



the
American Society
of Safety Engineers

vol. 2, num 1

Spring 2005

T H E J O U R N A L O F S H & E R E S E A R C H

Ratings of Perceived Loss of Balance: A Potential Safety Monitoring Technique for Workers Walking/Working on Sloped Surfaces

Sang D. Choi, Ph.D., CPE

Corresponding Author:

Sang D. Choi, Ph.D., CPE, Assistant Professor

Department of Occupational and Environmental Safety and Health

University of Wisconsin-Whitewater

Whitewater, WI 53190-1790

Phone: 262-472-1641

Fax: 262-472-1091

Email: chois@uww.edu



Author Biography:

Sang D. Choi is an assistant professor in the Occupational and Environmental Safety and Health Department at the University of Wisconsin-Whitewater. He earned his MSIE from Wichita State University in 1999 and Ph.D. in Industrial Engineering from Western Michigan University in 2003. He is a Certified Professional Ergonomist (CPE) and a member of ASSE, HFES, ISOES, and IIE.

Abstract

Falls from roofs account for the most work related fall injuries, and they also represent more than one-fifth of all occupational fatal falls (Bureau of Labor Statistics). In the fatality investigation reports or worker compensation descriptions, one of the most commonly mentioned initial reasons for falls was loss of balance. The purpose of this study was two-fold: (1) to develop ratings of perceived loss of balance (PLB) to detect changes in slope, and (2) to determine the relationships between the developed PLB and objective measures of postural sway. Twelve healthy male volunteers (age: 24.8 ± 3.4) participated in this study. The simulated roof-shingling task was performed at the slopes 18° , 26° , and 34° respectively. The obtained ratings of perceived loss of balance were compared with objective measurements determined by a strain gauge type force platform. Results from this study revealed that the PLB scale was sensitive enough to detect changes in slopes (i.e., steep roofs). The findings also indicate that a



strong correlation exists between the PLB scale and postural instability. The perceived loss of balance scale is a very reliable indirect measure of postural instability and is easy to use. In summary, the PLB scale may be used as a potential safety monitoring technique.

Keywords:

Roofing Industry; Construction Safety; Sloped Surface; Postural Stability; Perceived Loss of Balance

Introduction

The construction industry is a major industry in the United States, employing over 6 million of the nation's workforce. One of the most hazardous sectors within the construction industry is the roofing industry. The number of fatalities occurring in the roofing industry stood out among the highest in the construction industry (BLS, 2002). The occupation of roofers has been rated as one of the most dangerous occupations (Toscano, 1997). Roofers are at about six times higher risk for fatal occupational injuries than the average worker, with falls being fatal events in 75% of cases (Ruser, 1995). Additionally, typical injuries caused by falls from roofs are extremely severe, requiring long periods of treatment and recovery and resulting in substantial medical costs (Parsons & Pizatella 1985; Gillen et al., 1997).



While the exact causes leading to fall incidents are rarely found in the literature, fatality investigation reports or worker compensation descriptions indicate the most commonly mentioned initial reasons for falls were slips, trips and imbalance episodes that can all be regarded as loss of balance incidents (Hsiao & Simeonov, 2001). Workers either slipped while walking, lost their balance while on the roofing surface, or lost their balance when surface materials slipped, for example roofing shingles lying on the roof slipped (Parsons et al., 1986). Stepping on loose materials on pitched roofs, resulting in slips off the roof edge (Suruda et al., 1995), steep roofs causing slip or imbalance (Parsons & Pizatella, 1985), and inadequate worker's perceptions of the strength and load-bearing capacity of skylight elements (Bobick et al., 1994; NIOSH, 1989) were also reported as common incidents.

Monitoring techniques for the safety of workers walking/working on sloped surfaces are limited. A safety monitoring system is described by Occupational Safety and Health Administration (OSHA) as a "safety system in which a competent person is responsible for recognizing and warning employees of fall hazards" (OSHA, 1998). Safety monitoring systems are usually used in the absence of other protective measures. Employers designate safety monitors by ensuring that the human monitor is able to perform the tasks such as detecting and warning fall hazard dangers. Yet, very little information for safety monitoring systems (e.g., a human monitoring a roofing task on a sloped surface) currently exists in terms of capturing worker's subjective perceptions of the loss of balance while walking/working on steep roofs.

