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THE SEMMES-WEINSTEIN MONOFILAMENT EXAMINATION AND PURDUE PEGBOARDS TEST AS A SCREENING TOOL FOR PERIPHERAL NEUROPATHY CAUSED BY VIBRATIONS

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Abstract After an exposure to vibrations, the sensitivity of the mechanoreceptors in fingers is temporary altered and that the subjects suffer from paresthesia and numbness. So far it is not known how significant these temporary changes are, what is the frequency dependence or their likely repercussions on employment security. The subjects (10 men aged 20 to 25 years, perfectly healthy) were irradiated with vibrations with 1.2; 2.8; 5.8 şi 10.5 m/s^2, for 10 and 20 min; frequencies were: 4; 16; 31.5; 63; 125; 250 şi 500 Hz. Subsequent, the subjects were tested with the Semmes-Weinstein test and Purdue Pegboard test. It is found that the results almost coincide for the two tests. This means that a prolonged irradiation with accelerations exceeding 2.8m/s^2, subjects lose control of the fingers. If we compare the variation of the weighting factors based on the acceleration for these two tests with the variation of the weighting factors based on ISO 5349-1: 2001 we can see a total discrepancy. It can therefore be concluded that, as far as the vibration perception threshold is concerned, and therefore the sensitivity of the mechanoreceptors and the development of temporary neurological impairment, the ISO frequency weighting has no value.

Key words: vibrations, paresthesia, Semmes-Weinstein test, Purdue Pegboard test.

1. INTRODUCTION

Several authors [1, 2, 4–7, 9, 13–15], have shown that, following an exposure to vibrations, the sensitivity of the mechanoreceptors in fingers is temporary altered and that the subjects suffer from paresthesia and numbness [11]. However it is not known how significant these temporary changes are, what is the frequency dependence or their likely repercussions on employment security [8, 10].

In this study we will investigate the influence of vibrations (acceleration, frequency and exposure time) on fingers. This will be made using the Semmes-Weinstein monofilaments and in accordance with the procedure described by Bell-Krotoski and the Purdue Pegboard test.

2. MATERIAL AND METHODS

The vibrations were generated by a vibratory system and were analised with NetdB – a complex system of measurement and analysis of human transmitted vibration; the dBFA Suite software was used to control acquisitions and to post-processing data; the triaxial accelerometers are 356A16 PCB Piezotronics. The index, middle, ring and little fingers of the right hand were pressed on the vibrant system with a constant force by placing a 250 g weight on the fingers. The room temperature was kept constant at 20 °C. Subjects sat comfortably with the elbow placed on a soft pad.

The subjects were 10 men aged 20 to 25 years. They completed a questionnaire in which they stated that they are perfectly healthy and have agreed to participate in the experiments.

The acceleration, the frequency and the exposure time were varied. The increase of one of the parameters was done gradually while the other two parameters were kept constant. When the subject reacted, we passed to a decrease of that parameter. Each subject participated in only one experiment per day. The experiments were repeated three times for each situation.

The Semmes-Weinstein test: a monofilament nylon wire exerts a 10 g force when streched against the skin for 1 second. Patients who cannot feel this pressure on the surface of their legs are considered to have lost their tactile perception. The scale used is the Likert scale (1–5). We will do this test on the finger surface. The tests were repeated three times.

The Purdue Pegboard test: it is a test of manual dexterity [3, 12]. It is recorded the number of correctly placed nails in a 30 seconds period. The tests were repeated three times.

3. RESULTS AND DISCUSSION

Subjects were exposed to vibration with accelerations of 1.2; 2.8; 5.8 and 10.5 m/s^2. The frequencies were: 4; 16; 31.5; 63; 125; 250 and 500 Hz.

In the first part of the study the subjects answered to the Semmes-Weinstein test: they gave a grade on the Likert scale (1-5) according to the reaction that they had when they were press with the monofilament wire on the fingertips. As the frequency, the acceleration and the irradiation time increase, the subject's fingers become numb and do not feel anything, so they become unable to answer the Semmes-Weinstein test. The tests were repeated three times. The results are shown in Fig. 1 (irradiation time = 10 minutes) and Fig. 2 (irradiation time = 10 min).

Figure 1 shows that subjects' fingers sensitivity decreases with the increasing of acceleration, frequency and duration of exposure, according to a law which can be approximated by:

$$\text{S.W.} = -A \cdot 10^{-8} \cdot f^3 + B \cdot 10^{-6} \cdot f^2 - C \cdot f + D, \qquad (1)$$

where A, B, C and D are constants [$A \in (-9 \div -1)$; $B \in (1 \div 9)$; $C \in (-0.03 \div -0.02)$; $D \in (4 \div 4.1)$]. For $a = 0.5$ m/s^2, after 63 Hz, the subjects do not respond to this test, because they have totally numb fingers.

