CHAPTER IV

RESULTS AND DISCUSSION

Analysis of Work Situation

1. General Description of Work

In this study, the two selected forms of work were pipe cutting and pipe machining work. The work was performed from 8.00 a.m. to 5.00 p.m. for the day shift and from 6.00 p.m. to 3.00 a.m. for the night shift. The workers worked 6 days per week on alternate shifts. During the working period they put on a uniform: consisting of a shirt, trousers, leather shoes and gloves (some with hat and glasses). Their job was to cut and to machine a pipe using a different machine lathe. They worked in a standing position. Sound level intensity, illumination, WBGT index, humidity and air temperature were measured as shown in Table 4.1.

Table 4.1 Environmental conditions

Environmental conditions	Work	
	Pipe cutting	Pipe machining
Sound level (dB)	85.9-93.2	84.1-91.5
Light intensity (Lux)	61.0-319.7	85.9-383.4
WBGT index (^{o}C)	27.2-31.5	27.6-31.8
Humidity (%)	69.7-85.5	68.1-83.9
Wet bulb temperature (^{o}C)	24.3-28.0	24.4-27.6
Dry bulb temperature (^{o}C)	28.8-33.5	28.2-32.1

2. Task Description

The nature of each task was different. Task I and task II were cutting a pipe using a cutting tool. Task III and Task IV were machining a pipe using a machine lathe. The characteristics of workpieces are shown in Table 4.2. Additionally, the heights of the working area were 85 centimeters for pipe cutting work and 91 centimeters for pipe machining work.

Table 4.2 Workpiece characteristics

Type of task	Diameter in (inch)	Length (cm)	Thickness (cm)	Weight (kg)
Task I	0.5	600.00	0.65	11.00
Task II	2.0	85.00	1.00	3.00
Task III	2.0	6.00	1.00	0.35
Task IV	6.0	9.75	1.00	4.00

Before work, the workers had about thirty minutes to set up their machine and prepare the toolholder. The sequence of activities of all tasks are listed below:

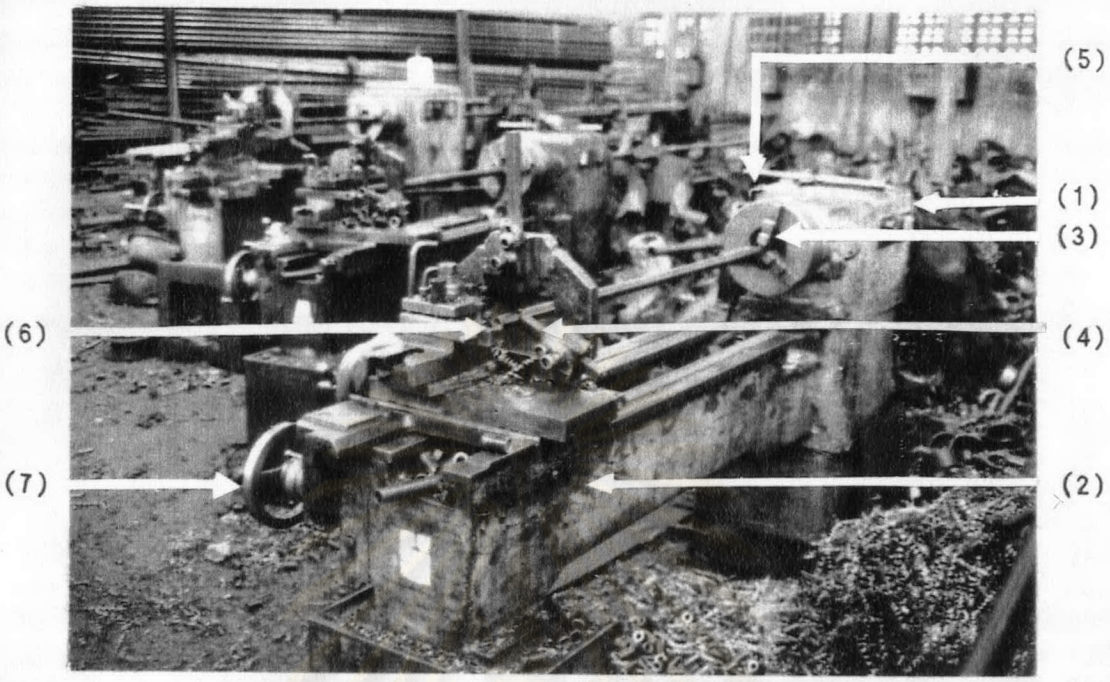

Figure 4.1 Cutting lathe used in the experiment

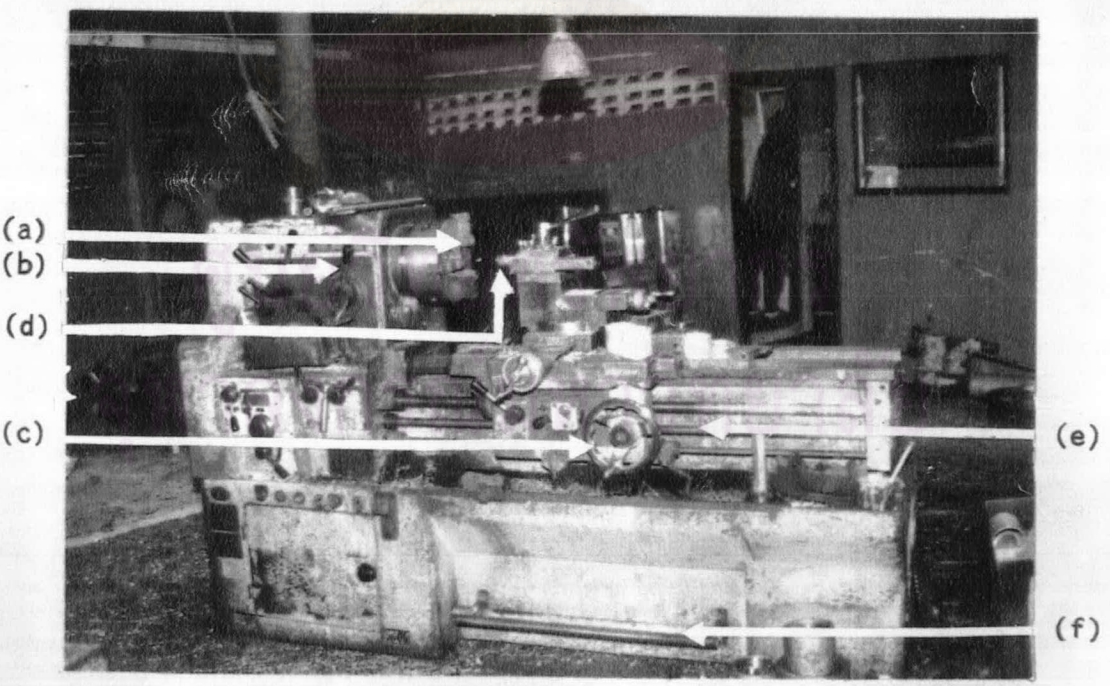

Figure 4.2 Machining lathe used in the experiment

Step	Details for task I
1	Get a long pipe from storage, and carry it for a distance of 5 meters.
2	Put pipe into back hole (1), then pull it forwards.
3	Attach pipe on bed way (2) with chuck (3) and tailstock (4).
4	Press button switch (5) on.
5	Paint cutting oil on rotated pipe.
6	Cut pipe using a cutting tool (6) when turning handwheel (7) counter-clockwise.
7	After terminating the part of pipe, press button switch (5) off.
8	Turn and pull handwheel (7) forward in the starting position.
9	Release pipe from chuck (3), then pull the rest of the pipe forward.
10	Repeat 3-9 until there is no pipe left.

Step	Details for task II
1	Get a short pipe with 3-wheel wagon from sawmill, and carry it for a distance of 15 meters.
2	Lift the pipe into bed (2).
3	Attach both ends of the pipe with chuck (3) and tailstock (4).
4	Press button switch (5) on.
5	Paint cutting oil on rotated pipe.
6	Cut pipe using a cutting tool (6) when turning handwheel (7) counter-clockwise.
7	Turn handwheel (7) clockwise with 2-3 rounds.
8	Throw a piece of cut pipe on floor.
9	Repeat 6-8 until there is no pipe left.
10	Press the button switch (5) off.
11	Turn and pull handwheel (7) forward in the starting position.
12	Release pipe from chuck (3) and throw away the rest of the pipe.

Step	Details for task III
1	Get a small cylindrical pipe with 3-wheel wagon from storage, and carry it for a distance of 12 meters.
2	Fit the pipe with chuck (a).
3	Press horizontal lever (b) for its rotation.
4	Turn handwheel (c) counter-clockwise, then adjust depth of machine tool (d).
5	Machine inside pipe for smooth surface.
6	Adjust machine tool (d) far from pipe, then turn handwheel (c) clockwise with 2-3 rounds.
7	Move the other side of machine tool (d).
8	Press screw lever (e).
9	Repeat 4, for maching pipe.
10	Put foot on the brake pedal (f) to stop the machine.
11	Repeat 6 and 7.
12	Release pipe from chuck (a) and obtain finished product.

Step	Details for task IV
1	Get a large cylindrical pipe with 3-wheel wagon from storage, and carry it for a distance of 12 meters.
2	Fit the pipe with chuck (a).
3	Press horizontal lever (b) for its rotation.
4	Turn handwheel (c) counterclockwise, then adjust depth of machine tool (d).
5	Machine inside pipe for smooth surface twice.
6	Adjust machine toolholder (d) away from pipe, then pull horizontal lever (b) to stop rotation.
7	Turn handwheel (c) clockwise with 4-5 rounds.
8	Change the other side of machine toolholder (d) and those of pipe.
9	Repeat 3 and 4.
10	Press screw lever (e) and machine inside pipe for screwing.
11	Put foot on the brake pedal (f) to stop the machine.
12	Repeat 6 and 7.
13	Release pipe from chuck (a) and obtain finished product.

3. Pattern and Variation of Work

The quantity of product output was expressed by the number of items processed. Table 4.3 indicates that the output produced in the morning and in the afternoon is different. This pattern (see Figure 4.3) was varied because there were many other factors such as production targets, social factors and attitudes to work. Moreover, a defective cutting tool was considered as an influence on work. The less experienced a worker was, the more time he spent. Additionally, the findings indicated that defective machines and accidents rarely occured in this study so they were not factors affecting variation of work.

Table 4.3 Quantity of product output

Type of task	Times	Product output
Task I	Morning	10.875
	Afternoon	11.000
Task II	Morning	47.000
	Afternoon	40.875
Task III	Morning	340.875
	Afternoon	319.875
Task IV	Morning	96.000
	Afternoon	110.000