The use of a subjective rating scale in matching human psychological feelings has long been in existence. Borg (1970) developed the rating of perceived exertion (RPE) scale to capture subjective perceptions of exertion. Subjective evaluation has been widely used as a simple and valid measure to estimate the physiological response in applied situations (Hart & Staveland, 1988; Kakizaki, 1987; Reid et al., 1982). Many investigations have also found that the psychophysical approach appears to produce reliable results for manual material handling tasks (Lu & Aghazadeh, 1994), and it requires the subjects to adjust one of the task variables (e.g., frequency of the object being handled) according to their own perception of muscular effort or force. The individuals adjust their workload to the maximum amount they can sustain without undue strain or discomfort, and without becoming unusually tired, weakened or overheated, or out of breath (Mital et al., 1997). Yet, similar research has not been conducted to



determine the perceived loss of balance to better understand workers' psychophysical safety requirements during roofing task performance associated with inclined surfaces (e.g., steep roofs). Such ratings are important complements to physiological and biomechanical measurements of task performance and work safety.

Postural-sway is the corrective body movement resulting from the control of body position and is determined by measuring the location and amount of change that occurs in the position of the vertical force vector projected onto a horizontal plane (Berg et al., 1992). Postural-sway is usually measured during quiet, upright standing (i.e., static balance) and thus reflects the body's effort to maintain balance in that posture, with increased sway indicating greater effort and thus suggesting poorer balance. Although many falls occur while a person is moving (i.e., dynamic balance), static and dynamic balance are correlated and increased static postural instability is often a common sign for many pathophysiologic mechanisms that increase the risk of falling (Thapa et al., 1994). Traditionally, postural stability has been measured by determining the degree of motion of the center of pressure (COP) at the surface of support through force platform technology (Berg et al., 1992; Hasan et al., 1990; Bhattacharya et al., 1987; Sahlstrand et al., 1978). The propensity of postural instability increases as the postural-sway induced body's COP movement approaches the stability boundary defined by the outer perimeter of one's feet (Bachee et al., 1998).

The purpose of this study was two-fold: (1) to develop ratings of perceived loss of balance (PLB) to detect changes in slope, and (2) to determine the relationships between the developed PLB and objective measures of postural sway. The postural sway of those participating in a roof-shingling task on the sloped surfaces (18°, 26°, and 34°) was measured using a strain-gauge force platform.

Methods and Procedures

Pilot Study

A pilot study to simulate the roof shingling task using experienced roofers was conducted. The purpose of this pilot study was to design and validate the experimental setup and procedure of the roof shingling task for a workday period using experienced roofers.



Four male volunteers from the construction industry participated in this pilot study. Their ages ranged from 19 to 21 years (mean=20, SD=1), their weight from 74 to 90 Kg (mean=79, SD=7.6), and their height from 1710 to 1940 mm (mean=1818, SD=100). All who participated in this pilot study had a minimum of two years of roofing experience. The participating roofers were screened for any history of musculoskeletal disorders (MSDs), especially back pain or back disorder, as well as balance-related diseases.

A workstation was constructed in order to simulate a roof-shingling task. The roofing workstation consisted of three components: base (5.49 m by 3.66 m), 26°-inclined surface (5.49 m by 3.96 m), and back support (5.49 m by 3.05 m) as shown in Figure 1.

Insert Figure 1 about here

Dimensional asphalt shingles were used in this pilot study. A dimensional shingle is textured, over-layered, or laminated and is designed to produce a three-dimensional effect. The size of one bundle is 1.00 m (39-3/8 in) by 0.32 m (13-1/4 in) by 0.10 m (4 in). One bundle yields a weight of 33.0 kg (73 lbs), while consisting of 20 individual shingles. A Hitachi NV45AB coil roofing nailer and an air compressor were used to apply nails (i.e., without nails in the nailer) on the shingles that were attached on the felted deck.

A multicomponent measuring platform (Type 9281B, Kistler Instrument Corp., Amherst, NY) was used for the postural sway measurement in this pilot study. The platform consists of a rigid metal plate (40 cm (16 in) × 60 cm (24 in) wide and 5 cm (2 in) in height), supported by four strain-gauge force transducers. The LabVIEW software recorded the 1500 data points (in X and Y coordinates) for each trial duration of 30 seconds and a Microsoft Excel worksheet was used to calculate the amplitude and speed in the anterior-posterior (A-P) and medial-lateral (M-L) directions and XY area (Berg et al., 1992).



A TEK anthropometric kit was used for taking anthropometric measures. A Jamar hydraulic hand dynamometer was used to measure grip strengths. A POLAR clip-on heart rate monitor and a Tango Stress Test Blood Pressure Monitor were used for taking the heart rate and blood pressure, respectively. A full body harness with a D-ring at center of back was designated for the simulated shingling task. This harness is designed to permit the participant freedom of movement as well as providing sufficient strength to safely arrest the most severe fall. Safety mattresses (impact resistant pads) were placed for use in abnormal landing situations during the simulated roofing task. The safety mattress is comprised of a foam block enclosed in a polyethylene cover.

