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Short Communication

Differences in Cardiovascular and Central Nervous System Responses to Periods of Mental Work with a Break

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Abstract: The purpose of the present study was to examine how an inserted break influences the cardiovascular and central nervous system responses during periods of mental work. Twelve males conducted two 20-min periods of mental work with a 3-min break between them. Cardiovascular and central nervous system responses were measured continuously. In comparison to the baseline, cardiovascular responses increased continuously even after the inserted break, while, on the contrary, central nervous system activity did not significantly increase during the work periods but relaxed during the break. The work performance increased during the second work period. These results suggest that the inserted break proposed by VDT guidelines in Japan was effective in relaxing the central nervous system but was insufficient to prevent the increase in cardiovascular load. The results also imply that taking rests frequently is important not only to maintaining performance but also to preventing cumulative physiological workloads.

Key words: Blood pressure, Cardiac output, Total peripheral resistance, Electroencephalogram, Work-rest schedule

Investigations of the health conditions of workers, performed every 5 yr by the Ministry of Health, Labour and Welfare in Japan, reported that the ratio of workers answering that they had “strong anxiety, worry, and stress” associated with their job was approximately 60%[1)]. Among these workers, 35% felt stress about the quality of their work, and 31% felt stress about the quantity of their work. Long-term exposure to work-related stress causes mental fatigue, increases the risks of hypertension and coronary heart disease, and even increases cardiovascular mortality[2–6)]. A prospective cohort study conducted from 1973 to 2001 in Finland reported that employees with high work stress had a 2.2- to 2.4-fold cardiovascular mortality risk, compared with their colleagues with low work stress, and suggested that attention should be given to reducing the harmful influences of work stress on general health[6)].

Nowadays, compared with physical work, mental work has remarkably increased in the workplace as a result of technological and scientific developments. Previous studies have reported that white-collar workers who have been exposed to cumulative mental work stress had a significant increase in systolic blood pressure (SBP)[7, 8)]. The increased SBP is considered a long-term predictor of incident hypertension[5)]. In addition, accumulated mental fatigue will reduce work performance and increase the possibility of human error[9–12)]. The electroencephalogram (EEG) power spectrum was reported to reflect the change of central nervous system activity and was important

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to maintaining work performance[9–11]. In particular, the increase in relative power density of the α-wave (8–13 Hz) reflects a diminished level of mental alertness and the relaxation of the central nervous system[12]. How to prevent the excessive increases in cardiovascular and central nervous system loads has become an important issue for white-collar workers' health and safety maintenance.

In Japan, according to the guideline regarding working with a visual display terminal (VDT), one or two breaks are proposed for a 1 h VDT work period[13]. However, this guideline mainly considers musculoskeletal and visual fatigue and does not consider the cardiovascular and central nervous system load. Some studies have examined the recovery from cardiovascular responses after mental work, but few have examined the effect of inserted breaks during work periods[14, 15]. Our previous study reported that BP shows a cumulative increase during a continuous 20-min mental arithmetic task, but the cumulative increase was not observed when a 20-min mental arithmetic task was divided into four 5-min periods interspersed with three 3-min breaks[16, 17]. The different response tendencies suggested that short breaks may be effective to prevent sustained increases in BP during mental works. The cardiovascular responses include not only the magnitude of blood pressure response but also the underlying hemodynamic aspect. According to the hemodynamic theory, mean arterial pressure (MAP) was elevated by increases of cardiac output (CO) and/or total peripheral resistance (TPR), and the relationship among the three indices can be described as MAP = CO × TPR. Increases in heart rate (HR) and/or stroke volume (SV) elevated CO. The underlying hemodynamic in increasing blood pressure was also considered a risk factor, and the exaggerated responses in TPR were associated with a high risk of hypertension[18, 19]. However, it is unclear how the underlying hemodynamic activity and central nervous systems were influenced by a break during mental work.

In the present study, subjects were asked to perform a 40-min laboratory mental task divided into two 20-min work periods by a 3-min break to examine how the inserted break influences the cardiovascular and central nervous system responses.

This experiment was approved by the Research Ethics Committee of the National Institute of Occupational Safety and Health of Japan. Twelve healthy males participated in this study. The ages, weights, heights, and BMIs of the subjects were 27.1 ± 4.4 yr, 69.5 ± 11.3 kg, 175.2 ± 5.6 cm, and 22.6 ± 2.4, respectively. Subjects were requested to refrain from exercise and alcohol intake on the night prior to the experiment and were prohibited from drinking caffeinated beverages or smoking during the 2-h period immediately preceding the experiment. After the details of the study were explained, the subjects were asked to sign written consent forms to allow for their participation in the study.

The subjects conducted a PC-based Stroop color-word (CW) task as their mental work. This task involved the successive presentation of a target word, the name of a color (e.g., green), which was printed in a different color (e.g., yellow). Around the target word (green), six buttons with printed names of colors were presented (green, yellow, black, red, blue, and purple). The subjects were to press the button that corresponded to the name of the color in which the target word was printed (in the case of the example, the correct reaction would be to press the button marked "yellow"). If the subjects pressed a wrong button or took over 3 s to press any button, a new trial would be automatically started after an alarm sounded and the error was recorded.