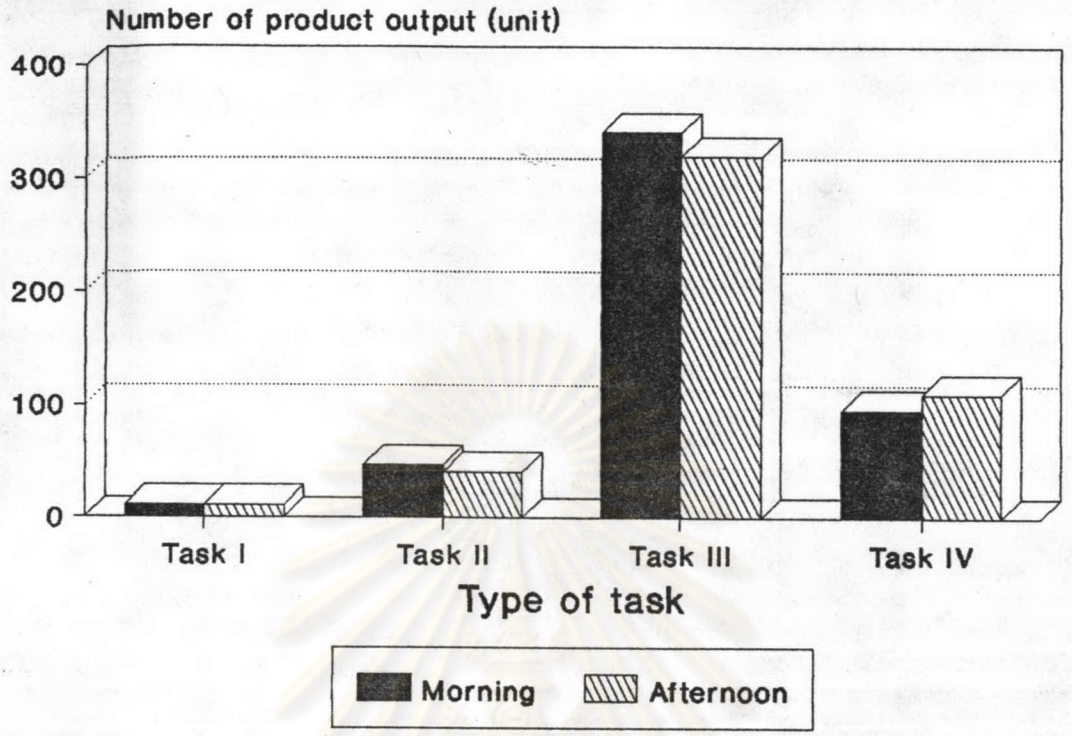

Figure 4.3 Product output in the day shift

Effects of Training

1. Effect of Training on Critical Flicker Fusion Frequency

Table 4.4 shows the means and standard deviations of flicker values for all subjects as a result of training. This table indicates the critical intervals of flicker values. They lay at 31-38 Hz while the flickering light appeared to fuse into a constantly shining light (up-measurement) and 29-38 Hz while a constantly shining light became flickering (down-measurement). In order to find the possibility of the values being the thresholds, the critical intervals were tested in the experiment by applying the fuzzy sets theory.

