Japanese Journal of Applied Psychology
2005, Vol. 30, No. 2, 73–78

Article

An Experimental Study on Mental Workload at an Elevated Workplace:

Comparing Elderly and Young Workers

Shinnosuke USUI*, Yoshiyuki EGAWA**, Takahiro NAKAMURA**, and Takuro SHOJI***

This study sought to experimentally assess the mental workload put on elderly workers by height at an elevated workplace for the prevention of falling accidents. In this experiment, a temporary scaffold 14.2 m high, 10.8 m long and 1.2 m wide was erected, and the elderly and young subjects walked on footing boards. The experimental conditions consisted of age, height of scaffold, footing board width, and carrying or not carrying the footing board. The degree of mental workload was evaluated by measuring the spare capacity of the subjects by the dual task method and subjective assessment by NASA-TLX. An increase in mental workload caused by the height was observed in elderly workers. Furthermore, it was proved that the mental workload of the elderly workers was larger than that of younger workers when potentially dangerous factors such as the narrowness of a footing board width and complication of the work were added to the factor of height.

key words: mental workload, elderly workers, accident, elevated workplace, human error

The number of fatalities due to industrial accidents in Japan in 2002 was 1,658, with the construction industry accounting for the greatest share (607 fatalities). The number of people who died from falling was 256, accounting for 42 percent, which means that the possibility of potential danger at elevated workplaces is extremely high. With the aging of the labor population, the number of work-related accidents by elderly workers has increased, and securing conditions of safety for the elderly has become an important problem. Looking at the number of people who died from work-related accidents in the construction industry in 2002, those younger than 29 years old accounted for 17.3 percent while those older than 60 accounted for 27.3 percent. There was no big difference in the two age groups in the number of accidents by falling (accidents resulting in more than four days off work), as those younger than 29 were 19.7 percent and those older than 60 years old were 20.3 percent. However, the possibility of potential danger among the elderly workers was high in comparison to that among younger workers. Calculating the accidental fall rate causing death and injury by age revealed that those younger than 24 years old accounted for 0.24 percent; those between 25 and 34 years old, 0.14 percent; those between 55 and 64, 0.43 percent; and those older than 65 years old, 0.54 percent. This was calculated from the number of employees excluding officers in the construction industry (research by Ministry of Public

* Graduate School of Human Sciences, Osaka University, Yamadaoka, Suita, Osaka 565–0871, Japan
** National Institute of Industrial Safety Independent Administrative Institution, Umezono, Kiyose, Tokyo 204–0024, Japan
*** University of Occupational and Environmental Health, Iseigaoka, Yahata-nishi-ku, Kitakyushu, Fukuoka 807–8555, Japan

Management, Home Affairs, Posts and Telecommunications).

As Reason (1990) has indicated, although hard measures such as the development of new technology are needed to prevent accidents, soft measures that will clarify the human factors behind accidents and take into account the characteristics of human beings also have to be studied.

Several studies have been made of human characteristics in elevated workplaces. Kobayashi & Tamura (1991) assessed the physical workload at height by looking at the relationship between the measured heart rates of people working on chimney maintenance and the kind of work done. Usui & Egawa (2002) measured the psychological and physiological responses during work at an elevated workplace of scaffolding workers and office workers, and evaluated the potential danger in working at an elevated workplace. Hsiao & Simeonov (2001) researched literature on balance control for factors related to falling, then classified these factors by environment, and by work and individual, and reviewed each of them. Egawa, Usui, Shoji, & Nakamura (2003) analyzed the investigation reports on falling death accidents, and clarified the pattern of falling accidents and causal factors in the elderly. However, there has until now been little ergonomic research in this area, and so the degree of mental workload of elderly workers at an elevated workplace remains largely unclear.

Therefore, in this research, an experiment was conducted in which both elderly and young construction worker subjects walked on footing boards put over a temporary scaffold either with or without carrying a footing board. This study aimed to obtain standard data, which would enable the establishment of a safe industrial environment for elderly workers at an elevated workplace. We measured the degree of mental workload under various work-environment conditions where the height of the workplace, footing board width, and carrying or not carrying a footing board load were variables. In the experiment, a dual task where subjects responded to a specific number announced to them while walking was conducted, and the spare capacity of the subjects at the elevated workplace was measured by the performance of a secondary task. When the footing board was narrow, the subject would have a greater workload in achieving the same task because of the strain and instability of walking, with a resulting decrease in spare capacity, and thus, it was expected that the performance of the secondary task would be reduced.

