Effect of Working Hours on Cardiovascular-Autonomic Nervous Functions in Engineers in an Electronics Manufacturing Company

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Received September 29, 1998 and accepted November 17, 1998

Abstract: A field survey of 147 engineers (23–49 years) in an electronics manufacturing company was conducted to investigate the effect of working hours on cardiovascular-autonomic nervous functions (urinary catecholamines, heart rate variability and blood pressure). The subjects were divided into 3 groups by age: 23–29 (n=49), 30–39 (n=74) and 40–49 (n=24) year groups. Subjects in each age group were further divided into shorter (SWH) and longer (LWH) working hour subgroups according to the median of weekly working hours. In the 30–39 year group, urinary noradrenaline in the afternoon for LWH was significantly lower than that for SWH and a similar tendency was found in the LF/HF ratio of heart rate variability at rest. Because these two autonomic nervous indices are related to sympathetic nervous activity, the findings suggested that sympathetic nervous activity for LWH was lower than that for SWH in the 30–39 year group. Furthermore, there were significant relationships both between long working hours and short sleeping hours, and between short sleeping hours and high complaint rates of “drowsiness and dullness” in the morning in this age group. Summarizing these results, it appeared that long working hours might lower sympathetic nervous activity due to chronic sleep deprivation.

Key words: Working hours, Fatigue, Heart rate variability, Noradrenaline, Sleeping hours

Introduction

In Japan there is the problem of health hazard with which work overload is associated. Long working hours is thought to be one of the main factors in work overload^{1,2)}. In order to establish health management guidelines on long working hours, we have been investigating the effect of working hours on biological indices and its confounding factors such as age and lifestyle.

In our previous paper³⁾ we reported a field survey of salesmen on the relationship between working hours and

biological functions related to the cardiovascular system (mean amplitude of respiratory sinus arrhythmia, blood pressure and the serum total cholesterol level). In this paper we will report a field survey of engineers who seem to routinely work for long hours on the relationship between working hours and cardiovascular-autonomic functions (catecholamines in urine, heart rate variability <HRV> and blood pressure <BP>).

Subjects and Method

Subjects

The subjects of this study were 147 male engineers (23–

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49 years of age) in an electronics manufacturing company. They regularly worked 5 days a week. Those who were under medical care and those who took any kind of medicine on the survey day were excluded from the study.

Procedure for field survey

Surveys were made on 5 working days in Nov., 1997. Each subject was examined on one of survey days. The survey consisted of (1) self-report questionnaires (working hours and health conditions, and fatigue), (2) measurement of cardiovascular-autonomic functions (catecholamines in urine in 2 hours during work in the afternoon, and HRV and BP at rest) and (3) body mass index (BMI) determined on the occasion of a regular health check (conducted in Sept. and Oct., 1997). A questionnaire on working hours and health conditions (including sleeping hours) during the latest full month was filled out on each survey day or the day before the survey day. Investigation by questionnaire on fatigue and measurement of cardiovascular-autonomic functions was conducted on each survey day. A questionnaire on subjective fatigue defined by the Japan Association of Industrial Health⁴⁾ was filled out twice on the survey day in the morning (before leaving home) and in the afternoon (just before measurement of cardiovascular-autonomic functions). In this questionnaire, subjective fatigue at the time of writing answers was asked about. Collection of urine and measurement of HRV and BP were conducted in the afternoon (15:00–18:30) at the workplace. For the determination of HRV and BP, the subjects took a rest for 5 min. or more. Then RR interval data were recorded by means of a heart rate monitor LRR-03 (GMS Co. Ltd., Japan) for 3 min. in a sitting position with respiration controlled to once every 5 sec. (0.2 Hz). Finally blood pressure was measured twice with a TM-2541 hemodynamometer (A & D Co. Ltd., Japan) and the mean value was calculated.

Analysis of heart rate variability

Analysis of the frequency with MemCalc⁵⁾ (Suwa Trust Co., Japan) was conducted to obtain HF (high frequency power, 0.15–0.30 Hz) and LF (low frequency power, 0.04–0.15 Hz). Mean amplitude of HF⁶⁾ was $\sqrt{2 \times \text{HF}}$. The LF/HF ratio was logarithmically converted to get a normal distribution in statistical analysis.

Analysis of catecholamines in urine

Collected urine samples were acidified to pH 2–3 with hydrochloric acid immediately after collection and stored at -80°C in a deep-freezer until analysis. Noradrenaline

(NA), adrenaline (Ad) and dopamine (DA) were analyzed with HPLC-ECD by modified Peaston's method⁷⁾. Vanilmandelic acid (VMA) was analyzed with HPLC-ECD by another method. The method for VMA analysis will be reported elsewhere later. The catecholamine level in urine was expressed as ng/mg creatinine or $\mu\text{g}/\text{mg}$ creatinine.

