Autonomic Stimulation and Cardiovascular Reflex Activity in the Hand-Arm Vibration Syndrome

MASSIMO BOVENZI

Institute of Occupational Health, University of Trieste, Centro Tumori, I-34129 Trieste, Italy

Received for publication May 22, 1989

Summary: Two experiments were carried out to investigate the cardiovascular responses of vibration-exposed workers to autonomic stimulation. In the first experiment blood pressures, heart rate and systolic time intervals (STI) were measured during a cold test in 63 vibration-exposed foundry workers and 41 controls. STI, such as total electromechanical systole (QS2I) and left ventricular ejection time index (LVETI), were found to be shorter in the vibration-exposed workers with and without vibration white finger (VWF) than in the controls, both at rest and during cold provocation and recovery (p<0.001). A significant inverse relationship between urinary excretion of free catecholamines and the duration of STI was observed under resting conditions (0.001<p<0.03). In the second experiment, the above mentioned cardiovascular parameters were measured in 11 grinding operators with VWF and 11 controls during a hand grip test, an arithmetic test and an orthostatic test. Finger systolic pressures (FSP) during local cooling to 30, 15 and 10°C were also measured. QS2I and LVETI were more abbreviated in the VWF subjects than in the controls at rest and during both the circulatory stress tests and the recovery periods (0.001<p<0.05). The reduction in FSP by local cooling from 30°C to 15 and 10°C was greater in the VWF workers than in the controls (p<0.001). Significant correlations were observed between the reduction in FSP at 15 and 10°C and the duration of STI during circulatory stress activities (p<0.01). A multiple regression analysis pointed out that vibration exposure was the major determinant of STI during circulatory stress, while the importance of age and smoking and drinking habits in predicting STI was negligible. The findings of these studies suggest that the level of cardiac sympathetic activity is increased in VWF workers in comparison with controls. These experimental results are consistent with those of other investigators, indicating that excessive sympathetic reflex activity plays an important role in the pathogenesis of VWF.

Key words: cardiac sympathetic tone — circulatory stress tests — finger systolic pressure — systolic time intervals — vibration-induced white finger.

Introduction

The whole collection of neurovascular symptoms and musculoskeletal disorders occurring in the upper limbs of vibration-exposed workers is called "Hand-Arm Vi-
bration (HAV) Syndrome”. Vibration-induced white finger (VWF) is the main component of the HAV syndrome and is classified as a secondary form of Raynaud’s phenomenon. The pathophysiology of VWF is not fully known. Some authors have hypothesized that locally mediated mechanisms are the most important factors for the triggering of digital vasospastic attacks (Gemne, 1982). On the other hand, various investigators have emphasized the role of sympathetic reflex overactivity in the pathogenesis of VWF (Olsen, 1987). The present study reports the results of two experiments designed to investigate the sympathetic nervous activity of vibration-exposed workers. For this purpose, the cardiovascular responses to various autonomic stimuli were assessed by measuring blood pressures, heart rate and time intervals of the left ventricular systole.

Materials and Methods

Experiment 1

Sixty-three vibration-exposed foundry operators and 41 comparable controls working at the same plant were examined. Nine vibration-exposed workers had no symptoms, 41 complained of sensorineural disturbances in the fingers and hands and 13 were affected with VWF. A cold provocation test (immersion of the right hand in ice water (4°C) for 2 min) was performed in a laboratory room with an ambient temperature of 22.5 (SD 0.4) °C. After a resting period in the supine position (20–30 min), an electrocardiogram, a phonocardiogram and an indirect carotid pulse tracing were simultaneously recorded on a C6b Ote Biomedica multi-channel recorder at a paper speed of 100 mm/s. From these recordings, baseline heart rate and systolic time intervals (STI) were obtained. Systolic and diastolic blood pressures were measured by a mercury sphygmomanometer. The same cardiovascular parameters were monitored during cold provocation and the recovery period. The following systolic time intervals were determined from the polygraphic tracing (Fig. 1), according to Weissler’s method (1969): total electromechanical systole ($QS_2$), left ventricular ejection time ($LVET$), and preejection period ($PEP$).

\[ PEP = QS_2 - LVET \]

