.199$). Finally, latency values at displacements

were compared also using a Kruskall-Wallis One Way ANOVA. Latency values at 1 mm were significantly shorter ($H_{4,208,0.05} = 46.680$, $p =<0.001$) than those values at 4 mm, 8 mm, and 16 mm. This may be due to the mechanics of the movement itself. One millimeter movements take a very short time to occur, while larger movements inherently need longer periods of time to complete, which may delay the time needed to perceive the movement by the subject.

To determine if the acceleration of the move had an effect on the latency time, the acceleration values were binned into categories based on the mean of all the trials (45.75 ± 59.08). Average latency times for these bins were taken for each group and can be seen in Table 46 and Figure 23.

Table 46: Average Latency Values in Milliseconds for Acceleration Bins for Each Gamma Group

Acceleration Bin	Acceleration Values ($mm/^{s2}$)	YA	NI	PN
Low (L)	0-30	1761.44 ± 90.195	1894.11 ± 115.08	1902.46 ± 154.04
Medium-Low (ML)	31-60	955.51 ± 277.53	1077.93 ± 377.48	1402.74 ± 227.53
Medium (M)	61-90	703.18 ± 435.68	855.50 ± 754.63	1636.21 ± 285.22
Medium-High (MH)	91-121	510.60 ± 754.63	1205.19 ± 377.31	1610.20 ± 533.60
High (H)	121-150	423.60 ± 745.63	671.35 ± 533.60	1262.10 ± 435.68
Very High (VH)	<150	454.08 ±533.60	839.34 ± 337.48	996.41 ± 209.29

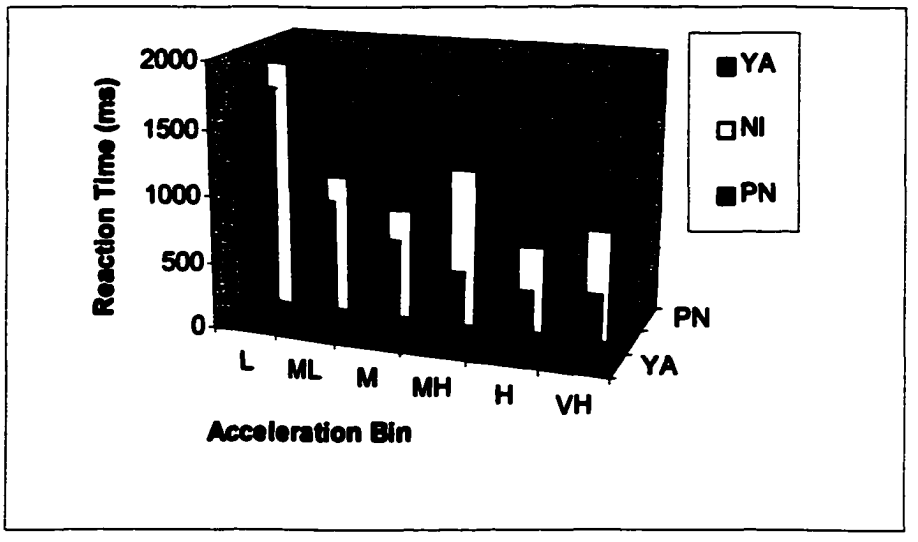


Figure 23: Average Latency Values for Acceleration Bins for Gamma Group

As can be seen in Figure 23, trials with low accelerations need much longer times to detect than trials with higher accelerations. This may be due to the fact that trials with high accelerations tended to be seen in 1 and 2 mm movements, which in the previous set of testing had significantly smaller latency times in all groups due to the fact that the move itself is very short. It can also be seen that, as acceleration increases, the time for detection in the young adults decreases on a log scale. This trend does not hold for healthy elderly or diabetic elderly subject. Healthy elderly show a higher time to detect motions at medium sized accelerations, and diabetics show a similar increase in both medium and medium-high accelerations. In general, although not significant, young adults had the shortest time to detect motions, followed by healthy elderly, and elderly adults with diabetes. This may indicate inadequacies in these adults due to both aging and disease state.

6.7.2 Reaction Time Analysis

Reaction times to a superthrehsold movement (4 mm at 100 mm/s^2), a plantar touch, and pure tone were measured in all subjects. All of these measurements involve the central nervous function of the cranial nerves, and any decline might indicate the presence of a central neuropathy. Measurements for reaction times were taken as the time between the beginning of the stimulus and the button press indicating subjects detected the stimuli. The Matlab program used to calculate this metric can be seen in Appendix I. Reaction times for each subject can be seen in Table 47. Averages for each group can be seen in Table 48 and Figure 24.

Table 47: Reaction Times in ms for Superthreshold movement (SST), Touch, and Tone for Each Subject in Gamma Group.

Subject	Group	SST (ms)	Touch (ms)	Tone (ms)
f21gl	YA	341.86	228.80	213.75
f22gc	YA	468.90	357.00	352.00
f23gd	YA	428.00	161.80	172.20
f24gi	YA	428.89	206.75	142.20
m22gh	YA	536.11	188.60	225.00
m22gj	YA	381.40	264.80	170.60
m23ge	YA	402.70	218.00	263.20
m24gg	YA	490.50	173.20	176.20
m25gf	YA	405.00	145.20	252.60
f54gn	NI	408.90	137.80	141.00
f58gq	NI	514.30	171.40	283.33
m50gt	NI	737.30	286.25	289.75
m53ga	NI	502.67	205.80	132.20
m58gr	NI	717.14	204.80	178.80
m66go	NI	730.70	218.33	202.00
f61gb	PN	565.20	210.20	145.40
m65gk	PN	1168.56	485.40	290.40
m67gm	PN	1029.25	443.60	265.60
m75gp	PN	795.56	608.80	330.80
f51gs	PN	535.30	365.00	213.20
f53gu	PN	717.30	249.80	208.50

Table 48: Average Reaction Times in ms for Superthreshold Movement (SST), Touch, and Tone for Gamma Group.

Group	SST (ms)	Touch (ms)	Tone (ms)
YA	431.48 ±59.08	216.02 ± 64.27	218.64 ± 67.32
NI	601.84 ± 143.51	204.06 ± 49.84	204.51 ± 68.42
PN	801.86 ± 253.15	339.8 ± 149.91	242.32 ±66.43

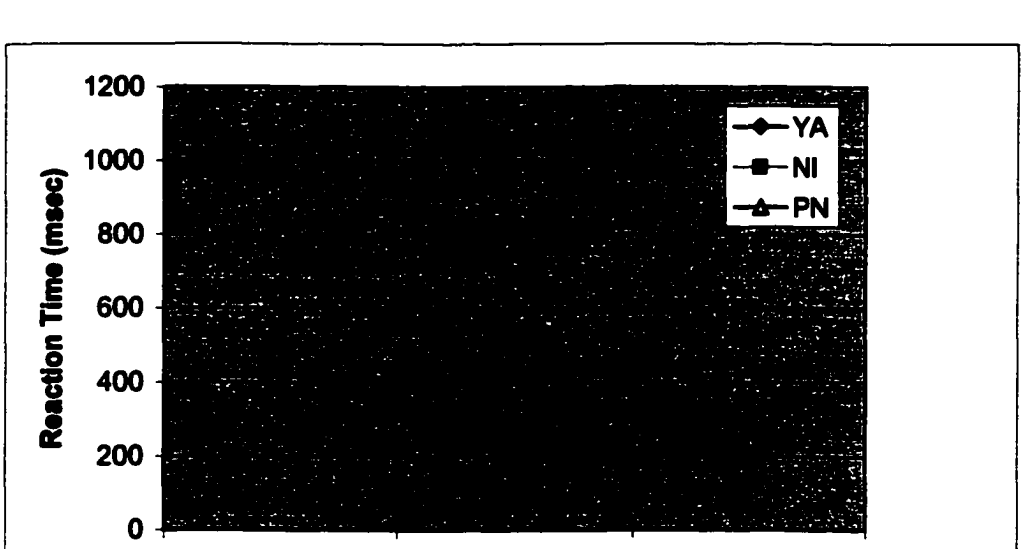


Figure 24: Plot of Average Reaction Times in ms for Superthreshold Movement (SST), Touch, and Tone for Gamma Group

The Two-Way Repeated Measures ANOVA table that was used to compare reaction times among groups and across modalities can be seen in Table 49.

Table 49: Two-Way Repeated Measures Table Comparing Reaction Times among groups and across modalities.

Source of Variation	DF	SS	MS	F	P
Group	2	402588.447	201294.224	8.573	0.002
Subject(Group)	18	422637.518	23479.862		
Modality	2	1824973.377	912486.688	123.918	<0.001
Group x Modality	4	241126.829	60281.707	8.186	<0.001
Residual	36	265091.306	7363.647		
Total	62	3002796.391	48432.200		

Because both group and modality were significant, as well as the interaction between them, a pairwise multiple comparison procedure (Tukey Test), was run to determine where significant differences lie. At superthrehsold, all groups are significantly different ($p < 0.05$) from each other, with reaction times in the diabetic elderly being highest, followed by healthy elderly. Young adults had the shortest reaction times to superthrehsold movements. For the touch modality, diabetic reaction times are significantly ($p < 0.05$) longer than both other groups. However, touch reaction times between young and healthy elderly adults were not significantly different. For the tone modality, no significant differences in reaction times were found between groups. For all groups, superthrehsold reaction times were significantly longer than the other two modalities.

6.8 Imparted Peak Energy

Imparted peak energy (IPE) is defined as the amount of energy presented to a subject during a perturbation. It is calculated by multiplying the mass of the subject, the length of the displacement, and the acceleration of the displacement. The usefulness of this measure comes in the cross comparison between displacement and acceleration. IPE

was validated using anterior perturbation data and results can be seen in Chapter 4. Unfortunately, analysis for lateral perturbations is a little more complicated because reaction times are not constant across displacements. Therefore, for this analysis, energy imparted to the subject at threshold is compared not only to the displacement length, but also to the reaction time of that movement. Table 50 shows the average reaction time and peak energy for each group at each displacement. These averages are plotted in Figures 25 and 26.

Table 50: Average Reaction Times and Imparted Peak Energy for Each Gamma Group at Each Displacement.

Group	Displacement (mm)	Reaction Time (ms)	Energy (mJ)
YA	1	933.78	4.23
	2	1652.78	1.44
	4	1528.78	4.18
	8	1873.15	7.39
	16	2237.89	12.95
NI	1	877.20	10.67
	2	1858.75	6.26
	4	1938.86	5.23
	8	1907.08	13.09
	16	2377.85	20.69
PN	1	1516.56	15.24
	2	991.07	21.84
	4	1450.82	15.11
	8	2141.97	10.91
	16	1795.03	32.65

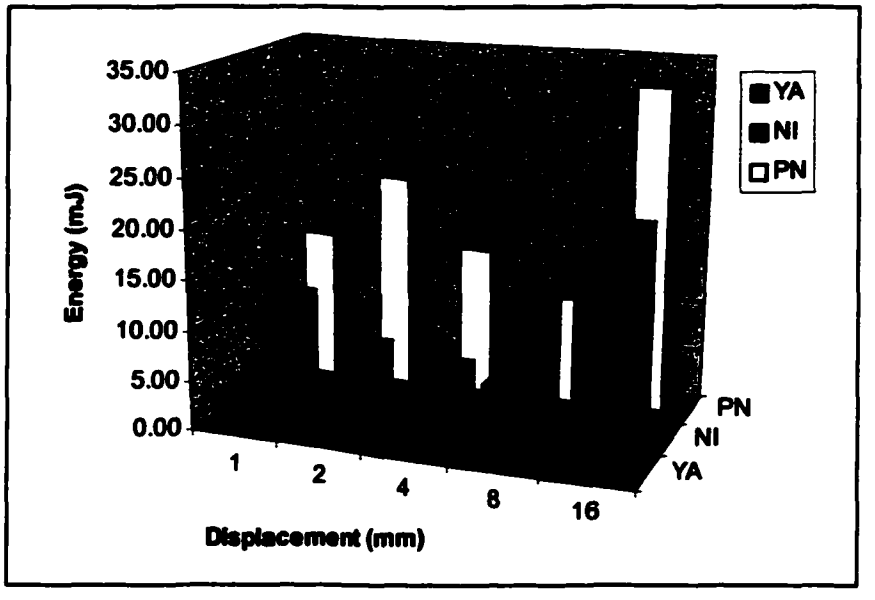


Figure 25: Average Imparted Peak Energy Verses Displacement for Gamma Groups

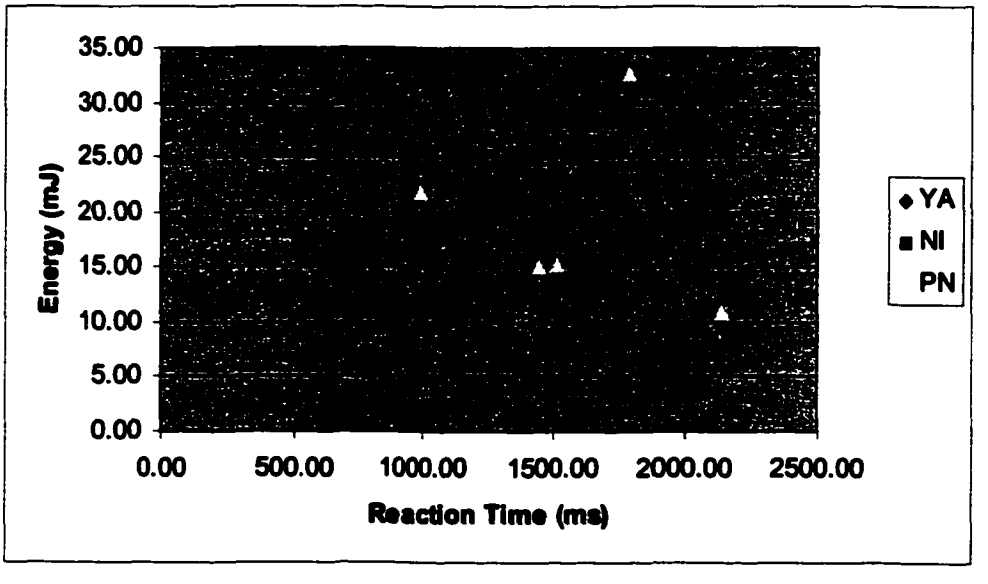


Figure 26: Average Imparted Peak Energy Verses Reaction Times to Those Movements for Each Gamma Group.

A Two-Way ANOVA was used to determine the effect of groups and displacements on imparted peak energy. All groups had significantly different ($p < 0.02$) imparted peak energy values at threshold. Young adults (mean = 5.98 mJ) needed the smallest amount of energy at threshold, while healthy elderly (mean = 11.19 mJ) needed

almost twice that amount of energy at threshold. Elderly adults with diabetes needed significantly higher energy (mean = 19.15 mJ) than both other groups to detect motion. When comparing energy at each displacement, 16 mm displacements were associated with a significantly ($p < 0.001$) increased amount of energy than all other displacements. This may be due to the fact that displacement is one of the factors that influences energy and this displacement is the largest one used, thus influencing the outcome more. The interaction between group and displacement was not significant in the amount of energy needed to detect motion.

Figure 25 shows the peak energy at each displacement for each group. Notice that each curve has a minimum at the same displacement as the "dip" in the threshold plots. This result was expected considering that threshold acceleration and displacement was used to calculate energy.

Figure 26 shows a distinct clustering of groups, with young adults having low imparted peak energies, while elders with diabetes have the highest imparted peak energies. Healthy elderly adults are scattered between the other two groups. This figure can be interpreted to say that to react to a threshold perturbation in a given time (i.e. 1000 ms), the strength of the perturbation has to be twice as large for healthy elderly as for young adults. In turn, diabetic elderly need a perturbation of four times the strength of the young adult's to react in the same time. One must caution that these across group comparisons have to be done carefully because the amount of energy is significantly different across displacements, and cross comparisons can be only be done within displacements.

6.9 Summary for Chapter 6

In this chapter, lateral perturbations of 1, 2, 4, 8, and 16 mm were presented to 9 young adults, 6 healthy elderly adults, and 6 elder adults with diabetes. Thresholds, clinical measures, COP modeling, EMG analysis, imparted peak energy, and reaction times were analyzed. Thresholds were significantly different between groups at small (< 4mm) movements, with elders with diabetes having the largest threshold, and young adults with the smallest threshold, and healthy elderly adults fall in between. Clinical measures show that elderly subjects with diabetes have slower lower nerve conduction velocities, higher air conduction velocities, higher plantar sensory thresholds (as tested though Semmes-Weinstein monofilaments), and show a trend in declining cognitive function. Elder subjects with diabetes also have slower reaction times, and need more energy imparted to them to respond to a movement in the same time as healthy elder adults. EMG analysis showed that all subjects adopted an anticipatory posture, regardless of group. Responses to perturbations were also modeled using an inverted pendulum model, and it was seen that the damping coefficients of elderly subjects with diabetes were lower than both other groups.

CHAPTER 7

AP verses ML Metrics

7.1 Acceleration Threshold

Anterior and lateral perturbation thresholds at 1, 4, and 16 mm were compared to determine differences in modalities. Acceleration threshold values for those subjects who were tested under both protocols can be seen in Table 51. Group averages are plotted in Figure 27.

Table 51: Acceleration Threshold for Both Anterior and Lateral Perturbation for Subjects Tested Under Both Paradigms.

		AP Threshold (mm/s^2)			ML Threshold (mm/s^2)		
Subject	Group	1 mm	4 mm	16 mm	1 mm	4 mm	16 mm
F54gn	NI	61.12	46.98	6.51	16.59	24.14	16.03
M66go	NI	103.37	29.01	16.03	92.71	18.83	20
M64eb	NI	164.86	89.40	15.54	200	6.465	22.8
M59eg	NI	98.97	45.35	14.53	191.22	11.77	19.04
F61gb	PN	85.75	44.36	16.03	59.44	16.19	13.31
M50ee	PN	94.58	77.02	24.57	182.43	9.12	7.00

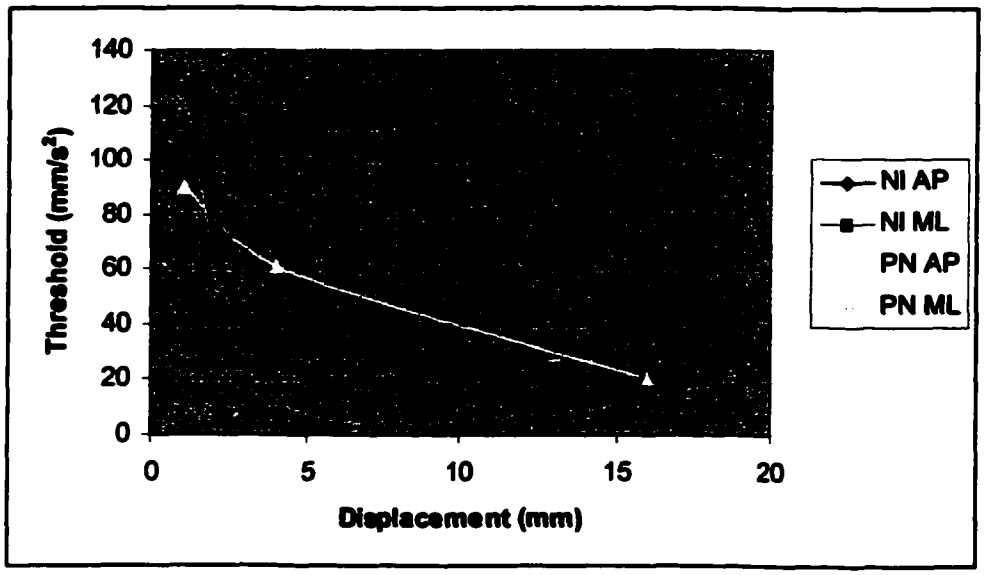


Figure 27: Average Acceleration Threshold for Each Group Tested in Both the Anterior and Lateral Paradigms.