Upon meeting with the roofers, the experimenter provided a background and brief description of this pilot study. The roofers were given the opportunity to ask questions and clarify their doubts regarding the procedures and practices of this study. The roofers' blood pressure and heart rate were measured using a Tango system. For a roofer to be eligible, the roofer's resting systolic and diastolic blood pressure had to be below 140 mm Hg or 90 mm Hg, respectively, and the roofer's resting heart rate had to be below 80 beats per minute (Fernandez & Marley, 1998). Also, the roofers were screened using a brief medical history form including heart problems, back injury, and balance-related diseases per self-report. After the roofers passed the primary screening, several anthropometric measures (such as height, weight, and foot size) and grip strengths in neutral posture (i.e., elbow at 90 degrees) were taken using Caldwell protocol (1974).

A schedule for the roof-shingling experiment was established next. The roofers were asked not to consume any tobacco products, alcoholic or caffeinated beverages 24 hours prior to the experiment. Before beginning the experiment, the resting blood pressure and heart rate were taken using the Tango system. As stated earlier, if the roofer's systolic and diastolic pressure were greater than 140 mm Hg or 90 mm Hg, respectively, or the heart rate was greater than 80 beats per minute, the roofer was not be permitted to start shingling. The roofers were asked to perform a series of warm-up exercises that typically last 2 to 4 minutes. These mild stretching exercises were intended to minimize any sprains or muscle pulls.



After the initial checks, the roofers were equipped with a safety harness (meeting Occupational Safety and Health Administration (OSHA) and American National Standards Institute (ANSI) Specifications) to prevent a fall. The safety harness requirement was in conformance with roofing safety regulations, which requires a fall arrest system to protect against any possible fall. Baseline postural sway measurements were taken via a multicomponent measuring platform. Sway is defined as movement from medial to lateral or anterior and posterior. Even when people stand still on both feet, the body sways over its base of support. Postural sway is determined by measuring the location and amount of change that occurs in the position of the total vertical force vector projected onto a horizontal plane. The roofers were instructed to step onto the multicomponent measuring platform with horizontal surface (0°). They were instructed to stand on the force platform for 30 seconds (Chiou et al., 1998; Bagchee et al., 1998) in a relaxed and balanced posture with their feet together. (The subject stood with both the feet beside each other with the medial aspect of both the feet touching each other.)

In the sessions 1-12, twenty-minute psychophysical sessions were performed. Total participation time for sessions 1-12 was approximately 4 hours (Choi, 2003). The roofers were allowed to adjust their own work pace of the shingling task by adjusting the up and down arrows on the keyboard. Depending on the frequency selected, an auditory signal cued the participants to perform shingling operation. The roofers were asked to start shingling on an inclined surface (26°) from the left corner to the right corner of the simulated roof on ground level. The roofers were asked to lay shingles on the slip resistance rubber pad using an empty roofing nail gun (i.e., without any nails in the nail gun). Upon the completion of a session, blood pressure, heart rate, and postural sway were measured.

Initially, a draft questionnaire was developed by the experimenter and included twelve questions regarding the roofer's experience of loss of balance and difficulty while performing the task on the inclined surface. Each question was scored between 0 and 7 by increments of 1. Zero meant that the participant perceived no loss of balance or difficulty. Seven meant the participant perceived the greatest loss of balance or difficulty. The descriptions of the scores are as follows: 0 = nothing, 1 = just noticeable, 2 = a little, 3 = moderate, 4 = somewhat strong, 5 = strong, 6 = very strong, and 7 = extremely strong.

Upon the completion of the pilot study, the roofers were asked to suggest any other questions to be added in the draft questionnaire. The common suggestion was to add a question regarding on the discomfort/pain in the back during the task. It was also interesting to know if the roofers were experiencing any discomfort/pain in different aspects of their feet (i.e., front, outside, inside, and back of the heel of the foot). As a result of the pilot study, the seventeen questions have been provided in Table 1. It was also determined that two hours is an appropriate psychophysical testing session to replicate a workday period for a roof-shingling task. Details of data collected have been previously documented by Choi (2003).



Insert Table 1 about here

Participants

Twelve volunteers from the student population (non-industrial workers) participated in this experiment. All of the participants used for the simulated experiments were males. This is primarily because of the fact that males (i.e., 180527 cases of 185662 cases) grossly outnumber females (i.e., 4904 cases of 185662 cases) injured in the construction industry (BLS, 2004). Participants were not recruited on the basis of any relevant industrial experience. Mital (1986) showed that, with proper instructions and task familiarization, there were no significant differences between non-industrial workers performing manual material handling activities. The age range for participation was 21 years of age to 30 years of age. Participants were screened for any history of musculoskeletal disorders (MSDs) including back injury and balance-related diseases.