Weekly working hours

The number of weekly working hours was calculated from the working conditions during the latest full month in the answers to the questionnaire. Working hours in this study was defined as follows³⁾: Working hours = "hours at workplace" + "one-way commuting time", where "hours at workplace" is defined as (hours from arrival at to leaving workplace) or (hours from start to finish of business in a day). From the viewpoint of workload, we considered that the commuting load was equivalent to half the actual business load.

Shorter (SWH) and longer (LWH) working hour subgroups

The subjects were divided into 3 groups by age: 23–29, 30–39 and 40–49 groups. Subjects in each group by age were further divided into shorter (SWH) and longer (LWH) working hour subgroups according to the median of weekly working hours (Table 1). Overall SWH (LWH) was the sum of the SWHs (LWHs) for the various age groups.

Other information

The difference between the mean values for SWH and LWH was found by t-test ($p < 0.05$). The difference between the complaint rates of fatigue I for 3 sleeping hour subgroups was found by one-way ANOVA, followed by Scheffé's method.

This study was carried out by permission of the Ethics Committee of our institute.

Results

Weekly working hours and other demographic characteristics

Weekly working hours in this study are shown in Table 1. In the overall group, working hours was 63.1 hr/week (shown under "Total") and the difference between SWH and LWH in working hours was 9.7 hr/week. In the comparison of different groups by age, both working hours and its difference between SWH and LWH were largest in the 40–49 year group. Sleeping hours was 6.2 hr/day in the overall group. Significant differences between SWH and LWH in sleeping hours were found in the 30–39 year and overall

Table 1. Weekly working hours and other demographic characteristics

	23–29			30–39		
	Total	SWH	LWH	Total	SWH	LWH
Number	49	25	24	74	37	37
Age (year)	26.9 ± 1.6	26.6 ± 1.9	27.3 ± 1.2	33.8 ± 2.8	34.2 ± 2.9	33.5 ± 2.7
Working hours (sum of A + B) (hr/week)	61.9 ± 5.7	57.7 ± 3.7 ***	66.2 ± 3.7	62.7 ± 6.5	57.7 ± 3.4 ***	67.8 ± 4.7
(A) Hours at workplace* ² (hr/week)	58.2 ± 5.8	53.9 ± 4.2 ***	62.6 ± 3.6	58.5 ± 6.3	54.0 ± 3.7 ***	63.0 ± 5.0
(B) One-way commuting time (hr/week)	3.7 ± 1.9	3.7 ± 1.9	3.7 ± 1.9	4.2 ± 2.0	3.7 ± 2.1 *	4.7 ± 1.9
Sleeping hours (hr/day)	6.2 ± 0.6	6.3 ± 0.6	6.1 ± 0.5	6.2 ± 0.8	6.5 ± 0.7 ***	5.9 ± 0.8
BMI (kg/m ²)	22.6 ± 3.3	22.7 ± 3.2	22.5 ± 3.4	22.6 ± 2.4	22.3 ± 2.3	22.9 ± 2.5
	40–49			Overall		
	Total	SWH	LWH	Total	SWH	LWH* ¹
Number	24	13	11	147	75	72
Age (year)	44.2 ± 2.9	45.1 ± 3.2 #	43.1 ± 2.3	33.2 ± 6.3	33.5 ± 6.8	32.9 ± 5.6
Working hours (sum of A + B) (hr/week)	67.1 ± 8.7	61.7 ± 4.8 ***	73.4 ± 8.2	63.1 ± 6.8	58.4 ± 4.0 ***	68.1 ± 5.5
(A) Hours at workplace* ² (hr/week)	62.1 ± 8.1	57.0 ± 5.3 ***	68.2 ± 6.5	59.0 ± 6.6	54.5 ± 4.3 ***	63.7 ± 5.2
(B) One-way commuting time (hr/week)	4.9 ± 2.3	4.7 ± 2.2	5.1 ± 2.5	4.2 ± 2.1	3.9 ± 2.1	4.4 ± 2.1
Sleeping hours (hr/day)	6.2 ± 0.7	6.4 ± 0.7	6.0 ± 0.5	6.2 ± 0.7	6.4 ± 0.7 ***	6.0 ± 0.7
BMI (kg/m ²)	24.6 ± 3.1	24.6 ± 3.1	24.5 ± 3.2	22.9 ± 2.9	22.8 ± 2.8	23.0 ± 3.0

Values are the mean ± SD. SWH: shorter working hour subgroup, LWH: longer working hour subgroup. *¹: SWH (LWH) in the overall group is the sum of SWH (LWH) in each group by age. *²: Defined as hours from arrival at to leaving the office or hours from start to finish of business in a day. #: p<0.1, *: p<0.05, ***: p<0.001.