At low (1 mm) displacements, ML thresholds are higher, although not significantly, than AP thresholds. This reverses at 4 mm, where ML thresholds are lower than their AP counterparts. At the longer 16 mm movements, the thresholds of AP and ML movements are approximately the same. In AP movement, an ankle strategy may be the only method for detection, which is why as the displacement gets longer the threshold decreases linearly on a log-log scale. ML movements are slightly different, and ankle strategy may be used at small movements, but after an input of 1.38 kgm of torque, the hips also play a part in balance strategy. The minimum at 4 mm may be due to a dual strategy, where input from both the ankles and hips allow for a super sensitivity to motion. After this point, a pure hip strategy is used.

Anterior perturbations were modeled previously using a power law function.[6] Those relations are as follows:

Accel. Threshold = 149 * (Disp)$^{-1/3}$, For Diabetic/PN

Accel. Threshold = 91 * (Disp)$^{-2/3}$, For age–matched neurologically intact

Accel. Threshold = 55 * (Disp)$^{-1/2}$, For young adults

However, lateral perturbations are not linear over the entire region of testing, only over those sections determined as "ankle strategy", which are defined as those displacements that are smaller than that at which the minimum threshold occurs. For young adults, this region is between 1 and 2 mm, for healthy adults, this region is between 1 and 4 mm, and for elder adults with diabetes, this region is between 1 and 8 mm. The linear regions of these three curves were also modeled using a power law function and the relations are:

Accel. Threshold = 188.61 (Disp)$^{-1.18}$, For Diabetic/PN

Accel. Threshold = 106.26 * (Disp)$^{-1.46}$, For age–matched neurologically intact

Accel. Threshold = 60.78 * (Disp)$^{-2.55}$, For young adults

A plot of these relations can be seen in Figure 28. All R^2 values for the three curves are above 0.96, indicating that these equations fit the experimental data well.

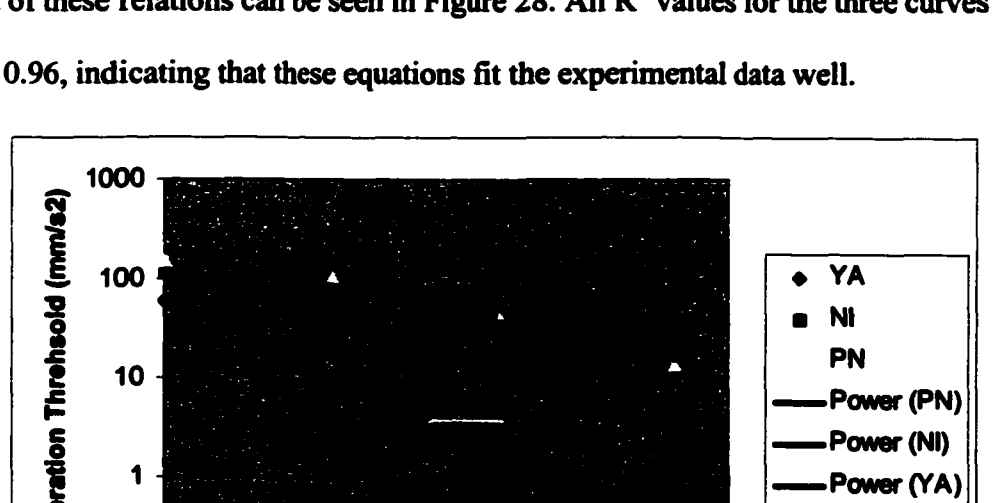


Figure 28: Power – Law relations for Lateral Perturbations

When comparing AP models to the ML models, one can see that although the slopes are different, the intercept values are remarkably close to one another. This may indicate that the same strategy is being used in both modes of testing. The differences come in when looking at the slopes of all three lines. In anterior testing, all slopes were greater than –1, while the lateral models have slopes all less than –1. This may be explained by looking at the physiology. Ankle joints are offset hinges with the primary motion being in the AP plane. Motion does occur in the ML plane, but the range is significantly less, which is why steeper slopes are necessary to describe thresholds in that plane.

7.2 Reaction Times

Reaction times to superthrehsold modalities can be cross-compared between groups. Metrics for a touch to the plantar sole, a tone, as well as superthrehsold movement of 4 mm at 100 mm/s^2 were taken for each subject for both AP and ML perturbations. Group averages can be seen in Table 52.

Table 52: Comparison of Reaction Times for platform movement, touch, and tone for subject who underwent testing in the AP and ML planes.

	AP Subjects			ML Subjects		
Group	Platform Movement (ms)	Touch (ms)	Tone (ms)	Platform Movement (ms)	Touch (ms)	Tone (ms)
YA	224.73 ± 101.98	314.36 ± 101.70	273.63 ± 88.00	431.48 ±59.08	216.02 ± 64.27	218.64 ± 67.32
NI	696.00 ± 452.85	371.43 ± 106.77	281.00 ± 54.98	601.84 ± 143.51	204.06 ± 49.84	204.51 ± 68.42
PN	732.29 ±302.12	508.43 ± 197.40	408.14 ± 133.94	801.86 ± 253.15	339.8 ± 149.91	242.32 ±66.43

A Three-Way ANOVA was used to compare reaction times among groups, across modalities and between AP and ML paradigms. Table 53 shows the resultant ANOVA table.

Table 53: Three-Way ANOVA comparing Reaction Times between AP and ML paradigms, among groups, and across modalities.

Source of Variation	DF	SS	MS	F	P
AP/ML	1	7550.976	7550.976	2.237	0.209
Group	2	197286.368	98643.184	29.225	0.004
Modality	2	287955.198	143977.599	42.656	0.002
Residual	4	13501.303	3375.326		
Total	17	628733.869	36984.345		

Results indicate that there is no difference between AP and ML paradigms. Multiple comparison procedures (Tukey's test) were run to determine where the other significant differences in reaction times lie. Subject with peripheral neuropathy had significantly higher reaction times ($p < 0.03$) than both other groups. Healthy elderly adults showed a trend ($p = 0.059$) in having higher reaction times than their young adults counterparts. Looking at modalities, platform movements had significantly higher ($p < 0.004$) reaction times than both other modalities, although touch and tone did not differ significantly. These results were seen in both studies, and therefore do not add any information to differences seen in AP and ML movements.

7.3 Summary for Chapter 7

This chapter compared previously acquired thresholds and reaction times on anterior perturbations to those acquired in this study for lateral perturbations. Acceleration thresholds were modeled using a power-law function, and results were

compared. Acceleration thresholds for small (< 4 mm) lateral translations showed a linear relationship similar to anterior perturbations. Reaction times for both anterior and lateral perturbations were also compared to determine that no differences in reaction time were seen between the two testing paradigms, only between groups.

CHAPTER 8

Discussion

8.1 Overview

Visual, vestibular, somatic, and kinesthetic sensory inputs are constantly being provided to the balance control system to maintain postural stability.[68,69,205,136] The fidelity of these inputs, the robustness of the response, the appropriateness of the compensation, and the speed of signal propagation help individuals remain upright during quiet standing or detect and avert an incipient slip during a dynamic movement. Many falls occur due to the failure of postural control mechanisms for correcting unexpected displacements of the body.[63] Lord, et al. argue that peripheral sensation is the most important sensory system in the maintenance of static postural sway.[63] A diminished vestibular and somatosensory functioning and slowing of sensorimotor reflexes accompanies the normal aging process and places elders at higher risk of postural instability. Those with diabetic peripheral neuropathy are at an even higher risk due to diminished somatic sensation, and a slower efferent motor nerve conduction speed.[99]

In this study the lateral acceleration threshold while standing was identified for healthy young adults, healthy elder adults, and elders with diabetes. Acceleration was used as the primary measure for sensitivity to motion since both vestibular, somatosensory, and neuromuscular systems are able to sense acceleration effects during

standing, walking, falls, and near–fall perturbations. Benson, et al. points out that most of the previous attempts to understand displacement, velocity, and acceleration thresholds in the past are suspect owing to the insufficient description of the experimentation including how the measurements were made, the nature and criteria governing subject's responses, and the means of expressing these responses as threshold values.[12]

8.2 Threshold

Lateral acceleration thresholds were measured for three different groups at five different movement lengths. For small displacements (1 to 2 mm), acceleration thresholds differ significantly between groups, with elders with diabetes having the highest thresholds, young adults having the smallest threshold, and healthy elderly adults falling in-between these extremes. Thresholds at larger (8 to 16 mm) movements show no significant differences between groups. This nonlinear response with respect to displacement is possibly due to physiological and kinematic properties of lateral sway control. Each group exhibits a linear decline (on a log-log scale) for small movements, with the range of this linear region being different between groups. Table 27 shows that large accelerations at small displacements decrease to a minimum value, then rebound slightly to a constant value for larger displacements. For example, young adults at 1 mm displacements have a threshold of 60.78 ± 51.83 mm/s^2, which rapidly decreases to a minimum of 10.39 ± 3.09 mm/s^2 at 2 mm of movement. For the movements larger than 2 mm, the threshold remains essentially constant between 13 and 14 mm/s^2. This trend holds for neurologically intact elders whose minimum occurs at 4 mm and elders with diabetes whose minimum occurs at 8 mm. These linear regions were modeled on a log –

log scale, and from this modeling it has been shown that the slopes of the elderly with diabetes are less steep than those of the healthy elderly subjects. In turn, the slope of the healthy elderly group is less steep than those of young adults. This difference in slope from young adults to healthy elderly can be attributed to normal changes in sensory organization and response systems due to aging. The additional decrease in slope seen in subjects with diabetes may be attributed to the additional sensory and nervous system changes seen as a side effect of diabetes.

So why is there a linear portion and a constant portion of the acceleration threshold plot? And why is there a "dip" or minimum in thresholds where these two portions intersect? It is well known that quiet standing using a side-by-side stance yields AP balance that is totally under ankle control, while ML balance is under hip control.[138] Unlike quiet stance, responses to external perturbations require active control of the trunk and hips to move the body COM back to equilibrum.[79] Henry, et al. saw similar force coupling and kinematic patterns from sagittal and frontal plane postural responses to large movements of 9cm at 13.5cm/s^2.[43]

Although no kinematic data was available for this study, we can compare AP and ML thresholds obtained via similar protocols. As stated before, ML thresholds are linear on log – log scale only over a portion of displacements. For AP thresholds, all groups show a similar power law relation with similar intercepts but slightly greater slopes than their ML counterparts. The difference in the slopes can be attributed to physiology. Because of the positioning of the offset hinge of the ankle, movements in the AP direction are larger in magnitude than the amount of motion possible in the ML direction. But, because of the similar intercepts between AP and ML thresholds and the power law

relationship seen, it indicates that small ML perturbations are under ankle control. However, in the ML plane, ankles have limited restorative ability. Larger motions are controlled via the hips, which are able to provide a much larger restorative force to remain upright. Therefore, we can assume for larger ML displacements hip strategy is used, which provides the constant portion of the ML threshold plot. In the in-between portions, seen as a "dip" or minimum in acceleration threshold, could be a region of sensitivity where control is shared between both the ankles and the hips.

Interestingly enough, this minimum or sensitivity was seen at different displacements for each group. Young adults showed a minimum at 2 mm, neurologically intact elders at 4 mm, and elderly with diabetes at 8 mm. This may be another indication of deficit in healthy and diabetic elderly. In ML motions, hip strategy yields a much more stable posture and a greater measure of control. Therefore, young adults who transition to hip strategy at smaller displacements are much more stable than healthy and elderly with diabetes. This can also be seen in COP sway measurements. The frequency of sway of healthy and diabetic elders are much larger than their young adult counterparts indicating a measurable loss of stability.

The peak acceleration detection threshold for a seated posture in young adults as detected by Benson, et al.,[12] was 57 mm/s^2 in the Y (ML) direction. The stimulus in that study was applied for a fixed duration of three seconds at a total displacement of 75.1mm. This length is almost five times the largest displacement used in this study, and therefore, it would be futile to make a one-to-one comparison. Also, during a seated posture, more surface area of the skin is in contact with a relatively stationary surface. This increases the tactile activation of the skin, and hence, might explain the lower

threshold than in standing. The above–mentioned study was performed to identify the detection threshold for linear acceleration investigating changes in threshold following space flight and not for investigating fall prediction, therefore care should be taken when comparing results. Hence the data on the linear acceleration threshold presented in this dissertation might be a more reliable indicator of balance control. However, during the fixed–level supra–threshold detection runs, the perturbation was alternated between the forward and backward direction. Subjects could clearly identify the perturbation but were not certain about the direction of the perturbation. Few reported perceiving the alternating direction of perturbation. This lack of sensing the direction of perturbation suggests that the physiological mechanism to detect the direction of acceleration could be different from the mechanism to detect acceleration. It can also be hypothesized that direction perception has a higher threshold than magnitude perception. This issue should be further investigated to identify the difference in the threshold for perceiving an acceleration perturbation and detecting its direction. This observation is comparable to the threshold level runs for seated subjects in that many subjects were confused with the direction of perturbation and reported a bi–directional perturbation.[12]

When looking at the percentage of trials detected during the 2AFC protocol, subjects averaged approximately 72% of trials detected correctly. This probability of detection is in agreement with the finding of Taylor, et al.[123] They performed tests with PEST runs targeted at a probability of 0.80 (staircase 79) and immediately followed by fixed–level trials at the difficulty level resulting from the PEST run. The fixed–level runs yielded a probability of about 0.75.

PEST permits the subject to keep track of what he is trying to detect; whereas, in the fixed–level method, performance is disrupted by memory failure.[123] This implies that the probability of detection is much higher if a subject detects a preceding move. This trend was observed in this study. However, owing to the limited number of trials at fixed–level threshold, this trend could be verified only anecdotally.

8.3 Clinical Metrics

Several clinical tests were performed to determine the breadth and severity of the complications of diabetes and the possible effects on balance. Quiet standing metrics, sensory thresholds (measured using Semms-Weinstein monofilaments), nerve conduction velocities, auditory air conduction thresholds, and cognitive impairment were all measured.

Quiet standing metrics including resultant sway distance, sway range, and mean velocity of sway were all significantly higher for subjects with diabetes when compared to young adults. Our values for young and healthy elderly sway metrics were approximately equal to those published by Preito, et al.[92] However, unlike Prieto, no significant differences were seen between young and healthy elderly adults. In this study, healthy elderly metrics fell in-between the young and diabetic elderly groups, being not significantly different from either.

No between-leg difference for threshold detection by Semms–Weinstein monofilament was found, but in all measures young adults had significantly lower thresholds than either elder groups. Healthy and elderly with diabetes did not differ significantly, although an increase in thresholds is seen in the diabetic group. The non-

significance of the increase in diabetic subjects shows the mild nature of the diabetics admitted to this study. For advanced diabetics studied by others, threshold for plantar sensory detection in their ulcerated foot was 10 grams.[17] Our diabetic and non–diabetic elderly had a much lower threshold for detection than this value, indicating that somatosensory receptors are still contributing to the perception of threshold level whole–body linear accelerations. However, the fidelity of this input is in question, especially in diabetics, who have compromised nerve conduction pathways.

Conduction velocities in subjects tested under this protocol show significant slowing of both the tibial and peroneal motor nerves, as well as the sural sensory nerve. These results were expected because peripheral neuropathy is a known side effect of diabetes.

The limited cognitive testing (using the MMSE) showed a trend of lower cognitive ability in elderly with diabetes when compared with healthy young adults. Cognitive decline appears to be a long–term effect of diabetes.[111] Many researchers have reported that elderly subjects with diabetes have shown cognitive performance deficits and increased risk of dementia in a wide range of neuropsychological tests including MMSE and the WAIS.[58,118] This decline in cognitions has been used to partly explain the increase in depression found in the elderly with diabetes.[64]

These mild neuropsychological deficits are not correlated with duration or severity of the disease,[37] but may be related to blood sugar regulation.[76,100] Animal models have been used to identify changes in hippocampal synaptic plasticity at the molecular level, but the central nervous changes associated with diabetes is not yet completely understood.[40]

Not expected were the differences in air conduction auditory thresholds between healthy and elderly with diabetes. Healthy elderly showed hearing degradation at high frequencies that could be classified as a mild loss. This loss is normal for aged individuals.[57] However, an additional loss greater to one expected for that age group was seen in subjects with diabetes. In these subjects, mild hearing loss is seen at 4 kHz, and by 8k Hz moderate hearing loss was manifest. No literature explaining this difference was found, but this decline may also be attributed to central nervous changes seen in diabetics, or a peripheral neuropathy of the VIII cranial nerve.

There were no significant differences between the two groups of elders in the various anthropometric measures except for weight. The mean weight of the diabetic population (97.20 kg) was significantly ($p < .003$) higher than the mean weight of the control (74.65 kg). It should also be noted that the population was small, and there were two unusually heavy (124.1 kg and 101.82 kg) subjects in the neuropathic group. Weight gain is a side effect of diabetes, and significant differences may have an effect on how individuals recover from slips and falls. In all models, weight was taken into account to negate the significant differences seen here.

8.4 COP Sway Modeling

To maintain balance, the postural control system integrates information from the visual, vestibular, and proprioceptive systems.[72,79,81] Generally, responses to perturbations are described using kinematic data. That data was unavailable here because current commercialized systems have errors of measurement that are approximately ± 1 mm. This was inadequate for our protocol because the smallest perturbation used was 1

mm, which falls in the realm of "noise" in kinematic measurement systems. Therefore, this system can be described through the use of control theory where the body is the plant, the output is the time series center-of-pressure sway, and the feedback comes from the sensory systems.[143] The presence and robustness of the feedback offers the ability to alter that stability and change the character of the natural response, which may modify the system substantially.

An inverted pendulum model was used to determine the characteristics of the transient response of the ML sway of an individual who was perturbed with an 8 mm lateral translation. Model characteristics were changed to match clinical data and then these characteristics were compared between groups. For all subjects, both the damping ration and the undamped natural frequency were nonzero and positive, indicating that the system is stable and a pair of poles are located in the left half plane. The undamped natural frequency of the system was not significantly different between groups, although the average for young adults was slightly larger than healthy elder adults, who in turn have a larger average frequency than elders with diabetes. The relationship between the undamped natural frequency and the time response tells us that because the undamped natural frequency (Wn) of the young adults was 1.23 times larger than the elderly with diabetes, the time it takes for young adults to reach steady state (or in this case to return to normal quiet standing sway) is only 81% of the time it takes diabetic elderly. Similarly, healthy elder adults need only 85% of the time it takes elders with diabetes to reach steady state. Young and healthy elder adults do not differ as much, as it takes young adults 95% of the time it takes healthy elders to reach steady state. This can have large implications in posture correction. The additional time healthy and diabetic elders

need to return to baseline indicate that the feedback the sensory systems are providing is either too variable, or not intact, thus prolonging the settling time. The robustness of this feedback is essential for proper maintenance and control, and degradation of the feedback may play a role in the instability, slips, and falls seen in the elderly and the elderly with diabetes.

