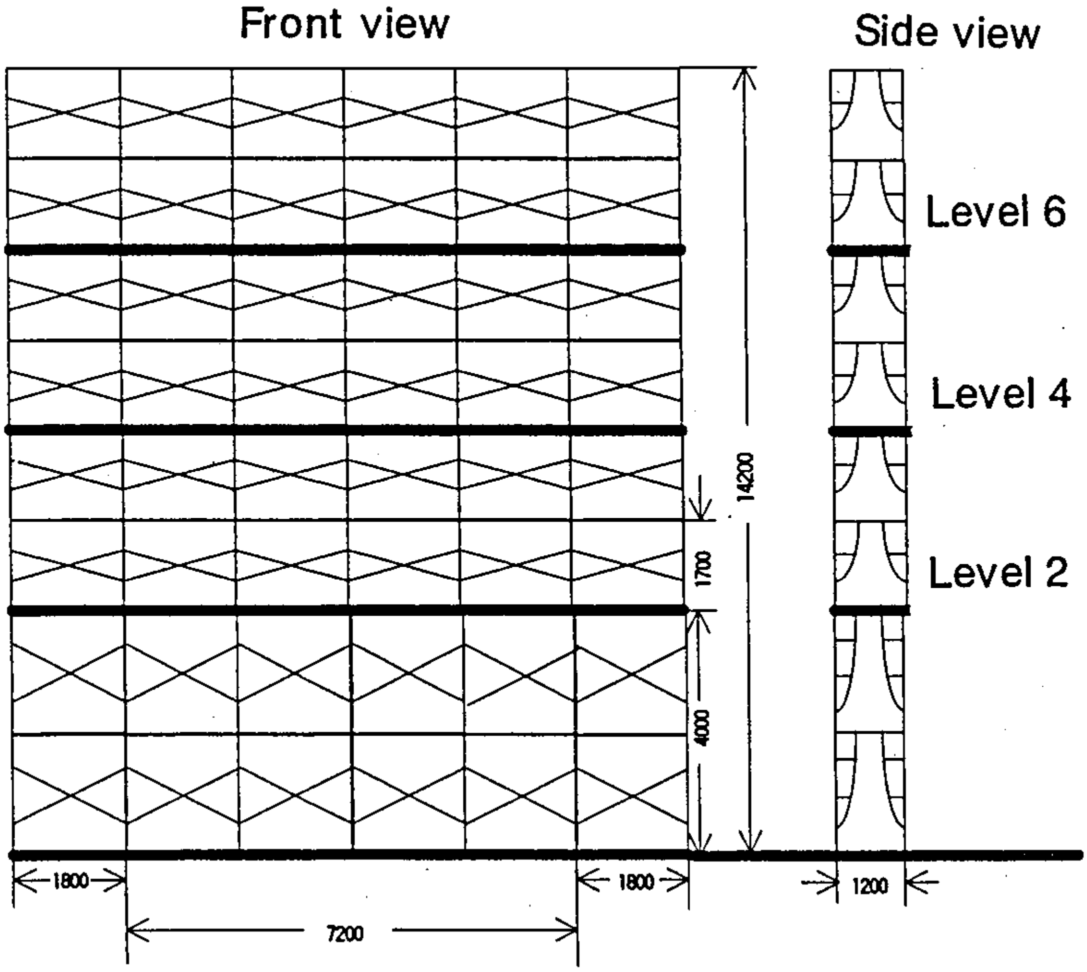

Figure 1. Front view and side view of the temporary scaffolding used in this experiment. Units = mm.

If we examine an electromyogram of the tibialis anterior musculus in a baby who is just starting to walk, however, these two peaks are absent. This is because the potential is high in the swing phase and the baby's pushing power and landing power are weak, and the baby walks with an awkward, unsteady gait. In other words, the electromyogram of this muscle is an indicator of walking difficulty.

The myogenic potentials measured in this experiment were sent by wireless transmission and recorded as electromyograms by a data recorder using a multitelemeter system (Nihon Koden WEB-5000).

Heart rate and blood pressure were measured while on the footing boards using a portable sphygmomanometer (Omron HEM-806F). The heart rate and blood pressure (maximum and minimum) readings from the sphygmomanometer were read out by the subject and recorded by an experiment assistant.

Subjective assessment. We devised a questionnaire in order to subjectively assess the scaffolding boards. The subjects were asked to indicate to what extent they felt: (i) the narrowness of the footing boards, (ii) fear of the height, and (iii) tension, by selecting an answer from the following: (i) none at all, (ii) not much, (iii) some, (iv) a lot, and (v) a great amount.

Experimental conditions. The conditions set in Experiment 1 were as follows:

- Level of height: level 2 = 3.9 m from the ground, level 4 = 7.3 m from the ground, and level 6 = 10.7 m from the ground.

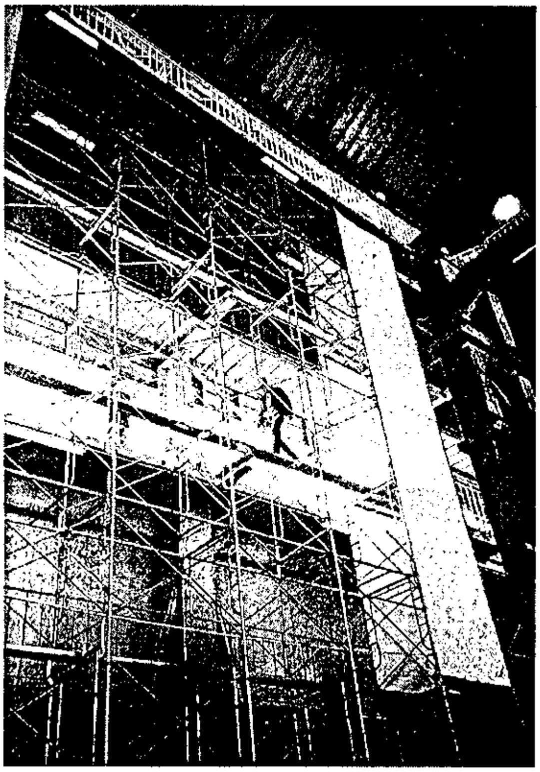

Figure 2. View of the experiment: The test being carried out is at level 4 with a 240 mm-wide footing board.

- Footing board widths: 240 mm and 500 mm.
- Direction of eyes (only when heart rate and blood pressure were measured): looking forward and looking downward.

Procedure. First, each subject was fitted with electrodes for recording electromyograms, after which he was made to rest for approximately 30 min. Then the subject moved to a level indicated by an experimenter and sat still in the chair on the right-hand side resting board for 3 min with his eyes closed. The subject was told to fit a safety belt to a lifeline for the duration of the experiment. After resting, he was told to walk four spans from the resting board and back again, during which time the myogenic potential was measured. Next, the subject was told to move to the center position of the four spans and rest for 30 s, after which heart rate and blood pressure were measured twice, once with the subject facing to the front and once turned 90 degrees and looking at the experimenter who was almost directly underneath. After this, the subject was told to return to the resting board and answer the questions on the subjective assessment sheet. This concluded one test, after which the subject was told to move to another level.