The subjects were asked to rest quietly for at least 30 min after entering the laboratory and before the recording sessions began. The experimental protocol consisted of a 5-min rest period as the baseline (Ba), a 20-min work period (CW1), a 3-min break (Br), another 20-min work period (CW2), and a 10-min rest at the end (Re).

Systolic and diastolic blood pressure (SBP and DBP), mean arterial pressure (MAP), cardiac output (CO), heart rate (HR), stroke volume (SV), and total peripheral resistance (TPR) were measured continuously as cardiovascular indices (Portapres Model-2, Finapres Medical Systems B.V.). Electroencephalogram (EEG) activity was measured continuously throughout the experimental periods at Fz, Cz, and Pz according to the international 10–20 system (EEG100C, BIOPAC Systems, Inc.). The α-wave (8–13 Hz) ratio was calculated from EEG as a central nervous system index. An electrooculogram (EOG) was also recorded to remove the eye movements from the EEG (EOG100C, BIOPAC Systems, Inc.).

EEG data were derived by fast Fourier transformation (FFT) for each 4096-point window without eye movements, and an α-wave ratio was defined at a relative density of 8–13 Hz/8–30 Hz.

The means of every measurement period for all cardiovascular indices and α-wave ratios at Fz, Cz, and Pz were calculated. A one-way repeated ANOVA test was conducted to compare the difference among measurement periods. Measures of effect size (partial η^2) and power were also reported. Multiple comparisons (Bonferroni) were conducted to further examine the significant results. Work performance was evaluated by the total number

Table 1. Values of each measurement period for cardiovascular and central nervous system indices and the results of one-way repeated ANOVA and multiple comparisons (n=12)

	Measurement Periods					ANOVA	
	Ba	CW1	Br	CW2	Re	F	p
Cardiovascular system							
SBP (mmHg)[a]	114.96	122.65	123.87	128.44	128.78	27.64	<0.01
SD	12.87	13.99	13.55	16.47	14.51		
DBP (mmHg)[a]	69.41	74.40	75.38	77.73	77.35	23.66	<0.01
SD	8.96	8.69	8.85	10.49	10.47		
MAP (mmHg)[a]	87.78	93.87	95.07	98.34	98.23	27.04	<0.01
SD	10.87	10.89	10.68	13.20	12.26		
HR (bpm)	68.71	71.06	69.34	71.43	68.65	2.82	ns
SD	11.10	10.00	11.52	10.07	10.94		
SV (ml)	89.92	89.49	89.71	90.16	91.69	0.57	ns
SD	10.89	8.51	9.50	8.59	9.99		
CO (l/min)	6.09	6.30	6.12	6.37	6.20	1.89	ns
SD	0.81	0.81	0.69	0.72	0.71		
TPR (MU)[b]	0.88	0.90	0.94	0.94	0.97	4.27	<0.05
SD	0.10	0.09	0.08	0.11	0.15		
Central nervous system (α-waves ratio)							
Fz[c]	0.57	0.51	0.61	0.52	0.56	5.04	<0.05
SD	0.11	0.08	0.11	0.08	0.12		
Cz[c]	0.58	0.53	0.64	0.54	0.58	7.38	<0.01
SD	0.14	0.07	0.11	0.07	0.13		
Pz[c]	0.59	0.52	0.67	0.54	0.61	11.09	<0.01
SD	0.15	0.08	0.13	0.07	0.14		

Values are presented as the mean and standard deviation (SD). Ba, the baseline; CW1, the first work period; Br, the break; CW2, the second work period; Re, the rest period at the end; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; HR, heart rate; CO, cardiac output; SV, stroke volume; TPR, total peripheral resistance; ns, not significant. *$p<0.05$. [a]The values of work periods were significantly higher than the baseline, and the second period was higher than the first work period (Ba < MA1 < MA2). The break and rest periods were significantly higher than the baseline (Ba < Br, Ba < Re). [b]The result of ANOVA were significant, but no significant difference was detected by multiple comparisons. [c]The break was significantly higher than the first and second work periods (CW1 < Br, CW2 < Br).

of trials and accuracy (the ratio of correct answers, by percent). Paired t-tests were conducted to compare the work performance between CW1 and CW2. The level of significance was set at $p<0.05$. Statistical analysis was carried out using IBM SPSS Statistics 19 (IBM Corp.).

The values of every measurement period for all cardiovascular indices and the results of one-way ANOVA and multiple comparisons are shown in Table 1. The difference among measurement periods were significant for SBP (F(4, 44)=27.64, $p<0.01$, partial $\eta^2=0.72$, power=0.99), DBP (F(4, 44)=23.66, $p<0.01$, partial $\eta^2=0.68$, power=0.99), MAP (F(4, 44)=27.04, $p<0.01$, partial $\eta^2=0.71$, power=0.99), and TPR (F(1.67, 18.34)=4.27, $p<0.05$, partial $\eta^2=0.28$, power=0.62).

