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EFFECT OF WHOLE-BODY VIBRATION AND DRIVING A FOREST MACHINE SIMULATOR ON SOME PHYSIOLOGICAL VARIABLES OF THE OPERATOR

PERTTI HARSTELA AND KIMMO PIIRAINEN

Seloste

KOKOKEHON TÄRINÄN JA METSÄKONESIMULAATTORIAJON VAIKUTUS ERÄISIIN FYSIOLOGISIIN MUUTTUJIIN

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We studied the influence of horizontal whole-body vibration of fairly low intensity alone and combined with the mental load and motor actions typical for the forest machine driver on heart rate variability (HRV), respiration rate (RR) and heart rate (HR). Five subjects were tested. Horizontal vibration had an influende on HR, HRV and RR. 'Control activities' had the most influence on RR and HRV, but some influence on HR, too. 'Moving the control devices' (motor action) gave the same response in HR as 'control activities', but not in HRV and RR. 'Control activities' together with 'vibration' had more effect on HRV and RR than these two factors singly, but not on HR. The possibilities of using these variables in field studies are discussed.

1. INTRODUCTION

There are a lot of investigations on the influence of low-frequency vibration on heart rate (HR) and pulmonary ventilation (Bogert, 1967, Coermann, 1965, Dieckmann, 1957, 1958, Hasan, 1970, Sjoflot and Suggs, 1973). There seem to be no investigations on the influence of the vibration on heart rate variability (HRV). In most terrain machines vibration occurs as a rule together with the other stress factors, i.e. mental load. Sjoflot and Suggs (1973) have studied the influence of vibration together with tracking on heart rate (HR) and on some other factors but not on HRV or respiration rate (RR). They did not study the influence of vibration singly compared with this kind of combined strain. But because the HR was slightly higher during the last 50 seconds of the tracking task than during the first 50 seconds, they concluded that this might be caused by the tracking or by the prolonged vibration exposure. Because HRV, HR and RR are interesting variables in intra-individual comparative studies on the mental strain of the driver, it is useful to know the influence of vibration and the combined effect of vibration, motor action and mental load on these factors.

The purpose of this study was to determine the influence of whole-body vibration of fairly low intensity and the combined influence of the mental load typical for the machine driver and vibration on HRV, HR, and RR. The influence of the physical work needed for moving the control devices alone and combined with the mental load and vibration was also studied.

Horizontal and rotational vibration is the most harmful vibration in terrain machines

(Siren, et al. 1979, Sjoflot and Suggs, 1973). The intensity of vibration typical for forest machines is greatest at the frequency area of ca. 2 Hz when compared with the ISO standard (Siren et al. 1979). So, experiment consisted of tests to ascertain the influence of rotational (horizontal) vibration at the frequency of 2 Hz. According to the pilot study this was the range with the most influence on the HRV.

2. METHODS

The subjects were five research assistants aged from 29 to 35. The experiment consisted of laboratory tests to ascertain the influence of rotational (horizontal) vibration on HR, HRV and RR. The influence of mental and motor activities typical for a forest machine driver was studied with and without vibration in a forest machine simulator built in the Finnish Forest Research Institute (Harstela, 1981). In the simulator there are normal size, two-lever control devices and seat for the operator. As the central machine element of most forest machines is the grapple loader, the grapple loader is the basic element of the simulator as well. It is a miniature model on a scale size of 1:8 to a real forest machine. The moving time of the machine elements from one position to the other correspond to that of the normal machine. A mobile forest on a scale size of 1:8 has been constructed on both sides of the stationary loader and load space. Under the seat there is a vibration simulator steered by a micro-computer.

Acceleration of vibration was adjusted according to "the fatique-decreased proficiency boundary" of ISO standard 2631 for 8 h, which means 0,315 m/s^2 at 4–8 Hz and 0,63 m/s^2 at 1 and 16 Hz frequency. This intensity of vibration is typical of many machines, for instance forest tractors (Siren et al 1979). The frequency of vibration was 2 Hz. In this area of the intensity of forest terrain machines the vibration is greatest compared with the ISO standard (Siren et al. 1979). The work load phases lasted 10 min and there was a 5 min pause between phases and 10 min rest before each replication. Five replications were used.