All responses, regardless of group, had damping ratios less than 1, meaning that the postural control system is an under-damped system. When comparing damping ratios across groups, young adults have significantly higher values than both elderly groups, although elderly groups did not differ significantly. This indicates that young adults are able to damp and shorten the magnitude and the time of the response to this type of perturbation much better than elderly subjects. The center-of-pressure of both elder groups oscillate much more than their young adult counterparts. This, in conjunction with the changes in undamped natural frequency show how deficit elders are when responding to perturbations, and how easily slight degradation of sensory inputs due to aging and mild diabetes affect posture control systems greatly. This also explains why similar perturbations, which are detectable and correctable in young adults might cause elderly adults to slip and fall.

It was also noted, that not only ML COP was affected by the perturbation. Changes in AP COP were also seen, although the responses to the perturbations were not as clean or apparent as their ML counterparts. AP sway has a larger magnitude than ML sway, lending itself to more "background noise" when looking at perturbation responses. Interestingly enough, perturbations in the AP direction also show COP responses in both the AP and ML planes. Physiologically, the ankle hinge is not oriented in either of these

planes, instead it is an offset hinge that allows for responses in both planes, although ML responses are always smaller than their AP counterparts.

8.5 Reaction Times

Reaction times to touch, tone, and superthrehsold (4 mm at 100 mm/s^2) were measured. An increased reaction time for foot touch sense might be a covariate with the ability of diabetics to recognize small perturbations, and could be a direct result from the diabetic peripheral neuropathy. Reaction times to a burst tone fall between 200 and 250 ms for all groups. Auditory stimuli evoke a muscle discharge at a minimum latency of 100 ms. It would take a few more milliseconds after the muscle discharge to move the digits to express a reaction. An auditory-command-triggered muscle movement in the form of supination takes in excess of 250 milliseconds,[29] which is within the standard error found in this study. We can then infer that aging or disease state does not impact auditory reaction times, even though air conduction velocities in healthy and diabetic elderly showed mild to moderate hearing loss at high frequencies.

Perceptual discrimination time is approximately 50 milliseconds, and response selection is approximately 150 milliseconds.[42] Hence, reaction times for platform perception of motion should be above these values. In an easy-to-detect superthrehsold trial, young adults averaged 431 ± 59 milliseconds, which is over the maximum time suggested by Gregory et al.[42] Because this modality presents a whole – body motion, with competing inputs from the proprioceptive and vestibular systems, we feel this reaction time is appropriate. Elderly have a significantly longer reaction time when compared with young adults, which we can attribute to normal changes due to aging. Diabetics also have

significantly larger reaction times to platform movement when compared to healthy elderly. This may be partly due to the peripheral nervous system changes seen in diabetics (seen in the lower nerve conduction velocities and higher Semmes-Weinstein monofilament thresholds in this experiment). However, this peripheral neuropathy cannot account for the entire deficit. A normal person has a nerve conduction velocity of approximately 60 m/s, which requires 16.67 ms for signals to travel up from the toe to the spinal cord of a 1.8-meter tall person. The nerve conduction velocities of the mild diabetics in this study were approximately 40 m/s, which increases the signal transmission time to be 25 ms. This is only 8.33 ms increase, which can not account fully for an increase in reaction times of 200 ms in suprathreshold movements. An additional central nervous system deficit may also play a role in slowed processing of sensory signals, and thus slowed reaction times.

When comparing reaction times of a superthrehsold movement of 4 mm at 100 mm/s^2, to reaction times of threshold and suprathreshold movements at 4 mm of all groups, it can be seen that when at or near threshold, reaction times increase at least by a factor of two. Instead of needing approximately 400 milliseconds to respond, young adults require at least 1000 ms. Healthy elderly adults increase their reaction times from approximately 600 ms to 1800 ms, and diabetics increase from approximately 800 ms to 1800 ms. This additional time needed to perceive and respond to the move allows for more time for a slip that may have been correctable to become a fall with the ability to incur serious injury. Therefore slips near or at threshold accelerations could well have a higher probability of causing falls.

8.6 Imparted Peak Energy

The energy imparted to a subject through the platform was compared to the reaction times to that movement. Unfortunately, unlike AP perturbation data seen in Chapter 4, reaction times to ML perturbations were significantly different over movement lengths, thus making data analysis more difficult. Like perturbations in the AP direction, imparted peak energy with respect to ML displacements looked similar to the ML threshold plots, with minimums in the same place as threshold minimums. This was expected because displacement is one factor used to calculate imparted peak energy. Also like its AP counterpart, ML perturbations showed that the amount of energy to produce approximately the same reaction time was significantly different among groups. Healthy elders as well as elders with peripheral neuropathy needed much more energy imparted to them to react at the same time as young adults. This indicates that for both elderly and adults with diabetes to be consciously aware of a perturbation, either the distance traveled, or the acceleration during the slip have to be increased. This may be a factor that contributes to the increased prevalence of falls in the elderly, and an even higher probability of falls among the elderly with diabetes. Slips experienced in everyday life may be below threshold level of detection, or the energy of the slip may be so low that the time it takes to react to it may be too long, not allowing for a proper postural readjustment, which leads to a fall.

8.7 Conclusion

One should remember that there is a diminished vestibular and somatosensory function and slowing of sensorimotor reflexes that accompanies the normal aging

process, which in themselves places the elderly at higher risk for falling. For those diagnosed with diabetes, there is an accelerated decline in the above functions, which further raises the risk. The ability to predict with confidence the risk of future falling in individuals is a necessity before balance tests find a clinical application for screening and targeting of high–risk individuals for preventive intervention.

Using the SLIP–FALLS system, it has been statistically verified that during short (< 4 mm) lateral perturbations, the elderly and elders with diabetes have higher acceleration thresholds when compared to healthy young adults. Hence, it can be concluded that the risk for falling is much higher in the elderly, and diabetics in particular, than the young adults.

Different mechanisms of the body are involved in detecting small and large perturbations. Elderly in general seem to have a decreased fidelity in detecting small perturbations mainly because these perturbations are under ankle control. This implies that in situations such as stepping on top of ice or walking on a wet floor, the diabetic would be gliding and yet would not detect the motion. This could partially explain the increased risk of falling in the diabetic population. Larger motions, which tend to be controlled via the hips, seem to be better detected and controlled.

It has also been shown that the fidelity of the inputs to the postural control system has a large influence of the system response. Small changes in sensory perception, slowing of sensory and motor nerves, and slower reaction times all play a role in changing the system dynamic of elder and adults with diabetes. This combination of input and feedback degradation may well make the system unstable, leading to a slip and/or fall.

One should remember the assumption that group effects seen here represent a population, and that people with decreased function have the same underlying predisposing influences. However, there are different postural strategies, as seen in the EMG studies, and perceptional weightings used by different individuals. The statistical evidence presented here cannot predict how a particular individual will weigh and use information derived from several sensory inputs, but it has instead shown how aging and the peripheral and perhaps central nervous system deficits seen as side effects of diabetes effects postural control systems.

8.8 Future Directions

For as many questions as are answered in this work, twice as many questions have arisen. Now that the thresholds has been measured for the elderly and elderly adults with diabetes groups, some sort of intervention can be designed to determine if some reduction in threshold can be attained. This intervention can be something as simple as an exercise program, yoga, or tai chi classes. Threshold can be measured at certain intervals through the program then again three to six months after the completion of the program to see if any changes are seen because of this intervention, or if the system reverts to the previous state.

Of course, some kinematic data is also needed to determine how subjects respond to the perturbations. The EMG data taken here does not allow insight as to how control of posture is undertaken, be it trunk or lower limb mediated. Unfortunately, kinematic systems currently on the market are not precise enough to work with the type of ultra-

short movements being used here, so perhaps the design and implementation of a new type of system is warranted.

Finally, diabetic elderly data measured here indicates that not only is there peripheral nervous system changes as a side effect of diabetes, but there may be some central nervous system changes as well. Reaction times and air conduction hearing latencies studies have given us a glimpse into the central nervous system; but other, more controlled tests should be done to determine what changes in the central nervous system are present in the diabetic population.

APPENDIX A:

Initial IRB Consent Form

[redacted]

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

We are asking you to volunteer to take part in a research study at the Shreveport Veterans Affairs Medical Center (VAMC) and Louisiana State University Medical Center (LSUMC). It is important that you read and understand the information on this form.

DEFINITION OF CONSENT FORM

This Consent Form gives detailed information about the research study which you will be able to discuss with your doctor. It is not meant to frighten or alarm you; it is an effort to make you better informed in order for you to make a decision as to whether or not you wish to participate. This process is known as "informed consent."

PURPOSE OF STUDY AND SELECTION OF SUBJECTS

Slips and falls, and even the fear of falling, can represent a major medical and functional barrier to living independently. A fall is normally prevented by the detection of abnormal motion and by strategies used to correct or compensate for imbalances. Therefore, to react to a potential slip or fall, one must be able to detect motion changes that may lead to slips or falls.

You are invited to participate in a research study related to standing balance and postural control. Researchers at the Overton Brooks VAMC and Louisiana State University Medical Center hope to learn how much the senses of the limbs (touch sense, joint angle sense, muscle tension sense) contribute to stability. Such knowledge may well lead to better evaluation and training methods in order to prevent slips and falls. You were selected as a possible participant in this study because you are an average healthy adult and your senses are intact. Your responses will be used as verification of results previously attained. You should be between 18 years or older to participate in this study. Before proceeding further, we need your permission to ask you if you have had certain illnesses or neurological problems which might confound our study results, and hence, make you not a candidate for this particular research study. Your answers will remain confidential.

May we ask you some questions about your medical history, and verify them from the information in your medical chart (if available within the VA)?

Yes or No: _____ Initials: _____

SUBJECT'S IDENTIFICATION (I.D. plate or give name - last, first, middle)

Subject's Initials: _____

VA FORM
[illegible] 10-1086

[redacted]

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 2)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

QUESTIONS

We must exclude you from this study if you have a current or past history of severe heart, circulation or breathing problems; chronic lower back spasms or pain; brain strokes, spinal cord injury or other damage to the nervous system, non-healing skin ulcers, current drug or alcohol dependence, or who are taking prescriptions that cause dizziness, or limiting deformities of the spine, bones or joints (such as abnormal spinal curvature, arthritic changes or amputation) repeated falls. (Any information obtained during this study and identified with you as a subject will remain confidential and will be disclosed only with your permission.)

You do not have now, or have ever had, a history of the problems just listed.

Yes or No: _____ Initials: ____

If you answered "Yes," thank you for your time and effort in volunteering to participate, but we cannot use you in this particular study. Please fill out the personal information on the last page before you go. If you answered "No," then you are a likely candidate for our study, which we will now explain to you.

PROCEDURES

If you are an older adult or a person with changes in the nerves in your limbs, you may have had a change in how you sense changes in the standing environment. If you are in good health, have no physical or neurological problems, you will serve in a group that we call "control." We will compare these two groups to better understand how the nervous system assists in maintaining postural stability and dynamic balance.

If you decide to participate in this research study you will be asked to answer a brief medical history questionnaire to determine which population group you belong, and a questionnaire that measures your mental status. This may be done over the phone or in the laboratory. All subjects will be evaluated for sensory and motor function, lower limb strength and joint range-of-motion, and any possible lower limb asymmetries. We will also measure how fast the nerves of your lower limb transmit their signals by doing nerve-conduction tests on both legs. This test requires that a small shock be delivered to the surface of the skin at one location, and the resultant nerve activity be measured via small patch electrodes taped to another location. The test will be carried out by a colleague who is trained in this procedure.

The main test will have you standing with bare feet on a platform that will be stationary for approximately 30 seconds then moving forward during randomized time intervals. You will be informed when a possible move may occur and you will be asked to state whether the device is moving. In these tests the plat-form will move your whole body. You will be wearing a blindfold that will restrict your vision and head-phone to reduce outside noise, so that you may only receive motion inputs from your sensory system or balance system. For all tests you will be wearing surface muscle activity sensors on your legs. If you go through all tests, we estimate that their completion will take less than four hours. We may stop testing if you become dizzy, or nauseous. You can stop the test at any time that you wish, without reprisal.

Subject's Initials _____

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 4)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

RESEARCH RESULTS

Information and research results will be used to further the field of posture and balance control and to benefit the evaluation and therapy processes related to posture and balance. Therefore the research results will possibly be used for scholarly papers, presentations, and future grant applications.
Any information obtained during this study and identified with you as a subject will remain confidential and will be disclosed only with your permission.
If results of this study are reported in medical journals or at meetings, you will not be identified by name, by recognizable photograph, or by any other means without your specific consent. Your medical records will be maintained according to this medical center's requirements.
By signing this form you are giving permission for us to make records available to the Shreveport VAMC and LSU Medical Center's Institutional Board for Human Research to which information will be released, all of whom must maintain confidentiality.

SPECIAL INFORMATION

You will be paid $25.00 by check for each session in which you participate. A session may last up to 4 hours. Payment will be through the Overton Brooks VAMC in Shreveport, LA.

1. You are not required to take part in this study — your participation is entirely voluntary.
2. You can refuse to participate now or you can withdraw from the study at any time after giving your consent. This will not interfere with your regular medical treatment, if you are a patient.
3. Your decision whether or not to participate in this study will not involve any penalty or loss of rights nor will it prejudice your future relation with the VAMC or LSUMC. If you decide to participate, you are free to discontinue participation at any time without penalty or loss of benefits to which you are entitled.
4. There will be no costs to you for any of the treatment or testing done as part of this research study.
5. Eligibility for medical care is based upon the usual VA eligibility policy and is not guaranteed by participation in a research study.
6. In case of adverse (bad) effects or physical injury resulting from this study, eligible veterans are entitled to medical care and treatment. Compensation may or may not be payable in the event of physical injury arising from this study under applicable federal law. Further information about compensation and medical treatment may be obtained from the medical administration service at this VA medical center. Non-eligible veterans are entitled only to medical emergency care and treatment on a humanitarian basis.
7. If you have questions about your rights as a research participant, you may contact the Chairman of the Institutional Review Board at (318)-675-5409 or the Chief of Staff, Overton Brooks VA Medical Center at (318)-424-6089.
8. If you are a patient, a copy of this consent form will be placed in your medical record.

Subject's Initials _____

VA FORM
JAN 1989 10-1086

[redacted]

VA RESEARCH CONSENT FORM

PROTOCOL # H00-022 (Continuation Page 3)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

DISCOMFORTS AND RISKS

All motions of the platform will be near your natural sway change of position. Because of this, you may not always be able to feel the device move. Also because the movements will be so slight, there is very little chance of your falling. During the times when the platform is moving and while your eyes are closed or blindfolded, and you are wearing the headphones to block out external noises, you may feel a slight loss of balance, dizziness or nausea. With your eyes closed or blindfolded and a slight change in the position of the platform, you may experience some fright as you begin to move. You will be spotted by an investigator standing behind you who will correct your position before a potential fall event can occur.

For all tests, all joint motions will be small and fairly slow. However there is a possibility that your ankle or knee joints could be injured in these tests, especially if the joints are already weakened. For this reason if you have a previous joint injury or have been diagnosed with a bone or articular cartilage disease, we ask you tell us now and not participate in this study.

Since we use properly isolated electrical amplifiers, there should be no risk of shock from our measurement of muscle activity. The muscle activity sensors will be held to your skin with a small piece of double sided tape. The gel that helps conduct your muscle activity the sensors may have a salt base. You may experience some redness from the tape or conduction gel. This is common and the redness should disappear within a few hours.

BENEFITS

You may not personally be helped by taking part in this study, but your participation may lead to knowledge that will help others. We will review your own results with you before you leave, and significant overall findings developed as a result of this study will be provided to you at the conclusion of the study.

OTHER TREATMENT AVAILABLE

Participation in this project will not effect your usual clinical treatment here at the VA. You are aware that you are under no obligation to participate in this study and you may withdraw at any time without prejudice to your medical care or loss of benefits to which you are entitled. Should you choose not to participate, you will still receive the usual medical care and treatment to which you are entitled. You may withdraw participation from the project at any time without prejudice.

Subject's Initials _____

[redacted]

VA RESEARCH CONSENT FORM

PROTOCOL # H00-022 (Continuation Page 5)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

AFFIRMATION FROM SUBJECT

RESEARCH SUBJECTS' RIGHTS: I have read or have had read to me all of the above. Dr. Charles Robinson or his associate has explained the study to me and answered all of my questions. I have been told of the risks or discomforts and possible benefits of the study. I have been told of other choices of treatment available to me.

I understand that I do not have to take part in this study, and my refusal to participate will involve no penalty or loss of rights to which I am entitled. I may withdraw from this study at any time without penalty or loss of VA or other benefits to which I am entitled.

In case there are medical problems or questions, I have been told I can call Dr. Charles Robinson at (318)-424-6080 or Dr. Anne Hollister (675-6181) during the day and Dr. Robinson at (318)-513-9122 after hours. If any medical problems occur in connection with this study the VA will provide emergency care.

I understand my rights as a research subject, and I voluntarily consent to participate in this study. I understand what the study is about and how and why it is being done.

I will receive a signed copy of this consent form.

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above. If you decide to participate you are free to discontinue at any time.

"I have been given the opportunity to ask questions and have them explained to me."

_____ _____

Subject's Signature Date

_____ _____

Signature of Witness Witness (print)

_____

Signature of Investigator

Institutional Review Board Approval Start Date 3/27/00 - End Date 03/26/02

Subject's Initials _____

VA FORM
JAN 1998 10-1086

APPENDIX B:

Renewed IRB Consent Form

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

We are asking you to volunteer to take part in a research study at the Shreveport Veterans Affairs Medical Center (VAMC) and Louisiana State University Medical Center (LSUMC). It is important that you read and understand the information on this form.

DEFINITION OF CONSENT FORM

This Consent Form gives detailed information about the research study which you will be able to discuss with your doctor. It is not meant to frighten or alarm you; it is an effort to make you better informed in order for you to make a decision as to whether or not you wish to participate. This process is known as "informed consent."

PURPOSE OF STUDY AND SELECTION OF SUBJECTS

Slips and falls, and even the fear of falling, can represent a major medical and functional barrier to living independently. A fall is normally prevented by the detection of abnormal motion and by strategies used to correct or compensate for imbalances. Therefore, to react to a potential slip or fall, one must be able to detect motion changes that may lead to slips or falls.

You are invited to participate in a research study related to standing balance and postural control. Researchers at the Overton Brooks VAMC and Louisiana State University Medical Center hope to learn how much the senses of the limbs (touch sense, joint angle sense, muscle tension sense) contribute to stability. Such knowledge may well lead to better evaluation and training methods in order to prevent slips and falls. You were selected as a possible participant in this study because you are an average healthy adult and your senses are intact. Your responses will be used as verification of results previously attained. You should be between 18 years or older to participate in this study. Before proceeding further, we need your permission to ask you if you have had certain illnesses or neurological problems which might confound our study results, and hence, make you not a candidate for this particular research study. Your answers will remain confidential.

May we ask you some questions about your medical history, and verify them from the information in your medical chart (if available within the VA)?

Yes or No: _____ Initials: _____

SUBJECT'S IDENTIFICATION (I.D. plate or give name - last, first, middle)

Subject's Initials: _____

VA FORM
... 10-1086

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 2)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

QUESTIONS

Persons with severe cardiac or cardiopulmonary involvement, chronic lower back spasms or pain, central neurological deficits, history of non-healing skin ulcers or peripheral vascular occlusive disease, current drug or alcohol dependence, or orthopaedic deformities (such as kyphosis, arthritic changes or amputation) must be excluded from this study. Those with a history of repeated falls, previous joint injury, or a bone or articular cartilage disease must also be excluded. (Any information obtained during this study and identified with you as a subject will remain confidential and will be disclosed only with your permission.)