Apparatus

The simulated roofing wooden deck was adjusted with three slopes (18°, 26°, and 34°). The rest of the equipment used during this experiment was the same as described in pilot study.

Experimental Procedure

The experimental procedure was similar to that of pilot study. However, the participants were trained until the experimenter was confident in their ability to perform the simulated task. Each participant was allowed to become familiar with the experimental conditions and procedures. The objectives of the familiarization period were



to: 1) allow participants to become familiar with the use of the equipment and laboratory surroundings; 2) train the participants in the method and procedure of shingling task; 3) increase cooperation between participant and experimenter. The experiment period (i.e., the shortest time period representative of a workday shingling task) for the experiment was determined from pilot study (i.e., 2 hours).

Experimental Design

Diagnostic tests such as normality checking were performed for each response variable (Neter *et al.* 1996). The experimental design for this experiment was a random block design with subjects as blocks. The analysis of variance (ANOVA) and the nonparametric analysis (Friedman Test) were accomplished by using Minitab statistical analysis package (Version 13.1). Significant effects ($\alpha = 0.05$) were further analyzed using Tukey's multiple comparison test to identify the specific levels of the independent variable (slope) that generated this significance.

Results and Discussion

Descriptive statistics

Table 2 provides descriptive statistics for the participant population including anthropometric, strength, resting physiological and postural sway measures. The anthropometric and other measurements in this experiment were not significantly different from that of the pilot study with experienced roofers.

Insert Table 2 about here

Table 3 provides summaries of the descriptive statistics for all response variables collected for this study at the slopes 18°, 26°, and 34°, respectively. As shown in Table 3, the means of postural sway in the anterior-posterior (Amp A-P) directions increased only 38.3% from 18° to 26°, while the Amp A-P increased an additional 67.4% from 26° to 34°. It seems, however, the slope did not have an effect on physiological responses.



Insert Table 3 about here

Table 4 provides summary of the results from the analysis of variance (ANOVA) for postural sway and physiological response variables. The slope had a significant effect on all of postural sway measures, while the slope had no significant effect on physiological responses. The results indicate that the postural sway response variables are sensitive to changes in slope.

Insert Table 4 about here

Table 5 shows descriptive statistics of all seventeen questions (see Table 1 for the list) at slopes 18°, 26°, and 34°, respectively. It appears that the corresponding answers increased when the slope increased. As seen in Table 5, the answers of the questions 1, 2, 3, 4, and 5 clearly stood out in terms of the perception of slip, trip, becoming unsteady, fear of fall, and maintaining balance, respectively. In the questions 1-5, participants were experiencing loss of balance categorized as “just noticeable” and “a little” at the slopes 18° and 26°, while being categorized as “somewhat strong” at the slope 34°.

Insert Table 5 about here

Table 6 summarized the results of a nonparametric analysis (Friedman Test) concerning the effects of slope (blocked by subject) on the seventeen questions. The Friedman test showed that the slope had a significant effect ($p < 0.05$) on the questions 1, 2, 3, 4, 5, 8, 13, 14, 15, and 16. A post-hoc analysis (Tukey Test), however, revealed



that the value from slope 18° was significantly different from that of slope 26°, while the value from slope 26° was significantly different from that of slope 34° in the questions 1-5, respectively. The results indicate that the questions 1, 2, 3, 4, and 5 may be able to detect changes in slope.

Insert Table 6 about here

Based on the results from the Friedman and Tukey Tests, the five questions have been provided in Table 7. The purpose of these questions was to obtain the participants' assessment of their ability to maintain balance while carrying out the roof shingling task on an inclined surface. The sum of the 5 answers was defined as the participant's perceived loss of balance (PLB). The maximum rating of 35 represents the greatest PLB, and the minimum rating of 0 means the least PLB.

Insert Table 7 about here

To study the relationship between PLB and each objective measure of postural sway (Amp A-P, Amp M-L, Speed A-P, Speed M-L, and XY area), repeated measure analyses of covariance (ANOCOVA) were performed using Minitab 13.1 (Minitab, 2000). The PLB and postural sway were performed on normality tests. The PLB data followed a normal distribution. The postural sway data were, however, transformed to their natural logarithm to achieve approximate normality of the statistical distribution. PLB was treated as a within-subject independent variable and objective measurements of postural sway were used as the dependent variables. The regression of PLB on each objective variable was calculated.

The repeated measure ANOCOVA revealed that there were statistically significant associations between PLB and Amp A-P ($p < 0.01$, $r = 0.65$) as well as between PLB and Speed A-P ($p < 0.01$, $r = 0.59$). The regression



coefficients for PLB on Amp A-P and Speed A-P were 0.229 and 1.839, respectively, indicating that the higher the PLB, the higher Amp A-P and Speed A-P. Additionally, there was statistically association between PLB and XY area ($p < 0.01$, $r = 0.59$). The regression coefficient for PLB on XY area was 2.514, indicating that the higher the PLB, the greater XY area. However, there were no statistically significant relationships observed between PLB and the two postural sway variables of Amp M-L and Speed M-L.