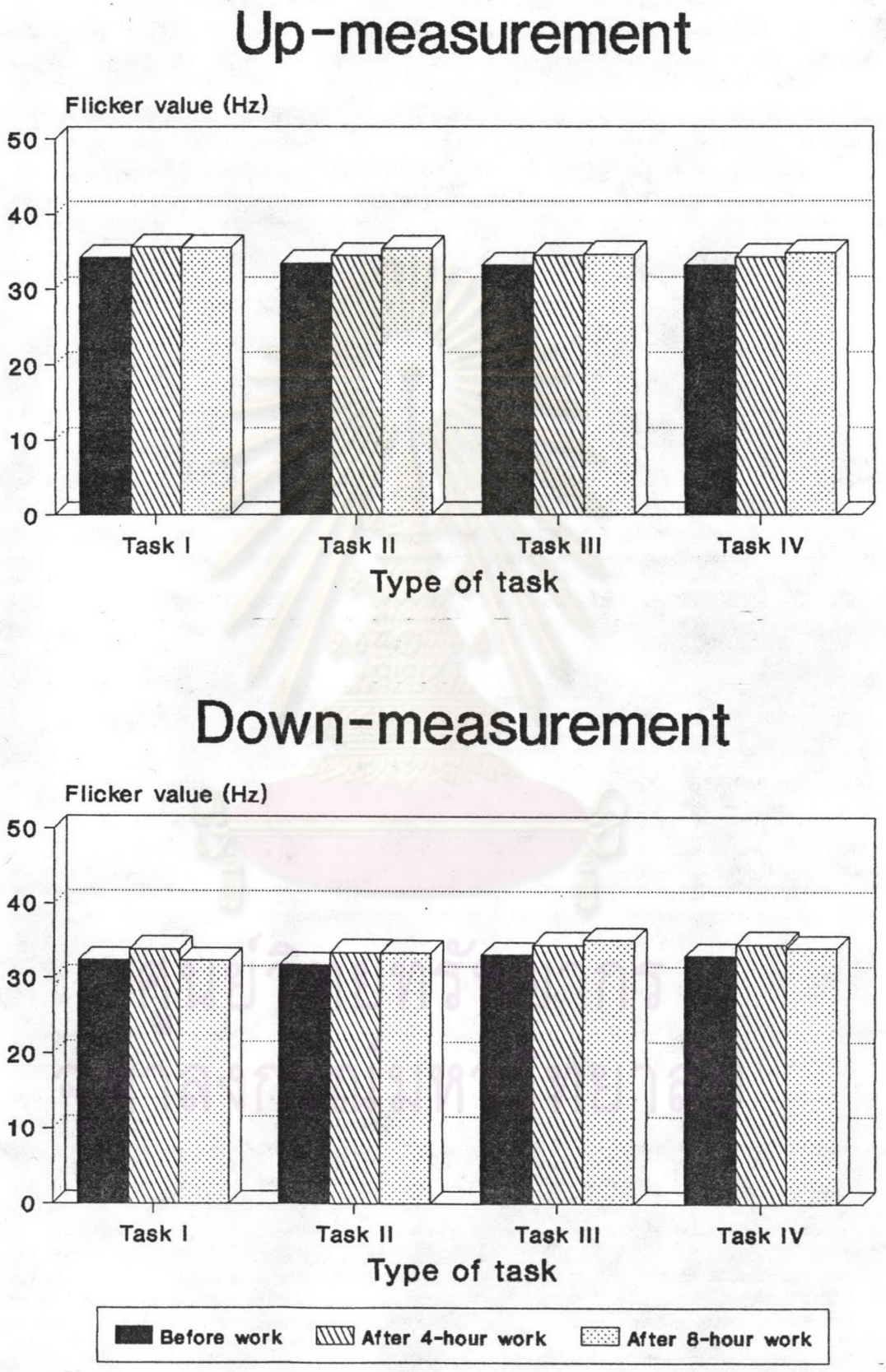

Figure 4.4 Means of flicker values during training

Table 4.4 Means and standard deviations of flicker values during training

Type of task	Flicker value (Hz)					
	Up-measurement			Down-measurement		
	Period			Period		
	I	II	III	I	II	III
Task I	34.250 ±2.223	35.675 ±1.405	35.575 ±1.320	32.425 ±2.130	33.875 ±2.078	32.400 ±2.374
Task II	33.525 ±1.803	34.475 ±2.380	35.450 ±1.914	31.775 ±2.733	33.500 ±2.714	33.450 ±2.339
Task III	33.250 ±1.085	34.475 ±0.665	34.675 ±0.793	33.200 ±1.158	34.575 ±0.947	35.225 ±1.913
Task IV	33.175 ±1.436	34.325 ±0.922	34.900 ±0.294	33.075 ±1.103	34.675 ±1.091	34.175 ±0.885

2. Effect of Training on Reaction Time

Training for reaction time resulted in response time of the subjects. A decrease in both reaction times, visual and auditory reaction times, occurred after training time. The percentage decrease for all subjects is given in Table 4.5 and Figure 4.5.

The mean values of percentage decrease for visual and auditory reaction time were 2.321 % and 12.521 % for task I, 12.564 % and 12.700 % for task II, 10.351 % and 10.625 % for task III, 6.078 %

and 13.301 % for task IV.

Therefore, in order to reduce the effect of learning on data collection, the subjects were trained for four days prior to the experiment.

Table 4.5 Effect of training on reaction time

Type of task	Period	Visual reaction time (1/100 second)			Auditory reaction time (1/100 second)		
		Means		Percentage decrease	Means		Percentage decrease
		The 1 st training	The 2 nd training		The 1 st training	The 2 nd training	
Task I	I	21.200	20.500	3.302 %	20.425	17.350	15.055 %
	II	21.200	20.450	3.538 %	19.500	16.575	15.000 %
	III	20.225	20.200	0.124 %	18.650	17.250	7.507 %
Task II	I	23.975	20.900	12.826 %	21.275	18.475	13.161 %
	II	22.775	19.200	15.697 %	20.000	17.325	13.375 %
	III	22.900	20.800	9.170 %	19.675	17.400	11.563 %
Task III	I	24.000	21.000	12.500 %	20.275	19.275	4.932 %
	II	25.550	21.875	14.384 %	20.475	16.975	17.094 %
	III	22.279	21.350	4.170 %	21.325	19.225	9.848 %
Task IV	I	22.875	21.875	4.372 %	20.950	17.300	17.422 %
	II	23.175	20.550	11.327 %	19.875	17.150	13.711 %
	III	21.925	21.150	2.535 %	19.100	17.425	8.770 %