You do not have now, or have ever had, any of the problems just listed. Yes or No: _____ Initials: ____

If you answered "Yes," thank you for your time and effort in volunteering to participate, but we cannot use you in this particular study. Please fill out the personal information on the last page before you go. If you answered "No," then you are a likely candidate for our study, which we will now explain to you.

PROCEDURES

If you are an older adult or a person with changes in the nerves in your limbs, you may have had a change in how you sense changes in the standing environment. If you are in good health, have no physical or neurological problems, you will serve in a group that we call "control." We will compare these two groups to better understand how the nervous system assists in maintaining postural stability and dynamic balance.

If you decide to participate in this research study you will be asked to answer a brief medical history questionnaire. This may be done over the phone or in the laboratory. All subjects will be evaluated for sensory and motor function, lower limb strength and joint range-of-motion, and any possible lower limb asymmetries.

The main test will have you standing with bare feet on a platform that will be stationary for approximately 30 seconds then moving forward during randomized time intervals. You will be informed when a possible move may occur and you will be asked to state whether the device is moving. In these tests the platform will move your whole body. You will be wearing a blindfold that will restrict your vision and headphone to reduce outside noise, so that you may only receive motion inputs from your sensory system or balance system. For all tests you will be wearing surface muscle activity sensors on your legs. If you go through all tests, we estimate that their completion will take less than four hours. We may stop testing if you become dizzy, or nauseous. You can stop the test at any time that you wish, without reprisal.

Subject's Initials _____

VA FORM
JAN 1990 10-1086

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 3)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

DISCOMFORTS AND RISKS

All motions of the platform will be near your natural sway change of position. Because of this, you may not always be able to feel the device move. Also because the movements will be so slight, there is very little chance of your falling. During the times when the platform is moving and while your eyes are closed or blindfolded, and you are wearing the headphones to block out external noises, you may feel a slight loss of balance, dizziness or nausea. You will be spotted by an investigator standing behind you who will correct your position before a potential fall event can occur.

For all tests, all joint motions will be small and fairly slow. However there is a possibility that your ankle or knee joints could be injured in these tests, especially if the joints are already weakened. For this reason if you have a previous joint injury or have been diagnosed with a bone or articular cartilage disease, we ask you tell us now and not participate in this study.

Since we use properly isolated electrical amplifiers, there should be no risk of shock from our measurement of muscle activity. The muscle activity sensors will be held to your skin with a small piece of double sided tape. The gel that helps conduct your muscle activity the sensors may have a salt base. You may experience some redness from the tape or conduction gel. This is common and the redness should disappear within a few hours.

BENEFITS

You may not personally be helped by taking part in this study, but your participation may lead to knowledge that will help others. We will review your own results with you before you leave, and significant overall findings developed as a result of this study will be provided to you at the conclusion of the study.

RESEARCH RESULTS

Information and research results will be used to further the field of posture and balance control and to benefit the evaluation and therapy processes related to posture and balance. Therefore the research results will possibly be used for scholarly papers, presentations, and future grant applications.
Any information obtained during this study and identified with you as a subject will remain confidential and will be disclosed only with your permission.If results of this study are reported in medical journals or at meetings, you will not be identified by name, by recognizable photograph, or by any other means without your specific consent. Your medical records will be maintained according to this medical center's requirements. By signing this form you are giving permission for us to make records available to the Shreveport VAMC and LSU Medical Center's Institutional Board for Human Research to which information will be released, all of whom must maintain confidentiality.

Subject's Initials _____

VA FORM
10-1086

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 4)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

OTHER TREATMENT AVAILABLE

Participation in this project will not effect your usual clinical treatment here at the VA. You are aware that you are under no obligation to participate in this study and you may withdraw at any time without prejudice to your medical care or loss of benefits to which you are entitled. Should you choose not to participate, you will still receive the usual medical care and treatment to which you are entitled. You may withdraw participation from the project at any time without prejudice

SPECIAL INFORMATION

You will be paid $25.00 by check for each session in which you participate. A session may last up to 4 hours. Payment will be through the Overton Brooks VAMC in Shreveport, LA.

1. You are not required to take part in this study — your participation is entirely voluntary.
2. You can refuse to participate now or you can withdraw from the study at any time after giving your consent.
3. Your decision whether or not to participate in this study will not involve any penalty or loss of rights nor will it prejudice your future relation with the VAMC or LSUMC.
4. There will be no costs to you for any of the treatment or testing done as part of this research study
5. In case of adverse (bad) effects or physical injury resulting from this study, eligible veterans are entitled to medical care and treatment. Compensation may or may not be payable in the event of physical injury arising from this study under applicable federal law. Further information about compensation and medical treatment may be obtained from the medical administration service at this.
6. VA medical center. Non-eligible veterans are entitled only to medical emergency care and treatment on a humanitarian basis.
7. If you have questions about your rights as a research participant, you may contact the Chairman of the Institutional Review Board at (318)-675-5409 or the Chief of Staff, Overton Brooks VA Medical Center at (318)-424-6089.
8. If you are a patient of the VAMC, a copy of this consent form will be placed in your medical record.

Subject's Initials _____

VA FORM
JAN 1990 **10-1086**

VA RESEARCH CONSENT FORM
PROTOCOL # H00-022 (Continuation Page 5)

Subject Name: _____ **Date:** _____

Title of Study: Threshold Detection of Postural Control in Diabetic Neuropathy and Aging

Principal Investigator: C. J. Robinson, DSc, PE; A. M. Hollister, MD **VAMC:** Shreveport

AFFIRMATION FROM SUBJECT

RESEARCH SUBJECTS' RIGHTS: I have read or have had read to me all of the above. Dr. Charles Robinson or his associate has explained the study to me and answered all of my questions. I have been told of the risks or discomforts and possible benefits of the study. I have been told of other choices of treatment available to me.

I understand that I do not have to take part in this study, and my refusal to participate will involve no penalty or loss of rights to which I am entitled. I may withdraw from this study at any time without penalty or loss of VA or other benefits to which I am entitled.

In case there are medical problems or questions, I have been told I can call Dr. Charles Robinson at (318)-424-6080 or Dr. Anne Hollister (675-6181) during the day and Dr. Robinson at (318)-513-9122 after hours. If any medical problems occur in connection with this study the VA will provide emergency care.

I understand my rights as a research subject, and I voluntarily consent to participate in this study. I understand what the study is about and how and why it is being done.

I will receive a signed copy of this consent form.

"I have been given the opportunity to ask questions and have them explained to me."

_____ _____
Subject's Signature Date

_____ _____
Signature of Witness Witness (print)

_____
Signature of Investigator

Institutional Review Board Approval Start Date 3/27/02 - End Date 03/26/03

Subject's Initials _____

VA FORM

APPENDIX C:

Flyer

Subjects Needed

Investigators:

Charles Robinson, DSc, PE, Anne Hollister, MD, and Samantha Richerson, B.S.
Overton Brooks VA Medical Center, Shreveport, LA and
Louisiana Tech University, Ruston, LA.

ADULTS AGED 50–80, WITH OR WITHOUT DIABETES, ARE BEING RECRUITED FOR A STUDY IN HUMAN MOVEMENT DETECTION

We are looking for individuals who are healthy or who have diabetes. All subjects must not have a history of acute heart or lung problems, back spasms, pain or other spinal problems, central neurological deficits, stroke or head trauma, or other problems that might preclude a person from standing blindfolded for 10 to 15 minute increments over a two–hour period. A neurological screening will be performed, and a psychological test also administered. Individual research results will be retained by the researchers and are not made part of the subject's clinical record.

Maximum time commitment: 4 hours (Usually 3–4 hours.)

Location: Overton Brooks VAMC, Shreveport,LA.

Compensation: $25 each session (up to 4 hours)

If you are interested in participating, or for further information,
Contact: Samantha Richerson
Or Charles Robinson, DSc., PE
Phone: (318) 424–6080 or Email: srichersonieee.org

APPENDIX D:

Start Up Protocol

Start-Up Protocol
Prior to Subject Arrival

On Entry to the Lab:

1. Check the following ON switches:

Lab Lights:____Daytronic Signal Conditioners: ____Gould Signal Conditioners: _____

SLIP Computer: _____ Delsys EMG Box: ____Headphone Transmitter: _____Mixer: _____

Speakers: _____ Doorbell:_____

2. Check Air Compressor:

Open Compressor and 2nd Tank Water Valves: _____ Close Compressor and 2nd Tank Water Valves: _____

Turn on Compressor, Check for Leaks and Dry air Conditioners: _____

3. Check the following CONNECTIONS:

SLIP computer Serial A to A/B Box (Switch to SLIP): _____

SLIP computer AT-MIO to Connector Box (Analog and Digital): _____

SLIP computer Sound-Blaster to Mixer: _____ SLIP computer to Laser Printer: _____

Power to Accelerometer: _____ Accelerometer X to Gould #3: _____

Accelerometer Y to Gould #6: ____

Accelerometer Z to Gould #5: _____ Gould #3 Monitor Out to Connector Block: _____

Gould #5 Monitor Out to Connector Block: ___Gould #6 Monitor Out to Connector Block: ____

AB, CD EMG Sensors and ground to Belt Box: __Belt Box to EMG Box Channels 1, 2, 3, 4: ___

Radio Shack Doorbell Alarm to Connector Block: __Radio Shack Doorbell Alarm to Mixer: ____

White Noise Generator (Radio) to Mixer: _____Mixer to Headphone Transmitter: _____

4. Have on Hand the following fresh BATTERIES:

Radio Shack Doorbell Receiver (3-AA): _____ Radio Shack Doorbell Transmitter (1-9volt): _____

5. Find the following "loose" ITEMS and place on Platform:

Radio Shack Doorbell Transmitter: _____ Blindfold: _____

Prepare Electrodes with One side of the adhesion pads: _____

Form Completed by: _____Date/Time: _____

Start-Up Protocol
Prior to Subject Arrival

Test Equipment by:

1. Turn on Air to Platform and turn on DMM-2100:
Air pressure @ platform >70psi: _____ DMM-2100 w/o reset light: _____Platform floats: _____

2. Open Continuous Acquire Buffered Chart.VI (Examples\Analogin\) Read Channels:
Channels 0:3, CoP: _____ Each channel lesser voltage as weight over each vertical force sensor increases.

Channels 4 and 5, Position of Platform: _____ Voltage increases as platform moves toward bookshelf. Acceleration: _____ Voltage is initially positive with towards the door movement.

Channels: 8:11, EMG: _____ Open EMGtest.VI, check each channel against Biceps.

Channels: 12,13,14,15, Head Accel: _____ Voltage = +/- 5V with gravity., Doorbell switch: _____ "rings" and gives approximately 4 volts spike.

3. Turn on Headset and Open Get_Sound.VI
Headphones / Mixer: _____

In headphones able to hear continuous "white noise", overlaid by wave file (*.wav), and/or doorbell: _____

4. Turn off: EMG box, Headphones, and Doorbell receiver.

5. Open "5 RANDOMS.VI" to determine the order of testing

__1__1 mm Forward Smooth: _____
__1__2 mm Forward Smooth: _____
__1__4 mm Forward Smooth: _____
__1__8 mm Forward Smooth: _____
__1__16 mm Forward Smooth: _____

6. Run VDA Initialize and Home.VI

7. Open the Following VI's.

***5Jog.VI*, *FC Learning7f.VI, *EMG_CoP Calibrate.VI*, *Reaction VDA5.VI* Forced Choice VDA 7f.VI, and *Latencies VDA7f.vi**

Form Completed by: _____Date/Time: _____

Testing Protocol
When Subject Arrives

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

1. Introduce Investigator: _____

2. Show Platform and run "5 jog.VI" which shows length of jogs and approximate speed (25mm/s2): _____

"This is the test platform that you will be standing on. It will be making very small moves (run VI) and you will have to determine when the move occurred." But before you step on the platform I need you to read and sign the informed consent document and take some clinical measurements."

3. Give subjects IRB approved consent form. Subjects must initial and sign form as appropriate: _____

4. Determine and record Subject "ID" and have them fill out Medical History form if not already completed: _____

5. Give the mini-mental evaluation form from Linda Ferguson (OT).

6. Based on the schedule take the subject over for Nerve conduction study at Dept. of Neurology (for elderly subjects only) or perform the perturbation study in RNL.

7. Have subject remove shoes and socks, and Perform Clinical assessment according to form/ protocol: _____

8. Perform Therapeutic/Anthropometrical measures: _____

9. Turn on Doorbell receiver, have them test transmitter, explain forced choice protocol: _____
"With this doorbell transmitter, you will be able to tell me when you feel the platform move."
"For (this) (the first test), you will be asked to step on the platform, place the headphones over your ears, and cover your eyes with the blindfold. From your headphones you will be hearing a constant 'masking white noise', and four verbal cues: 'Ready', 'One', 'Two', and 'Decide'. Each will be two seconds apart. If you think that the platform moved between the words 'One' and 'Two', press the button once; if between the words 'Two' and 'Decide', press the button twice. All decisions should be made as quickly as possible, but no later than two seconds after the word 'Decide'. Go ahead and try the button with your left hand to make sure you are comfortable with it. It may take several pushes to get the second doorbell chime."

10. Place EMG sensors on bilateral Tib. Anterior and Solius muscles, *A*=R. TA, *B*=R S., *C*=L. TA, *D*=L. S.: _____

"I will be collecting EMG data to determine how your muscles react to the slight movements the platform will be making, to help me determine if this is part of what helps YOU to decide if the platform has moved. After I'm done placing these sensors, I'll ask you to do some movements to help me calibrate them."

Testing Protocol
When Subject Arrives

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

11. Run "EMG_CoP Calibrate.VI" and cue subject to movements: _____
Wait for platform calibration, "Step up onto the platform and stand with even weight on both your feet." Record 20 seconds static eyes open. "Now stand on your toes." Record toes. "Now on your heels." Record heels. "OK, relax on both feet again" Record static. "You can now step off the platform, watch that you don't tangle the EMG lines."

12. Run FC Learning.VI for 10 trials at appropriate displacement (guaranteed detect) under FC protocol. _____
First 4 trials with eyes open for subject psychological safety, last 6 trials under eyes closed condition for learning under testing conditions. This VI can be repeated up to 3 times for learning purposes.
"I'd like you to try to feel the platform move a few times. After you decide when the platform moved, you will hear a response 'one' or 'two' stating when the platform actually moved. Do the first 4 trials with your eyes open, then close your eyes."

13. Explain forced choice protocol again and run "Forced Choice VDA.VI" for 1 condition: Note: First 20 seconds of test ask subject to stand still. _____

14. Allow subject 5-minute rests while checking summary file(s) for lowest detected acceleration, for the forced choice tests, write these thresholds below:

_____1 mm Forward Smooth: _____
_____2 mm Forward Smooth: _____
_____4 mm Forward Smooth: _____
_____8 mm Forward Smooth: _____
_____16 mm Forward Smooth: _____

15. Explain "Latency" test protocols: _____
"For these last sets of tests, I've chosen an acceleration level that you have previously detected. So while you're standing on the platform with the headphones and blindfold on, I want you to press the detect button as soon as you feel the platform move. However, to make sure you're not pressing the button at random, I'm going to have a few trials when after the word "Ready", there will be no movement."

17. Repeat steps 12-15 for other two displacements, then have subject rest 10-15 minutes.

18. Explain all portions of "Reaction time" tests, then repeat prior to testing each portion. Open "Reaction.VI" and run as stated, then allow 5-10 minute rest.
"To test your overall reaction time, I'm going to run 3 sets of tests. For the first test, I'm going to have you step on the platform, wear the headphones and blindfold. After the word "Ready", the platform will move within three seconds. I('ll) want you to press the door bell button as soon as you feel the platform move."
Run platform portion of test.

Testing Protocol
When Subject Arrives

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

18 continued:
Have subject sit in chair. "For the second reaction time test, I ('ll) want you press the door bell button as soon as you feel me touch you on your big toe with this force sensor." (Five trials)

Run toe-touch with press detect reaction portion of test.

"Finally, for the third reaction time test, I'll want you to press the force sensor as fast as you can, after you hear the doorbell." (Five trials)

Run sound with press detect reaction portion of test.

19. De-brief subjects: _____

20. Reschedule subjects for additional test time if needed: _____

Day/Date: _____
Time: _____

Alternate Day/Date: _____
Time: _____

21. Have Subject fill out payment slip to be kept as a receipt: _____

To: Overton Brooks VA Medical Center
510 East Stoner Avenue, Shreveport, LA 71101.
Phone: (318) 424-6080, Fax: (318) 429-5733.
Attn.: Ms. Linda Ritmo - Executive Director.

Re: Subject Reimbursement Date: _____

Please reimburse (subject) _____, (Soc. Sec. #) _____

For the amount of: _____dollars, for participation in the research protocol titled "Postural Control in Diabetes, Peripheral Neuropathy, and Aging", Charles J. Robinson, principal investigator. Rehabilitative Neuroscience Lab, Overton Brooks VA Medical Center, LA. (318) 424-6080.

The mailing address is as follows: (street, number and apartment): _____

(City, State and Zip): _____

(Subject Signature): _____ (Investigator Signature):_____

Date: _____

Within the next three weeks you should be receiving a check from the Overton Brooks VAMC. If you do not receive a check, please notify Charles J. Robinson or Samantha Richerson, at: (318) 424-6080, or E-mail at: srichersonn@ieee.org. Please leave your name and method(s) by which you can be contacted.

To: Overton Brooks VA Medical Center
510 East Stoner Avenue, Shreveport, LA 71101.
Phone: (318) 424-6080, Fax: (318) 429-5733.
Attn.: Ms. Linda Ritmo - Executive Director.

Re: Subject Reimbursement Date: _____

Please reimburse (subject) _____, (Soc. Sec. #) _____

For the amount of: _____dollars, for participation in the research protocol titled Postural Control in Diabetes, Peripheral Neuropathy, and Aging", Charles J. Robinson, principal investigator. Rehabilitative Neuroscience Lab, Overton Brooks VA Medical Center, LA. (318) 424-6080.

The mailing address is as follows: (street, number and apartment): _____

(City, State and Zip):_____

(Subject Signature): _____(Investigator Signature): _____

Date: _____

Within the next three weeks you should be receiving a check from the Overton Brooks VAMC. If you do not receive a check, please notify Charles J. Robinson or Samantha Richerson, at: (318) 424-6080, or E-mail at: srichersonn@ieee.org. Please leave your name and method(s) by which you can be contacted.

APPENDIX E:

Questionnaire

Initial Contact Questionnaire
Front Page

Name: _____Date of Contact(mm/dd/yy)_____

How did subject learn of study? Paper Announcement Internet Word of Mouth

Subject informed of: Age Criteria: _____ Exclusion Criteria: _____

Scope of Research: _____ Reason / Benefit of Research: _____

Time Required: _____ Financial Compensation: _____

Is subject interested in participating in study? Yes No

Has Subject been found to be Vestibularly Normal? Yes No
Unknown

Is subject able to get to the Overton Brooks VAMC lab? Yes No

Subject Contact via: Phone #: _____Internet: _____

Address:_____

Subject Availability / Scheduled Testing Date (mm/dd/yy)_____ Time(hh:mm)_____

(mm/dd/yy)_____ Time(hh:mm)_____

How has subject been given directions to lab? Phone Internet Mail Personally

Subject's Date of Birth (mm/yy): _____Subject's Gender: Male Female

Subject Code: _____ _____ _____ _____ _____
Gender Age Age Alpha Alpha

The above information, and provided medical history is true to the best of my knowledge.

