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THE EFFECT OF CHALLENGING SOMATOSENSORY INPUTS ON EYE MOVEMENT AND POSTURAL SWAY PATTERNS OF WORKERS

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For the construction industry, especially the roofing industry, slips/trips and falls have the highest incident rate leading to an injury and fatality. This study investigated the eye movement and postural sway patterns of industrial workers (n=48) with various work experience (months of work experience on inclined surfaces), fatigue conditions (none, half and full), visual cues (none, H cue), tasks (stationary, reach) and surface inclinations (0°, 14°, 26°). Eye movement variables of length and area of movement as well as fixation data and postural sway variables of area and length were significantly affected ($p < 0.05$) by incline, cue, task and work experience. The effect of the eye movement variables on the postural balance was limited and further study is necessary. The use of visual cues is an effective means of increasing postural stability and could be used in occupational situations where no vertical or horizontal cues are naturally available.

INTRODUCTION

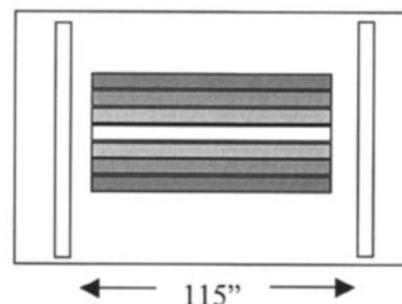
Out of all industries, the construction industry, especially the roofing industry, has slips/trips and falls causing the highest incident rate leading to an injury (BLS, 1998) and fatality (BLS, 1999). Humans are equipped with a complex system for maintaining upright balance that involves afferent systems (visual, vestibular and somatosensory) providing information on the body's position, the central nervous system (CNS) processing the information and appropriate efferent signals to the muscles (Shumway-Cook and Woollacott, 1995). If the somatosensory input is compromised, such as with roofers working on an inclined surface, the visual input becomes more important for maintenance of postural balance (Nashner, 1982). This study investigated the eye movement and postural sway patterns of industrial workers with various work experience, fatigue conditions, visual cues, tasks and surface inclinations.

METHODS

Experimental Design

This study was a repeated measure design. The dependent variables include postural balance as measured by a force platform and eye movement patterns from an eye tracking system. Independent variables were the levels of postural muscle fatigue (none, half and full), incline angles (0°, 14° and 26°), task (stationary or reach), visual cue (no or yes) and the level of experience (months of experience on a job requiring work on an inclined surface). The dependent

variables included two postural sway variables, sway area (SA) (cm²) and sway length (SL)(cm). Five eye movement variables used include the RMS velocity (EVEL) (°/s) and acceleration (EACC) (°/s²), the area (EA) (cm²) and length (EL)(cm) covered by the eye movement, the distance between clusters (CD) (fixations). Four eye fixation variables were also used: percent of time spent on four regions (fixations on the center cue, 0-5", 5-10" and 10-15" above/below the center cue) (see figure 1). A specialized black enclosure unit located in the laboratory was used and the lighting condition was poor (<1 footcandle) to control the visual environment presented to the subjects (see figure 2).



- The displayed "H" visual cue.
- 0-5" region away from the center cue.
- 5-10" region away from the center cue.
- 10-15" region away from the center cue.

Figure 1. The visual cue presented on the front wall and the regions of fixations used in the data analysis. note: the back panel was black and the "H" cue displayed was white, the other regions were not visible to the subjects.

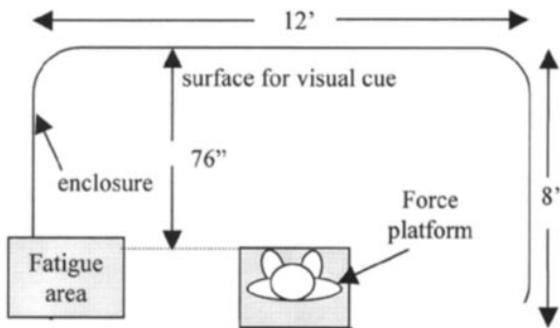


Figure 2. Layout of the testing facility.