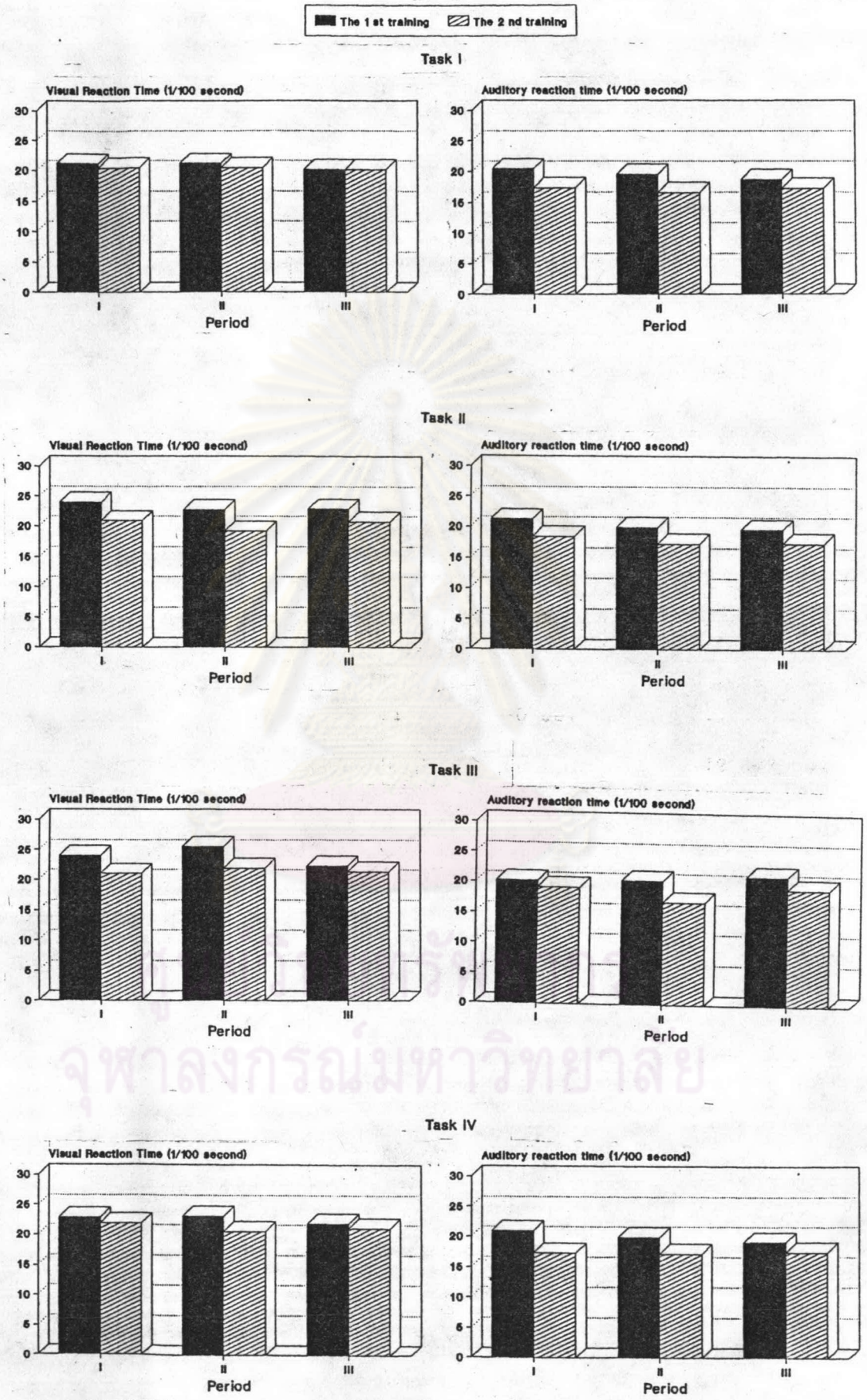

Figure 4.5 Effect of training on reaction time

Results of Experiment

1. Critical Flicker Fusion Frequency Based on Fuzzy Sets

The results as shown in Table 4.6 indicate that the flicker values are possibly accepted as the threshold values. In fuzzy set theory, the possibility of being a threshold for particular flicker values (u) is very important.

Table 4.6 Flicker values and their ratios for one subject

Flicker value u (Hz)	Number of responses where u is flicker light n_f	Number of responses where u is constant light n_c	Ratio p
34	10	0	0.000
35	7	3	0.429
36	4	6	0.667
37	2	8	0.250
38	0	10	0.000

The distribution of p is viewed as the possibility function and the ratio p is the possibility value in the interval [0,1] defined by

$$p(u) = \frac{n_f(u)}{n_c(u)} \quad \text{if } n_f(u) < n_c(u)$$

$$= \frac{n_c(u)}{n_f(u)} \quad \text{if } n_c(u) < n_f(u)$$

where: u = flicker value

$n_f(u)$ = number of responses where u is flicker light

$n_c(u)$ = number of responses where u is constant light

If the ratio p increases to one then the possibility of the flicker value being the threshold increases. Thus, u = 36 Hz (p = 0.667) has a greater possibility of being the threshold value than u = 35 Hz (p = 0.429).

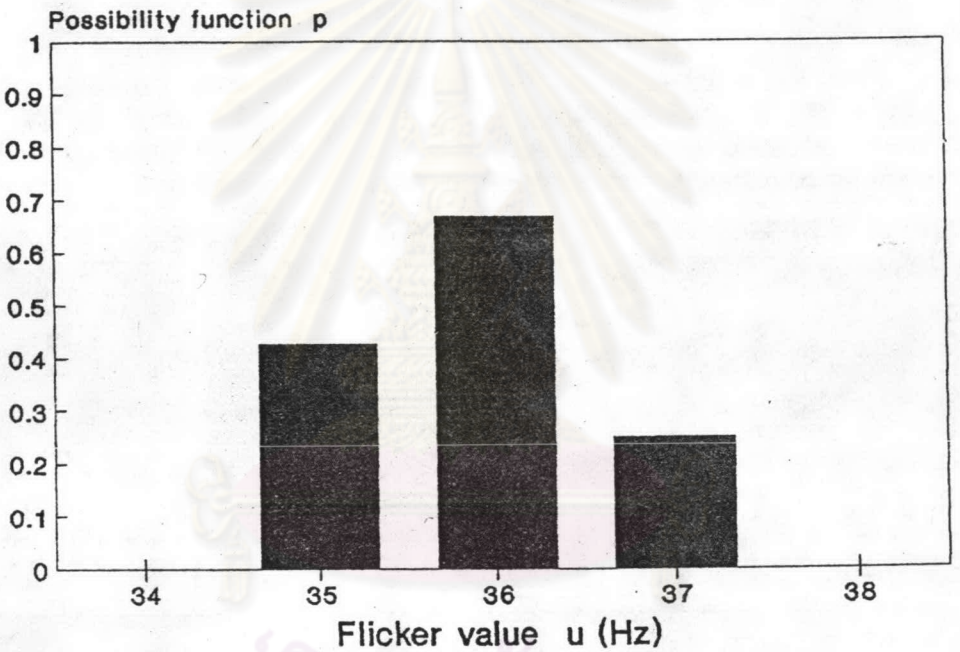

Figure 4.6 Show values of p from Table 4.6

In the actual experiment, all subjects were examined for three periods during the day shift. It can be seen that threshold values (p = 1) decrease in successive investigative periods: I, II, and III. According to these findings, the mean of threshold values for all subjects was 35.664 Hz for period I, 35.508 Hz for period II, 35.238 Hz for period III. Table 4.7 presents the p-values related to the critical interval of flicker values for four subjects in all tasks.

Table 4.7 The p-values related to the critical interval of flicker values for four subjects.

Type of task	Flicker value (Hz)	Means of p-values in three periods		
		I	II	III
Task I	33	0.000	0.000	0.000
	34	0.125	0.214	0.125
	35	0.458	0.181	0.458
	36	0.459	0.389	0.333
	37	0.125	0.056	0.000
	38	0.000	0.000	0.000
Task II	33	0.000	0.000	0.000
	34	0.056	0.111	0.000
	35	0.270	0.270	0.556
	36	0.500	0.429	0.125
	37	0.000	0.000	0.000
Task III	32	0.000	0.000	0.000
	33	0.000	0.000	0.125
	34	0.270	0.181	0.270
	35	0.339	0.429	0.833
	36	0.500	0.389	0.270
	37	0.214	0.125	0.111
	38	0.000	0.000	0.000
Task IV	34	0.000	0.000	0.000
	35	0.339	0.833	0.548
	36	0.250	0.111	0.111
	37	0.000	0.000	0.000

note 1. On the basis of the data obtained, the threshold value which was flicker value with possibility value p = 1 ranged between 35 and 36 Hz.

2. The missing flicker values from critical interval had no possibility (p = 0)

Previous research showed that the possibility value for flicker points had near a normal distribution. Therefore, formula (1) can be used to get estimates of possibility value in this study.

$$f(u) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}(u-\mu)^2/\sigma^2} \quad \ldots\ (1)$$

where: μ = mean

σ = standard deviation

$f(u)$ = possibility function

Table 4.8 contains means and standard deviations of flicker values for possibility function on the four subjects. It shows a decrease in flicker value with the work period.