METHOD

Subjects

The subjects were construction workers who have all worked at an elevated workplace. They consisted of eight elderly workers and eight young workers. Elderly workers ranged in age from 52 to 65 years with an average age of 57.5 years, $SD = 4.2$. Young workers ranged in age from 18 to 39 years with an average age of 30.3 years, $SD = 6.4$. Two elderly and two young workers were excluded from the analysis due to incomplete data. The details of the experiment were explained to the subjects and their agreement to participate was obtained.

The Temporary Scaffold

A temporary scaffold consisting of eight levels and six spans, with a frame width of 1,200 mm, span length of 1,800 mm and level height of 1,700 mm was erected in the experiment building. Figure 1 presents the front and side views of the scaffolding, and Figure 2 depicts a scene from the experiment. The levels are shown as horizontal lines and the spans as vertical columns, while the thick lines in Figure 1 represent the parts where the subjects could walk. The spans on the extreme left and right were fitted with footing boards across their entire width of 1,200 mm (called resting boards). Footing boards either 240 mm or 500 mm wide were also fitted in the four middle spans, on which the subjects walked during the experiment.

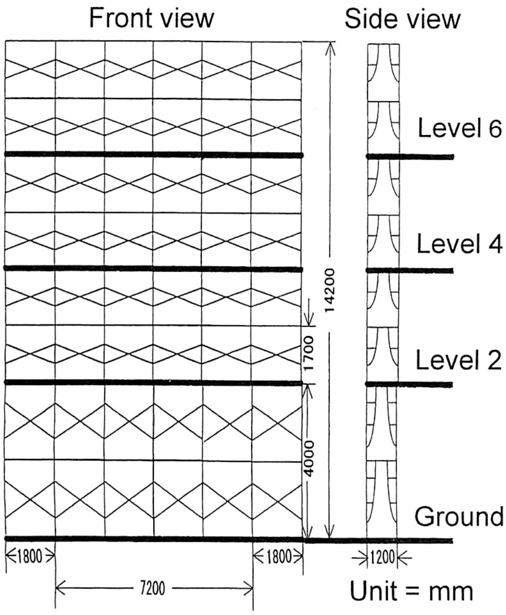

Figure 1 Front view and side view of the temporary scaffolding used in this experiment. Units are mm.

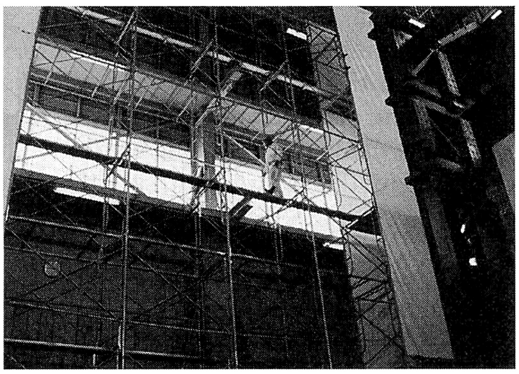

Figure 2 View of the experiment: The test being carried out is with a 240 mm-wide footing board.

Measurement of Spare Capacity

In the experiment, a system of measuring the mental workload was used. The secondary task for the subjects was to say "yes" as quickly as possible whenever they heard specific numbers ("4" and "9" by a male voice and "5" and "7" by a female voice) among random numbers from a speaker (seven numbers ranging from three through nine by male and female voices for a total of 14 numbers) at the rate of one number in two seconds. The reaction time was measured by a wireless system using a voice switch (the experimental apparatus was the same as that used by Usui & Egawa (2002).

Subjective Assessment

The subjects were asked to indicate to what extent they felt the mental workload by using the NASA-TLX immediately after each experiment.

Walking Speed

From the subject's walk recorded by the video camera, we measured the time required for the subject to walk two round trips, excluding the time spent turning around at each end of the footing board.

Experimental Conditions

The conditions set in the experiment were as follows.

- Height of work place: ground (walk on the footing board on the ground), and level 6 (10.7 m from the ground)
- Footing board width: 240 mm and 500 mm
- Load: carrying or not carrying a footing board, height 1,800 mm, width 500 mm, and weight 9,900 g
- Age: elderly and young workers

Procedure

One experiment lasted 280 seconds, during which time the numbers were announced 140 times. The numbers to be responded to were announced 40 times, or 28.6 percent.

First, each subject was given the opportunity to practice the secondary task three times by sitting on a chair on the ground to make sure that he was able to respond to the secondary task without a problem. In the experiment, the subject was instructed to walk back and forth along four spans starting from the resting board on the footing board between the signal of the "start of the experiment" and the "end of the experiment" by responding to the secondary task. The subject walked on the footing board eight times in total across the widths of 240 mm and 500 mm on the ground and level 6 with and without a footing board load. Finally, the secondary task alone was conducted as a control condition in a stable condition on the ground, and then the experiment was completed. The order for conducting eight experiments was counterbalanced.