Fig. 1. Correlation between weekly working hours and sleeping hours.
Working hours = (hours at workplace) + (one-way commuting time).

groups. Scattergrams of working and sleeping hours are shown in Fig. 1. Significant negative correlations between working and sleeping hours were found in the 30–39 and 40–49 year groups (30–39 group: $p<0.01$, 40–49 group: $p<0.05$). In BMI, there was no significant difference between SWH and LWH in any age group.

Working hours and cardiovascular-autonomic parameters

Cardiovascular-autonomic parameters in this study are shown in Table 2. Significant difference between SWH and LWH in urinary NA was found in the 30–39 year group (lower in LWH). Similarly to urinary NA, the LF/HF ratio for LWH was lower than that for SWH in the 30–39 year

Table 2. Cardiovascular-autonomic parameters

	23–29			30–39		
	Total	SWH	LWH	Total	SWH	LWH
NA (ng/mg Creatinine)	20.8 ± 6.2	21.7 ± 6.1	19.8 ± 6.2	21.7 ± 6.5	23.2 ± 6.6 *	20.2 ± 6.2
Ad (ng/mg Creatinine)	9.8 ± 5.3	9.8 ± 5.9	9.8 ± 4.7	8.4 ± 3.8	8.6 ± 3.5	8.2 ± 4.2
DA (ng/mg Creatinine)	159 ± 38	165 ± 36	152 ± 40	132 ± 31	133 ± 29	132 ± 34
VMA (μg/mg Creatinine)	2.81 ± 0.52	2.75 ± 0.44	2.88 ± 0.60	2.81 ± 0.62	2.87 ± 0.70	2.75 ± 0.53
Mean amplitude of HF (msec)	34.3 ± 17.6	34.6 ± 17.5	33.9 ± 18.1	29.8 ± 15.0	27.1 ± 11.3	32.6 ± 17.6
HR (bpm)	71.2 ± 10.8	69.4 ± 10.9	73.1 ± 10.7	73.1 ± 9.4	74.7 ± 9.9	71.6 ± 8.6
log (LF/HF)	−0.15 ± 0.37	−0.17 ± 0.41	−0.14 ± 0.32	−0.05 ± 0.41	0.04 ± 0.41 #	−0.14 ± 0.40
SBP (mmHg)	125.3 ± 10.5	123.5 ± 11.6	127.2 ± 9.2	126.6 ± 13.1	127.5 ± 14.4	125.6 ± 11.9
DBP (mmHg)	72.9 ± 8.7	70.6 ± 9.5 #	75.3 ± 7.2	75.8 ± 10.0	77.0 ± 11.4	74.5 ± 8.4
PR (bpm)	66.6 ± 10.1	64.7 ± 10.7	68.6 ± 9.4	68.7 ± 8.3	70.0 ± 8.9	67.5 ± 7.7

	40–49			Overall		
	Total	SWH	LWH	Total	SWH	LWH* ¹
NA (ng/mg Creatinine)	24.3 ± 8.2	22.9 ± 8.8	25.8 ± 7.4	21.8 ± 6.8	22.7 ± 6.8	20.9 ± 6.7
Ad (ng/mg Creatinine)	8.9 ± 4.4	9.5 ± 4.2	8.1 ± 4.8	8.9 ± 4.5	9.2 ± 4.5	8.7 ± 4.5
DA (ng/mg Creatinine)	130 ± 26	128 ± 16	133 ± 36	141 ± 35	143 ± 34	139 ± 37
VMA (μg/mg Creatinine)	2.77 ± 0.68	2.72 ± 0.84	2.83 ± 0.46	2.80 ± 0.60	2.80 ± 0.65	2.80 ± 0.54
Mean amplitude of HF (msec)	26.9 ± 19.2	30.7 ± 23.7	22.5 ± 11.5	30.8 ± 16.7	30.2 ± 16.3	31.5 ± 17.2
HR (bpm)	72.2 ± 9.6	74.2 ± 10.1	69.9 ± 8.9	72.3 ± 9.9	72.8 ± 10.4	71.8 ± 9.3
log (LF/HF)	−0.13 ± 0.39	−0.21 ± 0.46	−0.04 ± 0.29	−0.10 ± 0.39	−0.07 ± 0.43	−0.12 ± 0.36
SBP (mmHg)	134.7 ± 16.0	135.3 ± 17.4	134.0 ± 15.0	127.5 ± 13.2	127.5 ± 14.5	127.4 ± 11.8
DBP (mmHg)	86.1 ± 13.3	88.0 ± 14.0	83.8 ± 12.7	76.5 ± 11.1	76.8 ± 12.6	76.2 ± 9.3
PR (bpm)	68.3 ± 8.9	69.6 ± 10.3	66.7 ± 7.2	68.0 ± 9.1	68.2 ± 9.9	67.7 ± 8.1