This scaffold walking test was carried out a total of six times, at levels 2, 4 and 6 and using 240 mm and 500 mm footing boards at each height. The test sequence was counterbalanced.

Results

Subjective assessment. Table 1 shows the average scores in the subjective assessment by the subjects at levels 2 and 6.

Fear of the height. The skilled group felt little or no fear while the unskilled group felt some or much fear. There was a significant difference in the average scores between skilled and unskilled group ($t(226) = 8.75$, $p < 0.001$). In the skilled group, two-way ANOVA (level of height × footing board width) showed significant main effects for both level of height and footing board width, $F(2,54) = 3.31$, $p < 0.05$; $F(1,54) = 5.42$, $p < 0.05$, respectively. Similarly in the unskilled group, there were significant main effects for both the level of height and footing board width, $F(2,48) = 13.32$, $p < 0.001$; $F(1,48) = 59.67$, $p < 0.001$, respectively.

Tension. There was a significant difference in the average scores between the skilled and unskilled group ($t(226) = 5.75$, $p < 0.001$). Two-way ANOVA (level of height × footing board width) showed no significant main effects in the skilled group. This means that they felt hardly any tension, regardless of height or footing board width. In the unskilled group, on the other hand, two-way ANOVA (level of height × footing board width) showed significant main effects for both the level of height and footing board width, $F(2,48) = 3.56$, $p < 0.05$; $F(1,48) = 70.44$, $p < 0.001$, respectively.

Footing board width. There was a significant difference in the average scores between the skilled and unskilled group ($t(226) = 5.45$, $p < 0.001$). Two-way ANOVA (level of height

Table 1. Average scores in subjective assessment of footing boards

	Skilled group						Unskilled group					
	Fear of height		Tension		Footing board width		Fear of height		Tension		Footing board width	
Height (mm)	500	240	500	240	500	240	500	240	500	240	500	240
Level 6	1.6	1.7	1.7	1.8	1.4	2.3	2	3.3	1.9	3.1	1.6	3.3
Level 4	1.2	1.7	1.9	1.8	1.5	2.2	1.6	2.8	1.3	2.7	1.4	3.1
Level 2	1	1.4	1.4	1.5	1.2	1.9	1.1	2.2	1.2	2.9	1.4	2.9

Table 2. Average heart rate values at level 2 and 6

		Skilled group		Unskilled group	
Height (mm)	Direction of eyes	500	240	500	240
Level 6	Looking forward	73.2	73.7	72.3	75.3
	Looking downward	73.5	77.8	74	78.8
Level 2	Looking forward	74.1	74.6	71.4	72.7
	Looking downward	77.7	79.5	73.1	74.7

Table 3. Average blood pressure values at level 2 and 6

			Skilled group		Unskilled group	
Height (mm)	Direction of eyes		500 mm	240 mm	500 mm	240 mm
Level 6	Looking forward	Max.	141.9	138.1	131.9	135.2
		Min.	95.3	90.7	88.9	91.3
	Looking downward	Max.	152.7	152.1	134.4	142.3
		Min.	99.2	104.6	94.2	93.7
Level 2	Looking forward	Max.	150.6	143	130.8	139.6
		Min.	97	93.8	90.7	96.2
	Looking downward	Max.	148.2	144.6	133.9	138.7
		Min.	101.5	97.7	92.9	94.9

× footing board width) showed a significant main effect of footing board width in both skilled and unskilled groups, $F(1{,}54) = 20.61$, $p < 0.001$; $F(1{,}48) = 76.67$, $p < 0.001$, respectively. These results mean both the subjects of the skilled and unskilled groups felt that the 240 mm footing board was narrower than the 500 mm footing board.

Physiological measures

Heart rate. Table 2 shows the average heart rate values measured at levels 2 and 6. Three-way ANOVA (level of height × footing board width × direction of eyes) showed no significant main effect in either group.

Blood pressure. Table 3 shows the average blood pressure values measured at levels 2 and 6. In the skilled group, three-way ANOVA (level of height × footing board width × direction of eyes) showed a significant main effect of direction of eyes for both maximum and minimum values, $F(1{,}108) = 6.06$, $p < 0.05$; $F(1{,}108) = 8.18$, $p < 0.01$, respectively. This means that their

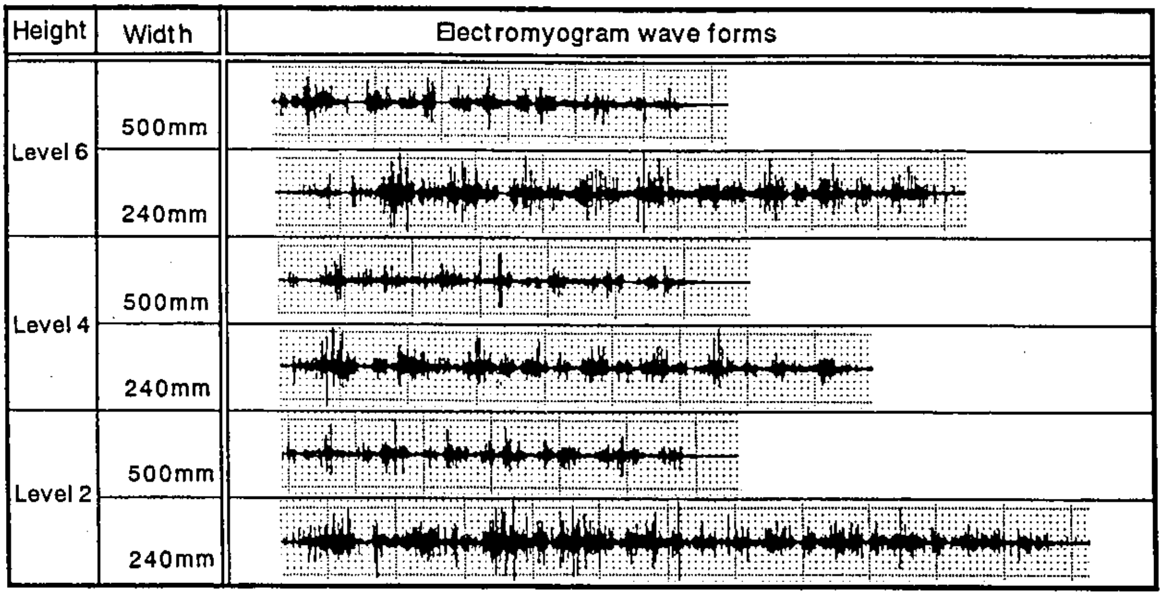

Figure 3. Electromyogram wave forms when walking on footing boards.

blood pressure rose when they looked down. However, three-way ANOVA (level of height × footing board width × direction of eyes) showed no significant main effects in the unskilled group.

Myogenic potential. Figure 3 shows typical electromyograms of the skilled scaffolding workers when walking along the footing boards. No disparity was seen in electromyogram wave forms with changes in layer height. However, some wave form variations were seen with changes in footing board width, a higher myogenic potential being recorded when walking along a 240 mm footing board than when walking along a 500 mm footing board. Furthermore, the two phases of the swing phase were not clearly seen in the case of the 240 mm footing board. The same phenomenon was observed in the unskilled group.

Experiment 2

In Experiment 2, we measured the spare capacity of the subjects using a dual task method. The scaffolding used was the same as in Experiment 1.