RESULTS

Walking Speed

We measured the time required for the subject to walk four times between the resting position and a point four spans away. Four-way ANOVA (age×height×footing board width×with or without load) revealed a significant main effect for age, height, footing board width and with or without load in regard to walking time for four spans, $F(1, 368)=162.94, p<0.001$; $F(1, 368)=86.76, p<0.001$; $F(1, 368)=36.17, p<0.001$; $F(1, 368)=6.48, p<0.05$. A significant interaction was found between age and height, and age and footing board width, $F(1, 368)=20.71, p<0.001$; $F(1, 368)=13.43, p<0.001$. Three way interaction between age, height and footing board width was also significant, $F(1, 368)=11.83, p<0.001$, but the interaction between age and with or without load was not significant. These results showed that elderly workers walked slower than young workers, and in addition, they walked much slower in comparison to young workers if the footing board was narrower at the elevated workplace. However, slow speed from carrying a footing board load had nothing to do with age.

Answer Rate for Secondary Tasks

The rate that the subjects did not answer the number they were supposed to answer (i.e., miss rate) was 2.4 percent for elderly workers and 2.1 percent for young workers. The rate that the subjects answered the number they were not supposed to answer by mistake (i.e., false alarm rate) was 0.64 percent for elderly workers and 0.2 percent for young workers. In other words, the subjects answered the secondary task almost correctly. Three-way ANOVA (age×height ×footing board width) showed no significant main effects for the miss rates. Table 1 lists the mean miss rates and mean FA rates in age group by experimental condition. The miss rates are low in general, but the miss rate in the elderly group is somewhat higher than other conditions in the most potentially dangerous working environment where the footing board width is 240 mm at level 6.

Table 1 Mean rates of miss and false alarms by age group

		Level 6		Ground	
		240 mm	500 mm	240 mm	500 mm
Elderly	Miss	3.46	2.31	1.89	2.11
	FA	0.66	0.72	0.30	1.01
Young	Miss	2.71	2.31	2.29	1.89
	FA	0.12	0.48	0.12	0.12

Table 3 Mean reaction times for the secondary task according to the phases of walking

		Level 6		Ground	
		240 mm	500 mm	240 mm	500 mm
Elderly	Turn	993	983	901	910
	Straight	953	942	946	955
Young	Turn	878	854	880	878
	Straight	846	857	847	827

Table 2 Mean reaction times (milliseconds) for the secondary task

	Level 6				Ground				
	240 mm		500 mm		240 mm		500 mm		
	Without load	With load	Without load	With load	Without load	With load	Without load	With load	Control
Elderly	962	960	964	936	930	931	954	937	959
Young	861	845	867	846	849	860	837	839	827

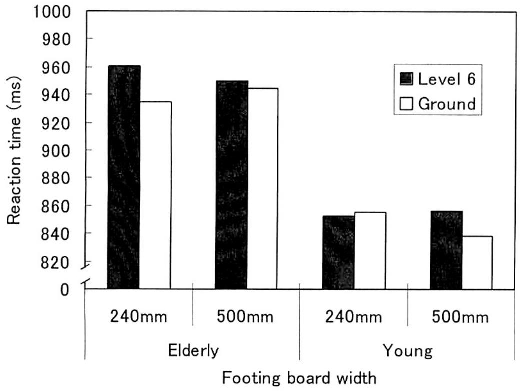

Figure 3 Mean reaction times for the secondary task.

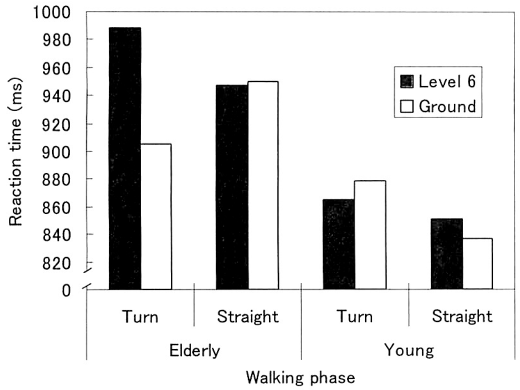

Figure 4 Mean reaction times for the secondary task according to the phases of walking.

Reaction Time

Table 2 presents the mean reaction times of the secondary task. Figure 3 depicts the result of the reaction time by the footing board width on the ground and level 6. Four-way ANOVA (age×height×footing board width×with or without load) indicated significant main effects for both age and height, $F(1, 3690)=273.22$, $p<0.001$ and $F(1, 3690)=4.14$, $p<0.05$. The main effect of footing board width was not significant. In addition, the interaction was not significant among the four factors of age, height, footing board width, and with or without the load. However, the three way interaction between age, height and footing board width was almost significant, $F(1, 3690)=2.88$, $p<0.10$.