Fig. 1. Simultaneous recording of an electrocardiogram, a phonocardiogram and an external carotid pulse at 100 mm/s paper speed. The method of measurement of systolic time intervals is shown. $QS_2$: electromechanical systole. $LVET$: left ventricular ejection time. $PEP$: preejection period.
VIBRATION-INDUCED SYMPATHETIC HYPERREACTIVITY

(LVET) and ejection period (PEP). The value of each STI (ms) was averaged from 8-10 consecutive cardiac cycles. Heart rate was derived from the average R-R interval measured on the electrocardiogram. STI were corrected for the influence of heart rate and expressed as indices (QS2I, LVETI, PEPI). In each subject, assays of free catecholamines in urine were performed with Bio Rad kits and fluorometric methods.

Experiment 2

Eleven vibration-exposed grinding operators affected with VWF and 11 comparable controls were examined. Hemodynamic tests were performed with the same apparatus and methodology as described for experiment 1. The stress activities consisted of a hand grip test, an arithmetic test and an orthostatic test. The subject performed the hand grip test in the supine position by squeezing a dynamometer in the right hand at 30% of his maximum voluntary contraction for 3 min. Mental activity consisted of an arithmetic test concerning complex additions of randomized numbers (1-20) for 2 min. To induce orthostatic stress, the subject was passively tilted to 50° for 5 min. Blood pressures, heart rates and systolic time intervals were measured before, during and after each circulatory stress test. Digital circulatory function was also assessed by plethysmographic measurement of finger systolic pressure (FSP) during local cooling according to the method proposed by Nielsen and Lassen (1977). In each subject FSP was measured from a test finger and a control finger after segmental cooling to 30, 15 and 10°C performed by means of a digit cooling system (Medimatic). The results of the cold provocation were expressed as the change in FSP on the test finger at 15 and 10°C as a percentage of the pressure at 30°C (FSP%), corrected for the change in blood pressure in the control finger during the test. The digital to brachial systolic pressure index in the test finger (DPI) was also calculated at 30, 15 and 10°C.

Statistical Methods

Statistical evaluation of the results was performed by the Statistical Package for the Social Sciences (SPSS). Both parametric (paired and unpaired Student's test, bivariate correlation, multiple linear regression) and nonparametric (Wilcoxon matched paired signed rank test, Mann-Whitney rank sum test) statistics were used. A probability level of 0.05 was taken as the limit of statistical significance.

Results

Experiment 1

The patterns of the cardiovascular parameters measured before, during and after the cold test are displayed in Figs. 2, 3 and 4. At rest the durations of QS2I and LVETI were shorter in the vibration-exposed workers than in the controls (p<0.001). The subjects with VWF (n=13) had shorter LVETI than those without VWF (n=50), (p<0.05). Among the groups examined no differences were found in the other cardiovascular parameters recorded under resting conditions. The vibration-exposed workers with and without VWF excreted larger amounts of urinary free catecholamines [mean (SD): 61.0 (23.2) and 53.9 (16.9) µg/g of creatinine, respectively] than the controls [49.1 (20.1) µg/g of creatinine], but the differences were not significant. Nevertheless, for all subjects the urinary levels of free catecholamines had significant inverse correlations with the durations of QS2, LVET and LVETI at rest (0.005<p<0.03). In the vibration and control workers, systolic and diastolic blood pressures, heart rate and PEPI significantly increased during
Fig. 2. Systolic and diastolic blood pressures (SBP, DBP) and heart rate (HR) before, during and after the cold test in vibration-exposed workers with (●) and without (○) VWF and in controls (●). Plotted values represent means and standard errors of means. Difference from controls: *p<0.05; **p<0.01. Difference from workers without VWF: ◀p<0.05; ◀◀p<0.01.

Fig. 3. Electromechanical systole (QS2) index before, during and after the cold test in vibration-exposed workers with (●) and without (○) VWF and in controls (●). Plotted values represent means and standard errors of means. Difference from controls: *p<0.01; **p<0.001. Difference from workers without VWF: ◀p<0.05; ◀◀p<0.01.