Conclusions

The rating of perceived loss of balance (PLB) that was derived in this study was sensitive enough to detect changes in slopes (i.e., steep roofs). The findings from this study also indicate that significant positive associations exist between the PLB and postural sway. Using the PLB scale, subjects were able to predict postural sway as measured by amplitude and speed in the anterior-posterior direction. Higher amplitude and greater speed in the anterior-posterior direction imply greater propensity of postural sway and instability, and higher PLB indicates greater perception of loss of balance.

The PLB scale allows subjects to describe their postural sway caused by changes in roof inclination. Reduction of the chance of a fall will result from workers acting correctly in response to task-related risk factors such as steep roofs. The PLB instrument applications for safety monitoring systems (e.g., detecting and warning fall hazard dangers) may alleviate the potential risks of falls in roofing construction. The perceived loss of balance scale is a very reliable indirect measure of postural instability, and provides a valid and promising method for evaluating the potential of loss of balance in the workplace.

Further investigation into the various components, such as the effect of individual characteristics (e.g., ethnics, age, smoking, alcohol consumption, inactivity, sleep disorders), that would lead to the perceived loss of



balance changes should be undertaken. Also, a study in the field would provide further insight into whether PLB scale may be potentially used as a safety monitoring technique.

References

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

Berg, K.O., Maki, B.E., Williams, J.I., Holliday, P.J., & Wood-Dauphinee, S.I. (1992). Clinical and laboratory measures of postural balance in the elderly population. *American Archives of Physical Medicine and Rehabilitation, 73*, 1073-1080.

Bhattacharya, A., Morgan, R., Shukla, R., Ramakrishnan, H.K., & Wang, L. (1987). Non-invasive estimation of afferent inputs for postural stability under low levels of alcohol. *Annals. Of Biomechanical Engineering, 15*, 533-550.

Bobick, T.G., Stanevich, R.L., Pizatella, T.J., Keane, P.R., & Smith, D.L. (1994). Preventing falls through skylights and roof openings. *Professional Safety, 39*, 33-37.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scand J Rehab Med, 2*, 92-98.

Bureau of Labor Statistics, (2004). *Bureau of Labor Statistics Data*. [On Line].

Available: <http://www.bls.gov/>

Caldwell, L. S., Chaffin, F. N., Dukes, D. B., Kroemer, K. E. H., Laubach, L. L., Snook, S. H., & Wasserman, D.E. (1974). A proposed standard procedure for static muscle strength testing. *American Industrial Hygiene Journal, 35*, 201-206.

Chiou, S., Bhattacharya, A., Lai, C., & Succop, P. (1998). Effects of environmental and task risk factors on workers' perceived sense of postural sway and instability. *Occupational Ergonomics, 1*, 81-93.

Choi, S.D. (2003). *Psychophysically Derived Work Frequencies Associated with Roof Shingling*



- Operations Involving Change in Grade*. Doctoral Dissertation. Western Michigan University, Kalamazoo, Michigan.
- Fernandez, J.E., & Marley, R.J. (1998). *Applied Occupational Ergonomics: A Textbook*. Iowa: Kendall/Hunt Publishing Company.
- Gillen, M., Faucett, J.A., Beaumont, J.J., & McLoughlin, E. (1997). Injury severity associated with nonfatal construction falls, *American Journal of Industrial Medicine*, 32, 647-655.
- Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: P.A. Hancock and N. Meshkati (Ed.), *Human Mental Workload*, Amsterdam: North-Holland, 139-183.
- Hasan, S.S., Lichtenstein, M.J., & Siavi, R.G. (1990). Effect of loss of balance on biomechanics platform measures of sway: Influence of stance and a method for adjustment. *Journal of Biomechanics*, 23, 783-789.
- Hsiao, H., & Simeonov, P. (2001). Preventing falls from roofs: a critical review. *Ergonomics*, 44, 537-561.
- Kakizaki, T. (1984). Relationship between EEG amplitude and subjective rating of task strain during performance of a calculating task. *European Journal of Applied Physiology*, 53, 206-212.
- Lu, H., & Aghazadeh, F. (1994). Psychophysical determination and modeling of load carrying capacity. *International Journal of Industrial Ergonomics*, 13, 51-65.



