FINAL PERFORMANCE REPORT

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"Fall Potential of Work on Elevated and Inclined Surfaces"

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LIST OF ABBREVIATIONS

IPSB: Index of Proximity to Stability Boundary

SAR: Sway Area Ratio

WRTI: Weighted Residence Time Index

FSB: Functional Stability Boundary

TSB: Theoretical Stability Boundary

CP: Center of Pressure

CG: Center of Gravity

p: Minimum distance between the stabilogram and the FSB

R_{max}: Radial distance of the point on the FSB that is closest in proximity to the CP

A_{sb}: Area of the FSB

α^i: Fraction of time spent in the proximity of zone i.

BOSA: Base of supporting area

PSOF: Perceived Sense of Slip or Fall

COF: Coefficient of friction

Fx: Horizontal force in the x-direction

Fy: Horizontal force in the y-direction

Fz: Vertical force

AP: Anterior-Posterior

ML: Medio-lateral

H/V or RCOF: Ratio of resultant horizontal force to vertical force or Required or Utilized coefficient of friction

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SIGNIFICANT FINDINGS

The results from the current study with 74 industrial workers suggest the following ordering for the effects of risk factors and covariates on postural balance: (1) task; (2) lighting; (3) visual cue; (4 and 5) inclination/elevation; (6) gender; (7) arm/leg reaction time; with weight, height, race and age all seldom significantly affecting postural sway. The task performed was found to significantly affect all ten outcome sway variables. For each postural sway outcome, the reach task evoked the greatest sway, followed by the bending task, with the stationary task evoking the least postural sway. Lighting was found to affect 8 of the 10 postural sway outcomes. In general, sway increased in poor lighting.; however, the maximum excursion in the anterior-posterior (AP) direction and the minimum Horizontal force/Vertical forces (H/V) were actually diminished in poor lighting as compared to good lighting. Low H/V values imply lesser demand on COF requirement. This could be due to "cautious" slow body motions (which in turn will decrease shear forces) used in poor light to prevent a potential fall. Presence of a visual cue significantly affected four of the ten postural sway outcomes, sway area, sway length, average excursion in the AP direction and minimum H/V. The presence of either visual cue tended to decrease sway relative to having no visual cue implying better balance. The effects of the inclination and elevation factors are difficult to separate, given the many models in which they significantly interacted with each other and with other factors and also the non-monotonic nature of many of their relationships with the outcomes. The subjective PSOF response to inclination (Table 20) showed that subject's were showing increasing sense of loss of balance (as PSOF values increased monotonically with increasing inclination levels) even though the objective measures of sway (sway length) were not giving consistent and significant association with increasing values of inclination (Table 7). This discrepancy between subjective and objective measures of postural balance imply that subjects were overcautious as they stood on inclined surfaces of increasing angles. This increased "awareness" of their own body sway might have elicited counteracting postural muscle activities to overcompensate which can only be validated with measures of electromyographic outcomes of the postural muscles. In the workplace, it is probably advantageous to have a somewhat overcautious response [i.e. a higher PSOF values even though the objective measures (i.e. sway length) show a smaller value] while performing tasks on inclined and elevated surfaces. In the present study, the WRTI values (Table 25) show monotonically decreasing with increasing inclination implying that the body is overcautious and is trying to keep the whole body CG closer to the center of its stability boundary as the inclination is increasing. The objective measure of sway length showed significant interaction between inclination and elevation (Table 7) but the subjective measure PSOF (Table 19) did not show a significant association. It is interesting to note that sway length was generally increased at higher elevations when the inclination angle increased, implying overcompensation by the postural muscles due to psychophysical fear of fall or height (Table 14). However, the subjective response of PSOF did not show significant inclination by elevation interaction (Table 19) implying that while working on elevated inclined surfaces there exists the potential mismatch between actual danger of loss of stability (as measured by sway variables) and the workers' ability to subjectively judge the need to deploy the necessary compensatory postural muscle contractions.

ABSTRACT

This study provides an experimental design for investigating the interaction between age, sex and other fall risk factors such as standing surface elevation/inclination, job-task and lighting. In this study, postural instability and propensity of loss of balance risk factors were evaluated for 74 industrial workers' performance (22 to 60 years of age) on test conditions which represent combinations of these risk factors. There are environmental (lighting), job-task (stationary versus dynamic) and personal (age) risk factors which can individually and/or collectively jeopardize one's ability to perform tasks on elevated/inclined surfaces without experiencing postural imbalance and, eventually, a fall. All test conditions (encompassing all fall risk factors) evaluated in the present study are rank-ordered for postural balance/instability. This study addressed the following questions: (a) How do work surface inclination and elevation and distraction affect postural balance under conditions of good and poor lighting? and (b) What type and positioning of visual cues are beneficial in reducing postural instability while performing simulated industrial tasks on inclined and elevated surfaces? Results obtained from this study with industrial worker subjects now provide the basis for future prospective studies using a larger sample from the worker population. The results obtained from this study will now help enhance our existing statistical model showing the relationship between propensity of loss of balance and the independent variables characterizing the environmental, job-task, and personal risk factors. A determination of which of the risk factors need to be corrected to reduce the fall potential at the workplace will then be possible. The significant findings from this study are given in the previous Section.

A. Specific Aims

A1. To determine the postural balance effects of performing simulated industrial tasks by industrial workers aged 21 to 29 years and 50 to 59 years while standing on three inclined surfaces (0°, 14° and 26°) at three elevations (ground/floor, one foot, and two feet above floor) under good (72 foot-candles) and poor lighting (0.2 foot-candles) conditions (Phase I).

A2. To determine the contributions of individual and combined risk factors of standing surface inclination, elevation, environmental lighting, and age on modifying the propensity for postural imbalance (which might contribute to fall potential) during performance of industrial tasks (Phase I). The terms propensity of loss of balance and propensity of momentary loss of balance are used interchangeably throughout this application.

A3. To determine the types (horizontal or vertical or horizontal plus vertical) and number of visual cues (in periphery or in central visual field or both) needed to help in the reduction of propensity for postural imbalance (which might contribute to reducing fall potential) while performing tasks under various combinations of risk factors (standing surface inclination, elevation, environmental lighting, and age) (Phases II and III).

B. BACKGROUND AND SIGNIFICANCE

Falls from elevations present significant potential for debilitating accidents causing permanent disability or fatality. Typically, workers in the construction industry and fire/emergency services are exposed to the greater risk of working at higher elevations. As per 1988 Bureau of Labor Statistics (BLS) data, fall was the third leading cause of work-related injuries.[1] The construction industry has the highest percentage (22%) of fall-related injuries, followed by the service, transportation, public utilities, trade, and wholesale/retail industries.[1] As per 1990 Ohio Injury Statistics from the Bureau of Workers' Compensation (BWC), 3322 injuries out of 10,120 were due to falls from a different level.[2] In this category, falls from a ladder/scaffold caused 1597 injuries. The severity of injuries due to fall from elevation is significantly higher than that of fall from the same level. Falls have been found to be a significant contributor in causing lumbar spine injury, fracture of bones, and disability.[3,4] In 1990, the Ohio BWC reported average days lost due to fall from elevation was the highest at 25.3 days compared to 18.9 days and 19 days due to fall at the same level and overexertion, respectively.[2] According to compensation data covering 91,953 construction accidents in New York from 1980-1988, falls had cost the second largest amount ($231,889,484).[5]

Nationally, in 1991, the National Safety Council[6] estimates that work-related falls caused the second highest level of fatalities. Among all industries, the construction trade has the highest rate of fall-related fatalities. An analysis of the database from the National Institute for Occupational Safety and Health (NIOSH) National Traumatic Occupational Fatalities (NTOF) for the period of 1980-1985 indicates that 17% of the workers had fatal falls while performing a task on a scaffold.[7] In another study of data from NIOSH's database of Fatal Accident Circumstances and Epidemiology (FACE) for 1987-1989, it was found that fatal falls have occurred from heights as low as three feet.[8] In an

analysis of accident profiles among New York industries, Cohen[9] found that falls were attributable to a combination of surface conditions and poor lighting. They also reported that 66% of these accidents occurred indoors where lighting conditions may be less than optimal, as in the case of new construction.

Generally, before a fall incident occurs, the worker first experiences postural imbalance or propensity for loss of balance increases. In many cases the time between the first experience of loss of balance and the actual event of fall is so short that the worker's postural corrective efforts are not effective. Inability to change the base of support due to poor environmental lighting (or poor vision), unavailability of support or friction demands usually constitute an increased fall or near fall potential in the event of a momentary loss of balance. If one can a priori determine the contribution of various risk factors' (at the workplace these risk factors could be related to task, the environment or personal factors), either alone or collectively, to increase the propensity for loss of balance, then intervention strategies can be devised and implemented. The assessment of propensity for loss of balance can be accomplished by evaluating the movement pattern of the body's center of pressure (CP) with respect to the subject's base of support[10]. Therefore, it is appropriate to synthesize the above information regarding existence of risk factors in the workplace which have the potential to produce increased propensity for loss of balance (or postural imbalance). Such risk factors exist almost daily in the workplace. For example, in the day-to-day performance of their jobs, construction workers have to work on rooftops (inclined surface), stand on ladders and/or scaffolding at various heights, stand on surfaces which may not be big enough to support the entire area of their feet (e.g., standing on a 2" x 4" piece of lumber or work while standing on the step of a ladder), and work in poor environmental lighting conditions.[11] Each of these factors is detrimental to the worker's ability to maintain postural balance while performing certain tasks such as bending down to pick up an object from the floor level, and reaching to pick up a weight. Nashner et al.[12] provided evidence that, if a person has to maintain balance while standing on a narrow beam (e.g. standing on a 2" x 4" piece of lumber or a step of a ladder), s/he will have to use a hip movement strategy which will produce excessive shear forces at the foot/floor interface. This type of postural control strategy might be inadequate for balance maintenance on surfaces with low friction.

The results from pilot studies provide some evidence as to how the performance of a dynamic task while standing on inclined surfaces and elevated surfaces produces excessive demand on the postural control system and increases postural instability.[13-14] This detrimental effect is further pronounced if the task is performed under poor environmental lighting conditions.[13] A similar effect of visual deprivation on postural balance has been noted by other investigators.[15,16] Previous researchers have shown that adults place significant reliance on visual information for proper maintenance of balance.[17-18] Proper maintenance of postural balance requires availability of visual cues congruent with the signals coming from other relevant afferent systems (vestibular and proprioception systems). While these systems are redundant for balance maintenance, previous researchers have shown that inaccurate cues from vision and proprioception places undue stress on the vestibular system.[12,15-19] With aging, both vision and proprioception systems are detrimentally affected.[19] Therefore, postural stability deteriorates with age.[20-21] The issue of our aging workforce, therefore, becomes a critical matter of concern in understanding the role of these factors in compromising an older worker's ability

to maintain balance while working on inclined/elevated surfaces.

A literature review indicates that availability of visual cues in the front (i.e., central) and peripheral visual fields are critical for maintenance of postural balance while standing at floor level.[22,23] However, the data are far from comprehensive regarding the role of visual cues needed for maintaining "safe" postural balance while performing industrial tasks on inclined surfaces and elevated surfaces. The "safe" postural balance is characterized by quantitating the movement pattern of the body's center of pressure (CP) with respect to the base of support (i.e., the outer perimeter of the feet). The propensity for loss of balance increases as the postural sway-induced movement of CP approaches the stability boundary defined by the outer edges of the subject's feet.

In the workplace, poor environmental lighting and/or poor vision (due to aging) can place excessive demand on the remaining afferent systems, thereby compromising the worker's ability to maintain a safe postural balance. Poor lighting along with obstruction of peripheral vision (due to poor workplace layout or due to use of respiratory protective devices) can place the worker at risk for a fall or other accidents to occur.[24-26]

The phenomenon of fall is dependent not only on physiological, environmental and frictional factors, but it is also heavily influenced by one's perceptions (or higher center input) of how one would handle an impending fall. This implies that the body's response to prevent a fall is not entirely reflexive in nature; rather, it utilizes a pre-programmed central nervous system-based sequence of postural corrective measures. Several investigators[26-29] have documented that, if a person moves her/his body segment (e.g., an arm) while standing upright, there exists a postural adjustment preceding this movement. In an occupational situation, an analogy to the above-mentioned scenario can be drawn. Workers, during their job performance, have to make decisions regarding how they should orient their bodies for postural stability. For example, a construction worker standing on an elevated/inclined surface may have to bend down or reach forward to perform a task. Such body movement will cause a displacement of body mass with respect to the support base such that postural adjustment will be needed to sustain postural stability. Under these circumstances, the worker's ability to perceive balance demands will be critical in deploying the centrally-initiated postural adjustment in advance of actual body movement. Appropriate assessment of balance demands will trigger the necessary postural stabilization processes to reduce postural sway produced by the actual or focal body movement and, thereby, reduce the chance of fall. Several questions remain unanswered, one of which is whether an appropriately-placed visual cue (in the subject's field of view) will minimize postural instability. Another important issue is the effect of distraction on the propensity for loss of balance while performing a task at an elevated/inclined surfaces. These issues have been further evaluated in this study.

While it is important to address the issue of the coefficient of friction (COF) and slipperiness, a thorough understanding of falls from elevated/inclined surfaces requires the study of personal factors as well, such as the effect of age on a person's ability to maintain balance, types of visual information needed, postural adjustment capability due to sudden movement of a body segment, the perception of an impending fall under various job-related risk factors (standing surface elevation/inclination),

and environmental risk factors (such as lighting). In other words, this study has attempted to address the following questions: (a) How do work surface inclination and elevation and **distraction** affect postural balance under conditions of good and poor lighting for various age ranges? and (b) What type and positioning of visual cues will be beneficial in reducing postural instability while performing simulated industrial tasks on inclined and elevated surfaces?

B.1. RELEVANCE AND SIGNIFICANCE TO WORKERS' HEALTH AND SAFETY: Results obtained from this study with i**ndustrial worker subjects** provided the basis for future prospective study using a larger sample from the worker population. For example, all test conditions (encompassing fall risk factors such as surface elevation, inclination, environmental lighting, and visual cues) evaluated in this study has been rank-ordered for propensity for loss of balance.These findings will provide the framework within which future worker-population-based prospective studies can be designed to address the following issues.

a. The results from this study can now further enhance an existing statistical model showing the relationship between propensity for loss of balance and the independent variables characterizing the Environmental, Job-Task and Personal risk factors for task performance on elevated/inclined surfaces[13, 29]. In future field studies, this statistical model can be used to help evaluate the propensity for momentary loss of balance by measuring, in a walk-through evaluation, existing risk factors at the worksite. A determination of which of the risk factors need to be corrected to reduce the propensity for loss of balance will then be possible. Availability of such models will have significant impact in identifying risk factors.

b. Based on the results of the present study, intervention strategies for fall prevention while working on elevated/inclined surfaces can be developed: (1) by placing appropriate visual cues needed to reduce propensity for postural instability (which might contribute to reducing fall potential) and (2) by identifying certain combinations of risk factors which are more dangerous in producing falls.

c. The results from the study can be readily generalizable, as the study population were obtained from the workforce representing various industries with special reference to age, gender and physical fitness.

C. METHODS

C.1. Worker-Subjects: A total of 74 subjects were recruited for this study which was carried out in three phases. Phases I, II and III used 40, 10 and 24 subjects, respectively.

The subjects were recruited from Unions, with whom we have established contact, which represent a variety of trades. These included service trades such as maintenance and janitorial, commercial food service workers, construction workers and plumbers/pipefitters.

Contact with potential subjects was made via fliers and via communication with subjects from previous studies performed in our laboratory. The fliers were either posted in the Union Hall, sent as direct mailings, or through informational meetings with groups. Once contact was established and potential subjects had volunteered, they were first screened using a preliminary questionnaire (see Appendix A) to determine both health status and occupational exposures to chemicals known to produce health and postural sway effects.