Fig. 4. Left ventricular ejection time (LVET) index before, during and after the cold test in vibration-exposed workers with (●) and without (○) VWF and in controls (●). Plotted values represent means and standard errors of means. Difference from controls: *p<0.02; **p<0.001. Difference from workers without VWF: ◀p<0.05.

the cold manoeuvre, whereas QS2I and LVETI significantly decreased (p<0.001). As under resting conditions, both during cold provocation and recovery the vibration-exposed workers with and without VWF had shorter QS2I and LVETI than the controls (p<0.001). During the recovery period systolic and diastolic arterial pressures were higher in the VWF subjects than in the other groups (0.005<p<0.05).

Experiment 2

The hand grip test (Fig. 5) caused a significant increase in systolic and diastolic blood pressures and in heart rate among the vibration and control groups (p=0.003). The change in heart rate was greater in the VWF workers than in the controls, but the difference was not significant. Both during the hand grip exercise and the recovery phase, STI indices were found to be significantly shorter
in the VWF subjects in comparison with the controls (0.001<p<0.03).

Systolic and diastolic arterial pressures significantly increased during mental activity in both groups (Fig. 6). The change in heart rate was greater and the duration of STI indices was shorter in the VWF patients than in the controls (0.001<p<0.01). During the recovery period, QS2I and PEPI were more abbreviated in the VWF group (0.001<p<0.03).
Among the VWF workers the increase in diastolic blood pressure during the 50° head-up tilt (Fig. 7) was greater (p=0.007) than the increase in systolic blood pressure (p<0.03). In the control group no differences in blood pressure changes were observed. During the gravitational stress, QS2 and LVET indices were shorter and the PEP index was higher in the VWF subjects than in the controls (p<0.001). As under resting conditions, STI indices during the recovery time were significantly shorter in the VWF group in comparison with the control group (0.001<p<0.05).

Table 1 reports the results of finger systolic pressure measurements during local cooling. Between the VWF workers and the controls no differences in the digital and brachial systolic pressures were found during warming to 30°C. Finger cooling to 15 and 10°C provoked a significantly greater decrease in FSP among the VWF workers as compared with the controls (p<0.001). In the VWF group total closure of the digital arteries in the test finger (i.e. 0 mmHg) was observed in 2 subjects (18.1%) at 15°C and in 8 subjects (72.7%) at 10°C. In the entire sample significant correlations were found between FSP% at 15 and 10°C and the duration of STI indices during the circulatory stress tests (0.001<p<0.01).

A multiple linear regression analysis (Table 2) pointed out that vibration exposure had a highly significant inverse relationship with QS2 and LVET indices during all three stress activities (p<0.001), while age had a slightly significant direct relation only with QS2 index during the tilt test (p<0.05). The PEP index was significantly associated with vibration exposure during hand grip (p<0.001) and head-up tilt (0.01<p<0.05). The values of the square of the part correlation coefficients (R²) indicated that vibration exposure accounted for changes in R² ranging from 4.4 to 84.1%, while R² changes for age varied from 0.6 to 10.2%. Smoking and drinking habits did not contribute substantially to the explained variation in the systolic time intervals.

**Fig. 7.** Systolic and diastolic blood pressures (SBP, DBP), heart rate (HR), total electromechanical systole index (QS2I), left ventricular ejection time index (LVETI) and preejection period index (PEPI) measured before, during and after a 50° head-up tilt in VWF workers (○) and in controls (●). Plotted values represent means and standard errors of means. *p<0.05; **p<0.001.
TABLE 1

Results of a cold provocation test with water at 30°C, 15°C and 10°C in VWF workers and controls. BSP, FSPt and FSPc denote brachial systolic pressure and finger systolic pressure measured on the test finger and a control finger, respectively. FSP% is finger systolic pressure at 15°C and 10°C as a percentage of pressure at 30°C. DPI is the digital pressure index (FSPt/BSP). Values are given as medians (range).