Values are the mean ± SD. SWH: shorter working hour subgroup, LWH: longer working hour subgroup. *¹: SWH (LWH) in the overall group is the sum of SWH (LWH) in each group by age. #: $p < 0.1$, *: $p < 0.05$.

group (tendency: $p < 0.1$). Scattergrams of working hours, urinary NA and the LF/HF ratio are shown in Figs. 2 and 3. In the 30–39 year group, the correlation between working hours and urinary NA was negative (significant), and the correlation between working hours and the LF/HF ratio was also negative (not significant). As for BP, DBP (diastolic blood pressure) for LWH was higher than that for SWH in the 23–29 year group (tendency: $p < 0.1$). As for the other cardiovascular-autonomic parameters, no significance ($p < 0.05$) or tendency ($p < 0.1$) to a difference between SWH and LWH was found in any age group.

Working hours and fatigue complaints

Fatigue complaints in this study are shown in Table 3. Fatigue complaints were divided into 3 categories: fatigue I (drowsiness and dullness), II (difficulty in concentrating attention) and fatigue III (feeling of local physical abnormality). In the overall group the complaint rates were fatigue I > fatigue II > fatigue III both in the morning and

afternoon (shown under “Total”). In the 30–39 year group the complaint rate of fatigue I in the morning for LWH was higher than that for SWH (tendency: $p < 0.1$). In the 40–49 year group the complaint rate of fatigue II for LWH was higher than that for SWH (morning: $p < 0.01$, afternoon: $p < 0.1$). Relationships between sleeping hours and the complaint rates of fatigue I in the morning are shown in Fig. 4. In the 30–39 year group the fatigue I rate in the morning for the shorter sleeping hour subgroup was significantly higher than that for the longer sleeping hour subgroup. The above relationship in the 40–49 year group was similar to that in the 30–39 year group, but weak.

Discussion

In the 30–39 year group, urinary NA in the afternoon for LWH was significantly lower than that for SWH and a tendency similar to urinary NA was found in the LF/HF ratio of HRV at rest. Urinary NA is used as an index of

Fig. 2. Correlation between weekly working hours and noradrenaline in urine.
Working hours = (hours at workplace) + (one-way commuting time).

Fig. 3. Correlation between weekly working hours and log (LF/HF).
Working hours = (hours at workplace) + (one-way commuting time).

sympathetic nervous activity and the LF/HF ratio is considered to reflect sympathovagal balance⁸). Therefore, the results in the 30–39 year group suggested that long working hours might lower sympathetic nervous activity to bring about a more vagal-dominant state.

In addition to the above results, there were significant relationships both between long working hours and short sleeping hours, and between short sleeping hours and high complaint rates of fatigue I in the morning in the 30–39 year group. These results suggested that the negative

correlation between working hours and urinary NA might be caused by sleep deprivation. On the other hand, in the 23–29 year group no significant correlation between working hours and urinary NA was found. And also there was no significant correlation related to sleep deprivation arising from long working hours in the 20–29 year group, which supports our conclusion concerning the 30–39 year group. In the 40–49 year group there was significant negative correlation between working hours and sleeping hours and also a significant difference between SWH and LWH in the

Table 3. Fatigue complaint rates of shorter (SWH) and longer (LWH) working hour subgroups