The results of multiple comparisons showed that during work periods, SBP, DBP, and MAP were significantly higher than during the baseline, and they were significantly higher during the second work period than during the first work period (Ba < CW1 < CW2). On the other hand, during the break and during the rest period at the end, SBP, DBP, and MAP did not significantly change compared with the work periods but were significantly higher than the baseline (Ba < Br, Ba < Re).

Cardiac indices (HR, SV, and CO) were not significantly different among measurement periods. TPR increased during work periods compared with the baseline, although the multiple comparisons did not detect significant results (Table 1). The correlation analysis showed that MAP was significantly correlated with CO during the baseline, the first work period (CW1), and the break, but was signifi-

Table 2. The correlation coefficients between MAP and CO, and between MAP and TPR during each measurement period (n=12)

	MAP				
	Ba	CW1	Br	CW2	Re
CO	0.69*	0.67*	0.68*	0.46	0.20
TPR	0.23	0.26	0.32	0.63*	0.67*

Ba, the baseline; CW1, the first work period; Br, the break; CW2, the second work period; Re, the rest period at the end; MAP, mean arterial pressure; CO, cardiac output; TPR, total peripheral resistance. *$p<0.05$.

cantly correlated with TPR during the second work period (CW2) and the rest period at the end (Table 2).

The values of every measurement period for the α-wave ratio at Fz, Cz, and Pz, and the results of one-way ANOVA and multiple comparisons, are shown in Table 1. The difference among measurement periods were significant at Fz (F(1.69, 18.53)=5.04, $p<0.05$, partial $\eta^2=0.31$, power=0.70), Cz (F(2.45, 26.97)=7.38, $p<0.01$, partial $\eta^2=0.40$, power=0.95), and Pz (F(2.49, 27.34)=11.09, $p<0.01$, partial $\eta^2=0.50$, power=0.99). The results of multiple comparisons showed that the α-wave ratio at Fz, Cz, and Pz did not significantly change during work periods compared with the baseline but significantly increased during the break (CW1 < Br, CW2 < Br).

The total number of trials during the second work period (CW2: 892.2 ± 111.7) was significantly higher than that of the first work period (CW1: 828.0 ± 102.2) (CW1 < CW2, $t=-4.62$, $p<0.01$), and the accuracy during the second work period (CW2: 95.6% ± 4.0) was also significantly higher than that of the first work period (CW1: 94.1% ± 4.2) (CW1 < CW2, $t=-2.59$, $p<0.05$).

In the present study, we examined a schedule of two 20-min mental work periods with a 3-min break, and the results illustrated that the cardiovascular and central nervous systems showed different response patterns during work and break periods. Blood pressures increased continuously even after the break, suggesting that the cardiovascular load increased with the extension of the work period. On the other hand, the central nervous system did not significantly change during work periods but relaxed during the break. The work performance increased during the second work period. Previous studies have reported that during a total 120-min VDT work period, a schedule of 15-min work periods followed by micro-breaks (30 s) resulted in lower subjective discomfort and higher performance compared with schedules of 30-min work periods followed by 5-min rest periods, or 60-min work periods followed by 10-min rest periods[20]. Our previous study showed that when a 20-min mental work period was divided into four 5-min work periods by 3-min breaks, blood pressure did not increase continuously with the extension of work periods[17]. According to these results, we believe that the imposed break in the VDT guidelines is insufficient to moderate the cardiovascular work-related loads, although it was effective to relax the central nervous system. We suggest that taking rests frequently is important not only to maintaining performance but also to preventing cumulative physiological workloads, including cardiovascular loads.

For the underlying hemodynamic in increasing blood pressure, MAP was correlated with CO during the first work period (CW1) but with TPR during the second work period (CW2), which suggested that the underlying hemodynamic activity changed with the extension of work periods. Ring *et al.*[21] reported that in order to maintain the increased blood pressure, CO rose during the first half of a total 28-min mental arithmetic task but returned to baseline levels during the last quarter of the task, whereas TPR increased with the task extension. In the present study, we could not detect significant differences in TPR and CO during task periods, but the tendency of the change in underlying hemodynamic activity was in agreement with the findings of Ring et al. We believe that sustained increased blood pressure was mainly supported by TPR through the extension of work periods. How to prevent the increase of TPR may be important for reducing mental work-related cardiovascular load, and this hypothesis should be examined further by including a larger sample size.

Some limitations should be acknowledged in the present study. It is known that the mental work that occurs in workplaces is usually more complicated, and the work period is longer, than in an experimental setting. Thus, it is difficult to generalize the results of the present study directly to the real workplace, and the absence of a control condition (such as a continuous 40-min work period or other work and rest conditions) also limits the conclusions of the present study. However, the tendency of the change in central nervous system activities was in agreement with the general knowledge on the subject, and we believe that the protocol of the present study was suitable to examine physiological loads caused by mental work.

In conclusion, the results of the present study showed that the 3-min break was not sufficient to prevent cumulative cardiovascular loads, although it was efficient to relax the central nervous system when the work period was set at 20 min. We think it is important to take into consideration physiological responses, especially cardiovascular responses, when creating guidelines for mental work. In the future, other schedules that incorporate various periods of work and breaks should be examined further before imposing work schedules.

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