Occupational Ergonomics 3 (2002/2003) 251–259
IOS Press

The effect of workload, work experience and inclined standing surface on visual spatial perception: Fall potential/prevention implications

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Abstract. Maintenance of upright balance involves interplay between sensory (somatosensory, vestibular and visual) inputs and neuro-motor outputs. Visual spatial perception (VSP) of vertical and horizontal orientation plays a significant role in the maintenance of upright balance. For this experiment, a custom designed computer program randomly generated 42 images of horizontal and vertical lines at various angles for 60 industrial workers (39 ± 9.8 years). Half of the workers had more than three years of experience working on inclined and/or elevated surfaces. The main effects investigated included within subject factors of standing surface inclination (0°, 14° and 26°), job experience (number of months), and postural workload (0%, 50% or 100%). The VSP outcome measure was the count of correct responses to the angles presented. The inclination did not have a significant effect on VSP, but the parameter estimates indicated less correct responses on the inclined surfaces. The postural workload significantly affected the VSP, indicating that with increased workload, less correct responses were given. Finally, job experience was found to improve VSP response scores. In summary, these results indicate that job experience increases accurate VSP, while workloads and inclined work surfaces decrease accurate VSP responses.

Keywords: Visual spatial perception, postural balance, postural workload, work experience, occupational falls

1. Introduction

A loss of balance that leads to a fall in the workplace is a major concern for occupational safety and health personnel. Slips, trips and falls were the third leading cause of injury involving days away from work in 1998 [14] and falls were the fourth leading cause of fatal occupational injuries in 1999 [15] for all private industries. Out of all industries, the construction industry, especially the roofing industry, has slips/trips and falls as the most common event leading to an injury. Slips and falls cause the most severely disabling occupational injuries that include fractures [7]. In a study published in 1995, looking

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at worker's compensation insurance claims in 1989 and 1990 the estimation for the average cost of a claim for slip and fall on the same level and fall from an elevation injuries was $4,363 and $7,058 with a total of 140,743 claims. For the construction industry, falls had the highest percentage by the cost of the claims over any other type of claim [9].

The roofing occupation has unique environmental/working conditions that compromise the worker's ability to maintain safe, upright balance. Hsiao and Simeonov [8] identified from literature several risk factors for roofers including confined and inclined work surface, unexpected changes in the work surface, load handling, physical exertion, fatigue, task complexity, individual differences, work experience and training and personal protective equipment. In addition to these risk factors, the role of altered or unstable visual input for roofers has been identified as a potential risk factor. The visual exposure from the elevation, unstable visual cues and inadequate visual information from the environment have all been identified as problems in the roofing industry. Therefore, under such compromised visual conditions, postural stability will be detrimentally affected.

Maintenance of upright balance involves interplay between sensory input and neuro-motor output. Afferent or sensory inputs that are present in a healthy individual include somatosensory, vestibular and visual inputs. Visual perception of vertical and horizontal orientation plays a significant role in the maintenance of upright balance [12]. The purpose of this study was to measure performance in the subjective assessment of vertical and horizontal orientation (visual spatial perception or VSP) from a projected image in the direct line of vision to determine the effect of: 1) standing on an inclined surface, 2) fatigued postural muscles, and 3) work experience on inclined surfaces.

2. Methods

2.1. Participant selection

Participants included in this study were sixty industrial workers. Thirty-one of the participants were experienced in working on inclined and/or elevated surfaces such as roofers, ironworkers, glazers, painters, etc. The remaining twenty-nine workers had no experience working on inclined and/or elevated surfaces. All participants were medically screened, which included cardiopulmonary, neurological, visual, proprioceptive, vestibular, and musculoskeletal checks, and completed a health history check-up. Exclusion criteria included daily requirements of prescription medication, current smoking and alcohol habits, history of dizziness, tremor, alcoholism, vestibular disorders, neurological disorders, cardiopulmonary disorders, diabetic symptoms, chronic or acute low-back or knee pain, aphasia, brain damage, vision related diseases (such as glaucoma, etc.) and those unable to perform the assigned task due to non-specific visual impairment. Each participant was also screened for visual performance including acuity, stereo depth perception, color discrimination and vertical and lateral phoria. Upon acceptance to the study, each participant completed a consent form.