Table 4.8 The means and standard deviations of flicker values for possibility function

Type of task	Flicker values (Hz) in each work period		
	I	II	III
Task I	35.500	35.467	35.343
	±0.399	±0.384	±0.384
Task II	35.569	35.472	35.275
	±0.398	±0.394	±0.394
Task III	35.529	35.445	34.918
	±0.397	±0.397	±0.385
Task IV	35.452	35.138	35.270
	±0.399	±0.399	±0.393

Table 4.9 The f-values related to the critical interval of flicker values for the four subjects.

Type of task	Flicker value (Hz)	Means of p-values in three periods		
		I	II	III
Task I	33	0.000	0.000	0.000
	34	0.001	0.001	0.002
	35	0.456	0.496	0.698
	36	0.456	0.396	0.240
	37	0.001	0.000	0.000
	38	0.000	0.000	0.000
Task II	33	0.000	0.000	0.000
	34	0.000	0.001	0.005
	35	0.362	0.494	0.794
	36	0.557	0.412	0.182
	37	0.002	0.001	0.000
Task III	32	0.000	0.000	0.000
	33	0.000	0.000	0.000
	34	0.001	0.001	0.060
	35	0.414	0.538	1.014
	36	0.496	0.376	0.020
	37	0.001	0.005	0.000
	38	0.000	0.000	0.000
Task IV	34	0.001	0.017	0.005
	35	0.526	0.943	0.801
	36	0.389	0.097	0.181
	37	0.001	0.000	0.000

Table 4.9 shows f-values calculated by using equation (1). Comparing the values from Table 4.7 and 4.9 it can be seen that the possibility p-values lie close to f-values. This means that f-values describe precisely the p-values for each flicker value in the interval. Therefore, instead of p-values the term f-values (see Figure 4.7-4.10).