- Mital, A. (1986). Subjective estimates of load carriage in confined and open spaces. In W. Karwowski (Ed.), *Trends in Ergonomics/Human Factors III*, (pp. 827-833). Amsterdam: North-Holland.
- Mital, A., Nicholson, A.S., & Ayoub, M.M., (1997). *A Guide to Manual Materials Handlings (2nd Ed.)*. London: Taylor & Francis.
- National Institute for Occupational Safety and Health (1989). *NIOSH alert: request for assistance in preventing worker deaths and injuries from falls through skylight and roof openings*, DHHS Publication 90-100, NIOSH, Cincinnati, OH.
- Neter, J., Kutner, M.H., Nachtsheim, C.J., & Wasserman, W. (1996). *Applied Linear Statistical Models (4th Ed.)*. Boston, Massachusetts: McGraw-Hill.
- Occupational Safety and Health Administration, U.S. Department of Labor. (1998). *Fall Protection in Construction*. OSHA 3146.
- Parsons, T.J., & Pizatella, T.J. (1985). *Safety Analysis of High Risk Activities within the Roofing Industry*, Technical Report, NTIS PB-85163236, National Technical Information Service, Springfield, VA.
- Parsons, T.J., Pizatella, T.J., & Collins, J.W. (1986). Safety analysis of high risk injury categories within the roofing industry. *Professional Safety*, 31, 13-17.
- Reid, G.B., Singledecker, C.A., Nygren, T.E., & Eggemeier, F.T. (1982). Development of multidimensional subjective measures of workload. *Proceedings of the Human Factors Society*, 403-406.
- Ruser, J.W. (1995). *A Relative Risk Analysis of Workplace Fatalities, Fatal Workplace Injuries in 1993: A Collection of Data and Analysis*, Report 891, US Department of Labor, BLS, Washington, DC, 18-22.
- Sahlstrand, T., Ortengren, R., & Nachemson, A. (1978). Postural equilibrium in adolescent



- idiopathic scoliosis, *Acta Orthopædica Scandinavica*, 49, 354-365.
- Suruda, A., Fosbroke, D., & Bradde, R. (1995). Fatal work-related falls from roofs. *Journal of Safety Research*, 26, 1-8.
- Thapa, P.B., Gideon, P., Fought, R.L., Kormicki, M., & Ray, W.A. (1994). Comparison of clinical & biomechanical measures of balance & mobility in elderly nursing home residents. *Journal of American Geriatrics Society*, 42, 493-500.
- Toscano, G. (1997). *Dangerous jobs, Fatal Work Place Injuries in 1995: A Collection of Data and Analysis*, Report 913, US Department of Labor, BLS, Washington, DC, 38-41.

Figure Caption

Fig. 1. Dimensions of the Roofing Workstation (26°).

Table Captions

Table 1. List of Revised Seventeen Questions (Pilot Study)



Table 2. Descriptive Statistics for the Participant Population

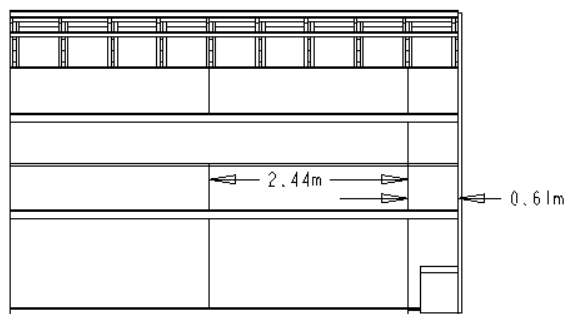
Table 3. Descriptive Statistics for Response Variables at Different Slope

Table 4. Analysis of Variance Summary of Experiment

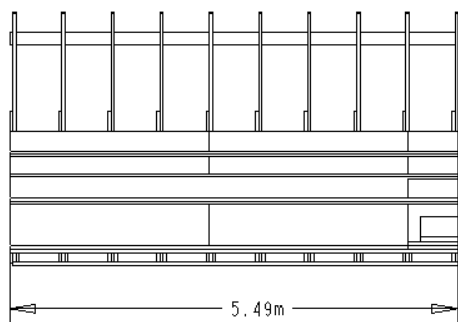
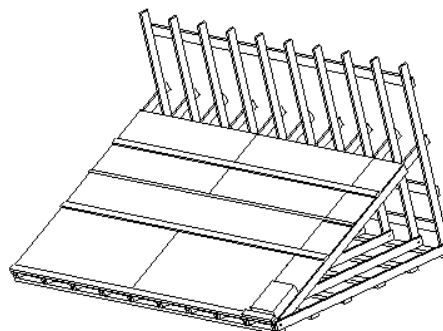
Table 5. Descriptive Statistics of the Seventeen Questions at Different Slope