2.2. Independent variables

2.2.1. Fatiguing workload task

Three levels of lower extremity fatigue were used in this study: none, half and full fatigue. The fatiguing task consisted of the participant maintaining a semi-squat position until he/she could not maintain the posture any longer. During the squat position, the participant was required to perform a manipulation task on a Minnesota Activity Board placed on a table at the participant's knee height and at a distance of the participant's forward functional reach. The manipulation task performed by the participant involved turning a small pawn with both hands on the Minnesota Activity Board. The time that the participant could voluntarily maintain the semi-squat position, which was until they experienced unbearable discomfort in their leg muscles, was recorded as the full fatiguing time [5]. The recorded maximum time was divided by two to obtain the half fatiguing time. For the no fatigue condition, the participant did not squat, but completed the VSP assessment immediately after resting.

After each fatiguing workload, participants were asked their perceived sense of exertion level using Borg's Self-Rating Scale [3] which ranges from 0, which is "very, very light", to 10, which is "very, very hard" perceived exertion. The participant's were also asked to rank bodily discomfort using a modified Bishop-Corlett diagram [6]. They ranked their back, buttocks, thighs, knees and lower legs on a scale from 0, meaning "no discomfort", to 3, meaning "extremely uncomfortable". These two subjective measures were used as a "dose" measure of the fatigue.

2.2.2. Inclined standing surface

Three surface inclinations were used for this study: 0°, 14° and 26°. A majority of buildings (both residential and commercial) use these roof inclination angles and these have been used in previous studies [2]. Two specially designed inclined surfaces, 14° and 26° were attached to a force plate to obtain the desired values of inclinations and the subject stood directly on the force plate for the 0° condition. The force plate was not used in this experiment so no kinetic data was obtained. The participants stood on the incline as if they were facing up the incline.

2.2.3. Work experience

Workers were recruited for this study based on their work experience. The criteria for placing a worker in the inexperienced category was a worker with less than 1-year experience of working on inclined and/or elevated surfaces. Workers with one to less than three years of experience were not included in the study. Workers with three years or more of continuous experience on inclined/elevated surfaces were considered experienced. A work history was completed to determine this criteria and to obtain the months of experience. The number of months of experience was then used as a continuous independent variable.

2.3. Dependent variable

The visual spatial perception (VSP) was the dependent variable in this study. A custom designed computer program, *Lines on Demand* (*ver.2.0.5*), was used to randomly generate images of horizontal and vertical lines. A total of 42 images were presented randomly and evenly divided between horizontal and vertical lines. The "dead" line was exactly vertical or horizontal. The angles presented ranged from −10° to 10° to the "dead" line at 1° intervals for both the horizontal and vertical directions. The images were displayed from the computer via an overhead projection system. The participant stood in a darkened room in a black enclosure that was 2.4 meters deep and 3.7 meters wide. The projection system was placed behind and slightly to the left of the participant and projected the images of lines to the front wall of the enclosure (Fig. 1). The edges of the display were concealed so that it appeared circular and offered no additional visual cues to be referenced by the participant. The participant responded to each angle presented either "tilt left" or "tilt right" for the vertical lines, "down left" or "down right" for the horizontal lines or "dead" if it was exactly horizontal or vertical. The outcome measure was the number of correct responses given during the trial.

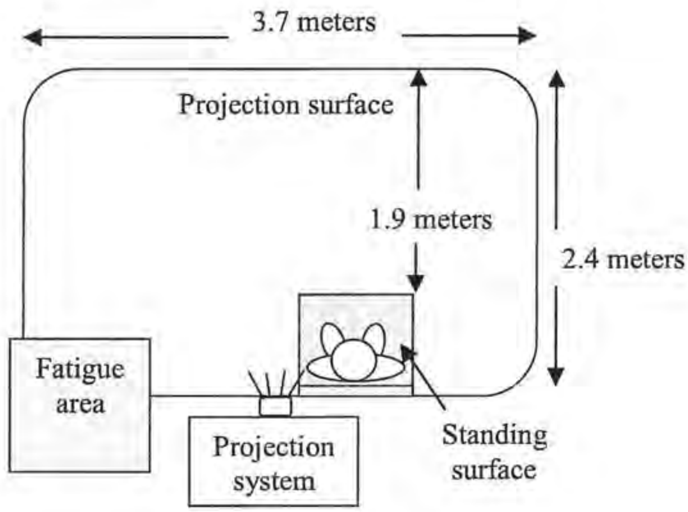

Fig. 1. Lab set-up for experiment.