Method

Subjects. Experiment 2 was carried out on 10 skilled scaffolding workers aged between 16 and 53 years, with an average age of 26.2 years, $SD = 10.8$, and an average of 5.6 years experience, and seven unskilled people who were office workers aged between 22 and 33 years, with an average age of 26.3 years, $SD = 4.8$. None of the subjects had taken part in Experiment 1. The details of the tests were explained to the subjects and their agreement was obtained. The skilled workers received a daily payment equivalent to their normal wages.

Measurement of spare capacity. We constructed a system for measuring mental workload. The secondary task for the subject was to respond by saying "yes" as quickly as possible whenever he heard the numbers 3, 5 or 7 among a series of random numbers between 3 and 9 said by a speaker once every 2 s. The response time was measured by radiowaves using a voice switch.

A computer controlled the audio stimulus given to the subject with numbers recorded on an AV tachistoscope (Iwatu Isel IS-701D). The subject's vocal response was recorded via a radio transmitter and a radio receiver. Two monitoring cameras filmed the subject's state and the counter showing the subject's reaction time, and these two video images were mixed and recorded on a video recorder.

Walking speed. As recorded by a video camera, we measured the time required for the subject

Table 4. Mean (*SD*) walking times (time in seconds) between the resting position and a point four spans away

	Ground	500 mm	240 mm
Skilled group	7.7 (1.18)	8.1 (1.39)	8.7 (1.62)
Unskilled group	6.8 (0.88)	11.9 (2.90)	21.1 (16.05)

to walk two round trips, excluding the time spent turning around at each end of the footing board.

Experimental conditions. The conditions set in Experiment 2 was types of scaffold: on the ground, the 500 mm footing board at level 6 (10.7 m from the ground), and the 240 mm footing board at level 6 (10.7 m from the ground).

Procedure. In each test, 91 numbers were given over a period of 182 s, 39 of these numbers requiring a response. First, each subject was given one practice of the secondary task for a period of 182 s while standing upright on the ground. During the test on level 6, the subject was instructed when to start and stop making return trips along the footing board between the resting position and a point four spans away while performing the secondary task. This test was carried out using both 240 mm and 500 mm footing boards. The subjects performed the test a total of three times, including the test at ground level. The test sequence was counterbalanced.

Results

Walking speed. Table 4 shows the mean walking times between the resting position and a point four spans away. One-way (types of scaffold) ANOVA showed significant main effect for both skilled and unskilled groups, $F(2,197) = 3.17$, $p < 0.05$; $F(2,197) = 16.5$, $p < 0.001$, respectively. Tukey's HSD test showed that the differences between the ground and 500 mm wide, the ground and 240 mm wide, and 500 mm wide and 240 mm wide were significant ($p < 0.001$) in the unskilled group, the difference between ground and 240 mm wide was almost significant ($p < 0.10$) in the skilled group.

These results indicate that the walking speed of the unskilled group was reduced when the height was increased, when the footing board was narrower. On the other hand, the walking speed of the skilled group with the 240 mm footing board tended to be slower than at ground level.

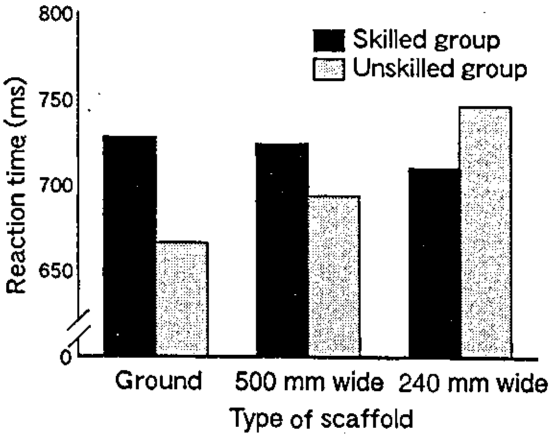

Figure 4. Mean reaction times for the secondary task.

Spare capacity. Figure 4 shows the mean reaction times of the secondary task. One-way (types of scaffold) ANOVA showed a significant main effect for the unskilled group ($F(2,797) = 22.64$, $p < 0.001$). Tukey's HSD test showed that the differences between the ground and 240 mm wide, 500 mm wide and 240 mm wide were significant ($p < 0.001$), and between the ground and 500 mm wide was almost significant ($p < 0.10$). In the skilled group, on the other hand, there was no significant effect ($F(2,1097) = 1.17$, *ns*).

The above results show the spare capacity in the secondary task was reduced with the footing board width and height in the unskilled group. But in the skilled group, neither footing board width nor height had any influence, suggesting that there was not much mental workload with tasks of this degree.

However, video monitoring suggested that the task demands in the walking test were greater when turning around because the subjects were paying attention to their footing in order to keep their balance. So we separated the reaction times of the secondary task into those when walking in a straight line and those when turning (phases of walking), and then totaled the two. Figure 5 shows the results thus obtained

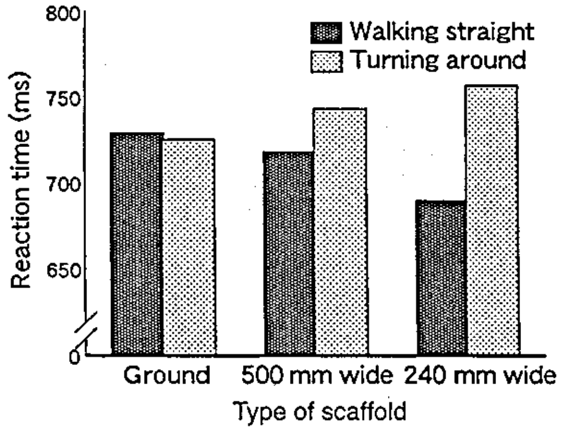

Figure 5. Mean reaction times for the secondary task according to walking form in skilled group.

from the skilled group. Two-way ANOVA (types of scaffold × phases of walking) showed a significant main effect of phases of walking ($F(1,1094) = 7.41$, $p < 0.01$). The interaction between types of scaffold and phases of walking was significant ($F(2,1094) = 3.58$, $p < 0.05$). On the 240 mm footing board there was a significant difference in the mean reaction times between walking straight and turning around ($t(358) = 3.52$, $p < 0.001$). These results suggest that there was less spare capacity at an elevated place when turning around than when walking in a straight line, an effect that was more pronounced with a 240 mm footing board.

Discussion

We did not obtain any results from our analysis of the physiological responses measured in these experiments to clearly indicate an increased mental workload due to height in either the skilled or the unskilled groups. One reason for these heart rates and blood pressure readings might have been the insertion of a 30-second rest period after the subject had moved to the measurement point, thus canceling the effects of walking.

One interesting result, however, was the tendency for blood pressure to rise in the skilled group when they looked downwards. Some subjects from the skilled group suggested in a post-experimental discussion that this may have been because when actually working at heights they are extremely careful not to drop tools and injure people on the ground below. This could explain why the skilled group became subconsciously tense and their physiological measurements increased in this test when asked to look at the experimenters on the ground.