Experimental Conditions

The *three postural muscle fatigue conditions* involved the subject maintaining a standardized semi-squat position until he/she could not maintain the posture any longer. The time that the subject could voluntarily maintain the semi-squat position was recorded as the full load (Corlett, 1980). The maximum time was then divided by two to obtain the half load and the subject did not squat for the no load condition. *Three incline angles* of typical roof pitches (0°, 14°, and 26°) were placed on the force platform, on which the subject stood facing upwards for the testing. *Two tasks*, stationary and reach were completed. For the stationary task the subject stood upright on the force platform for 30 seconds with his/her hands on his/her hips. For the reach task the subject (i) Stood upright on the platform for 8 seconds, (ii) reached forward to pick up a weight (5.2 lbs), placed at the waist height and at a functional reach in front of the subject, brought it to his/her abdomen, and replaced it on the shelf for 4 cycles, (iii) reassumed the upright position for the remaining time. *Two visual cue conditions* were used in this phase of the study, no cue and an “H” cue. The “H” cue was one horizontal cue with a vertical cue at either side of the horizontal cue (see Figure 1). These cues were made from self-illuminating strips and measured 104.5” x 3”.

Subjects

Forty-eight industrial workers participated in 4 sessions with 10 trials including 1 baseline condition and 9 with combinations of the independent variables blocked around the incline. Each trial lasted thirty seconds with a rest period between each trial. Experienced workers were identified as persons who have worked on an inclined surface, such as a roof or ramp, for more than three years. Upon acceptance to the study, a health and work history questionnaire was completed and the worker was medically screened, including vision

screening. Each subject signed a consent form approved by the University of Cincinnati Medical School Institutional Review Board.

Data Analysis Strategy

Separate structural equation models (SEMs) were performed for each postural sway outcome measurements and the nine eye movement measurements. In the SEMs, the eye movement data were treated as mediator variables, i.e., affected by other exogenous variables but predictors of the postural sway outcomes. In each of these analyses, the experimental conditions of task, incline, visual cue and the experience were treated as exogenous variables. The interactions between experience with load, task, incline and cue were also tested for significance on the eye movement and postural sway outcomes. Other covariates (e.g., age, gender, height and muscle strength) were analyzed for statistical significance. Covariates and interactions that were not significant were removed from the statistical models in a backward elimination process. The work experience and experimental condition variables were forced into each of the SEMs and their statistical significance evaluated in the final models that included only statistically significant covariates.

RESULTS

Table 1 shows the demographic information and some significant covariates for the subjects participating in this study.

Table 1. Demographic information by experience (exp.)

Variable	Non-Exp. Mean ± Std	Exp. Mean ± Std	2 tailed p-value
n	26 (9F)	22 (8F)	
Age (years)	37.6 ± 10.3	41.6 ± 9.6	0.71
Body mass index (kg/m ²)	28.8 ± 4.7	28.4 ± 4.8	0.78
Work experience (months)	0.5 ± 2.4	117.0 ± 96.6	<0.0001
Avg. alcohol consumption (drinks/month)	6.8 ± 12.4	15.3 ± 13.2	0.03
Avg. caffeine consumption (drinks/day)	1.3 ± 1.0	2.6 ± 1.6	0.001
Avg. tibialis strength (lbs.)	28.7 ± 8.4	38.8 ± 13.9	0.002
Age quadriceps strength (lbs.)	38.3 ± 13.9	53.8 ± 19.4	0.002
Avg. gastroc. strength (lbs.)	42.9 ± 17.7	63.7 ± 22.5	0.0008
Avg. hamstring strength (lbs.)	13.4 ± 6.6	18.7 ± 8.3	0.02

Eye Movement and Fixations

Experience was a predictor for the eye movement velocity (EVEL), eye movement length (EL), center cue fixation percentage, and cluster distance (CD). The subjects with more months of experience have larger EVEL and more fixations on the center cue, but shorter EL and CD. The interaction of experience and task was also significant for the percent fixation 5-10" above the center cue and the CD with more experience having lower values and the stationary task decreasing more than the reach task with greater experience (see Figure 3).

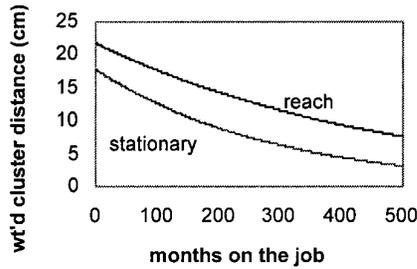


Figure 3. Interaction of experience and task for weighted cluster distance.