Upon satisfactorily completing the preliminary questionnaire phase of screening, potential subjects were then examined medically by a physician, who made the final determination as to whether the individual was in fact suitable for inclusion in the study. If the physician deemed it necessary to exclude individuals from participation, they were referred to their primary care physician for follow-up. Once an individual was included as a study participant, they were given a set of guidelines to clarify and reinforce the study protocol requirements.

Due to the number of visits to the laboratory required by subjects, every effort was made to schedule appointments with consideration given to individual work schedules. Recruitment was therefore conducted in an ongoing fashion to insure an evenly distributed workload and be able to accommodate the workers' schedules. This method of recruitment allowed the subjects will be actively involved over a shorter period of time, thereby increasing the participation rate and decreasing the potential attrition rate due to various reasons including loss of interest, conflict with workers' schedules and changes in lifestyle which might affect their health status.

The subject screening procedure involved obtaining medical and work history data by having the subject fill out a questionnaire developed for this study in collaboration with our occupational medicine physician faculty (Appendix A). This questionnaire was reviewed by an occupational medicine resident (under supervision by occupational medicine faculty), the project coordinator and the principal investigator to see if the potential subject has met all the criteria set in our original application. Any questions and unclear answers were clarified by a follow-up telephone call. Next, the subject was scheduled for medical screening at our department's occupational medicine clinic.

C.2. Risk Factors/Treatment Conditions (Independent Variables)

Inclined Surface (Condition 1): Three levels of inclination were used, 0°, 14° and 26°. A majority of constructions (both residential and commercial) use the above-mentioned roof inclination angles. Three specially-designed inclined surfaces (see Section C3 for details) were attached to the force plate to obtain the desired values of inclinations.

Elevated Surface (Condition 2): Floor (or ground), 12" and 24" above floor levels were used. In a workplace, it is not uncommon to have workers perform various tasks at elevations less than those found at the roof-top such as working while standing on a stepping stool or ladder (e.g. ceiling work, hanging drywall etc). Based on our preliminary studies, we have observed that elevations as low as 7" and 14" produce a significant increase in postural sway and increase activities of some of the postural muscle groups (anterior tibialis and gastrocnemius)[13] . A loss of balance occurring even

at smaller elevations might cause a serious injury if not fatal. Bobick et al.[8] have reported that consequences of falls are always severe no matter how low the elevation. Three specially-designed elevated surfaces (see Section C3 for details) were attached to the force plate to obtain the desired elevation levels.

Work Environment Lighting (Condition 3): Availability of proper visual cues are critical for maintenance of postural balance. In a poorly lit area, visual cues will be inadequate for the maintenance of balance. In a work environment, lighting has been found to be one of the critical factors related to accidents due to falls. In this study, subjects were tested for postural balance under two extremely different lighting conditions, using illumination guidelines for rough to moderately precise work: (1) Acceptable, good lighting: 320 - 800 lux (30 - 74 foot candles) and (2) Unacceptable, poor lighting: < 20 lux (< 2 foot candles). A light meter was used for measuring the lighting condition (in lux). All subjects were presented with these same two conditions of lighting.

Visual Cues (Condition 4): At least three types of cues were used: None, Vertical and/or horizontal cues (fluorescent material were used for visibility in poor light) in the central visual field, and visual cues in the periphery. Results from our preliminary study [30] and other investigators show evidence that vision plays an important role in postural balance control.[15,16,18] The type and location of visual cues needed for the maintenance of upright balance while performing industrial tasks at elevation and/or on inclined surfaces is not well understood.

Distraction Condition (Condition 5): Each task was carried out with and without exposure to actual construction site noise.

Postural Stability Tasks (Condition 6):

Stationary: Stand erect on the platform for 30 s with hands at the hip.

Bending: (i) Stand erect on the platform for 12 s, (ii) rapidly bend upper trunk to touch the knees, (iii) stay in this position for 5 seconds, and (iv) straighten back up for the remaining 13 seconds. (see figure 1)

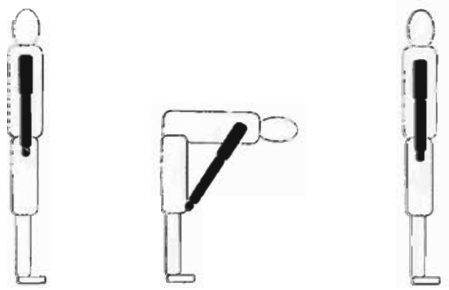
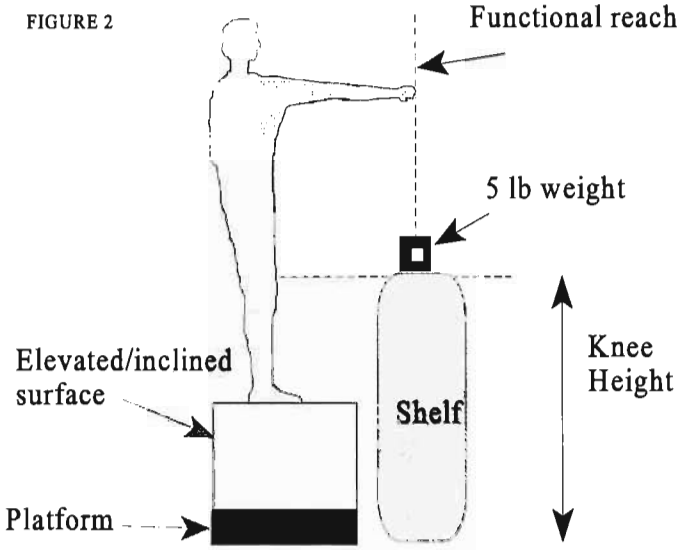


FIGURE 1

Reach: (I) Stand erect on the platform for 7 s, (ii) reach forward to pick up a weight attached to a 2x4x24 in^3 wood (cumulative weight of 5.2 lbs), bring it close to the belly, and replace it on the shelf, (iii) repeat step (ii) for 4 cycles, (iv) reassume the erect position for the remaining time. The shelf is placed at the knee height and at a functional reach away from the subject as shown in figure 2.

FIGURE 2



C.3 Elevation Study Facility:

Specialized Enclosure Unit: The unit consists of three modular framework structures, made of light-weight aluminum, that can be fitted with fabric panels. Figure 3 provides a schematic representation of the enclosure system. The first phase of the construction used only the front side panels. These enclosure walls (panel) uses a flat black felt-type fabric, that forms a uniform viewing surface offering minimal visual cues. The aluminum panel framework pieces are interconnected with removable screw-knobs. The cloth panels, made of feltwork fabric on fire-resistant plastic sheath are lined with magnetic strips. Matching strips are found on the framework pieces. As a preliminary setup, the enclosure framework was constructed to the height of the false ceiling (92 inches). The roof of the ceiling was constructed by adhering flat black chart paper to the false ceiling and painting the visible parts of the ceiling with compatible shade of spray paint. It was however discovered that the enclosure was restrictive towards the taller subjects, since the edge of the roof would have to be visible to the subject as s/he stands on the force platform.

This problem was alleviated by relocating the enclosure to a remote corner of the facility, where extra height was added to the enclosure wall (18 inches), using supplemental pieces. A rigid roof

structure, made of the similar material as the walls of the enclosure, was hung from the top to add uniformity to the appearance of the enclosure.

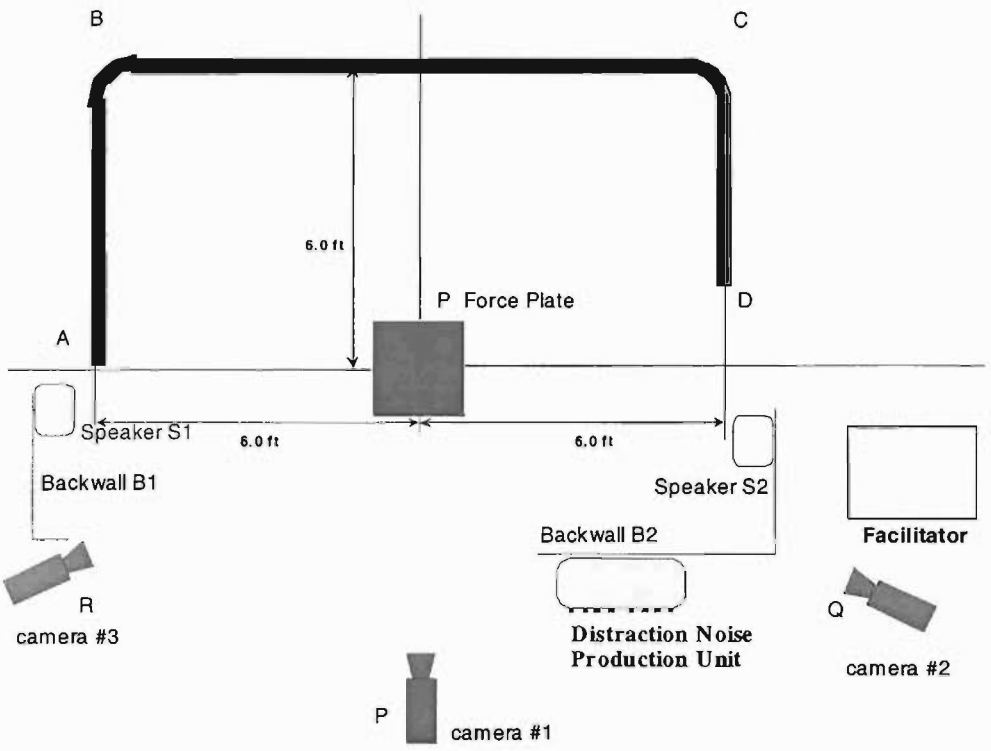


Figure 3: Schematic Layout of Test set up

The roof of the enclosure extends up to and above the subject's head. The floor of the enclosure was covered with a low-pile black carpet to minimize further visual cues. This facility has been enhanced to include a specially designed overhead single-point safety harness hookup. This system accommodates a hook that allows the whole body safety harness to be attached to it while the subject stands on an inclined/elevated surface at various elevations performing the assigned study protocol.

Repeated video recording of the sagittal and frontal plane (with the camera placed directly behind the subject) movements during task performance was made with the camera placement. The placement of the sagittal plane camera was found to interfere with continuous visibility of the relevant markers. After performing a detailed digitization session for the sagittal and frontal view video pictures, an alternate methodology was adopted to reduce errors that may be introduced due to missing marker views. The final version included three cameras (instead of two) and uses a three-

dimensional *direct linear transformation* (DLT) analysis for more accurate calculation of the marker movement and the movement of the center of gravity (CG). Figure 3 shows the final layout of the three cameras used in Phase I of this study. Specifications for the cameras: Camera #1: Pulnix 60 Hz (Peak Performance serial # 007041, with Fujinon TV zoom lens model # RH6X12.5A); Camera #2: Burle 60 Hz (model TC351A, serial # 909165); Camera #3: Burle 60 Hz (model TC351A, serial # 909047).

Distraction protocol setup

The distraction protocol was developed based on the audio channel of videographed construction site sounds where the workers were found to be working at elevated and/or inclined surfaces. This required reproduction of the environmental noise experienced by workers at the worksite under the laboratory conditions. The noise level (sound pressure) and the frequency response was to be reproduced with minimal loss in fidelity.

Distraction protocol for the study was determined on the basis of the pilot studies performed earlier in phase I. The protocol included the use of a radio frequency based (900 Hz) Wireless Remote Headphone (Optimus: Model 1682 K964), that was worn by the subject during the entire duration of the session. During the tasks requiring audible distraction (determined randomly), a pre-recorded segment of construction noise was played into the headphones using a high performance sound system(Pioneer Stereo Deck model CT-W404R; Pioneer Stereo Receiver model SX-203). External speakers (labeled as S1 and S2 in figure 3; Panasonic model 7173) were used to amplify the voice of the facilitator providing instructions and other verbal commands to the subject. The actual control unit of the audio system was rack mounted in a mobile unit and was placed outside of the test enclosure to minimize cues to the subject during testing.The distraction was started 3 seconds prior to each 30 sec. test and was turned off one second following the end of the test. At the culmination of the session, the headphones were connected to a battery charger for recharging.

Specially-designed inclined/elevated surface: A specially-designed structure was constructed to provide all possible combinations of the three inclinations (0, 14°, and 26°) and elevations (0", 12" and 24"). The structure was made of cast iron and consists of seven independent pieces that could be combined to achieve the required inclination and elevation. The surfaces of the unit were sand-blasted to remove the glare it may produce when videographed and to increase the friction between the subjects' shoe sole and the standing surface for a safer grip while standing. Special cotter pins were inserted at specific places to keep the modular structures together and prevent slip-outs and mechanical instability of the whole system. Special care was taken to ensure that there was minimal clearance for relative motion of the individual pieces, since this might introduce error in the force platform measurement. The subject was asked to step on the force platform before the commencement of the task. A specialized ladder, with an easy access system, was constructed for the subject to mount the surface.

C.4. Instrumentation and Measurements

Kinetic measurements

The kinetic measurements, which included the forces and moments exerted on the force platform, were collected using a piezoresistive force platform (Model OR-6-1000, Serial # 3371 manufactured

by AMTI, Newton, MA) capable of measuring forces and moments in the three orthogonal directions. The details regarding the accuracy of the force plate are available in Bhattacharya[18] . The force platform was placed flush with the floor. The signals from the plate were fed into an amplifier (AMTI, model SGA6). The signals coming out of the amplifier were then delivered to an IBM compatible 486 personal computer, using A/D board and Peak™ Performance Software (Peak Performance Technologies Inc., Englewood, CO) for data collection. The data collection frequency was set at 60 Hz for a duration of 30 seconds (1800 data points). Collected data was further processed to calculate the movement patterns of the body's CP which were then used to determine the variables of postural sway and postural instability.

Mathematical and experimental computation for the determination of the center of pressure (CP) using the force platform and the specially-designed inclined/elevated surface

The footprints, in conjunction with the CP trace, were used in the calculation of the indices of propensity towards Loss Of Balance (LOB). Since, the LOB indices are based on the physics of upright stability, it depends on the basal support area available to the subject. In the case of the inclined surface shown in figure 4, the basal support area is given by the cosine projection of the subject's footprints on the horizontal plane.

Mathematically,

$$\text{(Modified basal support area)} = \text{(Support area on the inclined surface)} \times \cos\theta$$

where, θ is the angle of the incline to the horizontal.

Hence, the LOB indices based on the CP data was evaluated by using the modified basal support area described by the above formulation.

Placement of the inclined and/or elevated surface displaces the actual point of application of the force from the top surface of the force platform. Thus, it requires special consideration when determining the value of the distance c of the point of application of the force from the electrical center of the platform. As shown in figure 4, the point of application of force is at a distance of C_s from the surface of the plate and at a distance of c ($= C_s + C_e$) from the electrical center of the plate. The equation for the calculation of the CP based on the forces and moments measured using the force platform may be given by:

$$x_p = \frac{(\vec{M}_z \ \vec{F}_y - \vec{M}_y \ \vec{F}_z)}{|\vec{F}^2|} - \frac{(\vec{F}_x^2 \ \vec{M}_y - \vec{F}_x \ \vec{F}_y \ \vec{M}_x)}{\vec{F}_z \ |\vec{F}^2|} - c \frac{\vec{F}_x}{\vec{F}_z}$$

$$y_p = \frac{(\vec{M}_x \ \vec{F}_z - \vec{M}_z \ \vec{F}_x)}{|\vec{F}^2|} - \frac{(\vec{M}_y \ \vec{F}_x \ \vec{F}_y - \vec{F}_y^2 \ \vec{M}_x)}{\vec{F}_z \ |\vec{F}^2|} - c \frac{\vec{F}_y}{\vec{F}_z} \qquad (1)$$

Here, c is calculated by adding the distances C_e and C_s as shown in the figure 4. Experiments were performed by placing a heavy cylindrical metal bar of known weight at pre-determined locations on the inclined surface. Our previous Progress Reports give the details of the experiment to validate the use of the equation (1) with modified c value. As concluded in our previous Progress Reports, the range of error of measurement was 1-4% and provide a good approximation of the movement of CP as calculated from the force platform. The movement of CP in terms of the center of the plate are combined with the projected footprints (to the horizontal plane at the force plate) of the subject to compute the Indices of postural stability.