	23–29			30–39		
	Total	SWH	LWH	Total	SWH	LWH
I. Drowsiness and dullness						
Morning	27.6 ± 21.1	28.0 ± 24.3	27.1 ± 17.6	26.8 ± 20.9	22.2 ± 19.3 [#]	31.4 ± 21.6
Afternoon	13.7 ± 16.4	14.0 ± 17.6	13.3 ± 15.5	14.5 ± 17.4	14.1 ± 17.4	14.9 ± 17.6
II. Difficulty in concentrating attention						
Morning	10.0 ± 12.9	10.4 ± 15.4	9.6 ± 10.0	13.8 ± 20.3	13.8 ± 21.6	13.8 ± 19.1
Afternoon	7.6 ± 11.3	9.6 ± 13.4	5.4 ± 8.3	8.6 ± 16.1	8.1 ± 15.6	9.2 ± 16.7
III. Feeling of local physical abnormality						
Morning	8.4 ± 10.3	9.6 ± 12.1	7.1 ± 8.1	8.6 ± 12.5	8.6 ± 10.8	8.6 ± 14.2
Afternoon	6.9 ± 9.8	7.2 ± 11.4	6.7 ± 8.2	7.7 ± 10.1	7.3 ± 9.3	8.1 ± 11.0
	40–49			Overall		
	Total	SWH	LWH	Total	SWH	LWH* ¹
I. Drowsiness and dullness						
Morning	22.9 ± 23.5	21.5 ± 28.5	24.5 ± 16.9	26.4 ± 21.3	24.0 ± 22.7	28.9 ± 19.6
Afternoon	13.8 ± 17.9	11.5 ± 18.6	16.4 ± 17.5	14.1 ± 17.0	13.6 ± 17.4	14.6 ± 16.7
II. Difficulty in concentrating attention						
Morning	25.0 ± 23.4	13.1 ± 16.5 [#]	39.1 ± 23.0	14.4 ± 19.3	12.5 ± 18.8	16.3 ± 19.7
Afternoon	18.3 ± 32.1	6.2 ± 13.3 ^{**}	32.7 ± 41.7	9.9 ± 18.7	8.3 ± 14.4	11.5 ± 22.2
III. Feeling of local physical abnormality						
Morning	14.6 ± 19.3	15.4 ± 23.7	13.6 ± 13.6	9.5 ± 13.3	10.1 ± 14.2	8.9 ± 12.4
Afternoon	10.0 ± 13.2	9.2 ± 14.4	10.9 ± 12.2	7.8 ± 10.6	7.6 ± 10.9	8.1 ± 10.3

The fatigue complaint rate is (number of "Yes" answers/number of questions) × 100 (%). Values are the mean ± SD. *¹: SWH (LWH) in the overall group is the sum of SWH (LWH) in each group by age. #: p<0.1, **: p<0.01.

Fig. 4. Sleeping hours (SH) and fatigue I in the morning.

The vertical lines indicate standard errors. The number of subjects in each subgroup is shown in each bar. Sleeping hour subgroups are defined as: shorter; ≤5.5 hr/day, medium; 5.6–6.5 hr/day, longer; ≥6.6 hr/day. *: p<0.05 (Scheffé's method).

complaint rate of fatigue II in the morning, but we could not find any relationship between these results and cardiovascular-autonomic parameters in this study. In our study the number of subjects in the 40–49 year group was smallest. The effect of long working hours on health in the 40–49 year group has to be surveyed further because workers in this age group have more risk factors for cardiovascular diseases than those in 20–39 years of age.

Osada⁹⁾ studied the effect of temporal and chronic sleep deprivation on cardiopulmonary and sympathetic nervous functions. In his study, two kinds of sleep deprivation were defined as: temporal; having not more than 3 hours sleep the previous night, chronic; having had less than 60% of normal sleep for the latest full month. He concluded that sympathetic nervous activity in chronic sleep deprivation was lower than that in controls and in temporal sleep deprivation. Working and sleeping hours in our study were the mean values during the latest full month, so that our results were considered to reflect the effect of chronic sleep deprivation on sympathetic nervous activity. Tochikubo *et*

al. concluded in their paper¹⁰⁾ that lack of sleep might increase sympathetic nervous activity on the following day, but their sleep deprivation was limited to only the previous night. Because most sleep deprivation arising from long working hours is likely to be chronic, most long hour workers may be in a state of lower sympathetic nervous activity. Kageyama *et al.* concluded in their paper¹¹⁾ that chronic stress or fatigue from extensive overtime caused workers to be in a sympathodominant state, as shown by the measurement of HRV. Their conclusion was different from ours, but in our study the effect of long working hours was different in the 23–29, 30–39 and 40–49 year groups. Our study suggested that the effect of long working hours greatly depended on confounding factors such as age, sleeping hours and fatigue. In Kageyama's study the quantitative relationship between working hours and the abovementioned confounding factors was not examined adequately.

In the 23–29 year group DBP for LWH was higher than that for SWH (tendency: $p < 0.1$). In contrast to the 30–39 and 40–49 year groups, heart rate (HR) and pulse rate (PR) at rest for LWH were higher than those for SWH in the 23–29 year group (not significant). It cannot be denied that long working hours may increase blood pressure and heart rate in the 23–29 year group. It is desirable to study the effect of long working hours further with special attention to confounding factors such as age, sleep, fatigue and stress.

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