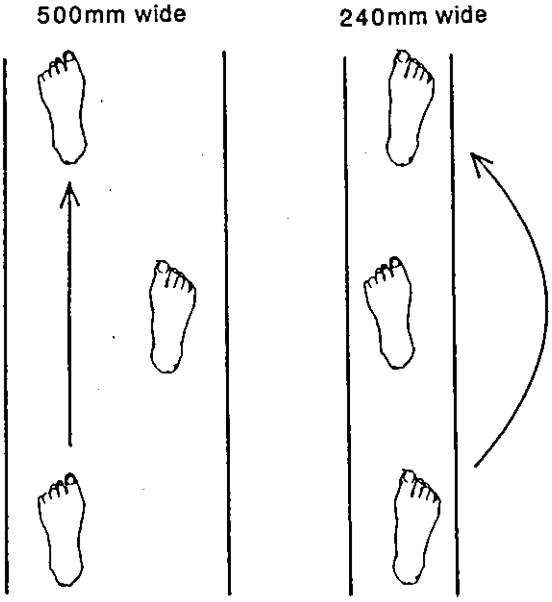

Figure 6. Walking style on footing boards.

The results of the electromyograms taken from both the skilled and unskilled groups showed different wave forms with the 240 mm and the 500 mm footing board tests, regardless of the height. The reason for this is discussed below.

Figure 6 shows the foot movement in the swing phase of a subject walking as monitored with the video camera. Although the subject was able to move each foot in a straight line forward on the 500 mm footing board, this was not possible on the 240 mm footing board and each foot had to be swung around the other. The average width of a Japanese foot is approximately 105 mm (Suzuki, 1996), so the width of both feet together with no space between is approximately 210 mm. In addition, the legs have to open by approximately 150 mm when walking. For this reason the feet have to swing outwards when walking on a 240 mm footing board, and during that swing they are not above the footing board, as shown in

Figure 6. This is probably the reason for the high myogenic potential of tibialis anterior musculus measured when walking on the 240 mm footing board (as shown in Figure 3), and the lack of two clear peaks during the swing phase. This means that 240 mm is not wide enough to be able to walk steadily without increasing the load on tibialis anterior musculus. It is also worthy of note that the skilled workers who answered in the subjective assessment that they were not effected by height also said that they felt the 240 mm footing boards were narrow.

Our analysis of the psychological responses clearly showed an increased mental workload on the subjects in the unskilled group at an elevated position. Their answers in the subjective assessment were that they felt more afraid and more nervous at a higher level with a narrower footing board. Moreover, their secondary task performance on the 240 mm footing board at height was significantly worse than on the ground. There was an almost significant difference between secondary task performance on the 500 mm footing board at height and at ground level, but this does not mean that the spare capacity when walking on the 500 mm footing board at height is about the same as when walking on the ground. It is probably valid for us to think of the walking speed on the 500 mm footing board becoming slower to a certain extent as the subject concentrated on the secondary task, a kind of tradeoff between walking speed and secondary task response. On the 240 mm footing board, however, the subjects lacked the spare capacity to compensate, even when they reduced their walking speed.

On the other hand, no increase in mental workload was indicated by the results from the skilled group. That is to say, they reported in the subjective assessment that they hardly felt any fear or tension. Their secondary task reaction times barely changed under any of the test conditions. This failure of the secondary task performance to drop can be explained by using the multiple resources theory put forward by Navon and Gopher (1979), which states that the attention required for walking at height is a separate resource from the attention needed for numerical detection. The secondary task used in our experiment was also comparatively simple and therefore might have been unsuitable for measuring spare capacity. Furthermore, the primary task of walking at a height of 10 m might have been too easy for the skilled group.

Whatever the reason, these points require clarification by further experiments in which there is a larger workload from the tasks themselves. This could be done by setting a more difficult secondary task to increase the memory workload, or by setting a more complicated primary task that calls for cooperation with another person, for example, or just by increasing the height at which the tasks are performed. This is another problem for the future.

When we separated the primary task of walking into two phases, walking in a straight line and turning around, and calculated the two corresponding secondary task performances, we found that the secondary task response time when turning was greater, and that there was interaction between walking direction and footing board width. This result shows that the mental workload increased when the task performed at height was made more difficult, and became even greater when using the narrower 240 mm footing board.

The results of our research show clearly that while there is a large mental workload at a height of approximately 10 m from the ground, this can be controlled to a large extent by practice. However, if the work involved is made more complicated or a sense of insecurity is introduced by making the footing board narrower, there seems to be an increase in mental workload even in skilled workers. The two main types of footing boards used on actual work sites at present are 240 mm and 500 mm wide, but the results of this experiment lead us to recommend the use of 500 mm footing boards in order to increase work safety.

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Tapping task as an index of mental workload in a time sharing task[1]

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Abstract: The sensitivity of tapping task to mental workload was investigated. Thirteen subjects were asked to produce 3 s intervals continuously while performing a time sharing task. The time sharing task was designed to manipulate a demand to allocate an attentional resource to one target and a demand to switch the target to which an attentional resource was mainly allocated. Results showed that produced intervals became shorter and more variable as the time sharing task became more demanding. The subjective workload assessment by the NASA Task Load Index (NASA-TLX) indicated that subjects experienced an increasing workload as the demand of the time sharing task increased. Two sub scales of the NASA-TLX, "effort" and "mental demand," were rated higher than other sub scales. These results suggest that the tapping task is sensitive not only to the motor output load but also to the central processing load.

Key words: mental workload, interval production, tapping task, attentional resource

Assessing mental workload is important for developing a complex system, especially when human operators must control the system in a multitask environment. Many measures for assessing mental workload has been developed and they are classified into three types: (i) performance-based assessment, (ii) subjective workload assessment, and (iii) physiological workload assessment (Eggemeier, Wilson, Kramer, & Damos, 1991). In the performance-based assessment, a secondary task is performed with a primary task. It is assumed that the variation of mental workload is reflected to performance of the secondary task. In the present study, a sensitivity of the tapping task as a secondary task was investigated.

In the time perception literature, it has been reported that perceived duration of the interval is shortened when a non-temporal task is performed in the interval to be estimated (e.g. Hicks, Miller & Kinsbourne, 1976; Brown, 1985). When subjects were asked to produce an interval, a produced interval is likely to be longer as a function of processing demand of non-temporal task (e.g. Fortin & Breton, 1995; Fortin & Rousseau, 1987; Fortin, Rousseau, Bourque & Kirouac, 1993).

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[1] The authors would like to thank Koji Kawaguchi for his contribution as an experimenter to this study.

These previous studies indicate that time estimation and interval production can be used as a secondary task to measure mental workload.

In fact, time estimation and interval production have been used in some mental workload studies. For example, time estimation and interval production were adopted to assess mental workload in driving a car (Brown, Simmonds & Tickner, 1967) and operating aircraft simulators (Casali & Wierwille, 1983; Zakay & Shub, 1998). When an interval that subjects experienced as performing a primary task was estimated by the prospective time estimation paradigm[2], the duration of the interval was likely to be underestimated as the primary task became more demanding. When interval production was combined with a primary task, the produced interval increased as the primary task became more demanding. The prospective time estimation is suggested to be sensitive to perceptual load (Eggemeier et al., 1991), while the interval production was suggested to be sensitive to motor output load (Eggemeier, 1988).