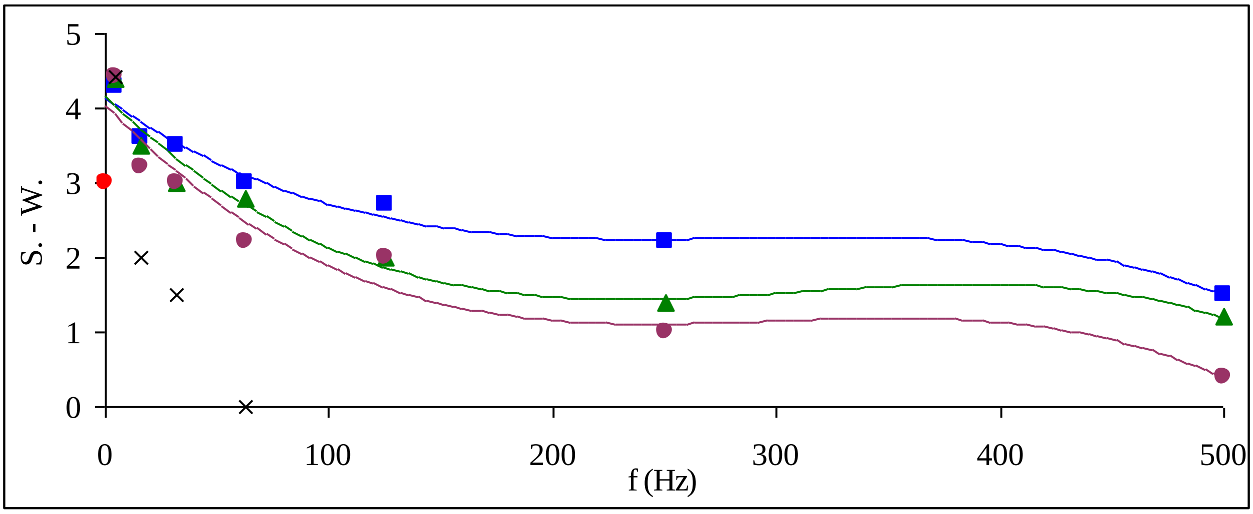

Fig. 1 – The average results of the test Semmes-Weinstein (S.-W.) for the subjects 1–10 ($t_{irradiation}$ = 10 min); (•) – reference test (without vibration):

(■)	$a = 1.2$ m/s^2	S.W.= $-9 \cdot 10^{-8} \cdot f^3 + 7 \cdot 10^{-6} \cdot f^2 - 0.0207 \cdot f + 4.1313$	$R^2 = 0.9712$
(▲)	$a = 2.8$ m/s^2	S.W.= $-1 \cdot 10^{-8} \cdot f^3 + 1 \cdot 10^{-6} \cdot f^2 - 0.029 \cdot f + 4.1538$	$R^2 = 0.9602$
(•)	$a = 5.8$ m/s^2	S.W.= $-1 \cdot 10^{-8} \cdot f^3 + 1 \cdot 10^{-6} \cdot f^2 - 0.0311 \cdot f + 4.0369$	$R^2 = 0.9404$
(X)	$a = 10.5$ m/s^2	For frequencies above 63 Hz, the subjects did not feel the monofilament.	

Figure 2 shows that the sensitivity of the subject's fingers has the same dynamic, except the fact that, having a double irradiation time, the subjects had their fingers totaly numb starting with $a = 2.8$ m/s^2 and $f =$ = 4 Hz. The only study that could be done is that for $a = 1.2$ m/s^2, the variation law being also of type (1).