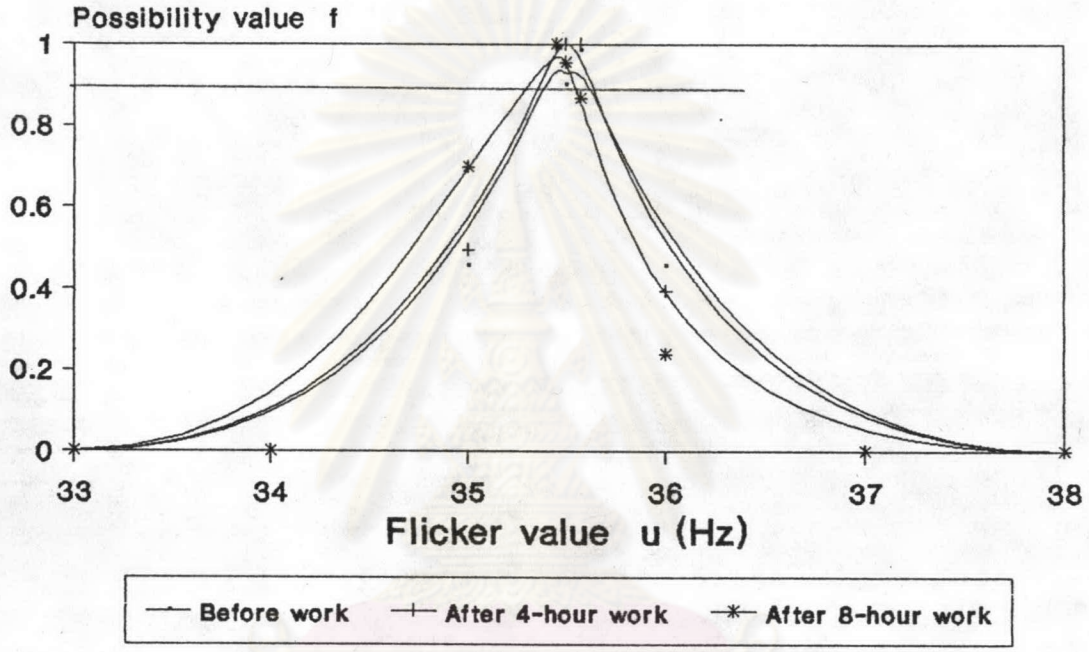

Figure 4.7 Graphs of three possiblity curves for one subject on task I

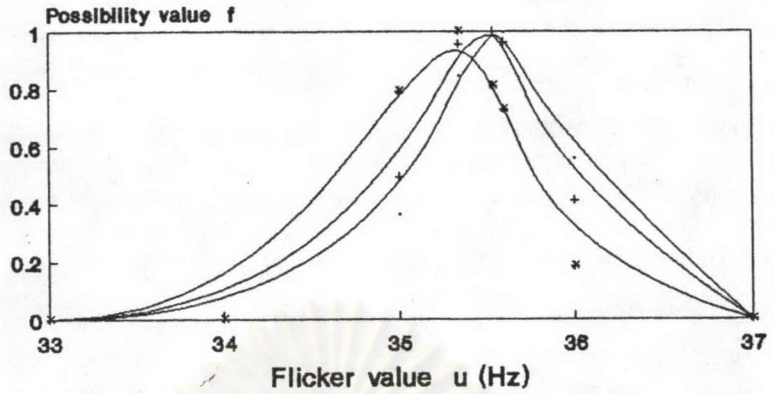

Figure 4.8 Graphs of three possiblity curves for one subject on task II

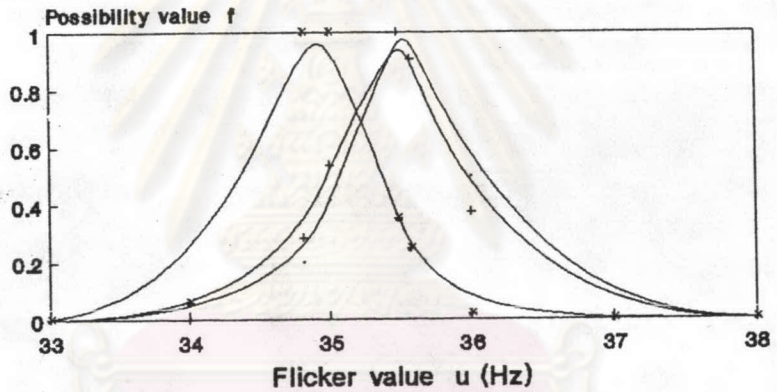

Figure 4.9 Graphs of three possiblity curves for one subject on task III

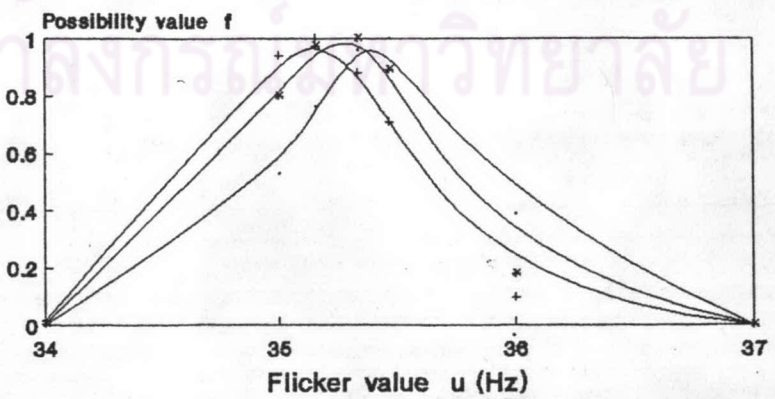

Figure 4.10 Graphs of three possiblity curves for one subject on task IV

In the Figure 4.7 there are different lengths of threshold interval for each curve, in each period: I, II, and III. Some values are mentioned below:

$|F_I| = 0.366 \quad L_I = 35.317 \quad R_I = 35.683$

$|F_{II}| = 0.411 \quad L_{II} = 35.262 \quad R_{II} = 35.673$

$|F_{III}| = 0.411 \quad L_{III} = 35.137 \quad R_{III} = 35.548$

where: $|F|$ = lengths of threshold interval for f(u) = 0.9

L = left end-point of a given threshold interval

R = right end-point of a given threshold interval

Table 4.10 Means and standard deviations of lengths of threshold interval (for f(u) = 0.9)

Type of task	Lengths of interval			
	I	II	III	III - I
Task I	0.382 ±0.019	0.436 ±0.024	0.446 ±0.057	0.064
Task II	0.381 ±0.012	0.390 ±0.005	0.419 ±0.051	0.038
Task III	0.375 ±0.022	0.438 ±0.057	0.455 ±0.042	0.08
Task IV	0.373 ±0.005	0.444 ±0.076	0.440 ±0.071	0.067

These lengths were used as an indicator of mental fatigue. Figure 4.7 indicates that an increase in mental fatigue occurred after mental stress. The more the difference of lengths between period III and period I increased, the higher the degree of mental fatigue appeared. However, these lengths in each task did not differ significantly. Therefore, the trend of degree of mental fatigue for task III was higher than those for task IV, task I, and task II. Table 4.10 contains means and standard deviations of tne lengths for all subjects.

2. Reaction Time

Hypothetically, reaction times will increase if mental stress is prolonged. Table 4.11 and Figure 4.11 show the reaction times for all subjects in three successive investigation periods: I, II, and III.

It can be easily seen that only the visual and auditory reaction times for task I and auditory reaction time for task III were consistent with the proposed hypothesis. This might be because the subjects were disturbed by factors such as noise and co-workers walking by during testing period.

Thus, the results of reaction times in this experiment were not used to assess mental fatigue.

Table 4.11 Reaction time resulted in three periods

Type of task	Period	Reaction time (1/100 second)	
		Visual	Auditory
Task I	I	19.423	16.478
	II	19.888	16.863
	III	20.081	17.406
Task II	I	20.135	17.481
	II	19.688	16.794
	III	20.123	17.631
Task III	I	20.825	16.425
	II	20.719	16.538
	III	20.481	17.025
Task IV	I	19.954	16.075
	II	19.663	15.938
	III	19.994	15.838