The following work load combinations were applied in every replication in different order:

1. vibration
2. control activities of the grapple loader (mental and light muscle activities)
3. movin the control devices of the grapple loader without intention (light muscle activities)
4. vibration + control activities
5. vibration + moving the control devices

Only very light muscle activities were needed to move the control devices because the control system consisted of only two levers and there were elbow rests for the arms.

The HRV index was calculated from the following equation, which imitates that which Luczak and Laurig (1973) assumed to be best for measuring mental load:

$$HRV = \frac{\sum_{i=2}^{N} | x_i - x_{i-1} |}{L}$$

x_i – the i^{th} interval, ms

$$L = \sum_{i=3}^{N} z_i, \quad z_i = 1 \text{ if } y_i < 0$$

$$z_i = 0 \text{ if } y_i > 0$$

$$y_i = (x_i - x_{i-1})*(x_{i-1} - x_{i-2})$$

The periodic variation in the HR was analyzed by computing the fourier transformation of the R-R interval signal. An analysis was made using successive windows of 2 min. The sampling frequency was 7,5 Hz.

3. RESULTS

Multiple linear regression analyses were calculated for HR, HRV and RR using the mean or the two-minutes HRV-value of the stress phases or rest pauses in each replication as observations for the dependent variable. The work load combinations and subjects were the independent dimmy-variables.

The following equation was achieved for HR:

Variable	Coeff.	T-value
Intercept	65.99	
s_1	– 8.20	– 11.86***
s_2	– 10.22	– 14.20***
s_3	3.15	– 3.28**
s_4	2.30	2.11
x_1	10.79	11.86***
x_2	5.01	5.80***
x_3	5.04	5.66***
x_4	8.70	– 9.55***
x_5	9.83	10.71***

F = 63.0***

s_i = subjects
x_1 = vibration
x_2 = control activities
x_3 = moving the control devices
x_4 = vibration + control activities
x_5 = vibration + moving the control devices

All the stress combinations had a statistically significant influence on HR. 'Vibration' had the greatest influence and 'control activities' and 'moving the control devices, the least.

The following equation illustrated the HRV:

Variable	Coeff.	T-value
Intercept	0.028	
s_1	– 0.039	– 9.86
s_2	– 0.040	– 9.76***
s_3	– 0.002	0.31
s_4	– 0.020	4.32***
x_1	– 0.027	– 5.27***
x_2	– 0.022	– 4.59***
x_3	– 0.006	– 1.19
x_4	– 0.033	– 6.41***
x_5	– 0.024	– 4.71***
x_6	0.014	7.94***

F = 63.0***

s_i = subjects
$x_1 \ldots x_5$ = seee the first equation
x_6 = time (60 = first 2 minutes of the load phase, 420 = last 2 minutes of the load phase)

'Vibration' and 'control activities' had a statistically significant influence on HRV, but 'moving the control devices' did not. The combination of control activities and vibration had the greatest influence. However, the influence of the work load partly disappeared during the 10-minute phase.

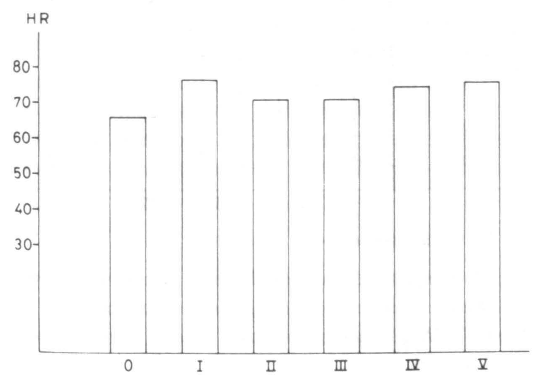

Fig. 1. Heart rate in the end of the work load phases according to the regression equation.
Kuva 1. Sydämen sykintä työjakson lopussa regressioyhtälön mukaisesti.