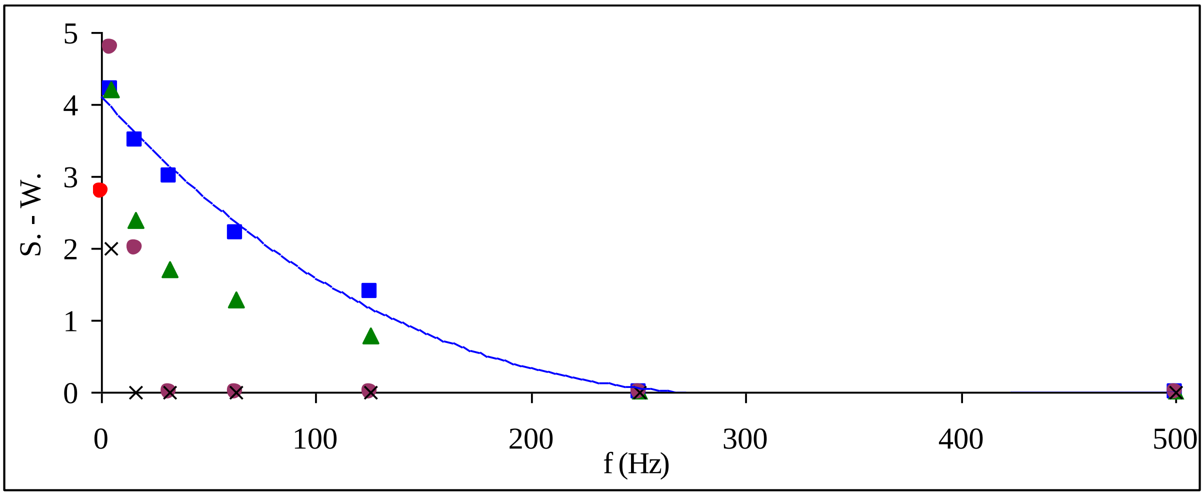

Fig. 2 – The average results of the test Semmes-Weinstein (S.-W.) for the subjects 1–10
($t_{irradiation}$ = 20 min); (•)*f* reference test (without vibration):

(■)	a = 1.2 m/s^2	S.W.= $-7\cdot10^{-8}\cdot f^3 + 8\cdot10^{-6}\cdot f^2 - 0.0328\cdot f + 4.1012$	R^2 = 0.9903
(▲)	a = 2.8 m/s^2	For frequencies above 125 Hz, the subjects did not feel the monofilament.	
(•)	a = 5.8 m/s^2	For frequencies above 16 Hz, the subjects did not feel the monofilament.	
(X)	a = 10.5 m/s^2	For frequencies above 4 Hz, the subjects did not feel the monofilament.	

In the second part of the study the subjects solved the Purdue Pegboard test, under the same types of vibration exposure. The Purdue Pegboard test uses a board with two parallel rows, each with 25 holes into which the examinee places cylindrical metal nails. There is a short briefing at the beginning of the test. The subsets for preferred, non-preferred, and both hands require the subject to place the pins in the holes as quickly as possible and the score is the number of pins placed in 30 seconds. The tests were repeated three times.

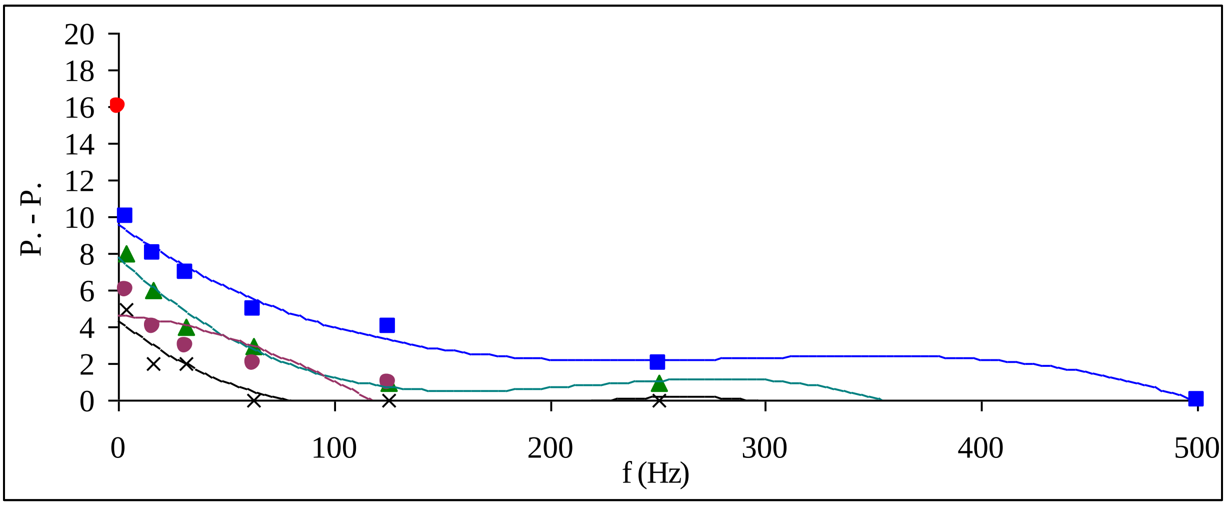

Fig. 3 – The average results of the Purdue Pegboard test for the subjects 1–10
($t_{irradiation}$ = 10 min); (•) – reference test (without vibrations):