<table>
<thead>
<tr>
<th></th>
<th>Controls (n=11)</th>
<th>VWF subjects (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BSP 30°C (mmHg)</strong></td>
<td>130 (108 -140)</td>
<td>130 (120 -150)</td>
</tr>
<tr>
<td><strong>FSPt, 30°C (mmHg)</strong></td>
<td>108 ( 96 -130)</td>
<td>116 ( 64 -145)</td>
</tr>
<tr>
<td><strong>FSPc, 30°C (mmHg)</strong></td>
<td>108 ( 98 -130)</td>
<td>120 ( 86 -145)</td>
</tr>
<tr>
<td><strong>DPI 30°C (%)</strong></td>
<td>90.7 (71.4 -94.5)</td>
<td>88.8 (49.2 -96.6)</td>
</tr>
<tr>
<td><strong>BSP 15°C (mmHg)</strong></td>
<td>125 (108 -140)</td>
<td>132 (120 -150)</td>
</tr>
<tr>
<td><strong>FSP% 15°C (%)</strong></td>
<td>100 (100 -100)</td>
<td>50.8 (0 - 89.1)*</td>
</tr>
<tr>
<td><strong>DPI 15°C (%)</strong></td>
<td>86.6 (78.6 -92.5)</td>
<td>42.3 (0 - 70.7)*</td>
</tr>
<tr>
<td><strong>BSP 10°C (mmHg)</strong></td>
<td>130 (110 -145)</td>
<td>140 (120 -175)</td>
</tr>
<tr>
<td><strong>FSP% 10°C (%)</strong></td>
<td>96.3 (67.8 -113)</td>
<td>0 (0 - 43)**</td>
</tr>
<tr>
<td><strong>DPI 10°C (%)</strong></td>
<td>83 (57.1-103)</td>
<td>0 (0 - 34.6)**</td>
</tr>
</tbody>
</table>

Mann-Whitney test: *P<0.0007; **P<0.00001

TABLE 2

Multiple linear regression of systolic time interval (QS₂, LVET, PEP) indices during stress activities (dependent variables) with age and vibration exposure (independent variables). The square of the part correlation coefficients (R²) and the unstandardized (B) and standardized (Beta) partial regression coefficients are reported.

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Age</th>
<th>Vibration exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>QS₂ index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand grip</td>
<td>0.014</td>
<td>0.510</td>
</tr>
<tr>
<td>Mental stress</td>
<td>0.064</td>
<td>1.042</td>
</tr>
<tr>
<td>Head-up tilt</td>
<td>0.064†</td>
<td>1.112†</td>
</tr>
<tr>
<td>LVET index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand grip</td>
<td>0.080</td>
<td>0.487</td>
</tr>
<tr>
<td>Mental stress</td>
<td>0.036</td>
<td>0.788</td>
</tr>
<tr>
<td>Head-up tilt</td>
<td>0.006</td>
<td>0.044</td>
</tr>
<tr>
<td>PEP index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand grip</td>
<td>0.010</td>
<td>0.038</td>
</tr>
<tr>
<td>Mental stress</td>
<td>0.031</td>
<td>0.245</td>
</tr>
<tr>
<td>Head-up tilt</td>
<td>0.102</td>
<td>1.050</td>
</tr>
</tbody>
</table>

†P<0.05; °P<0.01; *P<0.001
Discussion

Circulatory stress tests such as those used in this study are considered to be powerful activators of the sympathetic nervous system. Blood pressure and heart rate are the most common parameters employed for assessing the responses of the cardiovascular system to autonomic stimulation. Some authors have reported that the measurement of systolic time intervals represents a useful noninvasive method for evaluating the modifications of cardiac performance induced by autonomic stress (Frey and Kenney, 1979). It is well known that the duration of STI varies inversely with heart rate and that the alterations of STI are related to changes in stroke volume (preload), in aortic pressure (afterload) and in myocardial contractility (inotropism). As a result, stress tests can influence STI because of the hemodynamic changes caused by the increase in sympathetic nervous output. Patients affected with primary Raynaud's disease are believed to have an enhanced level of sympathetic nervous activity (Halperin and Coffman, 1979). As the circulatory symptoms in these patients closely resemble VWF, the measurement of STI in connection with autonomic manoeuvres may be a useful tool to assess whether altered cardiovascular reactivity occurs in workers affected with VWF.