Investigator signature: _____Date(mm/dd/yy): _____

Initial Screen Questionnaire
Medical History

Subject Code: _____ _____ _____ _____ _____
Gender Age Age Alpha Alpha

Subject weight as measured by the weighing scale: _____

Does the subject have any history of (Check if Yes):

Cardiac Problems: Tachy/Bradycardia: _____ Cardiac Arrhythmias: _____

Heart / Lung Disease: _____ Shortness of Breath: _____

Other: _____

Neurologic Problems: Stroke/TIA: _____ Head Injury: _____

Peripheral Nerve Injury: _____ Spinal Injury: _____

Advanced Diabetes: _____ Vision Loss: _____

Hearing Loss / Ear Infections: _____ Loss of Balance: _____

Memory/Concentration Deficits: _____ Sensory Loss: _____

Muscle Tone Abnormalities: _____ Coordination Deficits: _____

Other: _____

Orthopaedic Problems: Arthritis / Joint Disease: _____ Osteoporosis: _____

Lower Back Pain/Spasms: _____ Spinal Stenosis: _____

Fractures: _____ - Specify: _____

Other: _____

Alcohol Use / week: None < 3 Drinks 3-14 Drinks >14 Drinks

Record Caffinated Items within last 12 hours: _____

Medication / Drug Use: Pain Medication: _____ Depressants: _____ Anti-Depressants: _____

Psychoactive: _____ Other: _____

Initial Sensory-Motor Screen

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

Reflex Testing (+ = normal, - = abnormal, 0= absent):

Patellar Reflex: Right: _____ Left: _____

Achilles' Reflex: Right: _____ Left: _____

Vision Testing (+ = normal, - = abnormal, 0= absent):

Read Newsprint: _____ Read _____ point font @ 20 feet: _____

Uses Eyeglasses / Contacts: _____

Visual Fields: Right: _____ Left: _____ Up: _____ Down: _____

Sharpened Romberg Test Findings (+ = normal, - = abnormal, 0= absent):

Balance: _____ Recovery from Loss of Balance: _____

Time to Loss of Balance (seconds): _____

Precession Test: (Subject hops on one foot should remain facing forward)

Right Foot: _____

Left Foot: _____

Tactile / Somato-Sensory Tests with Stoelting Monofilaments to Foot Sole (mm diameter):

Right: Base MetaTarsal: _____ Base Digit IV: _____

Left: Base MetaTarsal: _____ Base Digit IV: _____

Initial Therapeutic Screen

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

Posture and Balance (+ = normal, - = abnormal, 0= absent):

Sit to Stand: _____ Standing eyes Closed: _____ Ambulation: _____

Joint Stiffness / Tone (+ = normal, - = abnormal, 0= absent):

Shoulder: _____ Elbow: _____ Hip: _____ Knee: _____ Ankle: _____

Limb / Body Segment Length (mm):

Length of Foot: Right: _____ Left: _____

Floor to Lateral Malleolus: Right: _____ Left: _____

Floor to Lateral Epicondyle of the Femur: Right: _____ Left: _____

Floor to Greater Trochanter: Right: _____ Left: _____

Floor to Lateral Aspect of Humeral Head Right: _____ Left: _____

Floor to Top of Head (Total Height): Dorsal Aspect: _____

Lat. Aspect Humeral Head to Lat. Epicondyle of the Humerus: Right: _____ Left: _____

Lat. Aspect Humeral Head to Tip Digit III: Right: _____ Left: _____

Time Sheet for Testing

Subject Code: _____ _____ _____ _____ _____ Date: _____
Gender Age Age Alpha Alpha

Subject arrival: _____

End introduction of subject to platform and people: _____

Start Informed consent: _____

End Informed consent: _____

Start Medical questionnaire (Page 2 plus Romberg and hop test): _____

End Medical questionnaire: _____

Start hooking up electrodes: _____

End hooking up electrodes: _____

Start EMG_COP calibrate routine: _____

End EMG_COP calibrate routine: _____

Start ____mm displacement practice: _____

End ____mm displacement practice: _____

Start ____mm displacement recorded: _____

End ____mm displacement recorded: _____

Start ____mm displacement latency test: _____

End ____mm displacement latency test: _____

Start ____mm displacement practice: _____

End ____mm displacement practice: _____

Start ____mm displacement recorded: _____

End ____mm displacement recorded: _____

Start ____mm displacement latency test: _____

End ____mm displacement latency test: _____

Start ____mm displacement practice: _____

End ____mm displacement practice: _____

Start ____mm displacement recorded: _____

End ____mm displacement recorded: _____

Start ____mm displacement latency test: _____

End ____mm displacement latency test: _____

Start sensory and other evaluation (page 3): _____

End sensory and other evaluation: _____

Time Sheet for Testing

Subject Code: ____ ____ ____ ____ ____ Date: _____
Gender Age Age Alpha Alpha

Start ____mm displacement practice: _____

End ____mm displacement practice: _____

Start ____mm displacement recorded: _____

End ____mm displacement recorded: _____

Start ____mm displacement latency test: _____

End ____mm displacement latency test: _____

Start ____mm displacement practice: _____

End ____mm displacement practice: _____

Start ____mm displacement recorded: _____

End ____mm displacement recorded: _____

Start ____mm displacement latency test: _____

End ____mm displacement latency test: _____

Start reaction test: _____

End reaction test: _____

Start Anthropometric measures (page 4): _____

End Anthropometric measures: _____

Start Mini-mental evaluation test: _____

End Mini-mental evaluation test: _____

Start walk to Neurologist: _____

Time when reaching the Neurologist: _____

Start nerve conduction study: _____

End nerve conduction study: _____

Start debrief: _____

End signing off: _____

APPENDIX F:

MMSE

MMSE

mini-mental state exam

(10) **Orientation** (5 points each)
( ) What is the (year) (season) (day) (date) (month)?
( ) Where are we: (state) (county) (town) (hospital) (floor)?

(3) **Registration**
( ) Name three unrelated objects. Allow one second to say each. Then ask the patient to repeat all three after you have said them. Give one point for each correct answer. Repeat them until he or she learns all three. Count trials and record. Trials: _____

(5) **Attention and Calculation**
( ) Ask patient to count backwards from 100 by sevens. Give one point for each correct answer. Stop after five answers. Alternatively, spell world backwards.

3) **Recall**
( ) Ask patient to recall the three objects previously stated. Give one point for each correct answer.

(9) **Language**
( ) • Show patient a wrist watch; ask patient what it is. Repeat for a pencil. (2 points)
( ) • Ask patient to repeat the following: "No ifs, ands, or buts." (1 point)
( ) • Ask patient to follow a three-stage command: "Take a paper in your right hand, fold it in half, and put it on the floor." (3 points)
( ) • Ask patient to read and obey the following sentence which you have written on a piece of paper: "Close your eyes." (1 point)
( ) • Ask patient to write a sentence. (1 point)
( ) • Ask patient to copy a design. (1 point)

Scoring:
24-30 Uncertain Cognitive Impairment
18-23 Mild to Moderate Cognitive Impairment
0-17 Severe Cognitive Impairment

*The score ranges listed here are widely used, but it should be noted that an MMSE score

is only an initial indicator of cognitive status, and norms for the MMSE vary greatly depending on a person's age, education level, and race.

Total Score: _____

Assess level of consciousness along a continuum:
Alert Drowsy Stupor Coma

Sources:
Crum, R. M., J. C. Anthony, S. S. Bassett, and M. F. Folstein. 1993. "Population-Based Norms for the Mini-Mental State Examination by Age and Educational Level." J. am. Med. Assoc. 269:2386-91.
Folstein, M. F., S. E. Folstein, and P. R. McHugh. 1975. "Mini-Mental State: A Practical Method for Grading the Cognitive State of Patients for the Clinician." J. Psych. Res. 12:196_8.
Revised October 2000

Instructions:

Orientation
Ask for the date. Then ask specifically for parts omitted, e.g., "Can you also tell me what season it is?" (1 point for each correct)
Ask in turn, "Can you tell me the name of this hospital, town, county, etc.?" (1 point for each correct)

Registration
Ask the patient if you may test his or her memory. Then say the names of three unrelated objects, clearly and slowly, allowing about one second for each. After you have said all three, ask him or her to repeat them. This first repetition determines the score (0-3), but keep saying them until the patient can repeat all three—up to six trials. If he or she does not eventually learn all three, recall cannot be meaningfully tested.

Attention and Calculation
Ask the patient to begin with 100 and count backwards by sevens. Stop after five subtractions (93, 86, 79, 72, 65). Score the total number of correct answers. If the patient cannot or will not perform this task, ask him or her to spell the word world backwards. The score is the number of letters in correct order, e.g., dlrow=5, drlow=3.

Recall
Ask the patient if he or she can recall the three words you previously asked him or her to remember. (1 point for each correct)

Language

Naming. Show the patient a wrist watch and ask him or her what it is. Repeat for a pencil. (1 point for each correct)

Repetition. Ask the patient to repeat the sentence after you. Allow only one trial. (Score 0 or 1)

Three-stage command. Give the patient a piece of plain blank paper and repeat the command. (Score 1 point for each part correctly executed.)

Reading. On a blank piece of paper print the sentence, "Close your eyes." in letters large enough for the patient to see clearly. Ask him or her to read it and do what it says. (1 point only if patient actually closes eyes)

Writing. Give the patient a blank sheet of paper and ask him or her to write a sentence. Do not dictate a sentence; it is to be written spontaneously. It must contain a subject and a verb and be sensible. Correct grammar and punctuation are not necessary.

Copying. On a clean piece of paper, draw intersecting pentagons, each side about one inch long, and ask patient to copy it exactly as is. All 10 angles must be present and two must intersect to score one point. Tremor and rotation are ignored.

Estimate the patient's level of sensorium along a continuum, from alert on the left to coma on the right.

Source: Folstein, M. F., S. E. Folstein, and P. R. McHugh. 1975. "Mini-Mental State: A Practical Method for Grading the Cognitive State of Patients for the Clinician." J. Psych. Res. 12:196_8. Revised April 1999

APPENDIX G:

Quiet Standing Matlab Program pos_steady_meas_sta.m

```
%This program calculates the time domain measures set forth in Prieto's paper
%for the standing data
%IEEE Trans on Biomedical Engineerng 43(9), pp. 956-966, 1996.
%Samantha Richerson

% clear previous entries
clear
pack

% Initial variables
substr={'m64ebc'};
trialstr={ '1as1rf' '2as2rf' '3as3rf'};
dirstr={'D:\epsilon\m64eb\'};
i1 = 1; i4 =0;
det11=0; det12=0;
det21=0; det22=0;
det31=0; det32=0;
platewt=0.646; %Plate weight in voltage. Actual Plate weight 101.34N
                %converstion 392.4N/V divided by 4 load cells.
% Condition loop

while i1 <= 3,          % Displacement criteria
  dstr=char(dirstr(1));
  sstr=char(substr(1));
      astr=char(trialstr(i1));
      fstr=[dstr sstr astr];
  sumstr=[fstr '.sta'];
  % Get calibration value
  calstr=[fstr '1.cal'];
  fid=fopen(calstr);
  CAL=fscanf(fid,'%f',[16,inf]);
      CAL=CAL';
      fclose(fid);
  mcal=mean(CAL(.10*length(CAL):.90*length(CAL),:));
  fpcal=mcal(:,1:4)-platewt; % Plate Weight is subtracted from calibration values
  clear CAL mcal

  % Get info from sta file
      fid=fopen(sumstr);
      for j1=1:2,
    A=fgetl(fid);
  end %j1
      STA1=fscanf(fid,'%f',[16,inf]);
      STA1=STA1';
      fclose(fid);
  %Subtract Calibration values from standing data
```

```
FP1=STA1(:,1)-fpcal(1);
FP2=STA1(:,2)-fpcal(2);
FP3=STA1(:,3)-fpcal(3);
FP4=STA1(:,4)-fpcal(4);
    %Calculate AP and ML COP
    APCOP=209.55*(FP4+FP1-FP3-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
MLCOP=174.625*(FP3+FP4-FP1-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
clear FP1 FP2 FP3 FP4 RAW


Wn = [5/500];       % Filter the signal at 5Hz using a 3rd order butterworth
    [B,A]=butter(3,Wn);
COPAP=filtfilt(B,A,APCOP);
COPML=filtfilt(B,A,MLCOP);
%subtract out mean from each signal so that signals are referenced to mean cop
COPAP=COPAP-mean(COPAP);
COPML=COPML-mean(COPML);
%calculate resultant distance
rd=sqrt(COPAP.*COPAP+COPML.*COPML);
%calculate mean distance ( average distance from Mean COP)
mdist=sum(rd)/(length(rd));
mdistap=sum(abs(COPAP))/(length(COPAP));
mdistml=sum(abs(COPML))/(length(COPML));
%calculate rms distance from mean cop
rdist=sqrt((sum(rd.*rd))/(length(rd)));
rdistap=sqrt((sum(COPAP.*COPAP))/(length(COPAP)));
rdistml=sqrt((sum(COPML.*COPML))/(length(COPML)));
%calculate total length of COP path
m=length(COPAP)-1;
totexap=0;
totexml=0;
totex=0;
for i=1:m
 temp1=(COPAP(i+1)-COPAP(i))^2;
 temp2=(COPML(i+1)-COPML(i))^2;
 totexap=totexap+abs(temp1);
 totexml=totexml+abs(temp2);
 temp3=sqrt(temp1^2+temp2^2);
 totex=totex+temp3;
end
%calculate mean velocity
mvelo=totex/(length(COPAP)/1000);
mveloap=totexap/(length(COPAP)/1000);
mveloml=totexml/(length(COPML)/1000);
%calculate mean, standard deviation and range of COP's
meanrd=mean(rd);
```

```
 meanap=mean(COPAP);
 meanml=mean(COPML);
 stddevrd=std(rd);
 stddevap=std(COPAP);
 stddevml=std(COPML);
 rng=range(rd);
 rngap=range(COPAP);
 rngml=range(COPML);
 %calculate the 95% confedence circle area
 areacc=pi*(mdist+1.645*(sqrt(rdist^2-mdist^2)))^2;
 %calculate the sway area
 areasway=0;
 for i=1:m
  temp1=(COPAP(i+1)*COPML(i));
  temp2=(COPML(i+1)*COPAP(i));
  temp3=abs(temp1-temp2);
  areasway=areasway+temp3;
end
areasway=areasway/(2*length(COPAP)/1000);
%calculate mean frequency
mfreq=mvelo/(2*pi*mdist);
mfreqap=mveloap/(4*sqrt(2)*mdistap);
mfreqml=mveloml/(4*sqrt(2)*mdistml)

data(i1,1)= i1
data(i1,2)= meanrd;
data(i1,3)= stddevrd;
data(i1,4)= stddevap;
data(i1,5)= stddevml;
data(i1,6)= rng;
data(i1,7)= rngap;
data(i1,8)= rngml;
data(i1,9)= mdist;
data(i1,10)= mdistap;
data(i1,11)= mdistml;
data(i1,12)= rdist;
data(i1,13)= rdistap;
data(i1,14)= rdistml;
data(i1,15)= totex;
data(i1,16)= totexap;
data(i1,17)= totexml;
data(i1,18)= mvelo;
data(i1,19)=mveloap ;
data(i1,20)=mveloml;
data(i1,21)=mfreq ;
data(i1,22)=mfreqap;
```

```
  data(i1,23)=mfreqml ;
  data(i1,24)=areacc;
  data(i1,25)=areasway;
  output=data
i1=i1+1
end
    save D:\Sam_Data_Analysis_Epsilon\m64eb_sta.txt output -ascii -double –tabs
```

APPENDIX H:

Latency Matlab Program latency_lag2.m

```
% This function loads the latency files (.lat).
% Detects the when platform moved.
% Determines the time when the first dectect pulse is sent.
% Computes the lag between platform movement and detect pulse.
% Saves the lag value in hard drive.
% Samantha Richerson


substr={'f53gun'};
trialstr={'5as1rf'};
dirstr={'g:\f53gu\'};
i1 = 1;
lag=0;
move_start=0;
% Condition loop

while i1 <= 1,          % Displacement criteria

  dstr=char(dirstr(1));
  sstr=char(substr(1));
        astr=char(trialstr(1));
        fstr=[dstr sstr astr 'lat'];
  sumstr=[fstr '.sum'];


% Trial Loop
        for i2=[1:10],
      if i2==10
        rawstr=[fstr num2str(i2) '.raw'];
      end
      if i2<10
        rawstr=[fstr '' num2str(i2) '.raw'];
      end
       fid=fopen(rawstr)
        for j1=1:7,
                 A=fgetl(fid);
                end %j1

     RAW=fscanf(fid,'%f',[16,inf]);
                RAW=RAW';
                fclose(fid);

    % Platform moves at 4 seconds

    move_start=4000;
```

```
% Find the first point of Detect pulse

      [j,buzz] = max(diff(RAW(:,16)));


 % Compute the lag in Latency (47ms to gate close subtracted off)
 lag(i2)=(buzz-move_start-47)
plate=RAW(:,5);
buzz=RAW(:,16);

 %Create String for Title of Graph
lat=lag(i2);
 string=['Determining Latency for' char(rawstr) '  Latency = ' num2str(lat)]%
figure
%plot plate movement, APCOP, MLCOP and the Buzzer
subplot(2,1,1); plot (plate)
ylabel ('Plate')
title(string)
subplot(2,1,2); plot (buzz)
ylabel ('Detect')
xlabel('time (ms)')

i2=i2+1
end %for

% To save the lag values.
output=lag;
i1=i1+1;
%save c:\Samantha\react_lag_m28ad1asufh output -ascii -double -tabs
end
```

APPENDIX I:

Reaction Time Matlab Program react_latency_lag_suprath2.m

```
% This function loads the reaction time (react).
% Detects the when platform moved by difference method.
% Determines the time when the first dectect pulse is sent.
% Computes the lag between platform movement and detect pulse.
% Saves the lag value in hard drive.
% Samantha Richerson


substr={'f53gu'};
trialstr={'react'};
dirstr={'g:\f53gu\'};
i1 = 1;
lag=0;
move_start=0;
% Condition loop

while i1 <= 1,          % Displacement criteria

        dstr=char(dirstr(1));
        sstr=char(substr(1));
        astr=char(trialstr(1));
        fstr=[dstr sstr astr];

% Trial Loop for 10 platform movements
        for i2=[1:10],
                rawstr=[fstr num2str(i2) '.raw'];
                fid=fopen(rawstr)
                for j1=1:7,
                 A=fgetl(fid);
        end %j1

        RAW=fscanf(fid,'%f',[16,inf]);
        RAW=RAW';
        fclose(fid);

        plate=RAW(:,5);
        detect=RAW(:,16);
    % Determine when the Platform moves
         movesize=abs(max(RAW(:,5))-min(RAW(:,5)))
        move_start=3000;

    % Find the first point of Detect pulse

            [j,buzz] = max(diff(RAW(:,16)))

      clear RAW
```

```
        % Compute the lag in Latency (47 ms lag between button push and gate open
        % is factored in).
                lag(i2)=(buzz-move_start-47)

       %Create String for Title of Graph
      lat=lag(i2);
       string=['Determining Latency for' char(rawstr) '  Latency = ' num2str(lat)]%
      figure
      %plot plate movement and the Buzzer
      subplot(2,1,1); plot (plate)
      ylabel ('Plate')
      title(string)
      subplot(2,1,2); plot (detect)
      ylabel ('Detect')
      xlabel('time (ms)')

      i2=i2+1
    end


%Trial Loop for touch trials
        for i3=[1:5]
     rawstr=[fstr num2str(i3) '.tch'];
      fid=fopen(rawstr)
        for j1=1:7,
                A=fgetl(fid);
   end %j1%

     RAW=fscanf(fid,'%f',[2,inf]);
          RAW=RAW';
     fclose(fid);
     toe=(RAW(:,1));
     bell=(RAW(:,2));

    % Determine when the toe was pressed

   ave_100_pts = sum(RAW(1:100,1))/100
  thresh=ave_100_pts-0.070*(ave_100_pts);
  for i=1:1:length(RAW)
     if RAW(i,1)<thresh, break
     end
  end
  move_start=i

   % Find the first point of Detect pulse
```

```
        [j,buzz] = max(diff(bell))

       % Compute the lag in Latency (47 ms lag between button push and gate open%
       % is factored in). The start of the data is when the toe is pressed, so the
        %latency is only the buzz -47ms
              lag_toe(i3)=(buzz-move_start-47)

     %Create String for Title of Graph
     lat=lag_toe(i3);
      string=['Determining Latency for' char(rawstr) '  Latency = ' num2str(lat)]%
     figure
     %plot plate movement, APCOP, MLCOP and the Buzzer
     subplot(2,1,1); plot (toe)
     ylabel ('Toe Press')
     title(string)
     subplot(2,1,2); plot (bell)
     ylabel ('Detect')
     xlabel('time (ms)')

     i3=i3+1
  end %for
 clear RAW

 %Trial Loop for bell trials
        for i4=[6:10],
    rawstr=[fstr num2str(i4) '.bel'];
     fid=fopen(rawstr)
       for j1=1:7,
              A=fgetl(fid);
   end %j1

    RAW=fscanf(fid,'%f',[2,inf]);
              RAW=RAW';
              fclose(fid);

   % Determine when the bell was pressed
  [j,buzz] = max(diff(RAW(:,2)));
   % Find the first point of touch sensor
  ave_100_pts = sum(RAW(1:100,1))/100;
  thresh=ave_100_pts-0.01;
  for i=1:1:length(RAW)
    if RAW(i,1)<thresh, break
  end
end
  detect=i
```

```
    % Compute the lag in Latency (47 ms lag between button push and gate open
    % is factored in).
                lag_tch(i4)=(detect-buzz-47);

     %Create String for Title of Graph
    lat=lag_tch(i4)
    string=['Determining Latency for' char(rawstr) '  Latency = ' num2str(lat)]%
    figure
    %plot plate movement and the Buzzer
    subplot(2,1,1); plot (RAW(:,1))
    ylabel ('Plate')
    title(string)
    subplot(2,1,2); plot (RAW(:,2))
    ylabel ('Detect')
    xlabel('time (ms)')

    i4=i4+1
  end %for

i1=i1+1;
end

save d:\Reaction_Time\m74dd_plat lag -ascii -double -tabs
save d:\Reaction_Time\m74dd_tch lag_toe -ascii -double -tabs
save d:\Reaction_Time\m74dd_bell lag_tch -ascii -double -tabs
```

APPENDIX J:

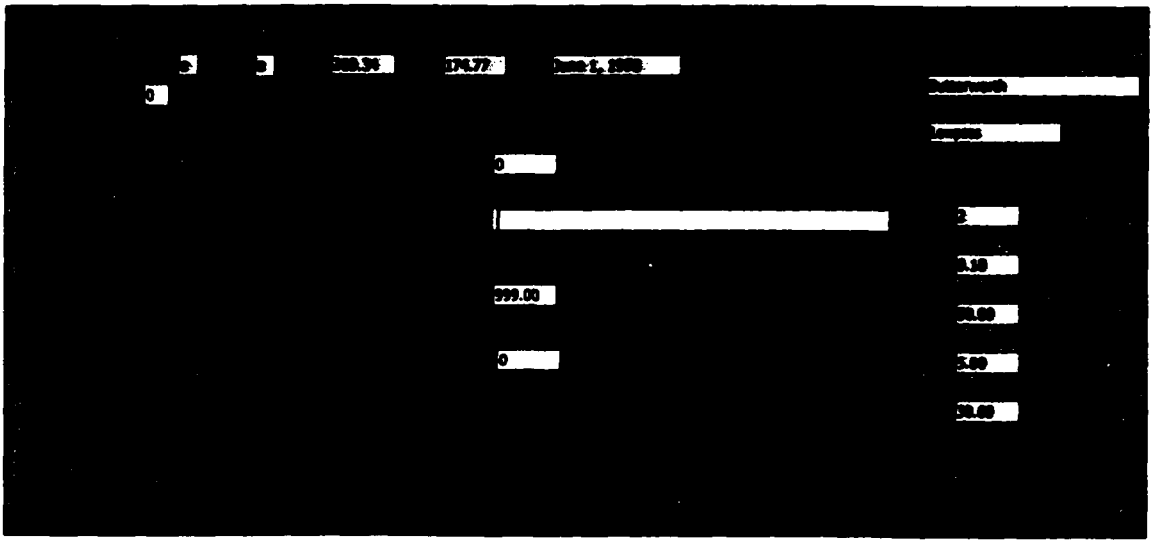
LabVIEW program Calculating Quiet Standing Metrics: Convert RAW to Prieto CoP metrics_no_graphs3.vi

Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM

Connector Pane

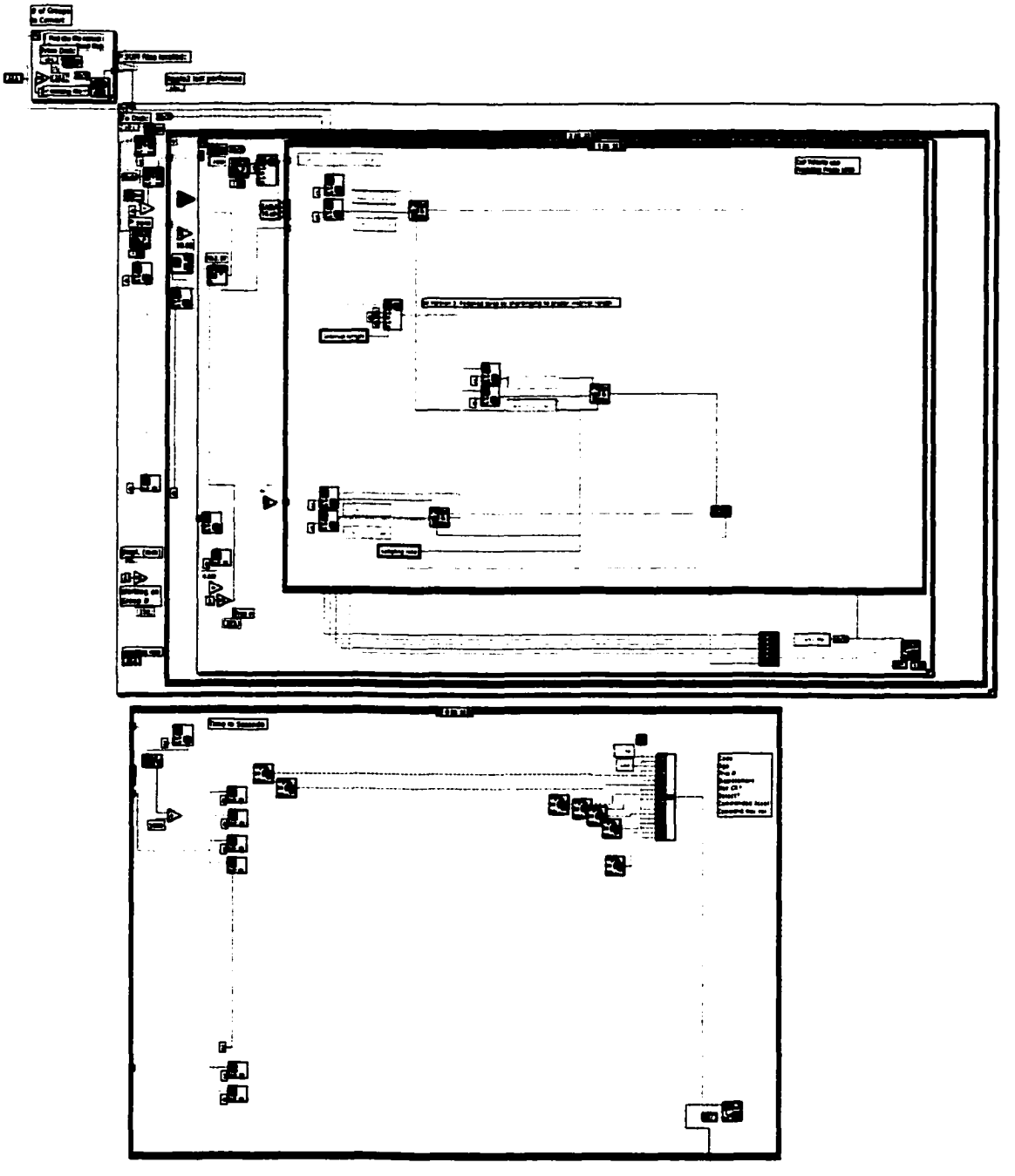
Convert RAW 2 Prieto CoP metrics_no_graphs3.vi

Front Panel

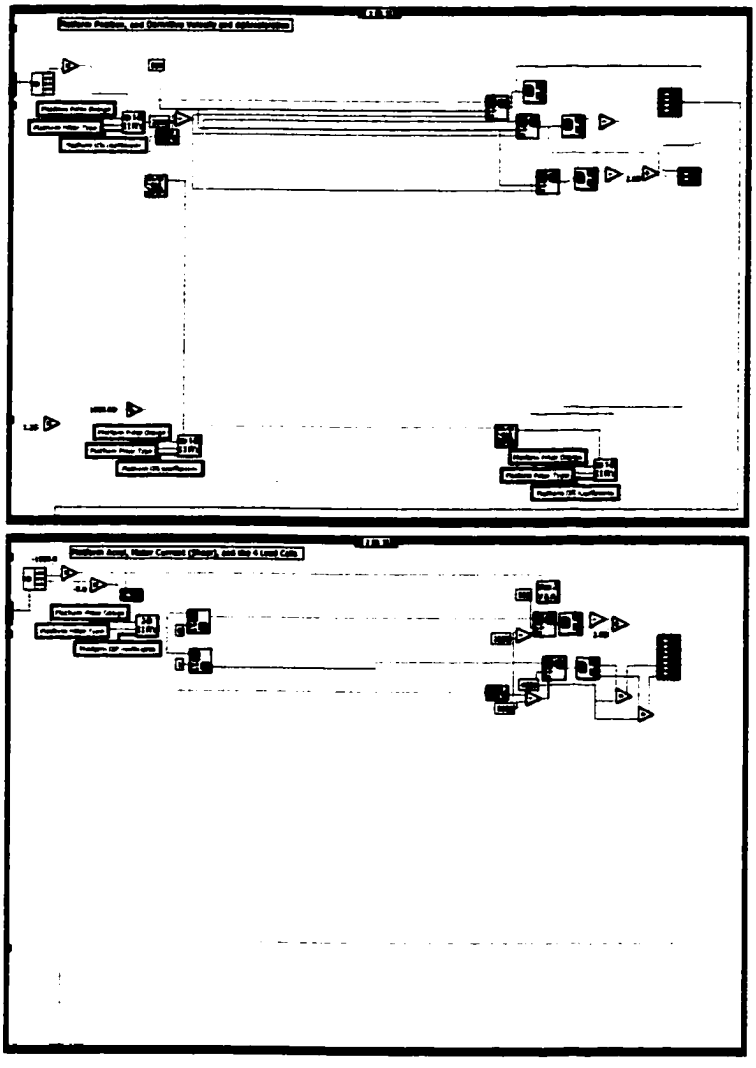


Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM

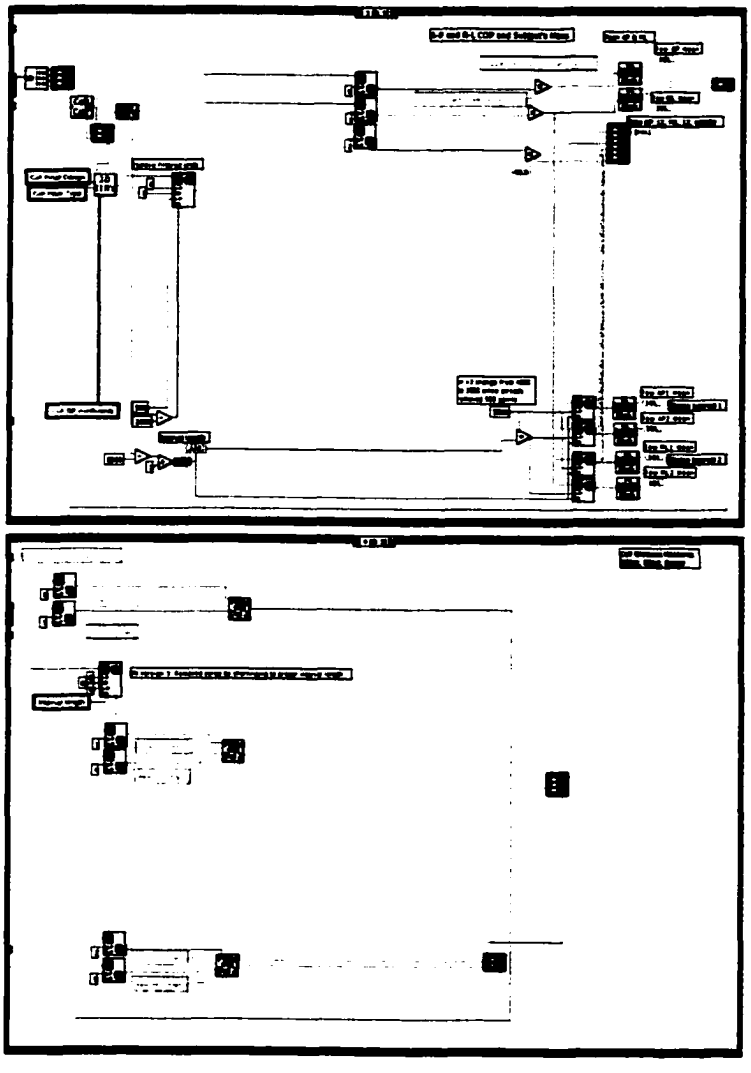
Block Diagram



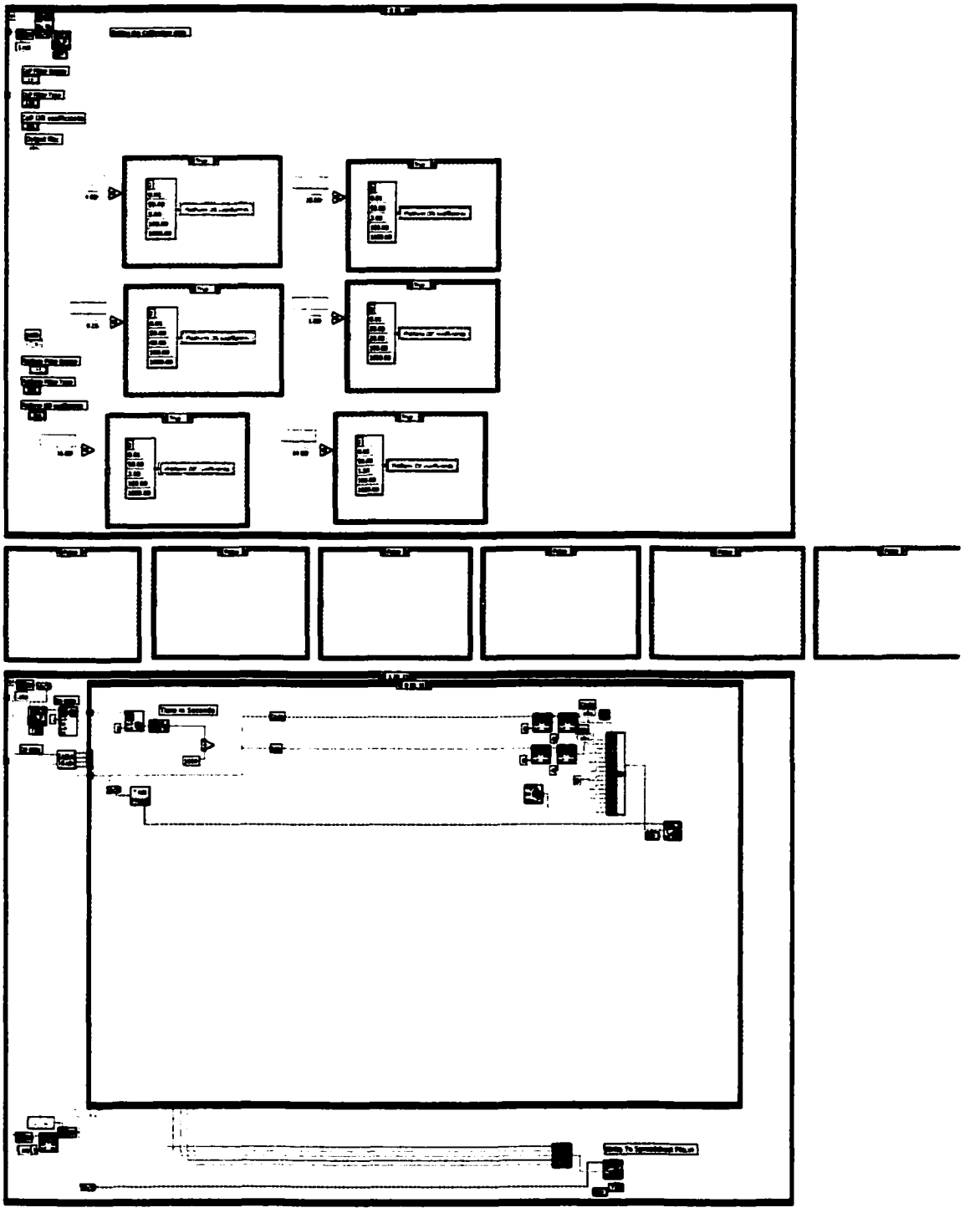
Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM



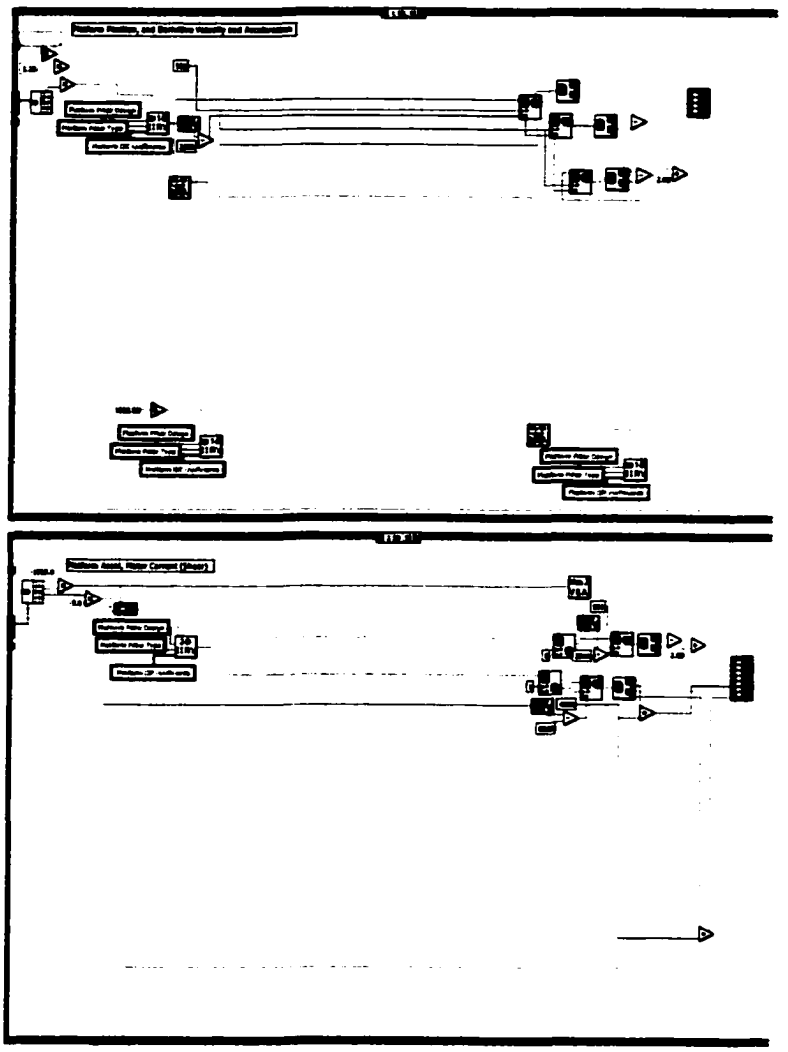
Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM



Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM



Convert RAW 2 Prieto CoP metrics_no_graphs3.vi
D:\Larry--Hard Disk_july 2002\PhD Ruston_July\VI's\Convert RAW 2 Prieto C metrics_no_graphs3.vi
Last modified on 3/31/2003 at 8:40 AM
Printed on 5/1/2003 at 2:53 PM



APPENDIX K:

COP Phase Plane Matlab Program cop_phase_plane.m

```
% This program calculates the COP from a raw data file, filters it, calculates the point
% by point differentiation, filters it, then plots the COP Phase plane and calculates
% the position and velocity of the COP at the start of the experiment, start of the move,
% middle of the move, end of the move, and end of the experiment
% 03/24/03
% Samantha Richerson and Poorna Yepru

% clear previous  entries
clear
pack
% Initial variables
substr={'f53gun'};
trialstr={ '4as0rf' '5as1rf' '1as2rf' '2as3rf' '3as4rf' };
dirstr={'F:\f53gu\'};
output=[];%Creating an empty array
i1=1; i3=2;
platewt=0.646;%Plate weight in voltage. Actual plate weight 101.34N
%conversion  392.4N/V divided by four load cells.
%Condition loop
  while i1 <=5,%Displacement criteria
    %sets the directory and filename specified
    dstr=char(dirstr(1));
    sstr=char(substr(1));
    astr=char(trialstr(i1));
    tstr=[sstr astr];
    fstr=[dstr sstr astr];
    sumstr=[fstr '.sum'];
    stastr=[fstr '.sta'];
    %Get info from summary file (skips the first four header lines of summary file)
    fid=fopen(sumstr);
      for j1=1:4,
      A=fgetl(fid);
      end%j1
    SUM1=fscanf(fid,'%f',[9 100]);
    SUM1=SUM1';
    fclose(fid);
    filenm=SUM1(:,1);
    buzz=SUM1(:,3);
    vel=SUM1(:,5);
    displ=SUM1(:,7);
    ltime=SUM1(:,9);
    clear SUM1
    %Get cal values
    calstr=[fstr '1.cal'];
    fid=fopen(calstr);
    CAL= fscanf(fid, '%f',[16 inf]);
```

```
CAL=CAL';
fclose(fid);
%calculates the calibration
mcal=mean(CAL(.10*length(CAL):.90*length(CAL),:));
%Plate Weight is substracted from the calibration values
fpcal=mcal(:,1:4)-platewt;
clear CAL mcal
%Threshold Testing loop.Opens different files and gets the information from them.
  for i3=[2:length(filenm)],
  if i3 < 10,rawstr=[fstr ' ' num2str(i3) '.raw']; end
  if i3 > 9,rawstr=[fstr  num2str(i3) '.raw']; end
  fid = fopen(rawstr);
    for j1=1:7, %Skips headers of the file
    A=fgetl(fid);
    end%j1
  RAW=fscanf(fid,'%f',[16,inf]);
  RAW=RAW';
  fclose(fid);
 %Assignment of information from the file
  Sheer=RAW(2000:9000,7);
  [start, move, stop] = Plat_Move(Sheer);%Determination of time of platform
movement
  move;
  start=round(move-(ltime(i3)*1000));
  stop=round(move+(ltime(i3)*1000));
  if start < 0
  else if move <0
     else if stop < 0
          i3=i3+1
       else if stop > length(Sheer)
            i3=i3+1
       else
          if start > stop
            temp1=start;
            temp2=stop;
            start=temp2
            stop =temp1
          end
  %Substract out calibration from force plate cells
  FP1=(RAW(:,1)+.0726)/-.0062;
      FP2=(RAW(:,2)+.0818)/-.0063;
      FP3=(RAW(:,3)+.0903)/-.006;
  FP4=(RAW(:,4)-0.1152)/-.006;
  %Calculate AP and ML COP
  APCOP=216.93*(FP1+FP4-FP3-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
  MLCOP=173.53*(FP3+FP4-FP1-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
```

```
%Calculating the mean APCOP & MLCOP
APCOP1=APCOP-mean(APCOP);
MLCOP1=MLCOP-mean(MLCOP);
%Filtering APCOP1 between 0.5Hz and 5Hz using a third order Butter worth
band pass filter
Wn=[0.5/500 5/500];
[b,a]=butter(3,Wn);
APCOP2=filtfilt(b,a,APCOP1);
APCOPrange=(max(APCOP2)-min(APCOP2));%Total APCOP range
%Getting all the APCOP values
APCOP3=APCOP2(2:end,1);
%APCOP at the start of experiment
APCOP4=APCOP2(1,1);
%APCOP at the end of experiment
APCOP5=APCOP2(end,1);
%Differentiating APCOP(position) to get APVEL(change in position)
APVEL=diff(APCOP2);
APVELrange=(max(APVEL)-min(APVEL));%Total APVEL range
%APVEL at the start of experiment
APVEL1=APVEL(1,1);
 %APVEL at the end of experiment
APVEL2=APVEL(end,1);

  %Determines the APCOP and APVEL values at the start,end of expt and
start,mid,end move
  apcopse=APCOP4;
  apcopsm=APCOP2(start);
  apcopmm=APCOP2(move);
  apcopem=APCOP2(stop);
  apcopee=APCOP5;
  apvelse=APVEL1;
  apvelsm=APVEL(start);
  apvelmm=APVEL(move);
  apvelem=APVEL(stop);
  apvelee=APVEL2;

 %Filtering MLCOP1 between 0.5Hz and 5Hz using a third order Butter worth
band pass filter
Wn=[0.5/500 5/500];
[b,a]=butter(3,Wn);
MLCOP2=filtfilt(b,a,MLCOP1);
MLCOPrange=(max(MLCOP2)-min(MLCOP2));%Total MLCOP range
%Getting all the MLCOP values
MLCOP3=MLCOP2(2:end,1);
%MLCOP at the start of experiment
MLCOP4=MLCOP2(1,1);
```

```
        %MLCOP at the end of experiment
        MLCOP5=MLCOP2(end,1);
        %Differentiating MLCOP(position) to get MLVEL(change in position)
        MLVEL=diff(MLCOP2);
        MLVELrange=(max(MLVEL)-min(MLVEL));%Total MLVEL range
        %MLVEL at the start of experiment
        MLVEL1=MLVEL(1,1);
        %MLVEL at the end of experiment
        MLVEL2=MLVEL(end,1);

          %Determines the MLCOP and MLVEL values at the start,end of expt and
start,mid,end move
          mlcopse=MLCOP4;
          mlcopsm=MLCOP2(start);
          mlcopmm=MLCOP2(move);
          mlcopem=MLCOP2(stop);
          mlcopee=MLCOP5;
          mlvelse=MLVEL1;
          mlvelsm=MLVEL(start);
          mlvelmm=MLVEL(move);
          mlvelem=MLVEL(stop);
          mlvelee=MLVEL2;

      %determine detection
      if buzz(i3)>=2
        detect = 1;
      else if buzz(i3)<2
          detect = 0;
        end
      end
        %figure
        %hold on
        %plot(APCOP3,APVEL,APCOP4,APVEL1,'kh
',apcopsm,apvelsm,'k*',apcopmm,apvelmm,'k+',apcopem,apvelem,'ko',APCOP5,APVEL
2,'k^');
        %hold off
        %legend('AP phaseplot','st expt','start move','mid move','end move','end
expt')%Legend box containing text in the figure
        %xlabel('APCOP position in mm')
        %ylabel('APVEL(Change in APCOP) in mm/sec')
        % Title string for figure
        %titlstr=[rawstr];
        %str=['AP phaseplot of ' titlstr];
        %title(str)
        %figure
        %hold on
```

```
%plot(MLCOP3,MLVEL,MLCOP4,MLVEL1,'kp',mlcopsm,mlvelsm,'ko',mlcopmm,mlv
elmm,'k+',mlcopem,mlvelem,'k*',MLCOP5,MLVEL2,'k^');
        %hold off
        %legend('ML phaseplot','st expt','start move' ,'mid move','end move','end
expt')%Legend box containing Text in the figure
        %xlabel('MLCOP positon in mm')
        %ylabel('MLVEL(Change in MLCOP) in mm/sec')
        %str=['ML phaseplot of '  titlstr];%Title string for figure
        %title(str)

        pstr=[i1 i3 apcopse apvelse apcopsm apvelsm apcopmm apvelmm apcopem
apvelem apcopee apvelee APCOPrange APVELrange mlcopse mlvelse mlcopsm
mlvelsm mlcopmm mlvelmm mlcopem mlvelem mlcopee mlvelee MLCOPrange
MLVELrange detect];
        output=[output; pstr];%Concatenation of the values of all trials
          i3=i3+1;
          end, end, end, end, end% Trial loop ends
      i1=i1+1;
      %Saves all the values to a ASCII file
      save e:\Samantha\cop_output\f53gu output -ascii -tabs
      end%Displacement loop ends
      output
```

APPENDIX L:

COP Phase Plane to Bins Matlab Program cop_bins.m

```
%Takes the output from the COP_Phase_plane.m file and calculates where the
%COM was at the start of the experiment, the start of the movement, the
%middle of the movement, and the end of the movement. Bins are taken as
%backward/moving backward, backward/moving forward, forward/moving backward
%and forward/moving forward. The number of instances of each are added and
%output.
%04/20/02
%Samantha Richerson

% clear previous entries
clear
pack

% Initial variables
i1 = 1;
det11=0; det12=0; det13=0; det14=0;
det21=0; det22=0; det23=0; det24=0;
det31=0; det32=0; det33=0; det34=0;
det41=0; det42=0; det43=0; det44=0;
det51=0; det52=0; det53=0; det54=0;
det61=0; det62=0; det63=0; det64=0;
det71=0; det72=0; det73=0; det74=0;
det81=0; det82=0; det83=0; det84=0;
det91=0; det92=0; det93=0; det94=0;
det101=0; det102=0; det103=0; det104=0;

detn11=0; detn12=0; detn13=0; detn14=0;
detn21=0; detn22=0; detn23=0; detn24=0;
detn31=0; detn32=0; detn33=0; detn34=0;
detn41=0; detn42=0; detn43=0; detn44=0;
detn51=0; detn52=0; detn53=0; detn54=0;
detn61=0; detn62=0; detn63=0; detn64=0;
detn71=0; detn72=0; detn73=0; detn74=0;
detn81=0; detn82=0; detn83=0; detn84=0;
detn91=0; detn92=0; detn93=0; detn94=0;
detn101=0; detn102=0; detn103=0; detn104=0;


% Get info from summary file
fid=fopen('e:\samantha\cop_output\f53gu');
for j1=1:2,
        A=fgetl(fid);
end %j1
SUM1=fscanf(fid,'%f',[27 inf]);
SUM1=SUM1';
fclose(fid);
```

```
disp=SUM1(:,1);
ap_soe=SUM1(:,3);
apvel_soe=SUM1(:,4);
ap_som=SUM1(:,5);
apvel_som=SUM1(:,6);
ap_mm=SUM1(:,7);
apvel_mm=SUM1(:,8);
ap_eom=SUM1(:,9);
apvel_eom=SUM1(:,10);
ap_eoe=SUM1(:,11);
apvel_eoe=SUM1(:,12);
ap_rng=SUM1(:,13);
apvel_rng=SUM1(:,14);
ml_soe=SUM1(:,15);
mlvel_soe=SUM1(:,16);
ml_som=SUM1(:,17);
mlvel_som=SUM1(:,18);
ml_mm=SUM1(:,19);
mlvel_mm=SUM1(:,20);
ml_eom=SUM1(:,21);
mlvel_eom=SUM1(:,22);
ml_eoe=SUM1(:,23);
mlvel_eoe=SUM1(:,24);
ml_rng=SUM1(:,25);
mlvel_rng=SUM1(:,26);
detect=SUM1(:,27);

clear SUM1
for i3=[1:1:length(disp)]
  if detect(i3) == 1,
    if (ap_soe(i3) <= 0 & apvel_soe(i3) <= 0), det11=det11+1; end
    if (ap_soe(i3) <= 0 & apvel_soe(i3) > 0), det12=det12+1; end
    if (ap_soe(i3) > 0 & apvel_soe(i3) <= 0), det13=det13+1; end
    if (ap_soe(i3) > 0 & apvel_soe(i3) > 0), det14=det14+1; end

    if (ap_som(i3) <= 0 & apvel_som(i3) <= 0), det21=det21+1; end
    if (ap_som(i3) <= 0 & apvel_som(i3) > 0), det22=det22+1; end
    if (ap_som(i3) > 0 & apvel_som(i3) <= 0), det23=det23+1; end
    if (ap_som(i3) > 0 & apvel_som(i3) > 0), det24=det24+1; end

    if (ap_mm(i3) <= 0 & apvel_mm(i3) <= 0), det31=det31+1; end
    if (ap_mm(i3) <= 0 & apvel_mm(i3) > 0), det32=det32+1; end
    if (ap_mm(i3) > 0 & apvel_mm(i3) <= 0), det33=det33+1; end
    if (ap_mm(i3) > 0 & apvel_mm(i3) > 0), det34=det34+1; end
```

```
  if (ap_eom(i3) <= 0 & apvel_eom(i3) <= 0), det41=det41+1; end
  if (ap_eom(i3) <= 0 & apvel_eom(i3) > 0), det42=det42+1; end
  if (ap_eom(i3) > 0 & apvel_eom(i3) <= 0), det43=det43+1; end
  if (ap_eom(i3) > 0 & apvel_eom(i3) > 0), det44=det44+1; end

  if (ap_eoe(i3) <= 0 & apvel_eoe(i3) <= 0), det51=det51+1; end
  if (ap_eoe(i3) <= 0 & apvel_eoe(i3) > 0), det52=det52+1; end
  if (ap_eoe(i3) > 0 & apvel_eoe(i3) <= 0), det53=det53+1; end
  if (ap_eoe(i3) > 0 & apvel_eoe(i3) > 0), det54=det54+1; end

  if (ml_soe(i3) <= 0 & mlvel_soe(i3) <= 0), det61=det61+1; end
  if (ml_soe(i3) <= 0 & mlvel_soe(i3) > 0), det62=det62+1; end
  if (ml_soe(i3) > 0 & mlvel_soe(i3) <= 0), det63=det63+1; end
  if (ml_soe(i3) > 0 & mlvel_soe(i3) > 0), det64=det64+1; end

  if (ml_som(i3) <= 0 & mlvel_som(i3) <= 0), det71=det71+1; end
  if (ml_som(i3) <= 0 & mlvel_som(i3) > 0), det72=det72+1; end
  if (ml_som(i3) > 0 & mlvel_som(i3) <= 0), det73=det73+1; end
  if (ml_som(i3) > 0 & mlvel_som(i3) > 0), det74=det74+1; end

  if (ml_mm(i3) <= 0 & mlvel_mm(i3) <= 0), det81=det81+1; end
  if (ml_mm(i3) <= 0 & mlvel_mm(i3) > 0), det82=det82+1; end
  if (ml_mm(i3) > 0 & mlvel_mm(i3) <= 0), det83=det83+1; end
  if (ml_mm(i3) > 0 & mlvel_mm(i3) > 0), det84=det84+1; end

  if (ml_eom(i3) <= 0 & mlvel_eom(i3) <= 0), det91=det91+1; end
  if (ml_eom(i3) <= 0 & mlvel_eom(i3) > 0), det92=det92+1; end
  if (ml_eom(i3) > 0 & mlvel_eom(i3) <= 0), det93=det93+1; end
  if (ml_eom(i3) > 0 & mlvel_eom(i3) > 0), det94=det94+1; end

  if (ml_eoe(i3) <= 0 & mlvel_eoe(i3) <= 0), det101=det101+1; end
  if (ml_eoe(i3) <= 0 & mlvel_eoe(i3) > 0), det102=det102+1; end
  if (ml_eoe(i3) > 0 & mlvel_eoe(i3) <= 0), det103=det103+1; end
  if (ml_eoe(i3) > 0 & mlvel_eoe(i3) > 0), det104=det104+1; end
end

if detect(i3) == 0,
  if (ap_soe(i3) <= 0 & apvel_soe(i3) <= 0), detn11=detn11+1; end
  if (ap_soe(i3) <= 0 & apvel_soe(i3) > 0), detn12=detn12+1; end
  if (ap_soe(i3) > 0 & apvel_soe(i3) <= 0), detn13=detn13+1; end
  if (ap_soe(i3) > 0 & apvel_soe(i3) > 0), detn14=detn14+1; end

  if (ap_som(i3) <= 0 & apvel_som(i3) <= 0), detn21=detn21+1; end
  if (ap_som(i3) <= 0 & apvel_som(i3) > 0), detn22=detn22+1; end
  if (ap_som(i3) > 0 & apvel_som(i3) <= 0), detn23=detn23+1; end
  if (ap_som(i3) > 0 & apvel_som(i3) > 0), detn24=detn24+1; end
```

```
    if (ap_mm(i3) <= 0 & apvel_mm(i3) <= 0), detn31=detn31+1; end
    if (ap_mm(i3) <= 0 & apvel_mm(i3) > 0), detn32=detn32+1; end
    if (ap_mm(i3) > 0 & apvel_mm(i3) <= 0), detn33=detn33+1; end
    if (ap_mm(i3) > 0 & apvel_mm(i3) > 0), detn34=detn34+1; end

    if (ap_eom(i3) <= 0 & apvel_eom(i3) <= 0), detn41=detn41+1; end
    if (ap_eom(i3) <= 0 & apvel_eom(i3) > 0), detn42=detn42+1; end
    if (ap_eom(i3) > 0 & apvel_eom(i3) <= 0), detn43=detn43+1; end
    if (ap_eom(i3) > 0 & apvel_eom(i3) > 0), detn44=detn44+1; end

    if (ap_eoe(i3) <= 0 & apvel_eoe(i3) <= 0), detn51=detn51+1; end
    if (ap_eoe(i3) <= 0 & apvel_eoe(i3) > 0), detn52=detn52+1; end
    if (ap_eoe(i3) > 0 & apvel_eoe(i3) <= 0), detn53=detn53+1; end
    if (ap_eoe(i3) > 0 & apvel_eoe(i3) > 0), detn54=detn54+1; end

    if (ml_soe(i3) <= 0 & mlvel_soe(i3) <= 0), detn61=detn61+1; end
    if (ml_soe(i3) <= 0 & mlvel_soe(i3) > 0), detn62=detn62+1; end
    if (ml_soe(i3) > 0 & mlvel_soe(i3) <= 0), detn63=detn63+1; end
    if (ml_soe(i3) > 0 & mlvel_soe(i3) > 0), detn64=detn64+1; end

    if (ml_som(i3) <= 0 & mlvel_som(i3) <= 0), detn71=detn71+1; end
    if (ml_som(i3) <= 0 & mlvel_som(i3) > 0), detn72=detn72+1; end
    if (ml_som(i3) > 0 & mlvel_som(i3) <= 0), detn73=detn73+1; end
    if (ml_som(i3) > 0 & mlvel_som(i3) > 0), detn74=detn74+1; end

    if (ml_mm(i3) <= 0 & mlvel_mm(i3) <= 0), detn81=detn81+1; end
    if (ml_mm(i3) <= 0 & mlvel_mm(i3) > 0), detn82=detn82+1; end
    if (ml_mm(i3) > 0 & mlvel_mm(i3) <= 0), detn83=detn83+1; end
    if (ml_mm(i3) > 0 & mlvel_mm(i3) > 0), detn84=detn84+1; end

    if (ml_eom(i3) <= 0 & mlvel_eom(i3) <= 0), detn91=detn91+1; end
    if (ml_eom(i3) <= 0 & mlvel_eom(i3) > 0), detn92=detn92+1; end
    if (ml_eom(i3) > 0 & mlvel_eom(i3) <= 0), detn93=detn93+1; end
    if (ml_eom(i3) > 0 & mlvel_eom(i3) > 0), detn94=detn94+1; end

    if (ml_eoe(i3) <= 0 & mlvel_eoe(i3) <= 0), detn101=detn101+1; end
    if (ml_eoe(i3) <= 0 & mlvel_eoe(i3) > 0), detn102=detn102+1; end
    if (ml_eoe(i3) > 0 & mlvel_eoe(i3) <= 0), detn103=detn103+1; end
    if (ml_eoe(i3) > 0 & mlvel_eoe(i3) > 0), detn104=detn104+1; end
      end
end
%Detects

det(2,1)=det21; det(2,2)=det22; det(2,3)=det23; det(2,4)=det24;
det(3,1)=det31; det(3,2)=det32; det(3,3)=det33; det(3,4)=det34;
```

```
det(4,1)=det41; det(4,2)=det42; det(4,3)=det43; det(4,4)=det44;

det(7,1)=det71; det(7,2)=det72; det(7,3)=det73; det(7,4)=det74;
det(8,1)=det81; det(8,2)=det82; det(8,3)=det83; det(8,4)=det84;
det(9,1)=det91; det(9,2)=det92; det(9,3)=det93; det(9,4)=det94;

det
%Non-Detects

detn(2,1)=detn21; detn(2,2)=detn22; detn(2,3)=detn23; detn(2,4)=detn24;
detn(3,1)=detn31; detn(3,2)=detn32; detn(3,3)=detn33; detn(3,4)=detn34;
detn(4,1)=detn41; detn(4,2)=detn42; detn(4,3)=detn43; detn(4,4)=detn44;

detn(7,1)=detn71; detn(7,2)=detn72; detn(7,3)=detn73; detn(7,4)=detn74;
detn(8,1)=detn81; detn(8,2)=detn82; detn(8,3)=detn83; detn(8,4)=detn84;
detn(9,1)=detn91; detn(9,2)=detn92; detn(9,3)=detn93; detn(9,4)=detn94;

detn
clear det detn
```