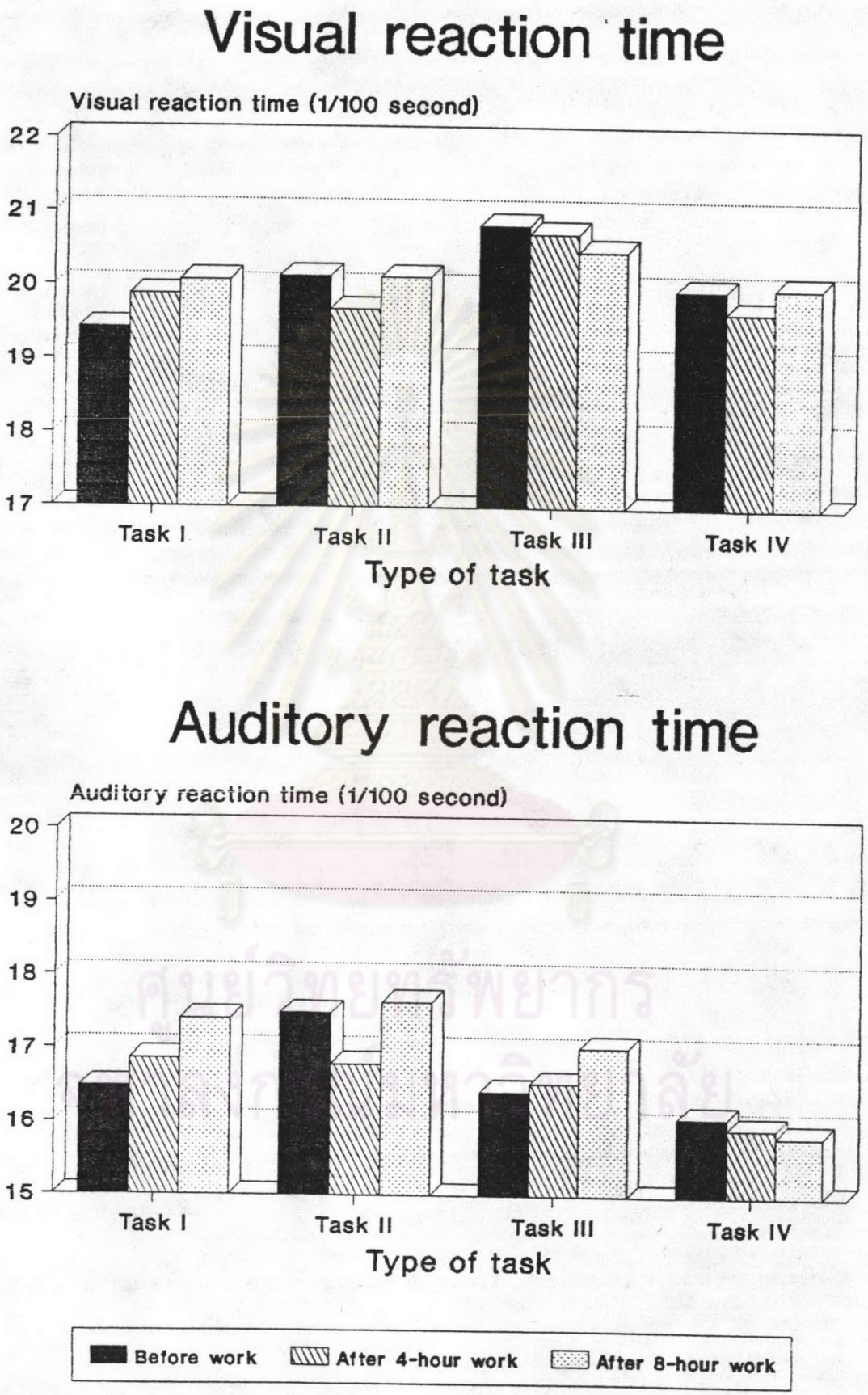

Figure 4.11 Reaction time in three periods

3. Hand Grip Strength

All subjects showed that an increase in hand grip strength took place after activity. These results are given Table 4.12.

Table 4.12 Hand grip strength in three periods for all subjects

Type of task	Period	Means of grip strength on right hand (Kg)
Task I	I	49.161
	II	51.716
	III	51.775
Task II	I	49.803
	II	52.783
	III	53.739
Task III	I	51.360
	II	51.896
	III	52.313
Task IV	I	49.161
	II	51.716
	III	51.775

The hand grip strengths in this study were not compatible with the expected hypothesis. The results of the experiment seem to indicate that there might be a positive correlation between strength and working period. However, no explanation will be given because little is known about this relationship in the present findings.

4. Self-scaling Questionnaire

Table 4.13 contains the data obtained using the self-scaling questionnaire. It is seen that after work the quantitative values of some opposite designations, refresh-tired, strong-weak and vigorous-exhausted, became distinctly lower as signs of a fall in mental fatigue. In other words, before work, all subjects felt refreshed and strong compared to those tested after work. Between vigorous and exhausted feelings, there was more feeling of exhaustion after work.

Table 4.13 Mean values of self-scaling of fatigue for all subjects

Opposite designation self-scaling of fatigue	Period	Means of self-scaling for all tasks			
		Task I	Task II	Task III	Task IV
interested-bored	I	1.875	2.625	2.875	3.625
	II	2.000	2.000	3.000	3.875
	III	1.125	-0.250	3.625	3.625
enjoying-disliking work	I	2.375	2.625	2.625	3.500
	II	3.250	3.000	2.875	2.875
	III	1.625	1.750	3.500	3.625
refreshed-tired	I	2.625	3.375	3.625	3.875
	II	1.25	1.375	3.000	2.750
	III	0.375	0.750	2.875	2.750
strong-weak	I	2.125	3.250	3.375	3.500
	II	0.875	1.000	0.875	0.375
	III	0.375	0.875	-1.125	-2.250
vigorous-exhausted	I	1.625	3.250	3.250	2.750
	II	-1.125	0.375	0.125	-0.500
	III	-1.625	-1.250	-1.500	-2.250
awake - sleepy	I	3.125	2.750	3.000	1.875
	II	3.000	2.625	1.875	1.750
	III	3.625	3.875	1.250	2.875
relaxed - tense	I	3.375	3.625	3.875	3.625
	II	2.000	2.000	2.875	3.625
	III	3.125	0.875	3.500	3.875

5. Relationship between Fuzzy Critical Flicker Fusion Frequency and Self-scaling Questionnaire Results.

Table 4.14 The correlation cofficients between the length of threshold interval and the self-scaling of fatigue for all subjects.

Opposite designation self-scaling of fatigue	Means of self-scaling for all tasks			
	Task I	Task II	Task III	Task IV
interesting-bored	0.507	1.000	0.772	0.540
enjoying-disliking work	0.096	0.862	0.845	0.402
refreshed-tired	0.968	0.818	0.999	0.999
strong-weak	0.990	0.722	0.967	0.868
vigorous-exhausted	1.000	0.902	0.990	0.922
awake - sleepy	0.457	0.947	0.988	0.367
relaxed - tense	0.526	0.924	0.645	0.453

Table 4.14 shows that the length of threshold interval (Table 4.10) is correlated highly with the self-scaling of fatigue (Table 4.13) only for refreshed-tired, strong-weak, and vigorous-exhausted (significant at 95 percent), since most of the subjects may believe that a negative attitude in remaining designations affects their work and well-being. These designations were: interested-bored, enjoying-disliking work, awake-sleepy, and relaxed-tense.

However, the length of threshold interval and some self-scaling of fatigue can show only the trend of mental fatigue after mental stress.