In the present study, the primary task was the time sharing task in which subjects were required to monitor several targets moving horizontally and to control them by changing the direction of movement. The secondary task was a tapping task that required subjects to produce a series of regular responses using their finger. Two kinds of task demands were manipulated: one was the speed of the targets related to the demand on allocating attentional resource to one target, and the other was the number of targets related to the demand on switching the target to which an attentional resource was mainly allocated. The purpose of this study was to examine the sensitivity of the tapping task to these task demands.

Experiment

Method

Subjects. Thirteen undergraduates and graduates (10 males and 3 females) of the department of psychology of Osaka University, Japan volunteered to participate in the experiment.

Apparatus. A PC-AT compatible computer was used to control the experiment. In order to measure produced intervals, the internal system timer of the computer was used via application programming interface of the operation system (Microsoft Windows 95). Stimulus was presented on a SVGA display monitor (SONY CPD-17sf2, Tokyo, Japan), which was placed approximately 60 cm from the subject. A 106-key type keyboard was used for the response both for the primary task and for the tapping task.

Tasks. The primary task was a time sharing task developed by Goldstein and Dorfman (1978). Subjects were presented rectangular frames on the computer screen. The size of a frame was approximately 191 mm long and 27 mm high (18.0 deg by 2.6 deg). Each frame contained a target moving at a uniform speed to the right or left. Subjects could reverse the direction of movement of the target by pressing the corresponding buttons assigned to each frame. Subjects were instructed to keep the moving targets in the frames and to prevent the targets from reaching both ends of the frames. When a target approached either end of the frame, subjects had to change the direction of the movement of the target by pressing the button corresponding to the frame.

Goldstein and Dorfman (1978) changed the number of frames and the speed of targets to manipulate load stress and speed stress, respectively. Also, in the present study, the number of frames varied from one to three. It was assumed that the more frames subjects had to monitor, the more switching of attention between frames was required. The target moved at one of three levels of speed: low (6.38 deg/s), medium (12.24 deg/s), and high (17.56 deg/s). It was assumed that manipulating the speed of target varied the demand to allocate an attentional resource to one target. When the targets moved faster, subjects were required to monitor them more carefully and to make responses to reverse the direction of movement

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[2] In the prospective time estimation paradigm, subjects are informed that they will be asked to judge duration of the dinterval prior to the beginning of task.

more frequently than when the target moved slowly. In this case greater attentional resources would have to be allocated to the target. As a result, demand on allocating attention to one target increased.

The secondary task was the tapping task. Subjects were asked to produce approximately 3 s intervals by pressing "z" key of the keyboard by the index finger of their left hand. Subjects were also instructed to make an effort to keep the rate of interval production constant over the experiment.

Subjective workload assessment. To assess a subjective mental workload in the present experiment, six scales in the Japanese version (Miyake & Kumashiro, 1993) of the NASA-TLX (Hart et al., 1988) were used. These scales were: (i) "mental demand," (ii) "physical demand," (iii) "temporal demand," (iv) "performance," (v) "effort," and (vi) "frustration level." In addition, subjects rated the overall workload on the scale that Haga and Mizukami, 1996) used. These seven subjective mental workload scales were presented on a sheet of paper with each of the scale titles followed by a 12-cm line marked with the appropriate end-point descriptors. Subjects marked the appropriate point on each line to indicate the extent of their experienced workload. The distance of the marks from the left end of each scale was measured for the raw rating (from 0 "very low" to 100 "very high").

Procedure. Subjects were tested individually. After instruction, subjects practiced the tapping task and the time sharing task separately for 30 s. Although subjects were instructed to produce 3 s intervals, no feedback on duration of produced interval was provided. Subjects were encouraged to minimize variation of produced intervals rather than to adjust produced interval to 3 s. Produced intervals in the practice were treated as in the control condition. The experiment session consisted of nine subsessions in three blocks. In each subsession, subjects experienced one of nine possible combinations of the number of frames condition and the target speed condition. In one block, subjects performed 40 s of the concurrent performance of the time sharing task and the tapping task.

At the beginning of each block, subjects were asked to start tapping after the warning signal. The frames were presented and the time sharing task began. The default location of the target ranged from 69 mm to 127 mm from the left end of a frame and it was varied among trials at random. The subject monitored the targets and pressed keys to reverse the direction of movement of the target by using the index finger of their right hand. Subjects had to select the corresponding key assigned to the frame which reversed the movement of the target. The "8" key of the 10-key board was assigned to the top frame of the target, the "5" to the middle frame of the target and the "2" to the bottom frame of the target, respectively. After completing each block of three trials, subjects were asked to complete seven measures of the NASA-TLX to access subjective workload. The total duration of the experiment was approximately 1 h.

Results

Primary task performance. The number of targets that reached either end of the frame was treated as the error of the primary task. Figure 1 indicates that the number of errors that occurred in each block. A two-way repeated

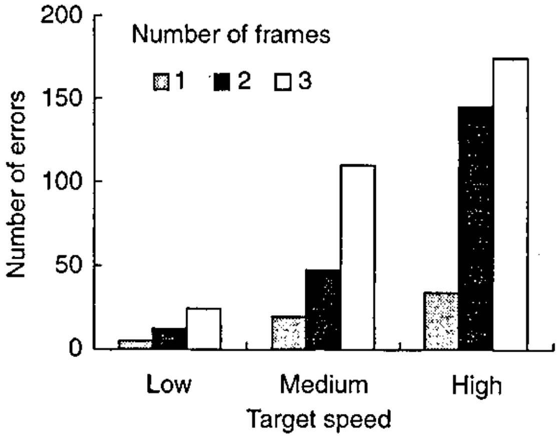

Figure 1. Number of errors of the primary task as a function of the number of frames and the speed of targets.

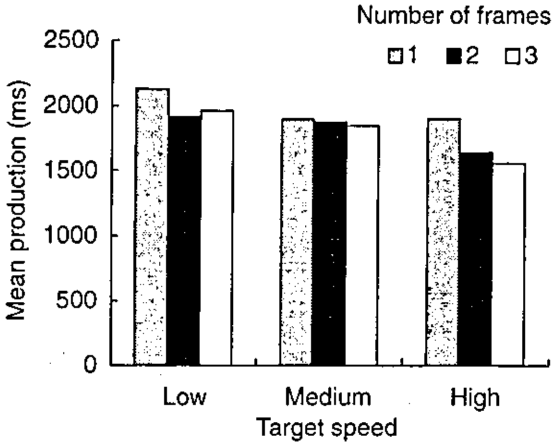

Figure 2. Mean produced intervals as a function of the number of frames and the speed of targets. Mean produced interval in the control condition was 2206 ms.

measure of ANOVA was used. The independent variables were the number of frames (one, two, or three) and the target speed (low, medium or high). The ANOVA indicated that the main effects were significant ($Fs_{2,24} >$ 69.98, $p < 0.001$). The interaction was also significant ($F_{4,48} = 17.33$, $p < 0.001$). Simple main effect analysis revealed that when the speed of the targets was low, there was no significant difference in the number of frames condition ($F_{2,24} = 1.28$, *ns*).