APPENDIX M:

Derivation of Transfer Function for Inverted Pendulum Model

Refer to Figure 15 for free body diagrams.

1. First forces are summed in the horizontal plane for the Slide

$$F := N + M \cdot \frac{d^2}{dt^2} x$$

2. Then forces are summed in the horizontal plane for the Pendulum

$$N := m \cdot \frac{d^2}{dt^2} x + m \cdot \cos\theta \cdot \frac{d^2}{dt^2} \theta \cdot \frac{L}{3} - m + \sin\theta \cdot \frac{d}{dt} \theta^2 \cdot \frac{L}{3}$$

3. Equation 1 is then subisituted into Equation 2 and simplified

$$F := (M + m) \cdot \frac{d^2}{dt^2} x + m \cdot \cos\theta \cdot \frac{d^2}{dt^2} \theta \cdot \frac{L}{3} - m + \sin\theta \cdot \frac{d}{dt} \theta^2 \cdot \frac{L}{3}$$

4. The forces are then summed in the vertical for the Pendulum

$$P \cdot \sin\theta + N \cdot \cos\theta - m \cdot g \cdot \sin\theta := m \cdot \frac{d^2}{dt^2} \theta \cdot \frac{L}{3} + m \cdot \cos\theta \cdot \frac{d^2}{dt^2} x$$

5. To remove the P and N terms, the moments are summed around the centriod

$$-P \cdot \sin\theta \cdot 2 \cdot \frac{L}{3} - N \cdot \cos\theta \cdot 2 \cdot \frac{L}{3} := I \cdot \frac{d^2}{dt^2} \theta$$

6. Subtituting Equation 4 into Equation 4 and simplifying yeilds

$$m \cdot g \cdot L \cdot \sin\theta + \frac{d^2}{dt^2} \theta \cdot \left(3 \cdot \frac{L}{2} + m \cdot \frac{L^2}{3} \right) := -m \cdot L \cdot \cos\theta \cdot \frac{d^2}{dt^2} x$$

7. Linearization is then done about the $\theta=\pi$ point. Thus $\theta=\pi+\phi$ where ϕ is a small angle from vertical. Therefore $\cos\theta=-1$, $\sin\theta=-\phi$ and $(d\phi/dt)2=0$. Assuming F = U for state space, Equation 3 becomes

$$U := (M + m) \cdot \frac{d^2}{dt^2} x - m \cdot \frac{d^2}{dt^2} \phi \cdot \frac{L}{3}$$

8. And Equation 6 becomes

$$-m \cdot g \cdot L \cdot \phi + \frac{d^2}{dt^2} \phi \cdot \left(3 \cdot \frac{L}{2} + m \cdot \frac{L^2}{3} \right) := m \cdot L \cdot \frac{d^2}{dt^2} x$$

9. Taking the Lapalce of Equation 7 yields

$$U(s) := (M + m) \cdot X(s) \cdot s^2 - m \cdot \Phi(s) \cdot s^2 \cdot \frac{L}{3}$$

10. And the Laplace of Equation 8 yeilds

$$-m \cdot g \cdot L \cdot \Phi(s) + \Phi(s) \cdot s^2 \cdot \left(3 \cdot \frac{L}{2} + m \cdot \frac{L^2}{3} \right) := m \cdot L \cdot X(s) \cdot s^2$$

11. Substituting 9 into 10 yeilds

$$U(s) := (M + m) \cdot \left[\left(\frac{\frac{m \cdot L^2}{3} + \frac{3 \cdot I}{2}}{m \cdot L} - \frac{g}{s^2} \right) \cdot \Phi(s) \cdot s^2 \right] - \Phi(s) \cdot s^2 \cdot m \cdot \frac{L}{3}$$

12. Putting this into transfer funciton form and simplifying yeilds the final transfer function

$$\frac{\Phi(s)}{U(s)} := \frac{6 \cdot m \cdot L}{\left(2 \cdot M \cdot m \cdot L^2 + 9 \cdot M \cdot I + 9 \cdot m \cdot I\right) \cdot s^2 - \left(6 \cdot M \cdot m \cdot g \cdot L + 6 \cdot g \cdot m^2 \cdot L\right)}$$

APPENDIX N:

COP reactions Matlab Porgram sub_COP_det_move

```
%Samantha Richerson
%Last Modified 03-24-03
%This program finds the COP,
%a raw data file, filters it, plots it, and saves it to an
%ascii file.

% clear previous entries
clear
pack

% Initial variables
substr={'f23gdc'};
trialstr={'5as3rf'};
dirstr={'D:\gamma\f23gd\'};
wt=52.73;
ht=1.6;
gravity=9.8;
i1 = 1;
platewt=0.646; %Plate weight in voltage. Actual Plate weight 101.34N
                                        %converstion 392.4N/V divided by 4 load cells.

% Condition loop
while i1 <= 1,          % Displacement criteria
%Sets the directory and filename specified
  dstr=char(dirstr(1));
  sstr=char(substr(1));
        astr=char(trialstr(i1));
        fstr=[dstr sstr astr];
  sumstr=[fstr '.sum'];
  stastr=[fstr '.sta'];


% Get info from summary file (skips the first four header lines of summary file)
        fid=fopen(sumstr);
        for j1=1:4,
        A=fgetl(fid);
                end %j1
        SUM1=fscanf(fid,'%f',[9,100]);
        SUM1=SUM1';
        fclose(fid);

  filenm=SUM1(:,1);
  buzz=SUM1(:,3);
  clear SUM1
```

```
% Get cal values
      calstr=[fstr '1.cal'];
      fid = fopen(calstr);
      CAL = fscanf(fid,'%f',[16 inf]);
      CAL=CAL';
      fclose(fid);
mcal=mean(CAL(.10*length(CAL):.90*length(CAL),:)); %Calculates the calibration
fpcal=mcal(:,1:4)-platewt; % Plate Weight is subtracted from calibration values
clear CAL mcal


% Threshold Testing loop. Opens three different files and gets the information from
them.
for i3=[1:2],
  if i3==1,rawstr=[fstr '19' '.raw']; end
  if i3==2,rawstr=[fstr '18' '.raw']; end

  fid=fopen(rawstr);
  for j1=1:7, %Skips headers of the file
    A=fgetl(fid);
          end %j1
          RAW=fscanf(fid,'%f',[16,inf]);
          RAW=RAW';
          fclose(fid);

      %Assignment of information from file
      plate=RAW(:,5);

% Subtract out calibration from force plate cells
FP1=(RAW(:,1)+.0726)/-.0062;
      FP2=(RAW(:,2)+.0818)/-.0063;
      FP3=(RAW(:,3)+.0903)/-.006;
FP4=(RAW(:,4)-0.1152)/-.006;
%Calculate AP and ML COP
      APCOPm=216.93*(FP1+FP4-FP3-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
MLCOPm=173.53*(FP3+FP4-FP1-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
APCOP=APCOPm-mean(APCOPm);
MLCOP=MLCOPm-mean(MLCOPm);
      clear FP1 FP2 FP3 FP4 RAW

Wn = [10/1000];     % Filter the signal
      [B,A]=butter(3,Wn);
COPAP=filtfilt(B,A,APCOP);
COPML=filtfilt(B,A,MLCOP);
```

```
%Determine if trial was a detect.
detect = 0;  % Initialize the detect to be false
            if (buzz(i3) == 2),
 detect = 1;
   elseif (buzz(i3)== 3),
   detect = 1;
 end

    %Create String for Title of Graph
 string=['ML COP from' rawstr]%  ' detect ' num2str(detect)]
 figure
 %plot plate movement, APCOP and the 4EMG on one plot

 title(string)
 subplot (2,1,1); plot(COPML(7000:14000))
 ylabel('ML COP')
 ylim ([-15 15])
 subplot(2,1,2); plot (plate(7000:14000))
 ylabel ('Plate')


 end
 i1=i1+1;
end
```

APPENDIX O:

Sway Modeling Matlab Program sway_tf_model.m

```
% This program uses an inverted pendulum model to calculate the
% sway of a person with mass m, inertia i, and height l to a
% perturbation
% Samantha Richerson
% 4/1/03
M=12;
m=80;
b=0;
i=252.9;
g=9.8;
l=1.185;

num=[6*m*l];
den=[(2*M*m*l^2+9*M*i+9*m*i) 0 -(6*M*g*m*l+6*g*m^2*l)];
t=0:0.001:8;


kd=2200;
k=12000;
ki=1;
numPID=[kd k ki];
denPID=[1 0];
numc=conv(num,denPID);
denc=polyadd(conv(denPID,den), conv(numPID, num));

[u,t] = gensig('sin',2,2,.001);
u(5001)=0
t=0:.001:5;

lsim(tf(-120*numc,denc),u,t)
sys=tf(-120*numc,denc);
[Wn,Z]=damp(sys)
```

APPENDIX P: EMG

Analysis Matlab Program EMGanalysis.m

```
%Samantha Richerson
%Last Modified 03-24-03
%This program finds the COP, and EMG
%a raw data file, filters it, plots it, and saves it to an
%ascii file.

% clear previous entries
clear
pack

% Initial variables
substr={'m65gkn'};
trialstr={'3as0rf'};
dirstr={'D:\gamma\m65gk\'};
i1 = 1;
platewt=0.646; %Plate weight in voltage. Actual Plate weight 101.34N
                                        %converstion 392.4N/V divided by 4 load cells.

% Condition loop
while i1 <= 1,          % Displacement criteria
%Sets the directory and filename specified
  dstr=char(dirstr(1));
  sstr=char(substr(1));
        astr=char(trialstr(i1));
        fstr=[dstr sstr astr];
  sumstr=[fstr '.sum'];
  stastr=[fstr '.sta'];


% Get info from summary file (skips the first four header lines of summary file)
        fid=fopen(sumstr);
        for j1=1:4,
        A=fgetl(fid);
                end %j1
        SUM1=fscanf(fid,'%f',[9,100]);
        SUM1=SUM1';
        fclose(fid);

  filenm=SUM1(:,1);
  buzz=SUM1(:,3);
  clear SUM1


  % Get cal values
        calstr=[fstr '1.cal'];
```

```
        fid = fopen(calstr);
        CAL = fscanf(fid,'%f',[16 inf]);
        CAL=CAL';
        fclose(fid);
  mcal=mean(CAL(.10*length(CAL):.90*length(CAL),:)); %Calculates the calibration
  fpcal=mcal(:,1:4)-platewt; % Plate Weight is subtracted from calibration values
  clear CAL mcal


% Threshold Testing loop. Opens three different files and gets the information from
them.
  for i3=[1:5],
    if i3<10,rawstr=[fstr '' num2str(i3) '.raw']; end
    if i3>=10,rawstr=[fstr num2str(i3) '.raw']; end

    fid=fopen(rawstr);
    for j1=1:7, %Skips headers of the file
      A=fgetl(fid);
              end %j1
              RAW=fscanf(fid,'%f',[16,inf]);
              RAW=RAW';
              fclose(fid);

        %Assignment of information from file
        plate=RAW(:,5);
   EMG1=RAW(:,9);
          EMG2=RAW(:,10);
          EMG3=RAW(:,11);
          EMG4=RAW(:,12);
    Sheer=RAW (:,7);
    [start, move, stop] = Plat_Move(Sheer);% Determination of time of platform
movement using plate_move function.

  % Subtract out calibration from force plate cells
  FP1=(RAW(:,1)+.0726)/-.0062;
        FP2=(RAW(:,2)+.0818)/-.0063;
        FP3=(RAW(:,3)+.0903)/-.006;
  FP4=(RAW(:,4)-0.1152)/-.006;
  %Calculate AP and ML COP
        APCOPm=216.93*(FP1+FP4-FP3-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
  MLCOPm=173.53*(FP3+FP4-FP1-FP2)./(FP3+FP4+FP1+FP2+(4*platewt));
 APCOP=APCOPm-mean(APCOPm);
 MLCOP=MLCOPm-mean(MLCOPm);
        clear FP1 FP2 FP3 FP4 RAW

  Wn = [10/1000];     % Filter the signal
```

```
      [B,A]=butter(3,Wn);
COPAP=filtfilt(B,A,APCOP);
COPML=filtfilt(B,A,MLCOP);
%Determination of placement of resultant sigal. If AP and ML COP are negative
%then the resultant is negative, if either one is negative, resultant is
%negative. If both are positive, then resultant is positive
sign=tan(COPML./COPAP);
signave=mean(sign);
if mean(COPAP) < 0
  if mean(COPML) <0
    temp=sqrt((COPML.^2)+(COPAP.^2));
    COPR=-temp;
  else
    temp=sqrt((COPML.^2)+(COPAP.^2));
    COPR=-temp;
  end
elseif mean(COPAP)>0
  if mean(COPML) <0
    temp=sqrt((COPML.^2)+(COPAP.^2));
    COPR=-temp;
  else
    COPR=sqrt((COPML.^2)+(COPAP.^2));
  end
end
  %Subtract out means of EMG signals
  Avg1=abs(EMG1-(mean(EMG1)));
  Avg2=abs(EMG2-(mean(EMG2)));
  Avg3=abs(EMG3-(mean(EMG3)));
  Avg4=abs(EMG4-(mean(EMG4)));
  %Filter EMG Signals
  [B,A]=butter(3,40/1000);
       RTib=filtfilt(B,A,Avg1);
  RSol=filtfilt(B,A,Avg2);
  LTib=filtfilt(B,A,Avg3);
  LSol=filtfilt(B,A,Avg4);

  %Determine if trial was a detect.
 detect = 0;  % Initialize the detect to be false
            if (buzz(i3) == 2),
   detect = 1;
 elseif (buzz(i3)== 3),
   detect = 1;
 end

      %Create String for Title of Graph
  string=['Rectfied Filtered EMG from' rawstr]%  ' detect ' num2str(detect)]
```

```
figure
%plot plate movement, APCOP and the 4EMG on one plot

title(string)
subplot (5,1,1); plot(COPAP)
ylabel('AP COP')
ylim ([-15 15])
subplot(5,1,2); plot (RTib)
ylabel ('R Tib')
ylim([-.15 .15])
subplot(5,1,3); plot (LTib)
ylabel('LTib')
ylim([-.15 .15])
subplot(5,1,4); plot (RSol)
ylabel('Rsol')
ylim([-.15 .15])
subplot(5,1,5); plot (LSol)
ylabel('LSol')
ylim([-.15 .15])
xlabel('time (ms)')

%plot plate movement, AP COP, ML COP and the sum of the sqares of the two
string3=['COP from' rawstr ' detect ' num2str(detect)]
figure
subplot(3,1,1); plot (plate)
ylabel ('Plate')
title (string3)
subplot(3,1,2); plot (COPAP)
ylabel ('AP COP')
ylim([-20 20])
subplot(3,1,3); plot (COPML)
ylabel('ML COP')
ylim([-20 20])



%little plots
%figure
%subplot (2,1,1); plot (COPAP)
%ylabel('AP COP')
%ylim ([-20 20])
%subplot(2,1,2); plot (RTib)
%ylabel ('R Tib')

%figure
%subplot (2,1,1); plot (COPAP)
```

```
    %ylabel('AP COP')
    %ylim ([-20 20])
    %subplot(2,1,2); plot (LTib)
    %ylabel ('L Tib')

    %figure
    %subplot (2,1,1); plot (COPAP)
    %ylabel('AP COP')
    %ylim ([-20 20])
    %subplot(2,1,2); plot (LSol)
    %ylabel ('L Sol')
    %figure
    %subplot (2,1,1); plot (COPAP)
    %ylabel('AP COP')
    %ylim ([-20 20])
    %subplot(2,1,2); plot (RSol)
    %ylabel ('R Sol')

  end
  %Save plate movement, AP COP, and 4 EMG to file to output to Kalidagraph
  %save d:\temp\plate_M23bp28.txt plate -ascii -double -tabs
  %save d:\temp\ACOP_M23bp28.txt COPAP -ascii -double -tabs
  %save d:\temp\RTib_M23bp28.txt RTib -ascii -double -tabs
  %save d:\temp\LTib_M23bp28.txt LTib -ascii -double -tabs
  %save d:\temp\RSol_M23bp28.txt RSol -ascii -double -tabs
  %save d:\temp\LSol_M23bp28.txt LSol -ascii -double -tabs
  i1=i1+1;
end
```

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