(■)	a = 1.2 m/s^2	P.P. = $-3\cdot10^{-7}\cdot f^3 + 0.0003\cdot f^2 - 0.0818\cdot f + 9.6159$	R^2 = 0.9785
(▲)	a = 2.8 m/s^2	P.P. = $-8\cdot10^{-7}\cdot f^3 + 0.00052\cdot f^2 - 0.1122\cdot f + 7.8405$	R^2 = 0.9965
(•)	a = 5.8 m/s^2;	P.P. = $-5\cdot10^{-7}\cdot f^3 + 0.00032\cdot f^2 - 0.0081\cdot f + 4.6443$	R^2 = 0.9828
(X)	a = 10.5 m/s^2	For frequencies above 31.5 Hz, the subjects did not feel the monofilament.	

While taking this test one could notice the same reactions as with the subjects exposed to high frequencies and high accelerations vibrations. Thus, if during 10 min of irradiation the subjects were able to insert – in a 30s period – a number ranging from 1 to 20 cylindrical parts (nails) into the holes, for frequencies up to 250 Hz, for a 20 min irradiation period, the subjects were able to insert – in a 30s period – a number ranging from 1 to 6 cylindrical parts (nails) into holes, for frequencies up to 31.5 Hz.

The average results of the Purdue Pegboard test for the subjects 1–10 are shown in Fig. 3 ($t_{irradiation}$ = 10 min) and Fig. 4 ($t_{irradiation}$ = 20 min).

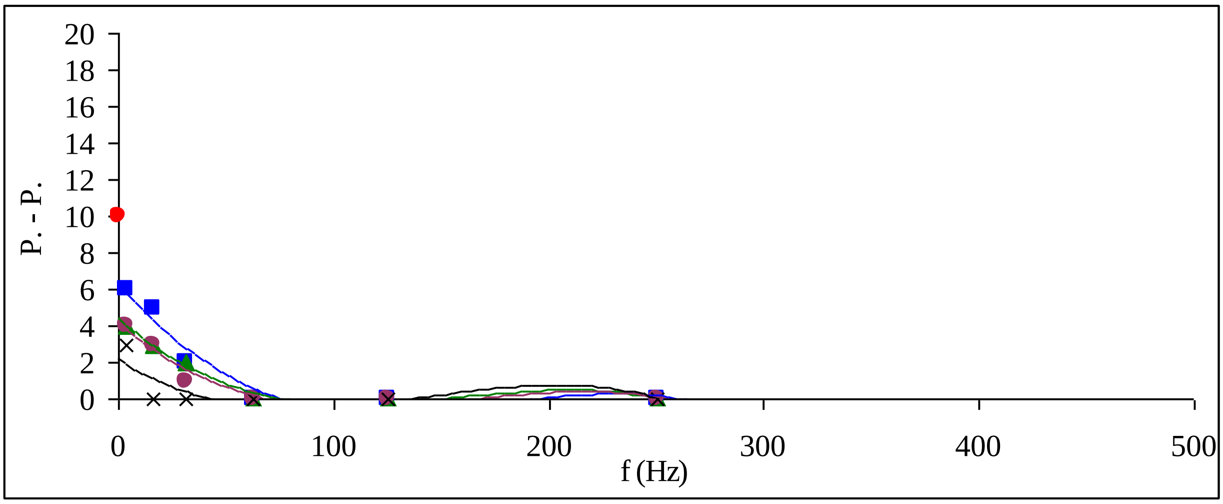

Fig. 4 – The average results of the test Purdue Pegboard for subjects 1–10 ($t_{irradiation}$ = 20 min); (•) – reference test (without vibration):

(■) a = 1.2 m/s² P.P. = $-2\cdot10^{-7}\cdot f^3 + 0.0009\cdot f^2 - 0.1399\cdot f + 6.3769$ $R^2 = 0.9992$
(▲) a = 2.8 m/s² For frequencies above 31.5 Hz, the subjects did not feel monofilament.
(•) a = 5.8 m/s² For frequencies above 31.5 Hz, the subjects did not feel monofilament.
(X) a = 10.5 m/s² For frequencies above 4 Hz, the subjects did not feel monofilament.

The analysis of the Purdue Pegboard test results during the 20 min irradiation is out of the question; the subjects' fingers were completely numb.

Table 1 shows that subjects inserted 16 nails (from 20) only at the reference test (without irradiation). After the subjects were exposed to vibrations, the number of nails inserted into the holes has decreased considerably. For a = 10.5 m/s², the subjects had numb fingers.