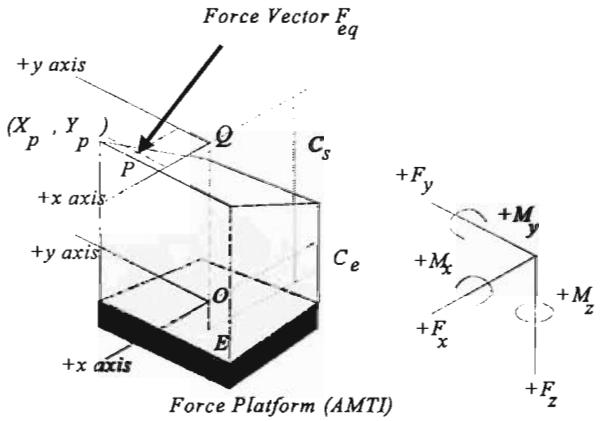


Figure 4 Forces and moments acting on the inclined surface placed on the force platform.

Kinematics Measurements

The kinematic measurements, which included linear and angular displacement, velocity, and acceleration, were collected using a videographic motion measurement system (Peak™ Performance Technologies Inc., Englewood, CO). An Infrared (IR) light source of 250 watts capacity was installed next to each camera in order to be able to record the marker movement in both good and poor lighting conditions. The video data was collected at a sampling rate of 60 Hz.

The Peak Performance system was used for the digitization of three-dimensional spatial movement of the markers. Calibration of each test session was performed to ensure the accuracy of the digitization. After digitizing the video pictures, the whole body CG movement was determined. The data from the force plate and videographic system were synchronized with the help of an event synchronization system.

C.5.. Final marker system for the study

The following 18 point marker system was adopted. Sixteen markers were placed on the following anatomical positions: Two each at (1) Top of first toes, (2) fifth metatarsophalangeal (MTP) joints, (3) heels (calcaneus), (4) Knees (fibular head), (5) hips (greater trochanter), (6) shoulders (acromion process), (7) elbows (lateral epicondyle), and (8) wrists (styloid process). The markers used at the first toes and the fifth MTP were used to define the stability boundary (SB) as per our earlier studies.[10, 31] Two markers were placed on the standing surface, one each on right and left side of the subject, to mark the central medial-lateral position of the subject's standing surface during the tests. The marker system is shown in in Appendix B.

C.6. Experimental Procedures

Phase I. **Effect of standing surface inclination, elevation, and environmental lighting on postural instability (Specific Aims A1 and A2):**

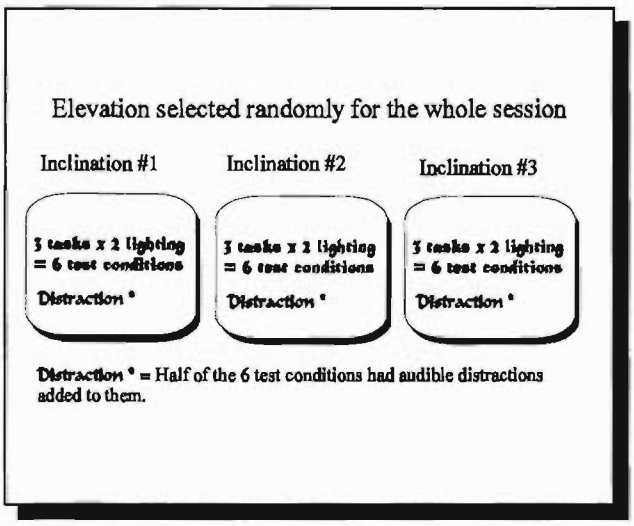


Figure 5 Study design

For this phase 40 subjects were recruited. Stratified sampling from two age groups was performed: 22 to 29 years old (younger) and 50 to 59 years old (older). Each group was represented by both genders. All testing was carried out in the specially prepared Elevation Study facility which is described elsewhere in this report. All subjects wore whole body safety harness during the test.

Study Design:

The treatment conditions were blocked within the three levels of elevation (0", 12", 24"), i.e. each session consisted of one of the three levels of elevation (chosen in random order) (Figure

5). The subject started the session by performing 3 baseline tasks (stationary, bending, reach) under ideal conditions (good light, no distraction, 0" elevation, 0° inclination). S/he then performed 18 tasks, as shown in figure 4. Each test was followed by a 1 min. rest during which the subject dismounted the test platform on to a level surface placed close to the test platform. At the end of each task, the subject was asked to evaluate his/her perceived sense of loss of balance, using a questionnaire, type scale (Appendix-C). Data from the force plate as well as the video was collected using Peak Performance System. A well-documented standard operating procedure has been developed for the operator at the Peak Data Acquisition Station (presented in our previous progress reports). The lighting in the testing chamber was controlled using independent lighting controls, described in detail in last year's progress report. At the culmination of the session, the lighting in the room was measured using a light meter (Sper Scientific; Model: 840021) and recorded.

The subject appeared for four sessions. The first session was used for (1) Briefing about the content of the study and signing the consent form, (2) measurement of detailed anthropometry (anthropometric measurement form shown in Appendix-A), (3)selection of the appropriate shirt and shorts provided by the laboratory, (4) selection of the appropriate shoes (Red Wing; model/style: GripTec Sole 2160), (5) detailed orientation of the subject to Protocol of the tasks and "Sense of fall" questionnaire (Appendix-C); c) a demonstration of the distraction protocol, including a sample run of the noise wearing the headphones], and (6) Measurement of the appropriate overhead lanyard length attachment to be used for each individual combination of elevation (0", 12", and 24") and inclination (0°, 14°, and 26°).

Sessions two through four were used for data acquisition on the various surface conditions. The blocked design allowed the use of only one elevation to be tested during one session. This was performed in order to limit the repositioning of the camera required for accommodating the complete subject into view, which needed adjustment each time the elevation was altered. On the start of a session, the subject was required to fill out a short questionnaire (Appendix-A). His/her blood pressure and heart-rate was measured. Subjects were disallowed to undergo testing if the subjects reported: (1) Alcohol consumption, (2) excessive stress at work/home, (3) consumption of medication affecting nervous system, and/or demonstrated abnormally high cardiovascular activity. The subjects were instructed to wear the designated shirt, shorts, and shoes, and were fitted with the appropriate full-body harness. They were then measured for baseline conditions for the three tasks of stationary, bending, and reach. A typical test session required about 2.5 hours for completion.

The three cameras were adjusted a-priori to make sure that they encompass the test area into their viewing field. At the start of the session, the force platform was calibrated and checked to ensure that the measurement error of the plate was within the acceptable 2% range (as per our previously published studies). The video system was calibrated next using a prefabricated frame device with 17 markers attached to the frame at known spatial distance from each other. The frame was videotaped for a duration of 5 minutes, and used later to obtain the DLT measurements during video digitization of the trials.

The experimental test conditions were determined *a-priori* as described earlier. Two staff members attended to the micro-computer which controlled and collected data from the video and force platform. One staff member acted as the facilitator to ensure that the subject complied with the individual test protocols. Another staff member was responsible for the operation of the distraction production unit. An additional member was responsible for the assemblage of the elevation surface units, ensuring the formation of the proper elevation/inclination combination required by the test protocol. This member also helped the subject dismount the surface at the end of the 30 second testing and ensured attachment and detachment of the lanyard to the harness to ensure subject safety. Phosphorescent tapes were attached on the floor (not in the visual field of the subject) to facilitate the movement of the staff members when the lights were dimmed.

Given the complexity of the protocol and the time constraint, it was of paramount importance that the four investigators/staff members communicated effectively and in a timely fashion. The facilitator acted as the key person in coordinating the activities of the data acquisition team and as the primary communicator with the subject. A standard operating procedure for the facilitator is presented as Appendix-A. All the data collected were stored on computer mass media storage disks and duplicated for data safety. The stored data were later analyzed with our custom developed software before it was used for statistical analysis.

Phase II. **Determination of location, number and types (vertical *vs* horizontal *vs* both vertical and horizontal) of visual cues needed for minimizing propensity for loss of balance while working on elevated surfaces (Specific Aim A3): A Pilot Study:**

Before initiating Phase-III to determine the effect of visual cue(s) in improving postural stability while performing tasks on inclined/elevated surfaces, a pilot study was carried out with 10 subjects (21 - 59 years old) to determine the number and location of cues required in the field of view. For each of these visual cues, the postural sway variables were evaluated to see which type(s) of visual cue produced the most reduction in these variables. This information was then used to design the experiments for Phase III.

A combination of two elevations (0" and 24"), two inclinations (0° and 26°), and seven visual cue arrangements were used. These visual cues are shown in Figure 6. The subjects performed two tasks of 30 second duration - Stationary: quiet stance, and Reach: reaching forward/downward to retrieve a 5.5 lb weight from the knee level. The subjects stood on a combination platform (with proper elevation and/or inclination) placed on a force plate. The enclosure walls were fitted with a combination of vertically and/or horizontally placed phosphorescent strips as visual cues.

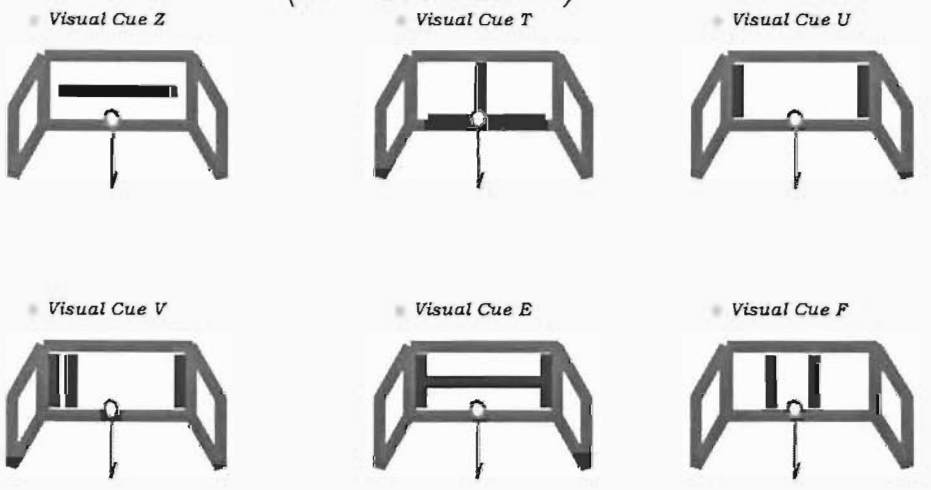
Phase III. **Effect of visual cues in minimizing the risk of postural instability while performing industrial tasks under exposure to two types of standing surface conditions, i.e., inclination, and elevation (Specific Aim A3):**

Based on data from the pilot test in Phase II, the experiments in this phase were conducted on a younger group (23 to 30 years) of 12 subjects and an older group (51-60 years) of 12 subjects. Equal number of male and female subjects were used in both the groups. All testing was carried out in the specially designed Testing Facility described earlier in this report. All subjects wore a whole body safety harness.

Study Design:

Each subject was exposed to randomized combinations of three inclinations (0,14, 26), three elevations (0", 12", 24") two light conditions (poor and good; except 14 degree inclination was tested in poor light only), and with three visual cues (no cue, cue types "N" and "F"). Subjects performed three tasks (Stationary, bending and reach) presented randomly during each treatment combinations of inclination, elevation, lighting and visual cue. This constituted a total of 126 trials (including baseline tests of good light, 0 degree, 0" no cue performed during each visit to the laboratory) performed during 3 visits (SESSION) to the laboratory. During each visit to the laboratory, each subject performed 42 tests. Each visit (or SESSION) to the laboratory was blocked on one elevation condition, inclination level was blocked within SESSION and tasks were nested within TRIAL.

Figure 6 *TYPES OF VISUAL CUES (N= NO CUE)*



Visual cue N represents "No Cues"

On the day of the test, the subject stood on the force platform facing the black display panel (Figure 3). An outline of her/his shoe placement on the incline/elevated surface was drawn and light reflective markers were placed on the shoes for the calculation of her/his stability boundary. Also,the subject's body joints were marked with a 18 -point marker system for three dimensional assessment of body movement and the motion of the whole body CG. During each trial, the subject's postural sway and stability parameters were measured with a force platform system and kinematic data were collected using the Peak Performance Human Body Measurement System. The body marker system used are described earlier in this report. At the end of each task, the subject was administered the Perceived Sense of Fall scale.

C.7.Dependent Variables:

Determination of Postural Sway and Instability

Objective Measures of Postural Sway: Sway area (SA) is the area of the projection of the body's CP on the xy plane due to sway, and sway length (SL) is the distance traveled by the CP. We have used these variables in several research studies in our laboratory (21, 10, 31-34). Sway Fy (RMS) [also known as F(AP)] and Sway Fx (RMS) [also known as F(ML)] are the root mean square values of the horizontal forces in the AP and ML directions respectively. The definition of Maximum Sway AP Excursion and Maximum Sway ML Excursion are given in the following. These definitions are also relevant for the variables used in the Dynamic balance evaluation section presented later in this report.

Excursion Parameters

The excursion parameters are defined on the basis of the lateral and medial deviation of the center of pressure (CP) trace under the feet during static task performance. Figure 7 shows the trace of the movement of the CP under the feet. The medial lateral (ML or x-direction) excursion is the net deviation of the CP in the ML direction. The anterior posterior (AP or y-direction) excursion is quantitated by measuring the net deviation of the CP in the AP direction.

The excursion parameters quantitate the extent of movement of the point of application of plantar force under the supporting feet. This movement of the CP under the foot is a time variant response to the momentary position of the whole-body center of gravity (CG) with respect to the basal supporting area provided by the feet. Thus, the excursion parameters provide an indirect measure of the dynamic stability performance during the posture.