Tapping task performance. Figure 2 indicates mean interval productions in each condition. The two-way repeated measures ANOVA indicated that the main effect of the target speed was significant ($F_{2,24} = 12.51$, $p < 0.001$), and the main effect of the number of frames condition was also significant ($F_{2,24} = 6.53$, $p < 0.006$). The interaction was not significant ($F_{4,48} = 1.79$, *ns*). Produced intervals decreased as the target speed increased and as more frames were presented. The mean produced interval in the control condition (2206 ms) was compared with mean produced intervals in experimental condition. The one-way ANOVA indicated that the main effect was significant ($F_{9,106} = 4.23$, $p < 0.001$), and the Tukey test showed that the intervals produced under control conditions were significantly longer than those in the experimental blocks ($p < 0.05$), except when one frame was presented at the lowest target speed.

The standard deviations in each condition are shown in Figure 3. The two-ways repeated measures of ANOVA indicated that both the main effect of target speed and that of the number of frames were significant ($Fs_{2,24} >$ 7.14, $p < 0.04$), suggesting that a variation of produced intervals increased as the primary task became more demanding. The interaction was also significant ($F_{4,48} = 2.70$, $p < 0.05$). Simple main effects analysis indicated that there was no significant difference among the number of frames condition when the target speed was high ($F_{2,24} = 0.76$, *ns*). When three frames were presented, no significant difference was found in the target speed condition ($F_{2,24} = 0.48$, *ns*).

Subjective mental workload. The original version of the NASA-TLX includes the process evaluating relative importance of the six subscales by each subject to calculate a weighted mean. Miyake and Kumashiro (1993) reported a high correlation ($r = 0.971$) between the weighted mean computed in the original NASA-TLX and the simple arithmetic mean ratings of the scales. Their results suggest that the mean ratings can be considered an appropriate subjective workload measure. Thus, in the present study this evaluation process was omitted. A simple arithmetic mean was computed across subscales of the NASA-TLX and it was treated as a subjective workload score.

Subjective workload scores for each condition (Figure 4) were submitted to the two-way repeated measures of ANOVA. The main effect of the target speed was significant ($F_{2,24} =$ 17.45, $p < 0.001$), and the main effect of the frames was also significant ($F_{2,24} = 23.86$, $p < 0.001$). The interaction was not significant ($F_{4,48} = 0.60$, *ns*). Subjective workload increased as a function of the number of frames and the target speed. Subjective workload scores were highly correlated with the overall workload rating ($r = 0.916$).

Each of the ratings were averaged and listed in Table 1. A one-way repeated measure of ANOVA indicated that the main effect was significant ($F_{6,72} = 4.46$, $p < 0.001$), and a Tukey

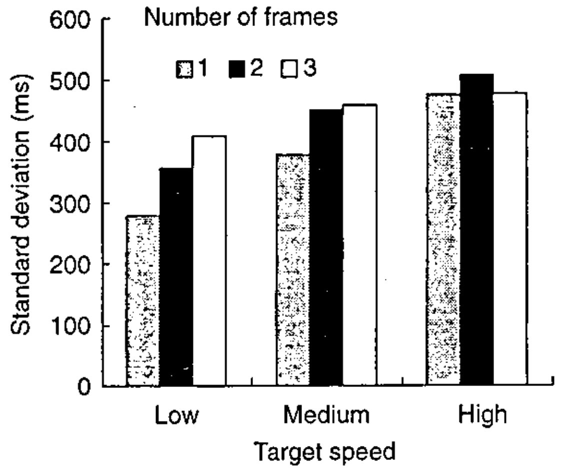

Figure 3. Standard deviation of produced intervals as a function of the number of frames and the speed of targets.

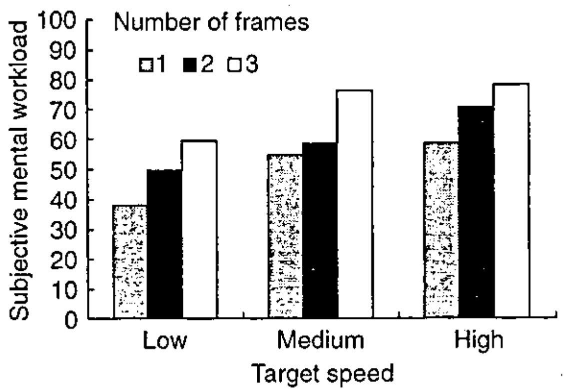

Figure 4. Mean subjective workload scores as a function of the number of frames and the speed of targets.

Table 1. Ratings of sub-scales of the NASA tesk load index and of overall workload

		Sub-scales						
Target speed	No. frames	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration level	Overall
Low	1	36.3	30.9	30.0	38.2	55.1	37.9	42.8
	2	50.2	45.8	44.7	53.8	59.6	43.7	50.5
	3	60.3	54.2	55.5	62.9	72.2	51.4	60.2
Medium	1	57.1	52.4	48.8	53.5	66.7	50.2	57.1
	2	63.9	60.1	58.8	54.1	64.6	48.6	59.6
	3	79.6	75.8	80.3	72.8	83.5	65.7	77.6
High	1	53.8	60.6	63.5	61.8	63.5	47.9	61.8
	2	73.8	72.8	74.4	64.7	77.9	58.8	71.0
	3	82.1	79.7	81.9	72.7	82.2	69.9	81.9
	M	61.9	59.2	59.8	59.4	69.5	52.7	62.5
	SD	24.0	24.4	25.8	24.6	20.2	24.1	21.2

test revealed that the ratings of "effort" and "mental demand" were significantly higher than the ratings of "temporal demand," "performance," "physical demand" and "frustration level" ($p = 0.05$).

To examine the relation between the tapping task performance and the subjective mental workload assessment, the correlation among ratings of scales were computed. The correlation among the scales ranging from 0.495 to 0.790 were significant ($p < 0.01$). The correlation between each rating of scales and the mean and standard deviation of produced interval was also analyzed. While the mean of produced intervals was significantly correlated only with the rating of "performance" ($r = 0.229, p < 0.013$), the standard deviation of intervals was significantly correlated with all scales ($r > 0.212, p < 0.022$).

Discussion

Performance of the primary time sharing task deteriorated as the number of frames increased and as the target speed increased. Subjective workload scores increased as the primary task performance decreased. These results indicate that the demand of the primary task is manipulated successfully by the number of frames and the speed of targets.

The mean and the standard deviation of produced intervals varied with the number of frames and the speed of the targets. This suggests that performance of the tapping task reflects the demand of the primary task.

Motor output load and tapping

In the present experiment, as the number of frames increased, subjects were required to monitor more frames, by switching the direction of their attention, than when they were required to monitor one frame only. As the target speed increased, time to reach the end of the frame became shorter. Therefore, when several frames were presented or when the target speed was high, subjects had to schedule and to execute a strict sequence of button pressing responses. This scheduling and executing process of motor output depends on a common timing mechanism that was accessed in a range of motor and perceptual tasks (Keel & Ivry, 1991). Although there are separate mechanisms regulating the timing of each limb, these two mechanisms are integrated prior to motor execution (Helmuth & Ivry, 1996). Thus, it is expected that the primary task will interfere with the tapping task when the motor output load increased, as Eggemeier (1988) stated. This interference seems to derive from the sharing of the central timing mechanism between the primary task and the tapping task, which causes interference between tasks.