2.4. Experimental design

The University of Cincinnati Institutional Review Board approved this experimental protocol. These experiments were conducted with three fatiguing loads and three inclinations for a total of nine trials for a testing session. The trials were blocked by inclination and the first fatigue condition on the inclination was "no fatigue" with the remaining two fatiguing conditions completed in random order. The order of the inclines was also randomized. For each trial the participant completed the designated fatigue load in an area adjacent to the testing enclosure. Immediately after the load the participant was asked to rate their perceived discomfort and exertion. The participants were then asked to stand on the inclined surface. Next, the Lines on Demand program was initiated and the participant responded to the lines generated. These responses were directly entered into the computer. Upon completion of the test, the participant was asked to rest, seated in a chair, until the next trial. During the entire testing session, the heart rate was logged using a real-time heart rate monitor as a safety precaution. The maximum heart rate was calculated as 220 – age [1]. Seventy-five percent of the participant's maximum heart rate was used as a ceiling value for the participant's heart rate during the session to stop the experiment.

2.5. Data analysis

A repeated measure logistic regression using backward elimination of insignificant covariates was used to determine the effect of fatigue and incline and their interaction on correct angle identification. The SAS procedure PROC GENMOD was used for the analysis of the VSP responses. The variables that remained after this process were identified as cofactors in the regression model. For all variables, a two-tailed alpha of 0.05 was used.

The dependent variable was the response to the angle of the line presented to the participant (correct or incorrect). The independent or main effect variables included the inclined surface (0°, 14° and 26°) and job experience (a continuous variable recorded in months). Three different models were run including either the Borg's perceived exertion level (0 to 10), the discomfort (the sum of the responses for the

Table 1
Demographics for participants by experience category

n	Inexperienced 29	Experienced 31
Age (years) ± s.d.	40.3 ± 11.2	39.1 ± 9.0
Height (cm) ± s.d.	170.5 ± 9.5	175.7 ± 7.1
Weight (kg) ± s.d.	83.5 ± 21.7	86.5 ± 15.4
Gender	15 F and 14 M	11 F and 20 M
Arm reaction time (ms) ± s.d.	36.8 ± 7.7	34.4 ± 5.2
Foot reaction time (ms) ± s.d.	40.8 ± 6.3	41.2 ± 4.6

Table 2
Vision testing results

	Inexperienced Avg ± s.d.	Experienced Avg ± s.d.	Score interpretation
Both eyes far acuity	9.7 ± 2.8	10.3 ± 2.4	10 is 20/20 vision
Both eyes near acuity	9.0 ± 3.5	9.5 ± 3.6	10 is 20/20 vision
Stereo depth	6.0 ± 2.6	6.6 ± 2.8	7 is normal
Vertical phoria far	3.4 ± 1.4	3.7 ± 1.4	2.5 to 5.5 is normal
Lateral phoria far	9.4 ± 2.3	9.3 ± 2.4	3.5 to 13.5 is normal

five body parts or 0 to 15) or the fatiguing load (none, half and full) as an independent variable. These were run in separate models since they are all an indication of the load, as the subjective responses of discomfort and exertion are the "dose" and the fatiguing load is the "exposure". Covariates used in all initial models were gender, race, age, reaction time (seconds), and the lagtime it took for the participant to respond when an angle was presented (seconds).

To graph some of the results, the probability of a correct response was used. The equations for all the effects graphed are shown in each figure. The probability was calculated according to the logistic function. To graph the effect of the lagtime in the response, the SAS procedure PROC MIXED was used with the final model determined from the logistic model for the VSP response.

3. Results

Basic demographics of the participants by experience are shown in Table 1. The results of the vision testing are shown in Table 2. The averages and standard deviations for near and far visual acuity, stereo depth and vertical and horizontal phoria demonstrate that the study participants were in the normal range. In addition, there are no major differences between the experienced and inexperienced groups vision.

The results for the fatiguing condition, analyzed in three separate models, was significant for the fatigue load model, marginal for the exertion model and not significant for the discomfort model. For the model with the fatiguing load variable included, the full and half load significantly decreased the number of correct visual spatial (VSP) responses of identifying the angle compared to no load. For the model with Borg's perceived exertion level, an increased exertion level marginally decreased the number of correct VSP responses of identifying the angle. For the model with the body discomfort variable, no significance was found for discomfort, but did show less correct VSP responses with increasing discomfort.