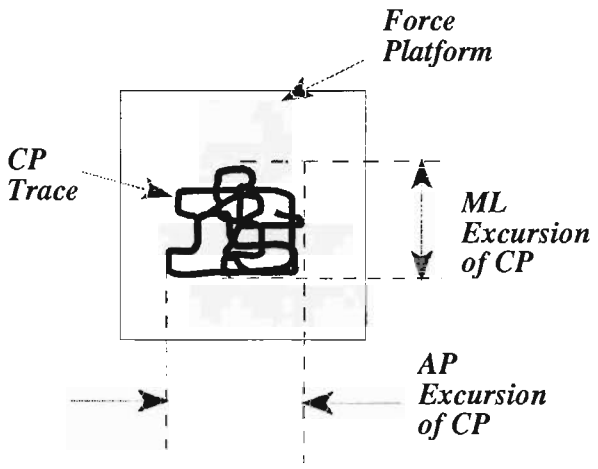


Figure 7

Objective Measures of Postural Instability:

Two non-dimensional indices, which are similar to those described by Bagchee et al[10], were used to quantitatively determine the propensity of momentary loss of postural instability associated with a sway pattern formed by the CG with respect to the postural stability boundary (basal support area). The stability boundary used to determine CG based postural instability was used for dynamic tasks and are described in our earlier publications.[10, 31] The two variables used to describe the propensity of postural instability are described as follows:

Index of Proximity to Stability Boundary (IPSB)

IPSB measures how close the body's CP or CG travels to a person's stability boundary, which is graphically shown in Figure 8 and Figure 9, respectively. The equation is as follows:

$$IPSB = \frac{p}{R_{\max}}$$

Figure 08
Illustration of the Concept of
CP Based IPSB and Stability Boundary

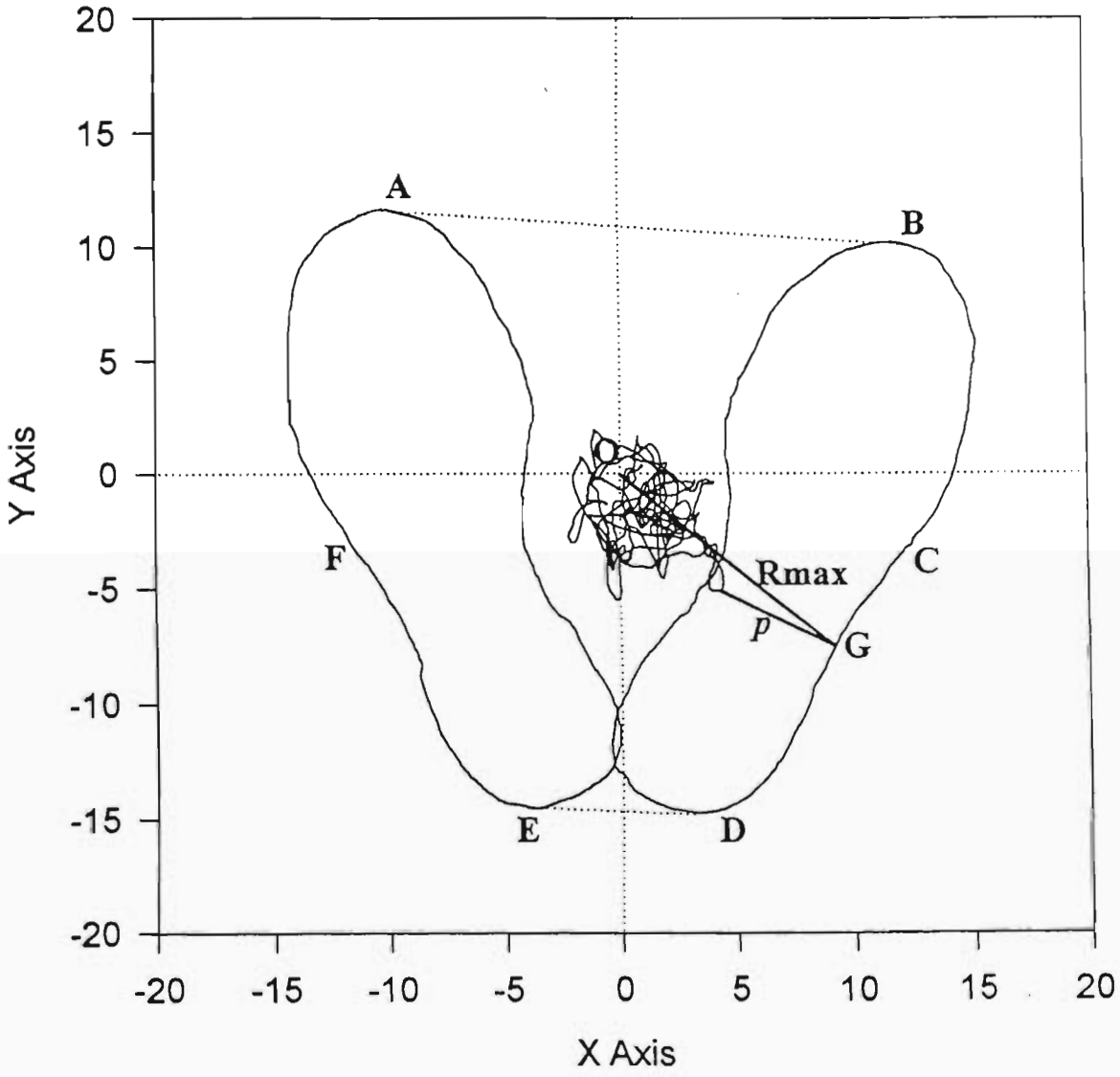
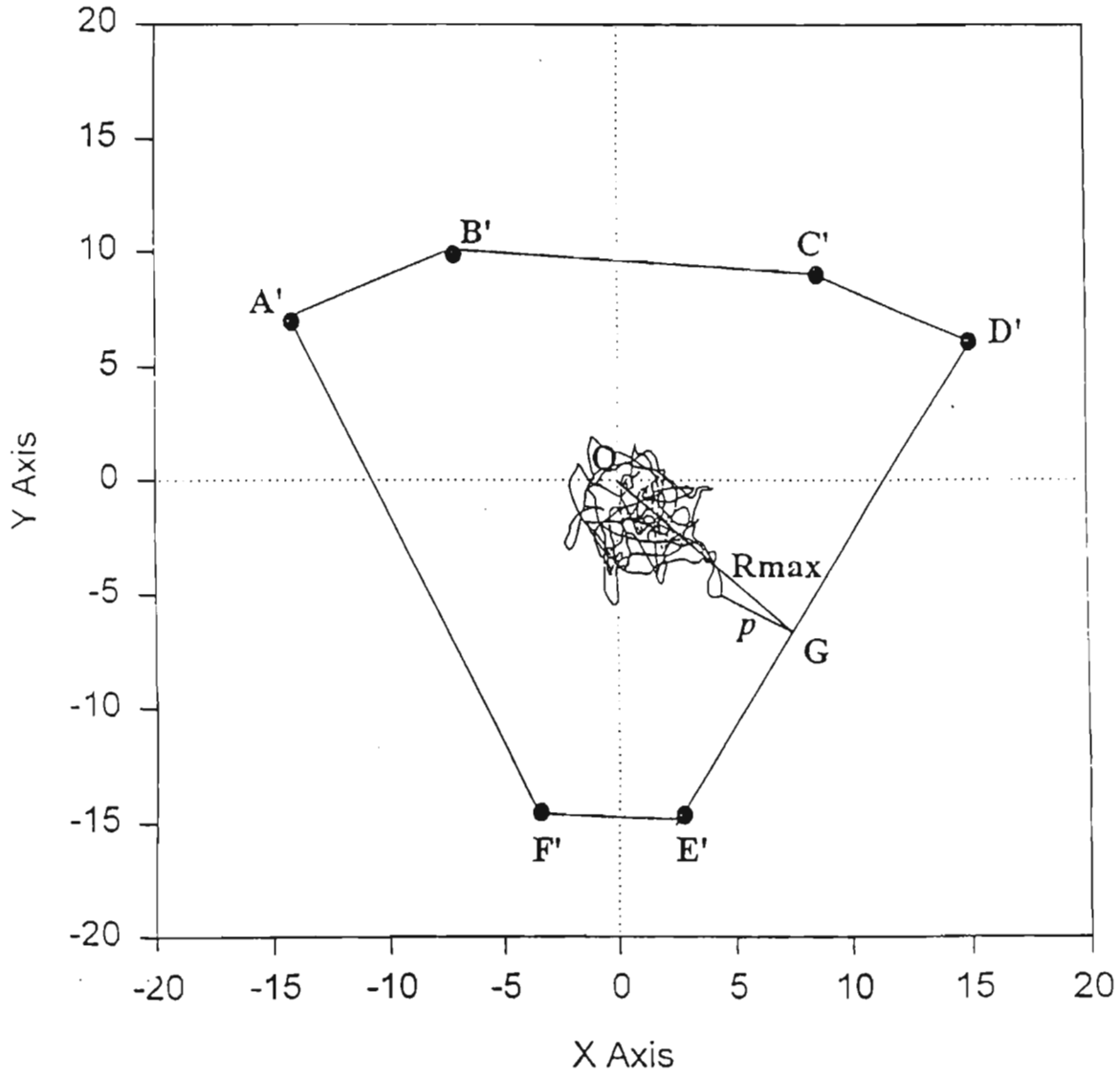


Figure 09

Illustration of the Concept of CG Based IPSB and Stability Boundary



A': 5th MTP of left foot
B': 1st MTP of left foot
F': left heel
C': 1st MTP of right foot
D': 5th MTP of right foot
E': right heel

where,

p = the minimum distance between the stabilogram and the stability boundary.

R_{max} = the radial distance of the point on the stability boundary that is closest to the CP or CG movement (either in Figure 8 or Figure 9).

A lower value of IPSB indicates that the subject has a greater propensity of postural instability while performing a given task. A negative value of IPSB implies that subjects' CP or CG are outside of the stability boundary.

Weighted Residence Time Index (WRTI)

WRTI is the weighted measure of time that the subject's CP or CG lies in various proximity zones to the stability boundary. The proximity zones (200%, 180%, 160%, 140%, 120%, 100%, 80%, 60%, 40%, and 20% distances of the stability boundary from the center) are constructed by drawing concentric lines to the stability boundary at the predetermined distances. The greater the residence time in the outer proximity zones, the greater is the propensity of postural instability for a given task under specified intrinsic and extrinsic conditions. The equation for determining WRTI is shown in the following:

$$WRTI = K\Sigma e^{i} z_i$$

where z_i = frequency count of zone i

$i = 3, 4, 5, 6, 7, 8, 9, 10.$

$K = e^{-4}$

Determination of Total Utilized COF or Required or Utilized Coefficient of Friction (RCOF or H/V :Objective Measure):

Maximum RCOF

The maximum RCOF is defined as the maximum ratio of shear force to normal force during the 30 second task performance. The shear force is the magnitude of the vector sum of shear forces in the medio-lateral (ML) and anterior -posterior (AP) directions (measured with the force platform). Mathematically,

$$RCOF = \frac{\sqrt{F_x^2 + F_y^2}}{F_z}$$

where Fx = horizontal force in ML direction.
Fy = horizontal force in AP direction.
Fz = normal (vertical) force.

Subjective Measures of Postural Instability:

Perceived Sense of Fall (PSOF): A short questionnaire-type rating scale was administered to determine the subjective perception of slip and/or potential fall of the subject during postural sway and gait tests. It consisted of simple questions which the subject had to answer immediately after each test. The results from this test were used to see how the subject's subjective perception correlates with the objective measures of postural stability as measured by the various postural sway parameters. A high score (max. score possible: 8; min. score possible: 0) implies a high subjective perception of slip or sway and/or fall. The questionnaire used for this study is given in Appendix C. The PSOF scale has been validated and tested in other studies conducted in our laboratories.[32-33]

D. RESULTS AND DISCUSSION

D.1. Phase-I Results

Effect of standing surface inclination, elevation, distraction and environmental lighting on postural instability (Specific Aims A1 and A2):

Forty worker subjects participated in this study. Most of the subjects were maintenance/construction workers recruited from the surrounding community. Half of the subjects were male. Descriptive statistics for variables common to the subjects are provided in the following Table 1.

Table 1. Demographic Data for Phase-I

	Male (n = 20)		Female (n = 20)	
	mean	s.d.	mean	s.d.
Age (year)	39.15	15.08	39.50	14.90
Weight (kg)	89.89	18.05	73.88	14.54
Height (cm)	175.15	6.33	162.13	5.57
Left Foot Length (cm)	27.19	0.95	24.81	1.04
Right Foot Length (cm)	27.23	0.90	24.88	1.09
Left Foot Width (cm)	10.23	0.60	9.27	0.46
Right Foot Width (cm)	10.12	0.52	9.28	0.47
Foot Reaction Time (m. second)	45.25	8.11	45.20	5.11
Hand Reaction Time (m. second)	39.87	10.51	41.57	7.71

Male subjects appeared to be slightly heavier than the average American man (83.2 kg ± 15.1 s.d.), and their stature was larger than the average American man (174.5 cm ± 6.6 s.d.) [18]. Female subjects were heavier than the average American woman (66.4 kg ± 13.9 s.d.), and their stature was comparable to the average American woman (162.1 ± 6.0 s.d.).[35-36]

Fall/near fall Occurrence during Static Task Performance

Only nine fall incidents were recorded during the Phase I trials. These were found to be related only to the experimental condition of task, with fewer falls being recorded during the stationary task. Fall incidence was not related to the other experimental conditions (inclination, elevation, lighting, surface condition or distraction) or any of the covariates investigated (age, gender, race, weight, height, right and left foot length and width, or arm or leg reaction time).

Data Analysis Strategy for Phase-I

A repeat measure analysis of covariance (ANCOVA) was performed to analyze the kinetic data. Two dependent postural sway variables, sway area and sway length, were used in the ANCOVA. The covariates of age, gender, baseline sway area or sway length and the height to weight ratio were the between-subject variables used to predict the postural sway outcomes. Within-subject, the experimental conditions of elevation, lighting, inclination and distraction were tested for their effect on postural stability. In addition, all possible two-factor interactions between the within-subject factors were investigated. The postural sway data were analyzed within the three tasks performed by the subjects (bending, reach and stationary tasks). Beginning from saturated models involving all covariates, within-subject factors and interactions, final models were derived through a backward elimination strategy of insignificant covariates and two-factor interactions. In the final models, only significant covariates and two-factor interactions were included, along with the within-subject main effects, which were not candidates for removal from the ANCOVA models. An alpha-level of 0.05 was used for all statistical tests.

D.1.a. Summary of Findings/Implications From Phase-I

Effect on postural sway/stability (kinetic outcomes):

The results of the ANCOVAs are shown in Table 2. The results presented were controlled for baseline data obtained on each day of the three testing days. The means for the levels of each within-subject factor, significant within-subject interactions and the significant covariate effects are shown in Table 3. Elevation significantly affected both sway length and sway area for all 3 tasks. However, an increasing monotonic relationship with elevation was observed only for sway length during the bending and stationary tasks. Sway length was greatest for the highest elevation (24") while subjects performed the reach task; however the difference between the lower elevations (0" and 12") was less than 1 cm and not statistically different. For all of the tasks, sway area actually decreased with increasing elevation. Lighting was found to affect both postural sway outcomes for all 3 tasks performed. Sway length and area invariably were found to increase in poor lighting as compared to good lighting. The inclination angle was found to be significantly related to both sway length and

sway area for 2 of the 3 tasks performed. Sway length increased monotonicly as the inclination angle increased for both the bending and the stationary tasks. Sway area was greatest for the largest inclination angle (26 degrees) during the bending task, however, the two lesser inclines did not differ statistically from one another. Sway area in fact decreased significantly as the angle of inclination increased during the reach task. Distraction was not found to be significantly related to sway length or area in any of the models investigated.

In addition to these findings for the within-subject variables, the covariates also were found to often affect the sway outcomes. The baseline sway length or area were found to be significantly and positively related to the comparable outcome for all 3 tasks. Age was a significant predictor of sway length during the bending and stationary tasks. In both cases, the older age group exhibited greater sway length. Gender was found to significantly affect both sway length and area during the bending and stationary tasks. In all of these models, males demonstrated greater sway than did females. The height to weight ratio was not found to be related to postural sway and was removed from all of these models.

The inclination and elevation were found to be significantly interacted in two of the postural sway models, affecting sway area during the bending task and sway length during the stationary task. The interaction for sway area during the bending task is difficult to interpret, since a monotonic increase in sway area occurs only for increasing inclination under the 12" elevation condition. The interaction of inclination and elevation during the stationary task is quite interpretable, since sway length was found to increase monotonicly as either condition increased, while holding the other constant. For example, sway length increased from 41.28 to 42.56 to 51.69 cm as the inclination angle increased from 0 to 14 to 26 degrees, respectively, while the subjects stood at ground level. Similarly, sway length increased from 41.28 to 44.16 to 54.80 cm as the elevation increased from 0" to 12" to 24", respectively, and the subjects stood on a flat (0 degree inclination) surface. Similar results occurred for all other combinations of the elevation and inclination factors' levels, implying a synergistic relationship of these two factors on sway length for the stationary task condition; i.e., as both factors increased (higher elevations and greater inclination angle), the postural sway increased even more than could be expected from these factors under the assumption of a linear additive model. Such an increase in sway length implies overcompensation by the postural muscles to overcome the psychophysical "fear" of loss of balance as the elevation and inclination increased together.

Ignoring the baseline postural sway observations for the purpose of rank ordering, the following ordering for the magnitude of the effects of these experimental factors and covariates on static postural balance is suggested:

(1) lighting;
(2) elevation;
(3) gender;
(4) inclination;
(5) age.