Although the previous studies (e.g. Eggemeier, 1988; Brown, 1997) have indicated that an increased task load lengthened produced intervals, the present results indicate an opposite trend; produced intervals increase as a function of task load. This could be caused by the experimental setting in which the primary task was performed by the right hand while the tapping task was performed by the left hand. Subjects had to produce responses for the primary task more frequently when the primary task became more demanding. This right hand response sequence, which included many motor responses incompatible with the tapping sequence, could have accelerated the tapping performed by subject's left hand.

Sensitivity of the tapping task to mental workload

Although primary task performance can be used as an index of workload, it cannot measure workload appropriately when two tasks are so easy that processing capacity is reserved (Wickens, 1992). When a task becomes more difficult, subjects try to spend the reserved attentional resource in maintaining performance. As long as reserved resource remains, deterioration of task performance is minimized. In the present study, when the target speed was low, the number of frames did not have significant effect on errors of the primary task (Figure 1). When several frames were presented, subjects had to monitor frames by switching the direction of attention among frames. This result implies that in the low target speed condition, subjects succeeded in maintaining primary task performance by using the reserved attentional resource to cope with an increase in time sharing demands. However, even when the target speed was low, the mean and the standard deviation of produced intervals reflected the difference of workload, based on the number of frames (Figures 2 and 3). The present study revealed that the tapping task was so sensitive that the task could detect an increasing time sharing demand, even though decreased performance of the primary task was observed.

When the target speed was low, the standard deviation of intervals increased as a function of the number of frames. When the target speed was high, however, there was no difference in standard deviation among the number of frames. Also, when three frames were presented, the effect of target speed on standard deviation was not significant. These results suggest that the standard deviation is not sensitive to the mental workload produced by the heaviest demand. The tapping task seems to be useful as an index suitable for relatively low or medium levels of workload.

Subjective mental workload assessment

The subjective workload assessment indicated that "effort" and "mental demand" were of relative importance in the present time sharing task. Hart and Staveland (1988) stated that "effort" relates to the extent of how hard subjects have to work mentally and physically to accomplish their level of performance, and "mental demand" relates to the extent how much mental and perceptual activity subjects were required to use. The results imply that the present task imposes on subjects not only motor output load, but also load relating to mental demand. Haga and Mizukami (1996) showed that when subjective workload while performing a mental arithmetic task was accessed by the NASA-TLX, mental demand was highly weighted. A mental arithmetic task requires a general attentional resource (Wickens & Kessel, 1980; Reisberg, 1983; Brown, 1997). Thus, it is supposed that the present time sharing task requires an attentional resource which the mental arithmetic task also requires, and that the tapping task reflects the amount of attentional resource allocated to primary task performance. This interpretation is consistent with the findings of several previous studies (Brown, 1997; Shinohara, 1999) that an interval production task requires a central and general purpose processing resource.

Analysis of correlation between the assessments of subjective workload and the tapping task performance indicates that the standard deviation of intervals varied with the subjective measures of workload; on the other hand, the means of intervals did not correlate with most of the ratings of subjective workload. This result suggests that the standard deviation can reflect workload assessed by subjective measures. Yeh and Wickens (1988) suggested that a subjective workload measure directly reflects the effort of task performance and the number of concurrent tasks. As described above, effort and mental demand were given relatively high importance in the present task. Thus, the standard deviation of intervals, rather than the mean of intervals, is supposed to be good measure of physical or mental effort and the amount of mental activity required by the task.

Summary

In the present study, increased demand of the primary time sharing task was successfully detected by the tapping task, even when primary task performance did not reflect this increase of demand. Results of the dual task experiment indicated that the tapping task was sensitive to the motor output load, and the result of subjective workload assessment implied that the tapping task also reflected a central processing demand of the primary task. While several previous studies (e.g. Brown, 1997) have proposed that a central processing resource is required to perform the tapping task, some other studies (e.g. Eggemeier et al., 1991) indicated a sensitivity of tapping task to motor output load. However, analysis of the present study implies that the tapping task reflects both motor output load and central processing load. Further study is required to investigate sensitivity to central processing load and to motor output load separately.

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PSYCHOLOGICAL ANALYSIS OF MENTAL WORKLOAD AT AN ELEVATED WORK PLACE: COMPARISON BETWEEN ELDERLY AND YOUNG WORKERS

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In this research, an experiment measuring the mental workload at the elevated place was conducted to prevent elderly workers fatalities at the elevated place by using dual task method. The results indicated an increase in mental workload caused by the height was observed in elderly workers. However, it was proved that the mental workload of the elderly workers was larger than that of younger workers when dangerous factors such as narrowness of a footing board width and complication of the work were added to a factor of height.

INTRODUCTION

The number of fatalities due to industrial accidents in Japan in 2001 was 1,790, with the construction industry accounting for the greatest share with 644 fatalities. Of which, the number of people who died from falling was 269 accounting for 42 percent, which means that the possibility of causing danger at the elevated place is extremely high. With aging of labor population, the number of labor disaster by the elderly workers tends to increase, and securing safety for the elderly is also becoming an important problem recently. Then, in this research, an experiment was conducted that both elderly and young construction workers as subjects walked on a footing board put over a temporary scaffold either with or without the footing board. This study aimed to obtain standard data, which will enable the establishment of a safe industrial environment for the elderly workers at the elevated place. We measured the degree of mental workload under various work-environment conditions where the height of work place, footing board width, and with or without carrying the footing board were adjusted. In the experiment, a dual task that subjects respond to a specific number announced auditoriarily during walking was conducted, and spare capacity of the subjects at the elevated place was measured by performance of a secondary task.

METHOD

Subjects

Construction workers who have all worked at the elevated place. It consists of 8 elderly workers and young workers respectively. 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 workers and young workers were respectively 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.

Temporary scaffold

A temporary scaffold consisting of 8 levels and 6 spans and with a frame width of 1,200mm, span length of 1,800mm and level height of 1,700mm was erected within the experiment building. Figure 1 shows the front and side views of the scaffolding. The levels are shown as horizontal lines and the spans by 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 1200mm (called resting boards), and footing boards either 240mm or 500mm wide were fitted in the four middle spans, on which the subjects walked during the experiment.

Measurement of spare capacity

In the experiment, a system of measuring the mental workload was used. The secondary task for the subjects was to respond by saying "yes" as quickly as possible wherever they heard specific numbers ("4" and "9" by male voice and "5" and "7" by female voice) among random numbers from a speaker (7 numbers ranging from 3 through 9 by male and female voice with total of 14 numbers) at the rate of 1 number per 2 seconds, and the reaction time was measured by wireless using a voice switch (the experiment apparatus was the same as that by Usui and Egawa 2002 1)).