For all three models age, job experience and lagtime significantly affected the VSP response. Increased age and a longer lagtime decreased the number of correct VSP responses and the more months of job experience increased the correct VSP responses. Figures 2 and 3 show the effect of the load and age on the probability of responding correctly by job experience. Figures 4 and 5 show the effect of the load

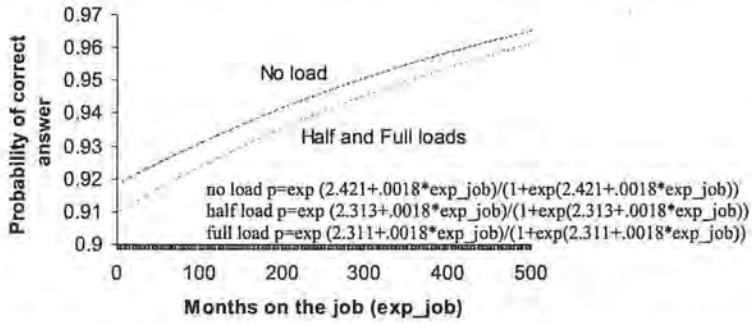

Fig. 2. The effect of load on the probability of responding correctly by months on the job (exp_job).

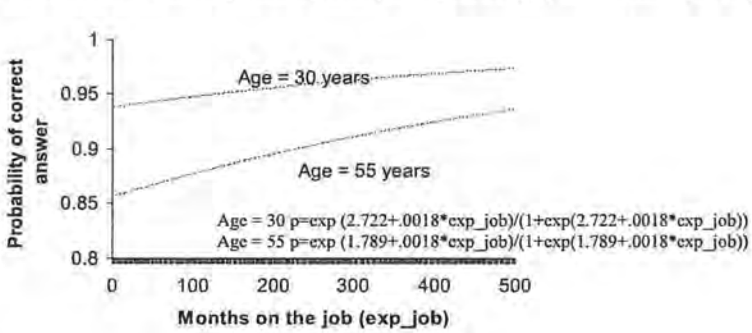

Fig. 3. The effect of age on the probability of responding correctly by months on the job (exp_job).

and age on the response time by job experience. The p-values and parameter estimates for the fatigue load level, perceived exertion and discomfort models are shown in Tables 3, 4 and 5, respectively. No interactions were significant and were dropped from the models.

4. Discussion

These results imply that with more months of job experience on inclined and/or elevated surfaces, participants were able to more accurately perceive the angle presented, despite the age of the worker. This implies that workers may be able to adapt their VSP with work experience on inclined and/or elevated work surfaces. In 1997 for all industries, workers with less than one year of experience accounted for 31% of nonfatal injuries and illnesses involving days away from work. For the construction industry, 41% of the injuries were workers with less than one year of experience, 33% for those between one to five years and 18% for those over five years [4]. Work experience is valuable for the workers to perform their specified job task well and also can make the workers safer during work. Further understanding into how experience helps the worker be safer is important for safety training of newer workers. If the VSP is better with more experience, this perhaps could be included in some type of visual perception training for the newer worker.

These results also indicated that younger participants were able to more accurately perceive the angle presented, demonstrating that with age, VSP may become weakened. This supports the earlier findings of Tobis et al. [13], which found errors in visual perception of the vertical and horizontal were correlated

Table 3
Regression model results with fatigue load level variable

Variable	Parameter estimate	p-value
100% load	−0.1095	0.03*
50% load	−0.1095	0.02*
Job experience (months)	0.0018	0.02*
Incline 26°	−0.0340	0.53
Incline 14°	−0.0241	0.68
Age	−0.0373	<0.0001*
lagtime	−0.2850	<0.0001*

Table 4
Regression model results with perceived exertion variable

Variable	Parameter estimate	p-value
Perceived exertion	−0.0138	0.07
Job experience (months)	0.0018	0.02*
Incline 26°	−0.0317	0.56
Incline 14°	−0.0182	0.76
Age	−0.0372	<0.0001*
Lagtime	−0.2693	<0.0001*

Table 5
Regression model results with discomfort variable

Variable	Parameter estimate	p-value
Discomfort	−0.0098	0.14
Job experience (months)	0.007	0.02*
Incline 26°	−0.0309	0.57
Incline 14°	−0.0166	0.78
Age	−0.0371	<0.0001*
Lagtime	−0.2653	<0.0001*

with age. They also found that people with a known history of falling, had more errors in perception of the horizontal and vertical lines. This supports the assumption that the postural balance will be more stable since the person is accurately perceiving the visual cues available to orient him/her self. The increase in errors in VSP could be due to the visual acuity decreasing, however the results from the vision testing show normal visual acuity (see Table 2). Visual acuity decreases in people age 20 to 50 years and after 50 years, decreases very rapidly [16]. Sensory degradation, not only visual but proprioceptive and vestibular, occurs with aging [10,11,13]. This degradation will also affect postural stability.