The *fatiguing workload* was not significant for any eye movement variable, but showed trends of increased eye movement as the fatiguing workload increased and decreased fixations on the center cue and 0-5" from the center cue as the workload increased. The *task condition* was significant for all eye movement variables. The reach task was always a greater value than the stationary task for every eye movement variable, ranging from 11% to 300% higher for reach. For the eye fixation variables, the 10-15" sway from the center cue was significant with the reach task having more fixations than the stationary. The *inclination* was a predictor of the EVEL, EL, the fixation percentage on the center cue and 0-5" from the center cue. For the EVEL and EL the 0° and 26° were higher than the 14° incline and a graph showing this trend with the EVEL is shown in Figure 4.

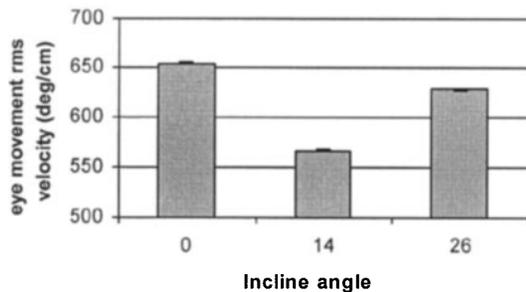


Figure 4. The EVEL response to incline angle.

For the eye fixations on the center cue and 0-5" from the center cue, the highest percentage was at the 0° inclination which decreased for 14° and 26° (see Figure 5).

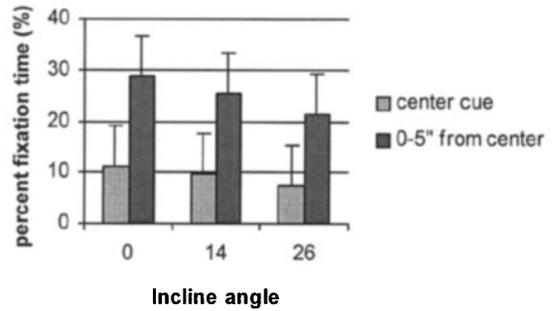


Figure 5. The percent fixation response to incline angle.

The *visual cue* was a predictor of the center cue and 10-15" fixation percentages and eye movement area (EA) and cluster distance (CD). For the center cue fixations, a higher percentage occurred when there was a cue present and the opposite happened for the 10-15" fixations (see Figure 6). The EA and CD both decreased when the cue was present (by 19% and 12%, respectively).

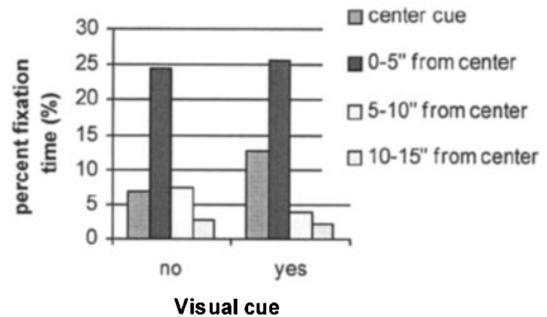


Figure 6. Effect of visual cue on fixation percentages.

The *interaction of task and incline* predicted the eye movement length (EL). For the reach task, the EL decreased (by 11% for 14° and 12% for 26°) with increasing inclinations while for the stationary task, the EL increased from 14° by 18% for 0° and 26°. The *interaction of task and cue* predicted the center cue fixation percentage. The fixation percentage increased by 127% for the reach task with a cue and by 46% for the stationary task. The *interaction of incline and cue* predicted eye movement acceleration (EACC). The EACC decreased by 5% and 3% for the 0° and 14° with the presence of a cue but increased by 4% for the 26° with a cue.

Postural Sway

Experience was a predictor of sway area (SA). As the experience increased, the SA increased. The *fatiguing workload* was not significant for any postural balance variable, but showed a trend of increasing sway area (SA) and length (SL) as the workload increased. The *task condition* was significant for the postural sway variables with the reach task ranging from 124% to 511% higher than the stationary task for SA and SL. The *incline* also predicted the postural sway variables; increasing the SA and SL from 10%-18% as the incline increased. The *visual cue* was significant for the SL, with the SL decreasing by 9% with the presence of the visual cue (see Figure 7).