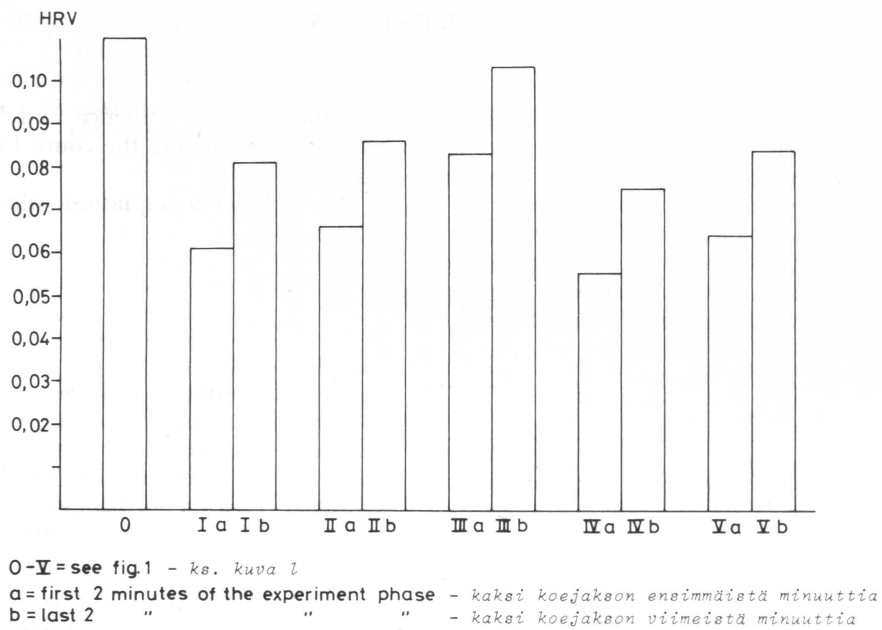

Fig. 2. Heart rate variability in the beginning and in the end of the work load phases according to the regression equation.

Kuva 2. Sydämen sykinnän vaihtelevuus työjakson alku- ja loppupuolella regressioyhtälön mukaisesti.

The following equation was achieved for RR:

Variable	Coeff.	T-value
Intercept	14.79	
s_1	1.97	6.4***
s_2	– 0.21	– 4.5***
s_3	0.01	0.3
x_1	2.23	5.1***
x_2	3.12	7.3***
x_3	0.97	2.3*
x_4	5.15	11.9***
x_5	2.13	5.0***

F = 36.8***

s_i = subjects

$x_1 \ldots x_5$ = see the first equation

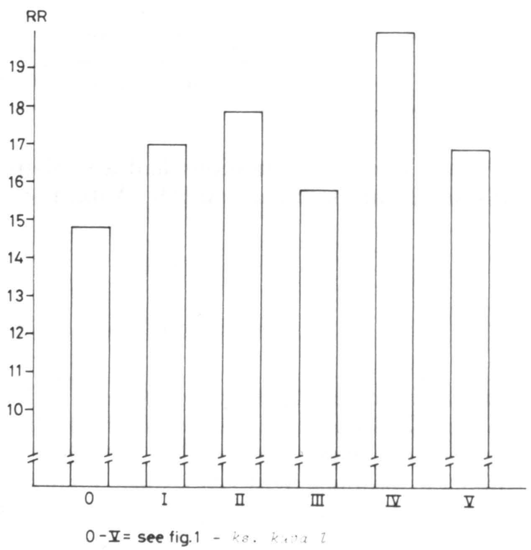

Fig. 3. Respiration rate in the end of the work load phases according to the regression equation.

Kuva 3. Hengitystaajuus työjakson lopussa regressioyhtälön mukaisesti.

The influence of stress combinations on RR was much the same as that on HRV. The combination of 'control activities' and 'vibration' had the greatest influence and 'moving the control devices' the least influence on RR.

4. DISCUSSION

It seems that low-intensity-horizontal vibration has an influence on HR, HRV and RR. It is well known that man is more sensitive to virations in the horizontal than in the vertical direction (Dieckmann 1957, 1958, Sjoflot and Suggs 1973). This may be due to the fact that man uses a reasonable amount of muscle activity to maintain his balance during horizontal vibration.