Similarly to Usui & Egawa (2002), we separated the reaction times of the secondary task into those when walking in a straight line and those when turning, from the viewpoint of what the task demands in the walking. Table 3 shows the mean reaction times for the secondary task according to the phases of walking. Figure 4 illustrates the results of the reaction time by walking phase on the ground and level 6. The four-way ANOVA (age, height, footing board width, walking phase) showed that the main effect of the walking phase was almost significant, $F(1, 3690)=3.38$, $p<0.10$, and that the three-way interaction between age, height and walking phase was significant, $F(1, 3690)=16.13$, $p<0.001$.

Table 4 Average scores in NASA-TLX

	Elderly	Young
Mental demand	42.9	42.3
Physical demand	44.4	41.5
Temporal demand	41.4	38.4
Performance	72.7	66.6
Effort	67.2	45.9
Frustration level	36.8	34.3
Mean	50.9	44.5

NASA-TLX

Table 4 shows the mean assessment score for each index in NASA-TLX. There was a significant difference in the index of "effort" (question: how hard a subject has to work mentally and physically to achieve and maintain the level of work achievement: $t(97)=4.21$, $p<0.001$) between elderly and young groups, but there was no difference between age groups in other indexes.

DISCUSSION

The results of reaction times suggested that the elderly workers responded to the secondary task more slowly than did young workers. A number of researchers have confirmed that there has been an aging effect on the reaction time in various tasks (for example, Welford (1980)), and the existence of such an effect was supported in the task of this research also. This experiment revealed a significant main effect for height, but it was different from the result reported by

Usui & Egawa (2002) where an experiment was conducted on the same temporary scaffold with scaffolding workmen. The reason given for this is that the secondary task by Usui & Egawa (2002) was simply to detect the times in which a woman's voice was used, and from which a specific number was detected, while this time an element where a male and female voice were distinguished was added to the secondary task, making the problem more difficult. It was also proved that, although the spare capacity at height decreased to a certain degree, it had nothing to do with age since the interaction between age and height was not significant.

Usui & Egawa (2002) revealed that subjects who had no experience of working at the elevated workplace performed the secondary task poorly; in other words, their spare capacity decreased when the footing board width was 240 mm at level 6. In contrast, this experiment showed the main effect of the footing board width for the elderly workers was not significant even though the secondary task became more difficult. Furthermore, from the results there was basically no effect of age on the spare capacity of subjects since the interactions between age and other factors were not significant. However, the three-way interaction between age, height and footing board width was almost significant. These results suggest that there was a potentially dangerous working environment for elderly workers such as the elevated workplace where the footing board was narrower and the spare capacity was decreased.

The results of the reaction time by walking phase suggest that there was a potentially dangerous working environment for elderly workers such as an elevated workplace and that the task demand was increased; in other words, the task became complicated where the spare capacity was decreased.

The result of the NASA-TLX shows that there was almost no difference between age groups in the subjective assessment of the mental workload including mental and physical hardship. However, elderly workers reacted more severely than young workers according to mental and physical effort to achieve and maintain the work performance. These results suggest the spare capacity of elderly workers decreased in the working environment where the task demand increased, including the case where the footing board became narrower at the elevated workplace.

The experiment using the secondary task method demonstrated that the mental workload of the elderly workers did not exceed that of the young workers when they worked at the elevated workplace in comparison to working on the ground. However, it was found that the mental workload of the elderly workers increased more than that of the young workers due to potentially dangerous factors such as a narrow footing board and when the work became more complicated in addition to the height. These results indicated that safety for the work environment must be secured, in particular when elderly workers work at an elevated workplace.

REFERENCES

Egawa, Y., Usui, U., Shoji, T., & Nakamura, T. 2003 Ergonomics study on high-rise working conditions in construction sites. *Specific Research Reports of the National Institute of Industrial Safety*, NIIS-SRR-NO. 28. (In Japanese.)

Hsiao, H. & Simeonov, P. 2001 Preventing falls from roofs: A critical review. *Ergonomics*, **44**, 537–561.

Kobayashi, K. and Tamura, Y. 1995 Fatigue of works in high-rise constructions. *Journal of Architecture, Planning and Environmental Engineering* (*transactions of AIJ*), **476**, 145–153. (In Japanese.)

Reason, J. T. 1990 *Human error*. Cambridge University Press.

Usui, S. and Egawa, Y. 2002 Psycho-physiological analysis of mental workload at an elevated work place. *Japanese Psychological Research*, **44**, 152–161.

Welford, A. T. 1980 *Reaction times*, Academic Press.