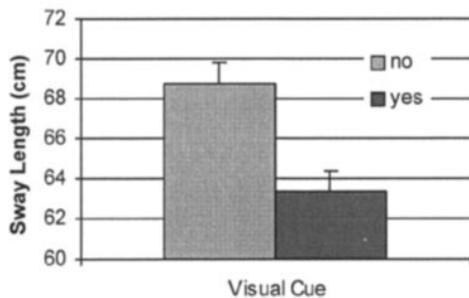


Figure 7. Effect of visual cue on sway length.

The *interaction of the task and incline* was a predictor of all postural balance variables. The SA decreased for the reach task as the incline increased, while SL did the opposite. For the stationary task, both variables increased as the incline increased.

Effect of Eye Movement on Postural Sway

The eye movement variable of the fixation percentage 10-15" away from the center cue was a predictor of SL. As the fixation percentage increased, the SL decreased (see Figure 8).

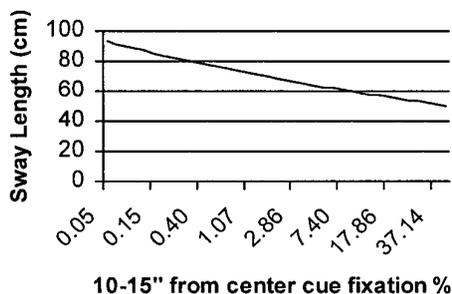


Figure 8. The effect of eye fixations 10-15" from the center cue on postural sway length.

DISCUSSION

The independent variables affected the eye movement, fixation and postural sway variables. An increase in the eye movement length (EL), area (EA), acceleration (EACC), velocity (EVEL) or cluster distance (CD) indicated that the subject looked around more or utilized more space for visual input. An increase in fixation to a region would indicate that the subject spent more time looking at this region. The regions were designed to capture the use of the visual cue. If the subject was not looking directly at the cue, then the regions surrounding the cue would have higher percentages of fixations. For the postural balance variables, an increase in sway area (SA) or length (SL) implies an increase in postural instability.

The *presence of the visual cue* altered the eye movement patterns by increasing the fixations on the center cue, decreasing all of the other eye movement variables and decreasing both sway variables. This indicates that the presence of the cue focused the visual attention of the subjects and thereby increased their postural stability. The *task*, as expected, had an impact on all variables and increased the eye movement and postural sway variables with the reach task. The task did not have a significant impact on the fixation percentages except for the 10-15" region away from the visual cue. This was likely due to the reach task requiring the subject to look down at the weight, which would put more fixations on the lower region of the visual field.

The *inclination* was expected to alter the somatosensory inputs and the effect on the eye movement variables was not in the expected pattern of changing as the incline increased. For the EVEL and EL, the lowest values were at 14°. This could possibly be due to the 14° change was sufficient to require more focused visual attention than 0° but at 26° was beyond some threshold of comfort and required more scanning of the visual field. The fixation variables showed more fixations in the center and immediately surrounding area at 0° and decreasing in percentage as the incline increased. The effect of inclination on the postural sway patterns showed an increase in postural instability as the incline increased. This was expected since the incline changes the biomechanical strategy for maintaining balance and alters the somatosensory input and this result was also seen in a previous study (Bhattacharya, 2001).

The effect of *experience* on EL and CD and fixations on the center cue demonstrated less visual searching by the more experienced subjects. In a previous study with this

same worker population, it was shown that experienced workers correctly perceived horizontal and vertical more than the inexperienced (Kincl, et al., 2001). The effect of experience on the postural sway variables was inconclusive since experience increased SA, but decreased SL (although SL was not significant). The effect of the eye movement variables on the postural balance was limited. The fixations 10-15" from the center decreased postural stability. This perhaps demonstrates that fixations further away from the cue are detrimental for postural balance.

CONCLUSION

Finally, the impact of several typical workplace conditions for workers who work on inclined surfaces seemed to impact both eye movement and postural stability variables. Further study on the relationship of eye movement variables and their effect on postural balance are necessary. The use of visual cues is an effective means of increasing postural stability. It is practical and could be used in situations where no vertical or horizontal cues are naturally available.

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