Table 6. Friedman Test Summary Results of the Seventeen Questions

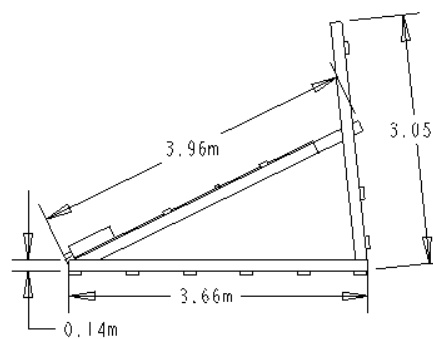
Table 7. Ratings of Perceived Loss of Balance (PLB)



Top View



Front View



Side View

Fig. 1. Dimensions of the Roofing Workstation (26° Slope)



Table 1. List of Revised Seventeen Questions (Pilot Study)

| No. | Questions |
|-----|---|
| 1 | Did you feel at any time that you would slip while walking/working? |
| 2 | Did you feel at any time that you would trip while walking/working? |
| 3 | Did you feel at any time that you would lose your balance or become unsteady while walking/working? |
| 4 | Did you feel at any time that you would fall while walking/working? |
| 5 | What would you say was the overall difficulty of this task in terms of maintaining balance? |
| 6 | What would you say was the mental and perceptual workload? |
| 7 | How much time pressure did you feel due to the rate or pace at which the tasks occurred? |
| 8 | Did you feel any insecure, irritated, stressed and annoyed during the task? |
| 9 | Did you feel any ache, pain, and discomfort in your hand, elbow, and shoulder during the task? |
| 10 | Did you feel any ache, pain, and discomfort in your back during the task? |
| 11 | Did you feel any ache, pain, and discomfort in your knee during the task? |
| 12 | Did you feel any ache, pain, and discomfort in the anterior (front aspect) of your foot during the task? |
| 13 | Did you feel any ache, pain, and discomfort in the lateral (outside aspect) of your foot during the task? |
| 14 | Did you feel any ache, pain, and discomfort in the posterior (back of the heel) of your foot during the task? |
| 15 | Did you feel any ache, pain, and discomfort in the medial (inside aspect) of your foot during the task? |
| 16 | Did you feel that the working space is too limited for walk/work movements? |
| 17 | Did you feel any unusual tired/fatigue during the task? |



Table 2. Descriptive Statistics for the Participant Population

| Variable (N=12) | Mean | SD | Range | |
|--------------------------------------|--------|--------|--------|--------|
| | | | Min | Max |
| Anthropometric Data | | | | |
| Age (years) | 24.8 | 3.4 | 21.0 | 30.0 |
| Weight (kg) | 72.6 | 5.5 | 64.0 | 83.0 |
| Height (mm) | 1746 | 39 | 1680 | 1800 |
| Left Foot Length (mm) | 251 | 12 | 231 | 275 |
| Right Foot Length (mm) | 250 | 12 | 231 | 275 |
| Left Foot Width (mm) | 94 | 4 | 85 | 99 |
| Right Foot Width (mm) | 94 | 4 | 83 | 99 |
| Dominant Hand Grip Strength (kg) | 47.1 | 3.9 | 42.0 | 54.0 |
| Physiological Data (Resting) | | | | |
| Heart Rate (bpm) | 71.6 | 5.0 | 61.0 | 80.0 |
| Systolic Blood Pressure (mmHg) | 121.2 | 6.0 | 113.0 | 133.0 |
| Diastolic Blood Pressure (mmHg) | 72.8 | 4.7 | 67.0 | 84.0 |
| Postural Sway Data (0° Slope) | | | | |
| Amp A-P (%) | 1.86 | 0.52 | 0.99 | 2.61 |
| Amp M-L (%) | 2.02 | 0.55 | 1.03 | 2.95 |
| Speed A-P (%/sec) | 74.74 | 20.72 | 40.57 | 106.21 |
| Speed M-L (%/sec) | 81.94 | 21.84 | 40.46 | 128.19 |
| XY area (mm ²) | 412.22 | 132.87 | 229.92 | 683.13 |



Table 3. Descriptive Statistics for Response Variables at Different Slope

| Variable (N=12) | Slope | | |
|----------------------------|-----------------|-----------------|------------------|
| | 18° | 26° | 34° |
| Physiology | Mean (SD) | Mean (SD) | Mean (SD) |
| Heart Rate (bpm) | 112.2 (9.9) | 113.1 (11.3) | 116.1 (10.5) |
| Systolic BP (mmHg) | 126.3 (8.2) | 132.0 (7.9) | 133.3 (9.4) |
| Diastolic BP (mmHg) | 76.3 (6.4) | 72.3 (7.6) | 77.2 (6.0) |
| Postural Sway | Median (SD) | Median (SD) | Median (SD) |
| Amp A-P (%) | 1.93 (0.45) | 2.67 (1.37) | 4.47 (1.33) |
| Amp M-L (%) | 1.77 (0.44) | 2.12 (0.63) | 2.46 (0.82) |
| Speed A-P (%/sec) | 72.39 (18.47) | 106.08 (67.77) | 171.26 (60.32) |
| Speed M-L (%/sec) | 68.10 (18.01) | 85.40 (24.48) | 94.04 (32.75) |
| XY area (mm ²) | 369.84 (151.98) | 639.85 (668.93) | 1077.78 (932.11) |