The tasks performed would also have been found to be highly significantly different had the data been analyzed across these three tasks. This result is expected, and has been demonstrated in each of our other studies that have investigated the effects of the static task factor, with the postural sway being greatest during the reach task, followed by the bending and stationary tasks.[34]

Table 2: P values for testing the effects of age, gender, elevation, lighting, inclination and distraction on sway length and sway area.

Experimental Condition	**Bending Task**		**Reach Task**		**Stationary Task**	
	Sway Length	**Sway Area**	**Sway Length**	**Sway Area**	**Sway Length**	**Sway Area**
Baseline	**0.0001**	**0.0014**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Age	**0.0275**	0.1069	0.3915	0.2817	**0.0289**	0.4881
Gender	**0.0092**	**0.0117**	0.2513	0.0546	**0.0450**	**0.0138**
Elevation	**0.0001**	**0.0003**	**0.0001**	**0.0002**	**0.0001**	**0.0085**
Lighting	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Inclination	**0.0001**	**0.0243**	0.2072	**0.0001**	**0.0001**	0.0981
Distraction	0.9725	0.8669	0.9491	0.9508	0.7451	0.9294
Elevation* Inclination		**0.0022**			**0.0069**	

Table 3: Geometric least square mean sway length and area by task, age, gender, elevation, lighting, inclination and distraction.

Experimental Condition	**Bending Task**		**Reach Task**		**Stationary Task**	
	GM Sway Length	**GM Sway Area**	**GM Sway Length**	**GM Sway Area**	**GM Sway Length**	**GM Sway Area**
Age						
Young	84.56	12.17	157.87	26.16	48.44	2.88
Old	89.28	13.54	159.03	27.02	51.68	2.89

Gender						
Female	83.78	11.47	155.95	25.12	48.41	2.50
Male	90.33	14.36	160.99	28.13	51.72	3.33
Elevation						
0"	81.76	13.74	152.85	28.34	44.95	3.06
12"	84.32	12.94	152.34	26.71	48.09	2.94
24"	95.50	11.90	170.84	24.82	57.96	2.68
Lighting						
Good	80.38	11.88	146.04	24.27	47.28	2.69
Poor	94.15	13.87	171.91	29.11	52.95	3.10
Inclination						
0 degrees	83.80	12.51	160.10	29.66	46.40	2.75
14 degrees	84.88	12.49	159.67	27.31	48.59	2.83
26 degrees	92.56	13.53	155.61	23.20	55.56	3.10
Distraction						
No	87.66	12.98	159.41	26.92	50.18	2.95
Yes	86.33	12.70	157.50	26.25	49.89	2.83

Elevation *Inclination		
0", 0 degrees	13.90	41.28
0", 14 degrees	13.40	42.56
0", 26 degrees	13.93	51.69
12", 0 degrees	11.69	44.16
12", 14 degrees	13.18	48.24
12", 26 degrees	14.06	52.19
24", 0 degrees	12.06	54.80
24", 14 degrees	11.04	55.86
24", 26 degrees	12.65	63.59

Effect on Perceived Sense of Fall (PSOF) response (Phase-I):

Statistically significant changes in perceived sense of fall were found for inclination (p=0.0001), task (p=0.0154), light (p=0.0001) and noise distraction (p=0.0017) (Table -4). The repeated measures analysis of variance for between subject effects on perceived sense of fall showed no significant association. Those between subject covariates (age, gender and h/w) were dropped in the final model. There was no significant 2-way interaction among any of the experimental conditions. The perceived sense of fall showed that the 26 degree inclination was significantly larger when compared to the 14 degree inclination and no inclination (Table-5). The PSOF of the bend and the reach tasks was found to be significantly greater when compared to the PSOF of the stationary task (Table -5).

Table -4: P- values for testing the effects of tasks, lighting and noise distraction (DIST) on PSOF

TEST CONDITION	ELEV	INCL	TASK	LIGHT	DIST	ELEV*INCL
F RATIO	1.68	114.11	4.38	58.69	11.14	0.89
P VALUE	0.1924	**0.0001**	**0.0154**	**0.0001**	**0.0017**	0.4722

Table -5: Mean values of PSOF

	MEAN	STD DEV
ELEV= 0	0.9902	1.2661
ELEV= 12	0.8636	1.1038
ELEV= 24	1.0315	1.2937
INCL = 0	0.5691	0.8808
INCL = 14	0.7086	0.9861
INCL = 26	1.6075	1.4581
BEND	1.0291	1.3032
REACH	1.021	1.2837
STATION	0.8352	1.0677
GOOD	0.7461	1.034
POOR	1.1774	1.3577

DIST= NO	0.9297	1.1909
DIST= YES	0.9938	1.2591

D.1.b. Implications of Objective vs. Subjective measures of postural balance while working on inclined/elevated surfaces (Phase-I)

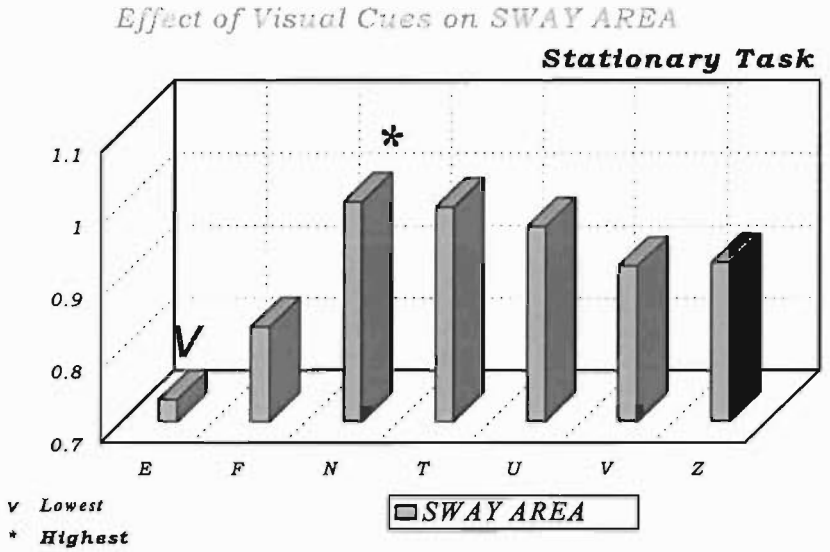
In an effort to relate the objective findings of postural balance presented in Tables 2 and 3 with those of subjective measures of postural balance (presented in Tables 4-5), the following comment are added here. While the objective measure of postural sway increased with the increasing combination of elevation and inclination, the subjective measure of PSOF did not show significant (see Table 4) two way interaction implying that subjects are not able to perceive the risk of postural imbalance causing potential inability to deploy appropriate postural muscle corrective actions. Hence, workers who must perform tasks at both on elevation and while standing on an inclined surface may have a greatly increased risk of losing their balance and falling, resulting in severe injuries or even fatality under this combination of these synergistic conditions.

D.2. Phase-II : Determination of location, number and types (vertical *vs* horizontal *vs* both vertical and horizontal) of visual cues needed for minimizing propensity for loss of balance while working on elevated surfaces (Specific Aim A3): A Pilot Study:

Results:

Analysis of data from ten worker subjects (age = 38.55 ± 9.2 years) who participated in the second phase of this study yielded the following findings. Length of the CP travel obtained from the force plate (sway length, SL) presents an indirect measure of the body's postural stability. Higher SL may be associated with greater effort in maintenance of balance. A repeated measures analysis indicated that SL increased significantly with increasing elevation and inclination ($p < 0.05$). Addition of visual cues significantly lowered the SL in stationary and reach tasks ($p<0.05$). The increase in the SL with elevation was minimal for both tasks when using a visual cue involving a vertical line and a horizontal line forming an inverted T, directly in front of the subject. It could be observed that all cues acted in a manner so as to reduce the Sway Area and Sway Length in both Stationary and Reach Tasks, when compared to the no-cues (Visual cue N) condition (figures 10-11). Thus, visual cues, when placed strategically, may reduce the postural instability during task on elevated and/or inclined surfaces.[13]

Figure 10



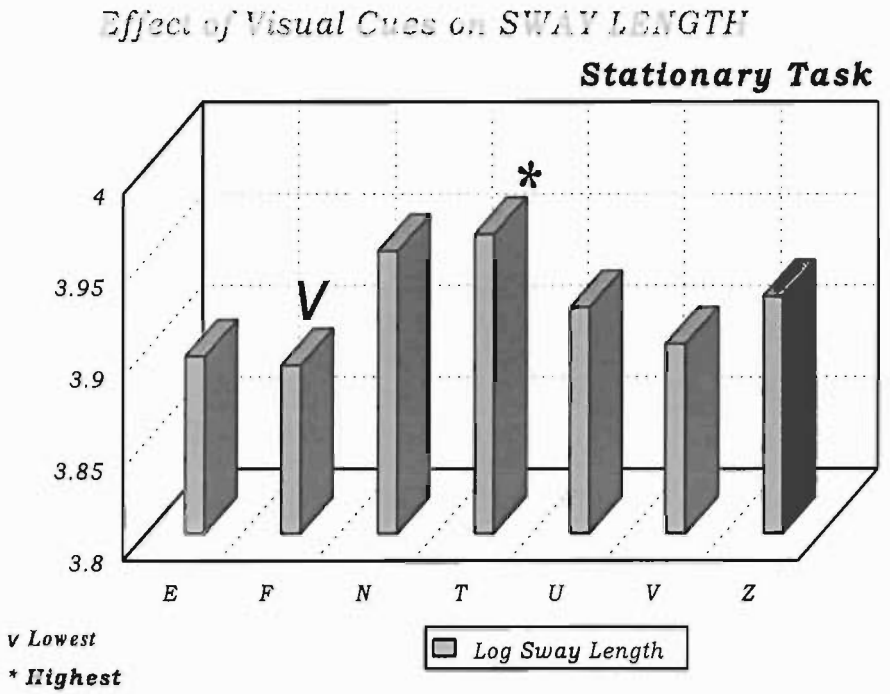


Figure 11

For the stationary task, the sway length and sway area responses were the lowest for the F and E visual cues, respectively. Since both E and F cues have both vertical and horizontal cues we decided to pick these two cues for further testing in the Phase-III. Findings from this phase of the study helped in establishing the specific visual cues for the third phase, which focused on designing intervention in the workplace in the form of carefully placed visual cues that would reduce the postural imbalance in workers at elevated/inclined surfaces.

D.3. Phase-III Results:

Effect of visual cues in minimizing the risk of postural instability while performing industrial tasks under exposure to two types of standing surface conditions, i.e., inclination, and elevation (Specific Aim A3)

The Table 6 provides demographics data on the subjects used in the Phase III of the study.

Table 6. Demographic Data FOR PHASE-III

	Male (n = 12)		Female (n = 12)	
	mean	s.d.	mean	s.d.
Age (year)	40.33	15.39	41.17	14.76
Weight (kg)	89.03	18.92	65.29	24.39
Height (cm)	173.47	6.88	149.24	47.29
Left Foot Length (cm)	27.10	1.14	22.89	7.27
Right Foot Length (cm)	27.16	1.12	23.01	7.31
Left Foot Width (cm)	10.22	0.68	8.48	2.71
Right Foot Width (cm)	10.17	0.61	8.49	2.72
Foot Reaction Time (m. second)	45.31	7.08	42.56	14.19
Hand Reaction Time (m. second)	41.36	9.33	38.97	15.14

Fall/near fall Occurrence during Static Task Performance
Only three fall incidents were recorded during the Phase III trials. These were not found to be related to the experimental conditions (inclination, elevation, task, lighting or visual cue) or any of the covariates investigated (age, gender, race, weight, height, right and left foot length and width, or arm or leg reaction time).

Data Analysis Strategy: A repeat measure analysis of covariance (ANCOVA) was performed to analyze the kinetic data. Ten dependent postural sway variables, sway area,

sway length, average and maximum excursion in the AP and ML directions, RMS F_x, RMS F_y, and maximum and minimum H/V were used in the ANCOVA. The covariates of the baseline measurement, age, gender, race, leg and arm reaction time, weight and height were the between-subject variables used to predict the postural sway outcomes. Within-subject, task, lighting, visual cue, inclination and elevation were tested for their affect on postural stability. In addition, all possible two-factor interactions between the within-subject factors were investigated. Beginning from a saturated model involving all covariates, within-subject factors and interactions, a final model was derived through a backward elimination strategy of insignificant covariates and two-factor interactions. In the final model, only significant covariates and two-factor interactions were included, along with the within-subject main effects, which were not candidates for removal from the ANCOVA model. An alpha-level of 0.05 was used for all statistical tests.

D.3.a. SUMMARY OF FINDINGS/IMPLICATIONS

Effect on postural sway/stability (kinetic outcomes):
The results of the ANCOVA are shown in Table 7. The means (all means are arithmetic except for sway area and length, which are geometric means) for the levels of each within-subject factor, significant within-subject interaction and the significant covariate effects are shown in Tables 8 through 18. The task performed was found to significantly affect all ten outcome variables. For each postural sway outcome, the reach task evoked the greatest sway, followed by the bending task, with the stationary task evoking the least postural sway. Lighting was found to affect 8 of the 10 postural sway outcomes, all except RMS F_y and the maximum H/V. In general, sway increased in poor lighting; however, the maximum excursion in the AP direction and the minimum H/V were actually diminished in poor lighting as compared to good lighting. Low H/V values imply lesser demand on COF requirement. This could be due to "cautious" slow body motions (which in turn will decrease shear forces) used in poor light to prevent a potential fall. Presence of a visual cue significantly affected four of the ten postural sway outcomes, sway area, sway length, average excursion in the AP direction and minimum H/V. The presence of either visual cue tended to decrease sway relative to having no visual cue implying better balance; however, the minimum H/V was slightly larger in the presence of either visual cue. The inclination angle was found to be significantly related to 2 of the 10 postural sway outcomes, average excursion in the AP direction and the minimum H/V. These results are inconclusive, however, since a monotonic relationship between inclination angle and sway did not hold for these outcomes. For example, the greatest average excursion in the AP direction and the largest minimum H/V occurred for the flat (0 degree inclination) surface. The elevation also significantly affected 2 of the 10 postural sway outcomes, sway length and average excursion in the AP direction. Once again, these results are not entirely conclusive, as only sway length demonstrated an increasing monotonic relationship with elevation. However, an increase in sway length is generally indicative of excessive muscular contractions of postural muscles, which could happen if the subject has a "fear" of falling.

In addition to these findings for the within-subject variables, the covariates also were found to occasionally affect the sway outcomes. Gender was found to significantly affect sway area, average excursion in both the ML and AP directions, both the RMS F_x and F_y, and both the maximum and minimum H/V. Males had greater sway area, average excursion in the ML and AP directions, greater RMS F_y and maximum H/V, but lesser RMS F_x and minimum H/V. Weight was found to be significantly and positively related to both RMS forces. Height was significantly and negatively related with both RMS forces, whites had lesser F_x but greater maximum H/V than did blacks. Age was significantly and positively related to F_x and maximum H/V. The positive relationship between sway area and age is consistent with literature indicating that with aging, postural sway increases. Leg and arm reaction times were statistically significant in the models for F_x, F_y and maximum H/V. In these models, faster reaction times were related to greater forces but lesser frictional demand.

A number of within-subject interactions were also found to be significant in the ANCOVAs. Inclination and elevation were found to be significantly interacted in four of the postural sway models, affecting sway length, maximum excursion in the AP direction, the RMS F_y and the maximum H/V. The effect of elevation on sway length was monotonic for constant inclination; however, the difference among the elevations tended to diminish as inclination increased.