In the 1st experiment of the present study (cold provocation), the vibration-exposed workers with and without VWF had shortened systolic time intervals (QS2I and LVETI) in comparison with the controls over the entire test period. The urinary excretion of free catecholamines was higher in the vibration-exposed groups and it was inversely associated with the duration of STI. These results may be related to an increase of sympathetic activity in the workers exposed to hand-arm vibration.

In the 2nd experiment the increase in diastolic blood pressure during circulatory stress activities was greater in the VWF subjects than in the controls, indicating that the vibration operators experienced a more powerful peripheral vasoconstriction. The change in heart rate during the hand grip and arithmetic tests was larger in the VWF group in comparison with the controls, and this may be due to a more intense reflex inhibition of vagal tone caused by isometric exercise or to an increased sympathetic outflow elicited by mental stress. Almost all STI indices were found to be shorter in the VWF subjects than in the controls both at rest and during the isometric and arithmetic tests and during the recovery periods. This finding indicates that the VWF workers have an increased myocardial contractility which probably results from enhanced sympathetic stimulation. The orthostatic test induced a greater shortening of LVETI and a more marked prolongation of PEPI in the VWF subjects, as compared with the controls. This may be due to the combination of several factors such as a more powerful peripheral vasoconstriction, a more intense postural cardiac sympathetic excitation and a slower isovolumic rise of the left ventricular pressure.

The findings of these experiments indicate that the level of cardiac sympathetic tone is increased in VWF workers. This appraisal seems to be confirmed by other investigators who used STI as measures of sympathetic activity. Lewis et al (1972) reported a linear correlation between the abbreviation of STI indices and the increased urinary excretion of catecholamines among 51 patients with suspected acute myocardial infarction. As the QS2 index lengthened significantly after the administration of propranolol, the authors concluded that the shortened STI indices measured in their patients were related to exaggerated adrenergic stimulation. Atterhög and Ekelund (1980)
found abbreviated STI in a group of asymptomatic young men with primary T wave aberrations in the electrocardiogram. An enhanced sympathetic tone was considered to be the cause of the electrocardiographic abnormalities.

In the 2nd experiment the measurement of digital systolic blood pressure during local cooling to 15 and 10°C showed an increased digital vasospasm among the VWF workers in comparison with the controls. It was noted that the reduction in FSP after local cooling was significantly associated with the duration of STI indices during circulatory stress tests. This finding suggests that in the study population there exists a relation between digital arterial hyperreactivity to cold and increased cardiac sympathetic tone. Thus the results of this experiment tend to support the opinion that digital vasospasm in VWF is mainly mediated through an exaggerated central sympathetic reflex mechanism (Olsen, 1987).

On the basis of multiple regression analysis, vibration exposure was the major determinant of STI during the circulatory stress activities, whereas the importance of age, alcohol consumption and tobacco consumption in predicting STI was negligible. These findings agree with the observations reported by Heinonen et al (1987) who found that in a group of lumberjacks the variation in heart rate during a deep breathing test was inversely related to total sawing time. It was hypothesized that a prolonged exposure to chain saw vibration may cause an autonomic dysfunction by depressing the activity of the parasympathetic nervous system.

In conclusion, the present study suggests an association between vibration exposure, digital vasospasm and increased cardiac sympathetic tone, the latter demonstrated by the shortened STI recorded during stress activities. These experimental results, however, cannot exclude the intervention of locally mediated mechanisms in the triggering of a finger blanching attack. Nevertheless, recent studies have reported that the local vasoconstrictor response to cold has a minor part in VWF (Olsen et al. 1985) and in Raynaud’s disease (Nielsen et al 1980). Some authors have hypothesized that a chronic excitation of subcutaneous Pacinian corpuscles from hand-arm vibration could provoke an enhancement of the sympathetic nervous output (Hyvärinen et al. 1973; Heinonen et al. 1987). In line with this theory, the findings of the present paper indicate that excessive sympathetic reflex activity plays an important role in the pathogenesis of VWF.

Acknowledgment: The author wishes to thank Mrs Luciana Cornuda and Mrs Elena Zoff for their valuable help in carrying out the experiments and Mrs Fulvia Marsi for preparing the manuscript.

References