Table 4. Analysis of Variance Summary of Experiment

| Response Variable | Slope F-value ($p>F$) | Tukey test† |
|---------------------------------|----------------------------|-------------|
| Physiology | | |
| Heart Rate (bpm) | 0.149 | |
| Systolic Blood Pressure (mmHg) | 0.060 | |
| Diastolic Blood Pressure (mmHg) | 0.081 | |
| Postural Sway | | |
| Amp A-P (%) | 0.001* | (1) (2) (3) |
| Amp M-L (%) | 0.001* | (1) (2) (3) |
| Speed A-P (%/sec) | 0.001* | (1) (2) (3) |
| Speed M-L (%/sec) | 0.001* | (1) (2-3) |
| XY area (mm ²) | 0.001* | (1) (2) (3) |

* Value of ($p>F$) which is less than 0.05 indicates that the effect of the factor is significant at $\alpha=0.05$.

† 1 = 18° slope, 2 = 26° slope, 3 = 34° slope
Groupings ranked from lowest to highest from left to right.



Table 5. Descriptive Statistics of the Seventeen Questions at Different Slope

| Variable (N=12) | Slope | | |
|-----------------|-------------|-------------|-------------|
| | 18° | 26° | 34° |
| | Median (SD) | Median (SD) | Median (SD) |
| Question 1 | 1.0 (0.7) | 2.0 (1.2) | 4.0 (1.1) |
| Question 2 | 1.5 (0.8) | 2.0 (1.2) | 4.0 (1.3) |
| Question 3 | 1.5 (1.1) | 2.0 (1.3) | 4.0 (1.2) |
| Question 4 | 1.0 (1.0) | 2.0 (1.3) | 4.0 (1.7) |
| Question 5 | 2.0 (0.8) | 3.0 (0.8) | 4.0 (0.9) |
| Question 6 | 3.0 (1.1) | 2.5 (1.4) | 3.0 (1.3) |
| Question 7 | 2.0 (1.3) | 2.0 (1.6) | 2.5 (1.7) |
| Question 8 | 1.5 (1.4) | 2.5 (1.4) | 3.0 (1.7) |
| Question 9 | 0.5 (1.7) | 1.0 (1.7) | 1.5 (1.8) |
| Question 10 | 4.0 (1.0) | 3.0 (1.2) | 3.0 (1.0) |
| Question 11 | 2.5 (1.6) | 2.0 (1.2) | 2.0 (1.7) |
| Question 12 | 3.0 (1.5) | 3.0 (1.5) | 3.5 (1.7) |
| Question 13 | 3.0 (1.4) | 3.5 (1.7) | 4.0 (1.4) |
| Question 14 | 2.0 (1.3) | 3.0 (1.6) | 5.0 (1.3) |
| Question 15 | 2.5 (1.4) | 2.5 (1.4) | 3.5 (1.7) |
| Question 16 | 1.0 (1.7) | 3.0 (1.4) | 3.0 (1.7) |
| Question 17 | 2.0 (1.4) | 2.0 (1.5) | 2.5 (1.5) |



Table 6. Friedman Test Summary Results of the Seventeen Questions

| Response Variable | Slope S-value ($p>S$) | Tukey test† |
|-------------------|----------------------------|-------------|
| Question 1 | 0.001* | (1) (2) (3) |
| Question 2 | 0.001* | (1) (2) (3) |
| Question 3 | 0.001* | (1) (2) (3) |
| Question 4 | 0.001* | (1) (2) (3) |
| Question 5 | 0.001* | (1) (2) (3) |
| Question 6 | 0.103 | |
| Question 7 | 0.558 | |
| Question 8 | 0.028* | (1-2) (2-3) |
| Question 9 | 0.076 | |
| Question 10 | 0.087 | |
| Question 11 | 0.408 | |
| Question 12 | 0.103 | |
| Question 13 | 0.038* | (1-2) (2-3) |
| Question 14 | 0.001* | (1-2) (3) |
| Question 15 | 0.018* | (1-2) (3) |
| Question 16 | 0.022* | (1-2) (2-3) |
| Question 17 | 0.338 | |

* Significant at $\alpha=0.05$ level.

† 1 = 18° slope, 2 = 26° slope, 3 = 34° slope
Groupings ranked from lowest to highest from left to right.