Subjective assessment

The subjects were asked to indicate to what extent they felt the mental workload by using 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 condition

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
With or without load: with or without carrying the footing board that height is 1,800 mm, width is 500mm, and weight is 9,900g)
Age: elderly and young workers

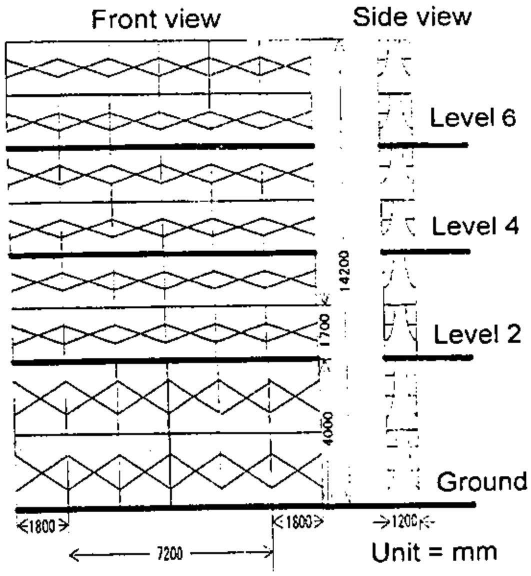

Figure 1. Front view and side view of temporary scaffolding.

Procedure

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

First, each subject was given 3 practice of the secondary task by sitting on a chair on the ground, and then made sure that he was able to respond to the secondary task without problem. In the experiment, the subject was instructed to walk back and forth 4 spans starting from 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 8 times in total by the width of 240 mm and 500 mm respectively on the ground and 6 level by possessing the footing board and without possessing. Finally, solely the secondary task 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 AND DISCUSSION

Walking speed

Four-way ANOVA(age × height × footing board width × with or without load) showed significant main effect for age, height, footing board width and with or without load in regard with walking time for 4 spans, $F(1,368)=162.94$, $p<0.001$; $F(1,368)=86.76$, $p<0.001$; $F(1,368)=36.17$, $p<0.001$; $F(1,368)=6.48$, $p<0.05$, respectively. The significant interaction was found between age and height, age and footing board width, $F(1,368)=20.71$, $p<0.001$; $F(1,368)=13.43$, $p<0.001$, respectively. 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 the elderly workers walked slower than young workers, and in addition, they walked much slower in comparison to young workers if the footing board width was narrower at the elevated place. However, slow speed by carrying the footing board had nothing to do with age.

Answer rate for secondary task

The rate that the subjects did not answer the number they were supposed to answer (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 (false alarm rate) was 0.64 percent and 0.2 percent respectively. In other words, the subjects answered the secondary task almost correctly, and there was not difference between age groups. Table 1 shows 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 condition in the most dangerous working environment where the footing board width is 240 mm at level 6.

Reaction time

Table 2 shows the mean reaction times of the secondary task. Four-way ANOVA (age × height × footing board width × with or without load) showed significant main effect for both age and height, $F(1,3690)=273.22$, $p<0.001$; $F(1,3690)=4.14$, $p<0.05$, respectively. A main effect of footing board width was not significant. In addition, the interaction was not significant among 4 factors such as age, height, footing board width, and with or without load respectively. However, three way interaction between age, height and footing board width was almost significant, $F(1,3690)=2.88$, $p<0.10$. These results showed that the elderly workers responded to the secondary task slower in comparison to young workers. A number of researchers have confirmed that there has been an effect of aging in the reaction time in various tasks (for example, Welford, 1980), and it turned out that the effect was supported in the task of this research as well. This experiment revealed significant main effect for height, but it was different from the result conducted by Usui and Egawa (2002) where an experiment was conducted on the same temporary scaffold with scaffolding men. It is explained that the reason is that the secondary task by Usui and Egawa was simply to detect in which solely a woman's voice stimulated was announced, and from which a specific number was detected, while an element where a male and female voice were distinguished was added to the secondary task this time, causing the problem to be more difficult. It was also proved that, although the spare capacity at the height decreased a certain degree, it had nothing to do with age since the interaction between age and height was not significant.

Table 1. Mean rates of miss and false alarm in each age group.

		Level 6		Ground	
		240mm	500mm	240mm	500mm
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

Usui and Egawa (2002) revealed that subject who has no experience of working at the elevated place performed the secondary task performance poorer, in other words, their spare capacity decreased when the footing board width was 240 mm at level 6. On the other hand, this experiment showed the main effect of the footing board width for the elderly workers was not significant in spite of the fact that the secondary task became more difficult. Furthermore, it turned out that there was basically no effect of age in the viewpoint of the spare capacity of subject 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. Figure 2 shows the result of the reaction time by the footing board width on the ground and level 6. These results suggest that there was a dangerous working environment for elderly workers such as the elevated place and the footing board width was narrower where the spare capacity was decreased.

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

	Level 6				Ground				
	240mm		500mm		240mm		500mm		
	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

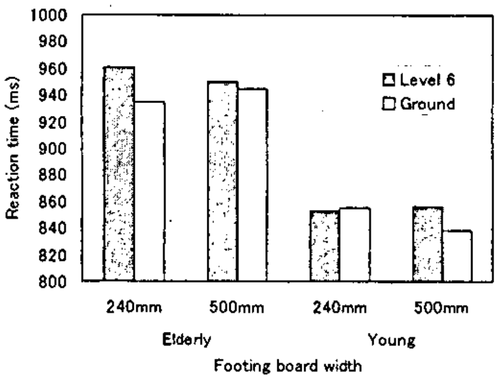

Figure 2. Mean reaction times for the secondary task.

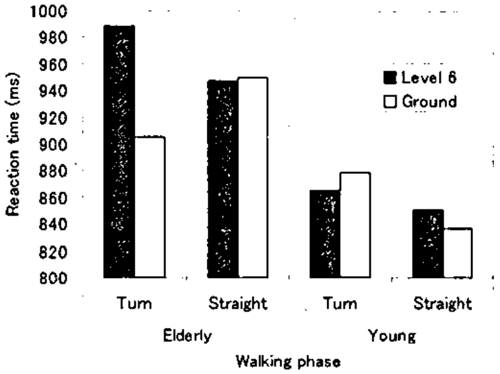

Figure 3. Mean reaction times for the secondary for according to the phases of walking.

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

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

Similar to Usui and 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 that the task demands in the walking. Table 3 shows the mean reaction times for the secondary task according to the phases of walking. Four-way ANOVA (age × height × footing board width × walking phase) showed that the main effect of walking phase was almost significant, $F(1,3690)=3.38$, $p<0.10$, and three-way interaction between age, height and walking phase was significant, $F(1,3690)=16.13$, $p<0.001$. Figure 3 shows the result of the reaction time by walking phase on the ground and level 6. These results suggest that there was a dangerous working environment for elderly workers such as elevated place and task demand was increased, in other words, the task became complicated where the spare capacity was decreased.

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	36.3	34.3
Mean	50.9	44.5

NASA-TLX

Table 4 shows a mean assessment score for each index in NASA-TLX. There was a significant difference in index of "effort" (question: to what degree a subject has to work hard mentally and physically to achieve and maintain the level of work achievement) between elderly and young group, but there was no difference between age groups in other index. That is to say, there was almost no difference between age groups in the subjective assessment of the mental workload including mental and physical hardship. However, elderly workers feel more severely than young workers according to make effort mentally and physically they manage to achieve and maintain the work performance. These results suggest the spare capacity was decreased for elderly workers as they concentrated on the work in the working environment where the task demand was increased including the case that the footing board width became narrower at the elevated place.

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