The interaction effect for the maximum AP excursion suggested that as inclination increased, the effect of elevation reversed from having a positive effect on sway (i.e., greater excursion for the higher elevations) to having a negative effect on sway (i.e., greater excursion in the lower elevations). Biomechanically speaking, when the subject stands on an inclined surface the body's CG moves posteriorly with respect to the base of support (BOS). In order to avoid loss of balance, the subject will tend to move his/her entire body segment above the foot forward so that the whole body CG stays within the BOS. This tendency for the whole body CG to move forward increases as the inclination angle increases. Since the body is forcibly trying to keep the whole body CG forward (within the BOS), the natural body sway in the AP will be reduced as the inclination angle increases. This is supported by the values of AP obtained for inclinations in Table 11. The amount of AP sway was found to decrease with inclination as the elevation increased. While biomechanically speaking, the amount of forcible forward motion of the whole body CG with an increase in inclination should not be changing with increasing elevation, it is quite possible that at higher elevations, an inclined surface might be causing psychophysical stress that induces additional forward motion of the CG. Under these circumstances, the natural body sway is forcibly reduced by a voluntary move of the body's CG in one direction (i.e. in the forward direction).

The inclination and elevation interaction effect on the RMS F_y suggested that the greatest force was exerted on a flat surface (0-degree inclination, 0" elevation) relative to an off-ground elevation; however, as the inclination increased, the greatest force was found for the 12" elevation. Finally, the maximum H/V tended to decrease as either the inclination or the elevation increased.

Lighting and inclination were found to be significantly interacted for sway length, the maximum ML and the RMS F_y. The sway length and the maximum ML tended to increase with inclination under either lighting condition; however, these increases were somewhat larger when the lighting was poor. An increase in sway length for lighting by inclination interaction implies that subjects were subconsciously overcompensating as they performed tasks on increasing angles of inlication in poor light. For the RMS F_y variable, a monotonic relationship was noted for inclination under good lighting; however, the 0-degree inclination demonstrated the largest force when the lighting was poor, followed by the 26-degree inclination.

Lighting and elevation also were found to significantly interact for three of the outcome variables, sway length and maximum excursion in both the ML and AP directions. For the sway length and maximum ML outcomes, a monotonic relationship between the sway outcome and elevation was found within both lighting conditions, with a slightly diminished gradient in the poor lighting condition relative to the good lighting condition. Although the relationship found for the maximum AP outcome was not strictly monotonic, it again suggested that the greatest excursion occurred for the 24" elevation but the difference among the elevations was somewhat diminished under poor lighting.

Finally, a single significant interaction between lighting and visual cue (on maximum ML) and two significant interactions between visual cue and inclination, for sway length and again on maximum ML were found. The lighting by visual cue interaction suggested that the cues were more effective in good lighting than in poor lighting for diminishing excursion in the ML direction. The visual cue by inclination interaction showed that the greatest excursion was found when no cue was available for subjects standing on a 26-degree inclination; similarly, sway length was greatest when no cue was available to subjects standing at either inclination (14 or 26 degrees).

These results suggest the following ordering for the effects of these factors and covariates on static postural balance: (1) task; (2) lighting; (3) visual cue; (4 and 5) inclination/elevation; (6) gender; (7) arm/leg reaction time; with weight, height, race and age all seldom significantly affecting sway. The effects of the inclination and elevation factors are difficult to separate, given the many models in which they significantly interacted with each other and with other factors and also the non-monotonic nature of many of their relationships with the outcomes.

Table 7: Repeat Measure ANCOVA (P values) results

Ind. Variable	SA	SL	ML	AP	MaxML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Baseline	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Age							0.0001*		0.0121*	
Gender	0.0001*		0.0086*	0.0001*			0.0001*	0.0001*	0.0001*	0.0385*
Weight							0.0001*	0.0001*		
Height							0.0001*	0.0023*		
Race							0.0001*		0.0001*	
Arm Reaction							0.0363*	0.0341*	0.0069*	
Leg Reaction							0.0001*	0.0005*	0.0002*	
Task	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Lighting	0.0004*	0.0001*	0.0001*	0.0353*	0.0001*	0.0005*	0.0001*	0.1761	0.4281	0.0074*
Visual Cue	0.0076*	0.0001*	0.0725	0.0008*	0.2443	0.6095	0.8950	0.2762	0.3670	0.0011*
Inclination	0.3402	0.1228	0.0691	0.0001*	0.1487	0.1661	0.6833	0.5762	0.8332	0.0001*
Elevation	0.1327	0.0001*	0.5360	0.0109*	0.4859	0.0868	0.0654	0.2816	0.6898	0.7394
Inclination * Elevation		0.0005*				0.0165*		0.0026*	0.0457*	
Lighting * Inclination		0.0238*			0.0420*			0.0039*		
Lighting * Elevation		0.0005*			0.0357*	0.0369*				
Lighting * Visual Cue					0.0411*					
Visual Cue * Inclination		0.0029*			0.0042*					

* Statistically significant at $p < 0.05$

Table 8 : Means and Standard Deviations by Task

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Bend	13.93	98.49	4.11	7.34	1.72	1.22	211.75	270.82	0.053	0.0012
	(1.48)	(1.18)	(1.30)	(2.00)	(1.31)	(3.04)	(56.55)	(90.84)	(0.031)	(0.0009)
Reach	27.74	160.61	5.75	10.05	2.46	4.85	238.95	398.34	0.064	0.0008
	(1.34)	(1.16)	(1.38)	(1.96)	(1.40)	(2.77)	(59.86)	(111.70)	(0.019)	(0.0006)
Static	2.22	59.16	1.73	2.66	0.55	-0.43	193.96	183.85	0.013	0.0043
	(2.02)	(1.27)	(0.94)	(1.26)	(1.23)	(2.76)	(49.94)	(36.20)	(0.003)	(0.0015)

Table 9 : Means and Standard Deviations by Lighting

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Good	7.48	94.03	3.46	6.27	1.39	2.13	213.19	290.25	0.038	0.0027
	(3.78)	(1.68)	(2.06)	(3.96)	(1.55)	(3.81)	(58.76)	(133.32)	(0.029)	(0.0021)
Poor	9.77	99.59	3.99	6.74	1.63	1.92	216.46	285.69	0.044	0.0021
	(3.29)	(1.58)	(2.16)	(3.57)	(1.56)	(3.62)	(58.94)	(124.28)	(0.031)	(0.0019)

Table 10 : Means and Standard Deviations by Visual Cue

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
E	8.82	96.53	3.79	6.52	1.53	2.02	215.00	286.01	0.042	0.0023
	(3.47)	(1.61)	(2.11)	(3.65)	(1.55)	(3.64)	(60.04)	(125.56)	(0.030)	(0.0020)
F	8.95	97.33	3.80	6.56	1.51	2.00	215.82	288.45	0.042	0.0023
	(3.48)	(1.61)	(2.10)	(3.67)	(1.54)	(3.65)	(58.83)	(129.59)	(0.030)	(0.0020)
N	9.23	99.72	3.90	6.70	1.64	1.94	215.53	286.83	0.042	0.0022
	(3.44)	(1.62)	(2.21)	(3.78)	(1.59)	(3.74)	(57.85)	(126.30)	(0.031)	(0.0019)

Table 11 : Means and Standard Deviations by Inclination

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
0	8.50	95.79	3.67	6.83	1.42	2.31	216.24	286.60	0.042	0.0025
	(3.90)	(1.67)	(2.18)	(4.10)	(1.57)	(3.88)	(55.23)	(117.00)	(0.031)	(0.0022)
14	10.09	99.64	4.09	6.77	1.60	1.70	217.80	283.88	0.044	0.0021
	(3.23)	(1.58)	(2.13)	(3.54)	(1.54)	(3.61)	(60.62)	(124.63)	(0.032)	(0.0019)
26	8.89	98.90	3.84	6.25	1.67	1.83	213.20	289.58	0.041	0.0021
	(3.15)	(1.57)	(2.10)	(3.33)	(1.55)	(3.48)	(61.39)	(138.25)	(0.028)	(0.0018)

Table 12 : Means and Standard Deviations by Elevation

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
0	9.27	88.77	3.85	6.77	1.48	1.94	209.12	288.50	0.043	0.0022
	(3.50)	(1.70)	(2.15)	(3.78)	(1.68)	(3.72)	(61.00)	(129.92)	(0.032)	(0.0019)
12	8.86	94.16	3.78	6.53	1.56	1.71	219.24	288.38	0.042	0.0023
	(3.42)	(1.60)	(2.15)	(3.63)	(1.55)	(3.58)	(57.42)	(132.39)	(0.030)	(0.0020)
24	8.88	112.02	3.86	6.50	1.63	2.32	217.65	289.58	0.042	0.0023
	(3.47)	(1.49)	(2.14)	(3.70)	(1.44)	(3.72)	(57.89)	(138.25)	(0.029)	(0.0020)

Table 13 : Means and Standard Deviations by Gender

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Female	7.52	96.18	3.61	6.08	1.58	2.03	190.85	248.19	0.038	0.0024
	(3.72)	(1.62)	(2.12)	(3.64)	(1.57)	(3.82)	(49.10)	(90.25)	(0.024)	(0.0021)
Male	10.73	99.51	4.04	7.09	1.54	1.94	39.51	325.09	0.046	0.0021
	(3.13)	(1.61)	(2.14)	(3.70)	(1.55)	(3.53)	(57.74)	(145.17)	(0.035)	(0.0018)

Table 14 : Means and Standard Deviations by Inclination and Elevation

Inclin / Elev	Area*	Length*	ML	AP	Max ML	MaxA P	Fx	Fy	MaxH/V	MinH/V
0		85.31				1.86		294.36	0.043	
/ 0		(1.78)				(3.97)		(115.30)	(0.033)	
0		91.80				2.13		283.82	0.041	
/ 12		(1.65)				(3.76)		(124.72)	(0.030)	
0		112.35				2.94		281.79	0.041	
/ 24		(1.52)				(3.85)		(110.06)	(0.030)	
14		90.22				1.63		281.40	0.044	
/ 0		(1.65)				(3.93)		(124.76)	(0.034)	
14		96.20				1.45		289.50	0.044	
/ 12		(1.58)				(3.48)		(133.59)	(0.032)	
14		114.19				2.04		280.36	0.043	
/ 24		(1.47)				(3.40)		(114.61)	(0.028)	
26		91.63				2.22		286.73	0.041	
/ 0		(1.63)				(3.27)		(146.83)	(0.028)	
26		95.36				1.44		292.34	0.041	
/ 12		(1.55)				(3.41)		(139.30)	(0.029)	
26		110.43				1.87		289.41	0.041	
/ 24		(1.48)				(3.69)		(128.89)	(0.028)	

Table 15 : Means and Standard Deviations by Lighting and Inclination

	Area*	Length*	ML	AP	Max ML	MaxA P	Fx	Fy	MaxH/V	MinH/V
Good/		93.01			1.32			285.63		
0		(1.75)			(1.57)			(119.86)		
Good/		95.10			1.46			295.00		
26		(1.62)			(1.54)			(145.86)		

Poor	97.71	1.49	287.24
/0	(1.62)	(1.57)	(115.12)
Poor	99.64	1.60	283.88
/14	(1.58)	(1.54)	(124.63)
Poor	101.52	1.81	285.95
/26	(1.53)	(1.54)	(132.89)

Table 16 : Means and Standard Deviations by Lighting and Elevation

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Good/		84.94			1.19	1.93				
0		(1.79)			(1.61)	(3.79)				
Good/		89.46			1.42	1.86				
12		(1.66)			(1.54)	(3.72)				
Good/		109.34			1.55	2.61				
24		(1.55)			(1.51)	(3.90)				
Poor		90.52			1.61	1.94				
/0		(1.66)			(1.70)	(3.69)				
Poor		96.34			1.62	1.64				
/12		(1.57)			(1.55)	(3.51)				
Poor		113.25			1.67	2.20				
/24		(1.47)			(1.41)	(3.64)				

Table 17 : Means and Standard Deviations by Lighting and Visual Cue

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
Good / E					1.41 (1.59)					
Good / F					1.34 (1.56)					
Good / N					1.41 (1.52)					
Poor / E					1.58 (1.53)					
Poor / F					1.58 (1.52)					
Poor / N					1.73 (1.61)					

Table 18 : Means and Standard Deviations by Visual Cue and Inclination

	Area*	Length*	ML	AP	Max ML	MaxAP	Fx	Fy	MaxH/V	MinH/V
E / 0		95.53 (1.67)			1.45 (1.60)					
E / 14		97.85 (1.58)			1.62 (1.56)					
E / 26		97.11 (1.57)			1.55 (1.49)					
F / 0		95.57 (1.67)			1.36 (1.58)					
F / 14		99.57 (1.58)			1.58 (1.49)					

F	98.10	1.62
/ 26	(1.57)	(1.51)
N	96.73	1.45
/ 0	(1.69)	(1.53)
N	102.08	1.61
/ 14	(1.59)	(1.57)
N	101.66	1.84
/ 26	(1.56)	(1.64)

* Geometric Means and Standard Deviations

Effect on Perceived Sense of Fall (PSOF) response (Phase-III):

The p-values for the Phase III repeat measure ANOVA are shown in Table-19.The least squares means for this analysis are shown in Table 20. A subject can obtain a maximum PSOF score of 8 implying highest fear of loosing balance or fall and a minimum PSOF scores of 0 implied no fear of loss of balance/fall. The cofactors used were age, gender and height/body weight which were found to be insignificant.

The independent variable of elevation produced a marginal significant difference in the PSOF (p=0.0565). Inclination was a significant factor for PSOF (p=0.0001). The PSOF response to 26 degree inclination was found to be significantly greater, when compared to that obtained for 14 degree inclination and no inclination. No significant 2-way interactions among the experimental conditions were found in the final model. Task was not found to be a significant factor for PSOF. Lighting conditions differed significantly in terms of the PSOF (p=0.0046). The poorer the light, the higher the PSOF value. The independent variable, Visual cue, was a significant factor for PSOF (p=0.0415). The PSOF for E or F visual cues was significantly better (lower value of PSOF) compared to no visual cues (N).

Table-19 P- values for testing the effects of elevation, inclination, tasks, lighting, and visual cue on PSOF

TEST CONDITION	ELEV	INCL	TASK	LIGHT	CUE	ELEV*INCL
F RATIO	22.9	23.03	1.35	10.31	3.46	0.5
P VALUE	**0.0565**	**0.0001**	0.2705	**0.0046**	**0.0415**	0.7323

Table -20: **Mean values of PSOF**

	LSMEAN	STD DEV
YOUNGER	0.7278	1.0253
OLDER	0.6129	1.0695
ELEV= 0	0.5503	0.9629
ELEV= 12	0.7455	1.0623
ELEV= 24	0.7153	1.1086
INCL = 0	0.4292	0.772
INCL = 14	0.4965	0.9691
INCL = 26	1.0854	1.214
BEND	0.5974	0.9197
REACH	0.6919	1.109
STATION	0.7218	1.1266
GOOD	0.5725	0.9178
POOR	0.7683	1.1006
E visual cue	0.6556	1.0558
F visual cue	0.6235	0.9938
No visual cue	0.732	1.0933

Effect of task, lighting, elevation, inclination, visual cues on indices of postural stability (Whole body C.G. based Kinematic outcomes)

The video data was digitized for fourteen subjects to obtain three dimensional whole body center of gravity (CG) motion (kinematic data) associated with tasks performed in the Phase-III. Based on the CG data, a custom software (IPSB software developed in our laboratory) was used to obtain the postural stability indices of WRTI and minimum IPSB. During each task, the video data was also digitized to obtain the minimum value of the stability boundary (MIN. SB) defined by the shoe marker system defined earlier in this report.

As per the definition of IPSB given earlier in this report, the lower the value of IPSB, the closer is the location of the whole body CG to the subjects' stability boundary implying increase in postural instability. A lower value of stability boundary implies smaller base of support available for the whole body CG to project in the horizontal plane which might give rise to postural instability. In other words, a lower IPSB and a lower stability boundary implies that the subject's postural stability is jeopardized.