For the fatiguing effect, the half and full load significantly decreased the number of correct VSP responses at the same rate over the no fatigue condition (Fig. 2). The half and full fatigue did not create a linear effect probably due to the determination of half and full fatigue conditions. By decreasing the squat time by half for the half fatigue condition does not necessarily create half of the muscle fatigue effect, since muscular fatigue is not linear. The response time, however, was only longer than the no load for the full fatigue condition and not the half fatigue (Fig. 4). The subjective responses of discomfort and exertion did not show any significant changes in VSP, but did show a trend that as perceived discomfort or exertion increased, the VSP response decreased. This could be due to the lack of perception of fatigue of the workers since the "exposure" to fatigue had an effect, but the "dose response" showed only a marginal effect. This could be an indicator that even if a worker does not feel fatigued, fatigue may be affecting their visual spatial as well as other types of performance. In addition, this experiment tested acute lower extremity muscular fatigue. Future experiments may investigate the effect of mental fatigue

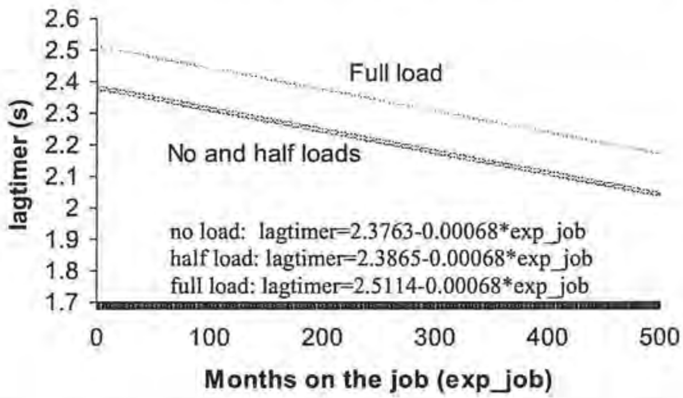

Fig. 4. The effect of load on the response time (lagtimer) by months on job (exp_job).

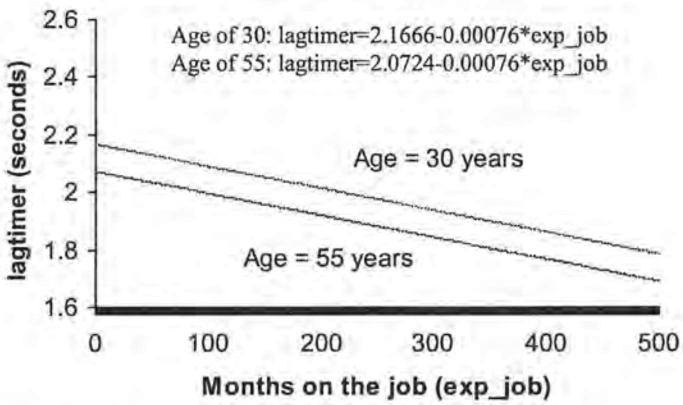

Fig. 5. The effect of age on the response time (lagtimer) by months on the job (exp_job).

and more chronic muscle fatigue. Fatigue, both physical and mental is often a problem in the workforce, especially at the end of a shift and with the type of labor that construction workers complete in a shift.

Finally, the study showed that those who took more time answering (had an increased lagtime) were able to more accurately perceive the angle presented. It is expected that taking more time would lead to more correct responses and this emphasizes the safety risks of hurried tasks or actions on the job. This may even indicate that training the workers to take time to observe their visual cues before a task may aid them in performing the task more safely.

In summary, this study showed that work experience, fatigue, age and response time was important for a worker to accurately perceive the visual-spatial environment. Since it is assumed that the VSP would have an effect on postural balance, future research of the impact of visual spatial perception with objective measures of postural balance is important.

5. Conclusions

In summary, the conclusions reached from this study were:

1. Participants with more months of job experience on inclined and/or elevated surfaces were able to more accurately perceive horizontal and vertical visual cues.
2. Younger participants were able to more accurately perceive horizontal and vertical visual cues, demonstrating that with age, spatial perception may become weakened.
3. Postural muscle fatigue decreased the participant's ability to accurately perceive horizontal and vertical visual cues. The perceived exertion and discomfort showed the same trend, but not significantly indicating the effect before the participant "felt tired".
4. Finally, the study showed that those who took more time answering were able to more accurately perceive horizontal and vertical visual cues.

Acknowledgement

This study was supported by National Institute for Occupational Safety and Health (NIOSH) Grant Number RO1-OH03400. The authors would also like to thank Terry Mitchell, Cyndy Cox, and the students of the Biomechanics and Ergonomics Research Team (BERT) for their assistance in the data collection and analysis.

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