The 'control activities' involving neurosensoral load had the most influence on RR and HRV, but some influence on HR, too. They had more influence on RR and nearly the same influence on HRV as vibration had, but less influence on HR. 'Control activities' together with 'vibration' had more effect on HRV and RR than these two factors singly, but not on HR. Sjoflot and Suggs (1973) concluded in their study that tracking task together with horizontal vibration could cause more response in HR than vibration singly. This higher HR might be caused by the prolonged vibration or prolonged tracking task, too. They could also have more muscle activities during the tracking task than in our study, because the subject had no elbow rests in the seat.

'Moving the control devices' gave nearly the same response in HR as the 'control activities', but not in HRV and RR. As Luczak (1979) assumed, it may be that frequently measured increase in HR under mental load conditions can be ascribed either to a simultaneous increase in motor actions or to emotional strain. The influence of 'control activities' on RR and HRV seemed to be nearly independent of this kind of very light motor action, because 'moving the control devices' evoke only a very slight response.

Price (1975) and Sharit and Salkvendy (1982) have suggested that reduced HRV is accompanied by mental stress due to sustained attention and low informational processing rates, but high demands on detection of environmental events. On the other hand, HR should be more susceptible to mental effort. Driving the simulator (grapple loading) is just the kind of work requiring sustained attention and detection of environmental events, but with practice the steering of the work shifts to the lower levels of the central nervous system. Early studies contains observations of HRV or RR being indicators of sensitivity in driving work or mental load. Egelund (1982) and Mulders et al. (1982) reported that 0.1 Hz HRV seems to be a sensitive indicator of driver fatigue and psychophysiological reactivity of city bus drivers. In this region HRV may be connected with RR, but other factors affecting the homeostatic maintenance of blood pressure may also be involved. Hitchen et al. (1980) have shown that the respiratory frequency increases with mental load.

The 'control activities' together with 'vibration' gave only the same effect on HR as vibration alone, but had more influence on RR and HRV than those factors singly. It may be that the influence on HR is mainly caused by muscle activities, but on RR and HRV it is caused by muscle activities and mental load. This combined effect of 'control activities' and 'vibration' on RR and HRV is less than the sum of the influence of these two factors separately. This is a very common phenomenon in physiological variables which change curve-linearly as a function of stress.

Because of the great inter-individual variation of HRV and RR, these seem to be usable only in comparative intra-individual studies. In practical conditions it seems to be possible to obtain relative values for the mental strain of working systems which are similar to other stress factors, such as vibration and motor actions. However, if these other stresses are strong, it may not be easy to find differences between the different degrees of mental strain because of the "curve-linearity" of the HRV and RR change.

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SELOSTE

KOKOKEHON TÄRINÄN JA METSÄKONESIMULAATTORIAJON VAIKUTUS ERÄISIIN FYSIOLOGISIIN MUUTTUJIIN

Tutkittiin horisontaalisen kokokehon tärinän vaikutusta yksin ja metsäkonetyössä tyypillisen mentaalisen kuormituksen ja lihasaktiviteetin kanssa kuljettajan sydämen sykintään (HR), sydämen sykinnän vaihtelevuuteen (HR) ja hengitystaajuuteen (RR). Viisi koehenkilöä testattiin. Kokokehon tärinä vaikutti merkitsevästi HR, HRV ja RR:ään. Ohjaustoiminnot vaikuttivat eniten RR, HRV, mutta jossain määrin myös HR:ään. Ohjausvipujen liikuttelu vaikutti HR yhtä paljon kuin ohjaustoiminnot, mutta ei HRV ja RR:ään. Ohjaustominnot yhdessä kokokehon tärinän kanssa vaikuttivat enemmän HRV ja RR:ään kuin kumpikaan näistä muuttujista yksin, mutta eivät HR:ään. Näiden muuttujien käyttöä kenttätutkimuksissa pohdittiin.