ANCOVA (Analysis of Covariance) was performed to analyze the kinematic data. The covariates of age, weight, height, hand reaction time, and foot reaction time were the between-subject variables used to predict the postural sway/stability outcomes. Within-subject, the experimental conditions of elevation, lighting, inclination, and visual queues were tested for their effect on postural stability. In addition, all possible two-factor interactions between the within-subject factors were investigated. The postural sway data were analyzed within the three tasks performed by the subjects (Reach, Bending, and Stationary tasks). Beginning from the saturated models involving all covariates, within-subject factors and interactions, final models were derived through a backward elimination strategy of insignificant covariates and two-factor interactions. In the final models, only significant covariates and two-factor interactions were included, along with the within-subject main effects, which were always included in the ANCOVA models. An alpha-level of 0.05 was used for all statistical tests.

The results of the ANOCOVA are shown in Table 21. The means for the levels of each within-subject factor are shown in Tables 22-26. Task significantly affected all the dependent variables (WRTI,_Minimum IPSB, and Minimum FSB). Reach task had the smallest Minimum IPSB and Minimum FSB values. Stationary task had the largest Minimum IPSB and minimum FSB values. Lighting factor had marginal ($p=0.0615$) effect on WRTI. Data showed that good lighting condition tended to have bigger WRTI value. Poor lighting tended to correspond to smaller WRTI value implying overcautious movement by keeping the body's CG near center of its stability boundary. Inclination factor had marginal ($p=0.0554$) effect on minimum FSB variable. The smallest minimum FSB values were related with 14° inclination. The largest minimum FSB values were corresponded with 0° inclination.

Table 21: Anocova Analysis Result (P Value Table)

	WRTI	MIN IPSB	MIN_FSB
AGE	**0.0467***		
WEIGHT			**0.0438***
HEIGHT			
HAND_RECTION			
FOOT_RECTION			
VISUAL CUE	0.6969	0.4848	0.7044
ELEVATION	0.6944	0.3285	0.4131
INCLINATION	0.5416	0.4597	**0.0554**
TASK	**0.0001***	**0.0005***	**0.0001***
LIGHTING	**0.0615**	0.1650	0.3242
VISUAL * ELEVATION			
VISUAL * INCLINATION			
VISUAL * LIGHTING			
ELEVATION * INCLINATION			
ELEVATION * LIGHTING			
INCLINATION * LIGHTING			

*: Statistically significant at $\alpha < 0.05$

Table 22: Arithmetic Mean and Standard Deviations by Task

TASK	WRTI*	MIN_IPSB*	MIN_FSB*
REACH	0.39358 ± 0.59224	0.28261 ± 0.56379	518.185 ± 111.907
BENDING	0.41389 ± 0.57169	0.30719 ± 0.30319	518.841 ± 110.919
STATIONARY	0.52254 ± 0.75563	0.36255 ± 0.27516	530.492 ± 111.410

*: There's significant effect by Task factor in the model.

Table 23: Arithmetic Mean and Standard Deviations by Visual Cues

Visual Queues	WRTI	MIN_IPSB	MIN_FSB
F	0.43990 ± 0.64230	0.32054 ± 0.34117	524.260 ± 112.489
E	0.45765 ± 0.66153	0.30520 ± 0.57978	522.707 ± 112.204
N	0.45793 ± 0.64735	0.33162 ± 0.25896	522.278 ± 110.213

Table 24: Arithmetic Mean and Standard Deviations by Elevation

Elevation	WRTI	MIN_IPSB	MIN_FSB
0	0.49626 ± 0.68628	0.26202 ± 0.59430	533.009 ± 112.534
12	0.39270 ± 0.55294	0.37291 ± 0.29771	519.068 ± 109.607
24	0.45824 ± 0.68643	0.33007 ± 0.24682	516.588 ± 111.782

Table 25: Arithmetic Mean and Standard Deviations by Inclination

Inclination	WRTI	MIN IPSB	MIN_FSB
0	0.48809 ± 0.66356	0.33689 ± 0.22322	533.263 ± 122.416
14	0.45843 ± 0.64142	0.27632 ± 0.67731	505.564 ± 102.285
26	0.41142 ± 0.64034	0.32694 ± 0.35383	523.393 ± 104.177

Table 26: Arithmetic Mean and Standard Deviations by Lighting

Lighting	WRTI^	MIN_IPSB	MIN_FSB^
Good	0.47456 ± 0.69530	0.34088 ± 0.29143	529.969 ± 113.764
Poor	0.44178 ± 0.62906	0.30940 ± 0.46109	520.009 ± 110.494

^: Lighting factor has effect close to 0.05 significant level.

D.3.b. Implications of Objective vs. Subjective measures of postural balance while working on inclined/elevated surfaces (Phase-III)

In an effort to relate the objective findings of postural balance presented in Tables 7-18 with those of subjective measures of postural balance (presented in Tables 19-20), the following comment are added here. It is interesting to note that while subjective indicator PSOF of perceived sense of fall showed statistically significant association with increasing values of inclination, it only showed marginal significance with elevation (Tables 19-20). The PSOF response to inclination (Table 20) showed that subject's were showing increasing sense of loss of balance (as PSOF values increased monotonically with increasing inclination levels) even though the objective measures of sway (sway length) were not giving consistent and significant association with increasing values of inclination (Table 7). This discrepancy between subjective and objective measures of postural balance imply that subjects were overcautious as they stood on inclined surfaces

of increasing angles. This increased "awareness" of their own body sway might have elicited counteracting postural muscle activities to overcompensate which can only be validated with measures of electromyographic outcomes of the postural muscles. In the workplace, it is probably advantageous to have a somewhat overcautious response [i.e. a higher PSOF values even though the objective measures (i.e. sway lenght) show a smaller value] while performing tasks on inclined and elevated surfaces. In the present study, the WRTI values (Table 25) show monotonically decreasing with increasing inclination implying that the body is overcautious and is trying to keep the whole body CG closer to the center of its stability boundary as the inclination is increasing.

The objective measure of sway length showed significant interaction between inclination and elevation (Table 7) but the subjective measure PSOF (Table 19) did not show a significant association. It is interesting to note that sway length was generally increased at higher elevations when the inclination angle increased, implying overcompensation by the postural muscles due to psychophysical fear of fall or height (Table 14). However, the subjective response of PSOF did not show significant inclination by elevation interaction (Table 19) implying that while working on elevated inclined surfaces there exists the potential mismatch between actual danger of loss of stability (as measured by sway variables) and the workers' ability to subjectively judge the need to deploy the necessary compensatory postural muscle contractions.

An increase in objective measure sway length for lighting by inclination interaction implies that subjects were subconsciously overcompensating as they performed tasks on increasing angles of inlication in poor light however, the subjective response variable PSOF did not show such significant interaction implying potential mismatch between objective measures and the subjective perception of postural balance. This type of mismatch potentially be detrimental to workers' ability to use proper corrective measures to prevent loss of balance while working on inclined surfaces in poor environmental lighting conditions. In the present study, 2 out of 3 indices of postural instability (Minimum IPSB and Minimum FSB) shows a lower value for the poor light compared to the good light implying potential decrease in postural instability (Table 26).

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List of current and possible future Publications

Shiowyi Sharon Chiou, Bhattacharya, A, Succop, P.A. and Lai, C.F., "Effect of environmental and task risk factors on workers' perceived sense of postural sway and instability" **Occupational Ergonomics** 1(2): 81-93, 1998.

Bagchee, A., Bhattacharya, A., Succop, P and Emerich, R. "Postural stability assessment during task performance" **Occupational Ergonomics** 1 (1): 41-53, 1998.

Bagchee, A Bhattacharya, A, Succop, P.A Medvedovic, M and Mitchell, T., "Risk factors of task performance at elevated and inclined surfaces" Presented at the National Occupational Injury Research Symposium, Morgantown, WV, Oct. 15-17, 1997.

Bagchee, A Bhattacharya, A Succop, P.A., and Lai C.F., "Development of a risk factor analysis model for prdicting postural instability at workplace" Presented at the XII Annual International Occupational Ergonomics and Safety Conference, June 1-4, 1997, Washington D.C.

Bagchee, A Bhattacharya, A Succop, P and Medvedovic, M., "Use of visual cues in reducing the risk of fall during work at elevated and/or inclined surfaces" presented at the American Industrial Hygiene Association Conference, Dallas, Texas., May 17-23, 1997.

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Appendix A

Medical Screening/Preliminary Questionnaire
Medical Screening/Subject Screening Exclusion Summary
Anthropometry
Session Interview

NAME:_____DATE:_____ID:_____

SSN: _____ TELEPHONE: _____

SEX: Female ____ Male ____ BIRTHDATE: _____

EDUCATION:(circle one) 1=less than 12th 2=high school grad

3=undergraduate degree 4=graduate degree

RACE (Please Circle NUMBER):

WHITE.....1

BLACK/AFRICAN AMERICAN.....2

HISPANIC.....3

NATIVE AMERICAN OR ALASKAN NATIVE.....4

ASIAN OR PACIFIC ISLANDER.....5

OTHER.....6

EMPLOYER_____

OCCUPATION:_____Shift:_____

JOB DUTIES: _____

ARE YOU CURRENTLY EXPOSED TO ANY OF THE FOLLOWING ON YOUR JOB? (Please Circle)

0. None 1.Solvents	5. Arsenic	9. Acrylamide
2. Lead	6. Kerosene/Mineral Spirits	10. Pesticides
3. Tolune	7. Perchloroethylene	11Combination
4. Styrene	8. Trichloroethylene	

DID YOU <u>EVER</u> HAVE A JOB IN ANY OF THE FOLLOWING INDUSTRIES FOR MORE THAN ONE YEAR?

0. None 1.Rubber/Tire Manufacture	5. Commercial Painting	9. Printing
2. Chemical or Paint Manufacture	6. Foundry	10. Lead Industry
3. Petroleum Refining	7. Dry Cleaning	11. Sand Blasting
4. Smelting Industry	8. Battery Plant (Lead or Storage)	12.Combination

HOBBIES (circle <u>all</u> which apply):

0. None 1.Stained Glass Work 7.Paint Removal 10.Pottery/Ceramic
2.Mimeographing 8.Silk Screening 11.Making Bullets
3.House Painting 9.Furniture Finishing 12.Indoor firing range
4.Melting Metal for any purpose 13.Cutting wood with Chain Saw
5.Model Plane/Car Building 14. Combination
6. Jewelry Making

MEDICAL CONDITIONS (list all):

_____

_____

CURRENT MEDICATIONS

	Name of Medication	How Much?	How Often?
Prescription			

	Name of Medication	How Much?	How Often?
Non-Prescription *(For instance: cold remedies, decongestants, minor pain medications, and others.)*			

ALCOHOL

Do you now (within the last month) drink alcoholic beverages? Y N

If no, did you <u>ever</u> drink alcoholic beverages (more than one glass of beer, wine, or mixed drink per month)? Y N

How old were you when you first started drinking alcoholic beverages? ____

If you stopped drinking alcoholic beverages completely, how old were you when you stopped? ____

About how often do/did you drink some kind of alcoholic beverage? (Chose ONE answer)

(Circle One)
1. Almost every day ____
2. Three or four times a week ____
3. Once or twice a week ____
4. Once or twice a month ____
5. Less than once a month ____

Based on the average of the entire time you drank alcoholic beverages, how often did you drink? (Chose ONE answer)

(Circle One)
1. Daily ____
2. Weekly ____
3. Monthly ____

Enter the number of drinks you consumed(per day, week, or month depending on how you answered the above question) ____

How many caffeinated drinks per day do you consume? ____

How many cigarettes do you smoke per day? ____

THE FOLLOWING IS A LISTING OF HEALTH PROBLEMS WITH WHICH YOU MAY HAVE HAD TROUBLE.

IF YOU HAVE HAD THIS PROBLEM AT ANY TIME, CIRCLE "Y" IN THE "EVER" COLUMN. ALSO WRITE THE *MONTH AND YEAR* WHEN THE PROBLEM *LAST OCCURRED*.
IF YOU HAVE NEVER HAD THIS PROBLEM, PLEASE CIRCLE "N" UNDER "EVER".

IF YOU ARE HAVING THIS PROBLEM RIGHT NOW, CIRCLE "Y" UNDER "CURRENT".
IF YOU ARE NOT HAVING THIS PROBLEM CURRENTLY, PLEASE CIRCLE "N" IN THE "CURRENT" COLUMN.

PROBLEM	EVER	CURRENT	MONTH/YEAR LAST EPISODE
Problems with vision	Y / N	Y / N	_____
Shortness of breath with exercise	Y / N	Y / N	_____
Weakness in legs	Y / N	Y / N	_____
Numbness in legs	Y / N	Y / N	_____
Seizures, fits or convulsions	Y / N	Y / N	_____
Stroke	Y / N	Y / N	_____
Sudden blackouts	Y / N	Y / N	_____

PROBLEM	EVER	CURRENT	MONTH/YEAR LAST EPISODE
Chronic or recurring spinning dizziness	Y / N	Y / N	_____
Chronic or recurring light-headedness	Y / N	Y / N	_____
Meniere's disease	Y / N	Y / N	_____
Problems with maintaining balance	Y / N	Y / N	_____
Parkinson's disease	Y / N	Y / N	_____
Multiple sclerosis	Y / N	Y / N	_____
Intermittent claudication (poor circulation in the legs)	Y / N	Y / N	_____
Anemia	Y / N	Y / N	_____
Chronic lung disease (emphysema or bronchitis, for instance)	Y / N	Y / N	_____
Heart disease	Y / N	Y / N	_____
Abnormal heart rhythm	Y / N	Y / N	_____
Heart attack	Y / N	Y / N	_____
Angina	Y / N	Y / N	_____
Congestive heart failure	Y / N	Y / N	_____
High blood pressure	Y / N	Y / N	_____
Chest pain	Y / N	Y / N	_____
Alcoholism or alcohol abuse	Y / N	Y / N	_____
Drug addiction or abuse	Y / N	Y / N	_____
Chronic foot or leg disability	Y / N	Y / N	_____
Diabetes mellitus (sugar diabetes)	Y / N	Y / N	_____
Arthritis or pain involving:			
Neck	Y / N	Y / N	_____
Lower Back	Y / N	Y / N	_____
Hips	Y / N	Y / N	_____
Knees	Y / N	Y / N	_____
Ankles	Y / N	Y / N	_____

PROBLEM	EVER	CURRENT	MONTH/YEAR LAST EPISODE
Require use of cane or other walking aid	Y / N	Y / N	_____
Head, neck or back injury/surgery	Y / N	Y / N	_____
Cancer requiring chemotherapy	Y / N	Y / N	_____

Have you ever had a fall for which there was no clear or identifiable reason (e.g. slippery walk, darkness)? Y / N

If yes:

List the month and year this last occurred? _____

How many times in the past year has this occurred? _____

Approximately how many times has this ever occurred? _____

How would you describe your present state of health? (Circle One)

1.excellent
2.Good
3.Fair
4.Poor

Have you had an ear infection within the last month? Y / N

Do you have any ear problems? Y / N

If yes, please describe: _____

_____

Have you ever had any other injuries or surgeries? Y / N

If yes, please describe:

_____

_____

_____

Are you involved in any regular exercise program? Y / N

If yes,
circle: 0.None 1.walking 2.jogging 3. bicycling

4. swimming 5. weight lifting 6. racket sports

7. (specify)_____

☐ Pre-employment
☐ Return to work
☐ Disability evaluation
☐ Periodic
✓ STUDY BASELINE

PHYSICAL EXAMINATION

NAME _____ (LAST / FIRST / MIDDLE) | SEX M F | DATE OF BIRTH | MARITAL STATUS S M W D Sep

HOME ADDRESS _____ (STREET / CITY / STATE) PHONE _____

COMPANY _____ DEPARTMENT _____ JOB TITLE _____

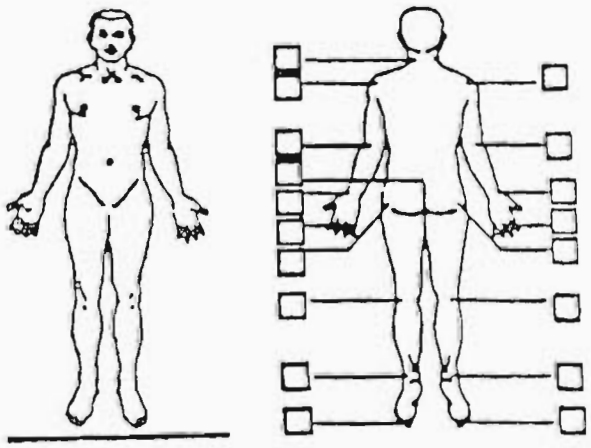
HEIGHT	WEIGHT	RECHECKS	BLOOD PRESSURE Sys	RECHECKS	
TEMPERATURE	PULSE		Dias		

CHEST X-RAY	NORMAL / ABNORMAL	VISION		DEPTH	
SEROLOGICAL TEST	NEGATIVE / POSITIVE	Far	UNCORRECTED / CORRECTED R 20 L 20	COLOR	
URINALYSIS	Alb ____ Sugar ____ Bld ____ pH ____ S.G. ____ Ketone ____ Bilirubin ____ Urobil ____	Near	UNCORRECTED / CORRECTED R 20 L 20	PERIPHERAL	
ELECTROCARDIOGRAM	NORMAL / ABNORMAL	AUDIOGRAM Normal Range: 0-26 Decibels Loss (ANSI '969)			
HEMATOCRIT			500 1000 2000 3000 4000 6000 8000		
OTHER LAB		LEFT			
		RIGHT			Tester

CODE NORMAL ✓ ABNORMAL X NOT EXAMINED •

1	APPEARANCE	
2	EYES	
3	EARS	
4	NOSE	
5	MOUTH	
6	TEETH & GUMS	
7	PHARYNX	
8	NECK & THYROID	
9	BREASTS	
10	THORAX	
11	LUNGS	
12	HEART	
13	ABDOMEN	
14	INGUINAL REGION	
15	ANUS & RECTUM	
16	GENITO - URINARY	
17	MUSCULO - SKELETAL	
18	EXTREMITIES	
19	SKIN	
20	LYMPH NODES	
21	NEUROLOGICAL	
22	MENTAL ATTITUDE	

MARK SCARS:



SIGNED _____ M.D. DATE _____

University of Cincinnati
Medical Center

Department of Environmental Health
University of Cincinnati
PO Box 670056
Cincinnati OH 45267-0056

Delivery Address:
123 East Shields Street
Cincinnati OH 45220

MEDICAL EXAM/SUBJECT SCREENING
EXCLUSION SUMMARY

NAME:_____ DATE:_____

REASON FOR EXCLUSION:

_____

_____

_____

FOLLOW-UP WITH PRIMARY CARE PHYSICIAN: YES:_____ NO:_____

_____

_____

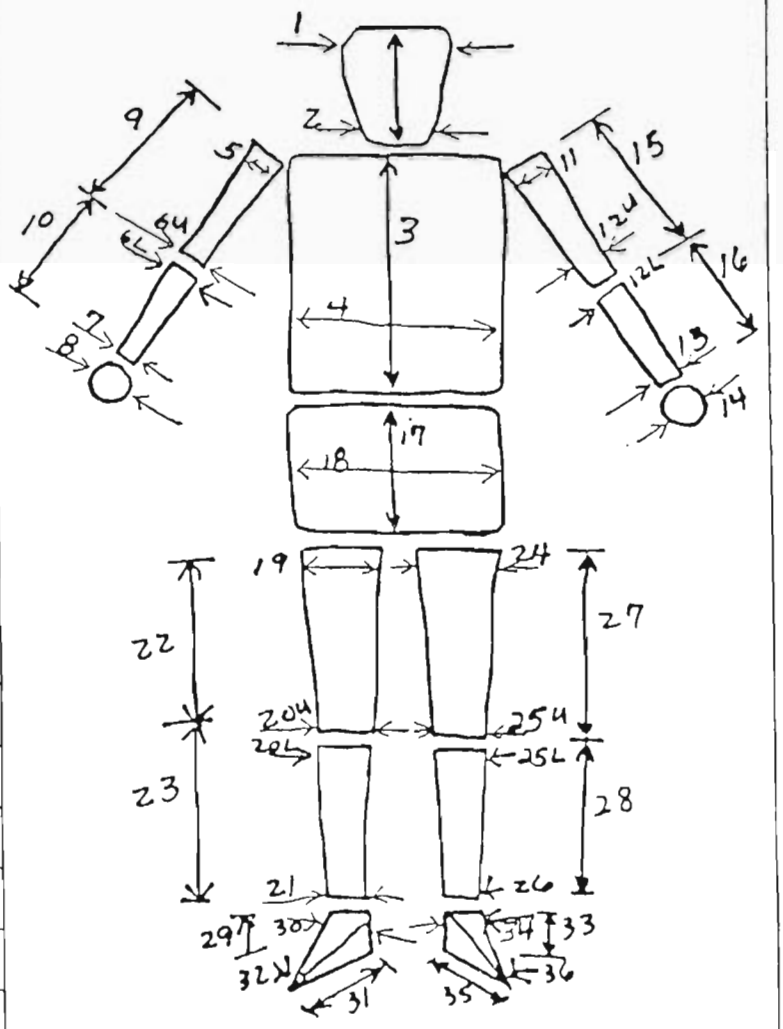
_____

PHYSICIAN:_____ DATE:_____

SLIP STUDY - SUBJECT MEASUREMENTS

NAME _____ ID _____ DATE _____

BODY SEGMENT		MEASUREMENT (CM)		BODY SEGMENT		MEASUREMENT (CM)	
HEAD: Upper	1			FOOT: Rt. Height-ankle	29		
Lower	2			Rt. Width -ankle	30		
Trunk: Length	3			Rt. Length(Brannock)	31		
Diameter	4			Rt. Width(Brannock)	32		
Arm: Rt. upper	5			FOOT: Lft. Height-ankle	33		
Rt. elbow	6	UPPER	LOWER	Lft. Width-ankle	34		
Rt. wrist	7			Lft. Length(Brannock)	35		
Rt. hand	8			Lft. Width(Brannock)	36		
Rt. upper length	9			Height: total body length	37		
Rt. lower length	10						
Arm: Lft. upper	11						
Lft. elbow	12	UPPER	LOWER				
Lft. wrist	13						
Lft. hand	14						
Lft. upper length	15						
Lft lower length	16						
Abdomen: Length	17						
Diameter	18						
Leg: Rt. upper	19						
Rt. knee	20	UPPER	LOWER				
Rt. ankle	21						
Rt. upper length	22						
Rt. lower length	23						
Lft. upper	24						
Lft knee	25	UPPER	LOWER				
Lft. ankle	26						
Lft. upper length	27						
Lft. lower length	28						



A-8

ELEVATION STUDY - SUBJECT MEASUREMENTS

NAME_____ ID_____ DATE_____

BODY SEGMENT		MEASUREMENT (CM)		BODY SEGMENT		MEASUREMENT (CM)
HEAD:Upper	1			FOOT:Rt.Height-ankle	29	
Lower	2			Rt.Width -ankle	30	
Trunk: Length	3			Rt. Length(Brannock)	31	
Diameter	4			Rt. Width(Brannock)	32	
Arm: Rt. upper	5			FOOT:Lft. Height-ankle	33	
Rt. elbow	6	UPPER / LOWER		Lft. Width-ankle	34	
Rt. wrist	7			Lft. Length(Brannock)	35	
Rt. hand	8			Lft. Width(Brannock)	36	
Rt. upper length	9			Height: total body length	37	
Rt. lower length	10					
Arm: Lft. upper	11					
Lft. elbow	12	UPPER / LOWER				
Lft. wrist	13					
Lft. hand	14					
Lft. upper length	15					
Lft. lower length	16					
Abdomen: Length	17					
Diameter	18					
Leg: Rt. upper	19					
Rt. knee	20	UPPER / LOWER				
Rt. ankle	21					
Rt. upper length	22					
Rt. lower length	23					
Lft. upper	24					
Lft. knee	25	UPPER / LOWER				
Lft. ankle	26					
Lft. upper length	27					
Lft. lower length	28					

BIOMECHANICS AND ERGONOMICS RESEARCH LABORATORY
SESSION INTRVIEW

NAME:_____SUB ID:_____ DATE:_____ SESSION#:_____

1. Asleep:_____ Woke:_____ #hrs slept: _____

2. Sleep uninterrupted: 1=yes 2=no 3=unknown _____

3. Time ate last:_____ #hrs since last meal _____

4. Caffeine last 12 hours: 1=yes 2=no 3=unknown _____

   type: 1=coffee 2=tea 3=soda 4=cocoa 5=combo 6=none _____

   amount: enter # ounces _____

5. # cigarettes smoked in last 12 hours: _____

   time last cigarette: _____

6. Sick in the last week: _____
   hx_____
7. Any recent surgery including dental: _____
   hx_____
8. Ear infection since last visit: _____
   hx_____
9. Currently taking any meds (last 24 hrs): _____
   hx_____
10. Injuries to head neck or back since last visit: _____
    hx_____
11. Have you fallen on the job since last visit: _____
    hx_____
12. In the last 24 hours, strenuous activity: _____
    hx_____
13. Stressful events at home or job in last 24 hrs: _____
    hx_____
14. Alcohol consumption in the last 48 hours: _____

    type: 1=beer 2=liquor 3=wine 4=none _____

    amount consumed: enter # ounces _____

15. Recreational drugs ingested in the last 24 hours: _____

    type: 1=marijuana 2=cocaine 3=narcot. 4=other 5=none _____

    freq./amount in last 24 hours _____

16. Did you work in the last 12 hours: _____

    # hours worked _____
    type work_____
17. Have you changed shifts in the last week: _____

    last shift worked _____

    current shift _____

18. BP_____ Pulse:_____

19. Are you pregnant? yes no LMP_____

ELEVATION STUDY
RAW DATA SHEET

Name: ____________________ **Date:** ___/___/___ **Sub ID:** __________ **Session #** _____

Age: ________ (months) Weight: (1) ________ kg; (2) _________ kg

ELEV	INCL	LIGHT	TASK	DISTR	FILENAME	SMPTE CODE				COMMENTS			

Calib. Time Code: ___:___:___:___ **Tape #:** ELEV-____ **Disk #:** ELEV-____ **Operator:** __________

Appendix B

Marker System for Elevation Study

Marker system used in the study: Figure A-1 shows the 18 point marker system used for the study. Sixteen markers were placed on the following anatomical positions: Two each at (1) Top of first toes, (2) fifth metatarsophalangeal (MTP) joints, (3) heels (calcaneus), (4) Knees (fibular head), (5) hips (greater trochanter), (6) shoulders (acromion process), (7) elbows (lateral epicondyle), and (8) wrists (styloid process). Two markers were placed on the test surface, one each on right and left side of the subject, to mark the central medial-lateral position of the subject's standing surface during the tests.

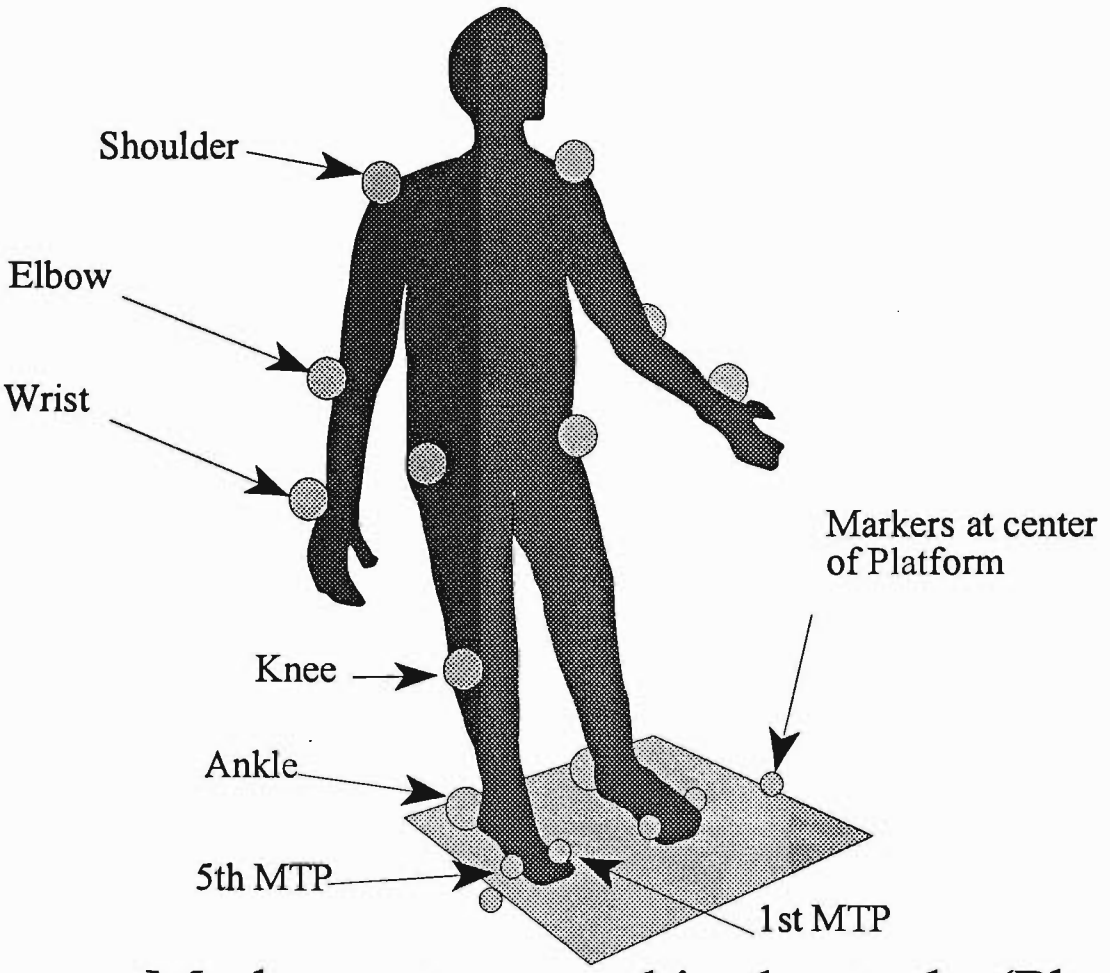


Figure A-1 Body marker system used in the study

Appendix C

Perceived Sense of Fall

NAME: _____ DATE: _____ SUB ID: _____ SESSION:_____ FILE:_____

RATING OF PERCEIVED SENSE OF FALL DURING A POSTURAL STABILITY TEST

Sway is defined as movement from side to side or back and forth. Even while standing still, everyone experiences body sway. This can be felt by the individual as a gentle pendulum like movement in seemingly random directions of the body. In reality, the body's sway is caused by contraction and relaxation of muscle groups. This causes the body to sway or pivot at joints such as the ankles, knees, waist, and neck. After each Postural Stability Test you will be asked to estimate your total body sway. Point to the description or number that corresponds best with what you felt. For instance, if you felt your body sway somewhere between a little and some, you may use the rating -0.5-.

1. How much did you feel your body sway (i.e., rotate, pivot)?

a little		**some**		**a lot**
-0-	**-0.5**	**-1-**	**-1.5-**	**-2-**

2. Did you have any difficulty in maintaining balance (how much did you or your muscles compensate for your movement)?

none		**a little**		**a lot**
-0-	**-0.5-**	**-1-**	**-1.5-**	**-2-**

3. Did you feel at any time that you would fall?

none		**a little**		**a lot**
-0-	**-0.5-**	**-1-**	**-1.5-**	**-2-**

4. What would you say was the overall difficulty of this task?

very easy	**easy**	**moderate**	**somewhat hard**	**hard**
-0-	**-0.5-**	**-1-**	**-1.5-**	**-2-**

SLIP: YES NO

ADMINISTERED BY _____
(STAFF MEMBER NAME)