Table 1

Number of nails which subjects have put into the holes ($t_{irradiation}$ = 10 min)

f(Hz) / a(m/s²)	0	4	16	31.5	63	125	250	500
0 (ref)	**16**							
1.2		10	8	7	5	4	2	0
2.8		8	6	4	3	1	1	0
5.8		6	4	3	2	1	0	0
10.5		5	2	2	0	0	0	0

Table 2

Number of nails which subjects have put into the holes ($t_{irradiation}$ = 20 min)

f(Hz) / a(m/s²)	0	4	16	31.5	63	125	250	500
0 (ref)	**10**							
1.2		6	5	2	0	0	0	0
2.8		4	3	2	0	0	0	0
5.8		4	3	1	0	0	0	0
10.5		3	0	0	0	0	0	0

Table 2 shows that subjects inserted 10 nails (from 20) only at reference test (without irradiation). After the subjects were exposed to vibrations, the number of nails inserted into the holes dropped excessively.

The weighting factors for Semmes-Weinstein test results are shown in Fig. 5. It can be seen that the variation law of the weighting factors based on acceleration, can be written as:

$$WF_{SW} = -0.00004 \cdot a^3 + 0.001 \cdot a^2 - 0.0092 \cdot a - 0.0019 \quad (R^2 = 1). \tag{2}$$

The weighting factors for the Purdue Pegboard test results are shown in Fig. 5 (■). It seems that the variation law of the weighting factors based on the acceleration ($t_{\text{irradiation}}$ = 10 min) can be written as:

$$WF_{PP} = 0.0117 \cdot a^2 - 0.0657 \cdot a - 0.0198 \quad (R^2 = 1). \tag{3}$$

If we compare the variation of the weighting factors based on the acceleration for these two tests with the variation of the weighting factors based on ISO 5349-1: 2001 (Fig. 6) we can see a total discrepancy. In ISO 5349-1: 2001 the curve is exponential and is given by:

$$WF_{ISO} = 1{,}4793 e^{0{,}2502 \cdot a} \quad (R^2 = 1). \tag{4}$$

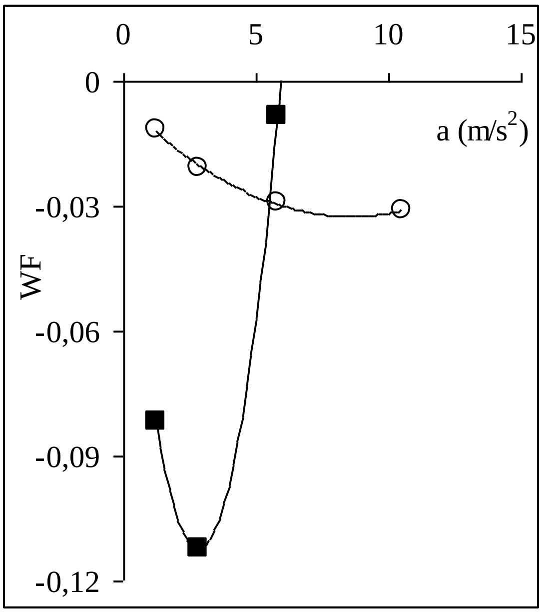

Fig. 5 – The variation of the weighting factors on acceleration for the Semmes-Weinstein test and Purdue Pegboard test ($t_{\text{irradiation}}$ = 10 min).

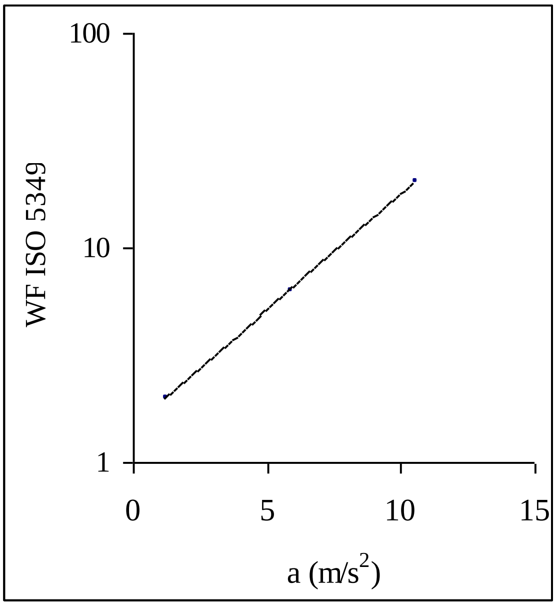

Fig. 6 – The variation of the weighting factors – ISO 5349-1:2001.

If we make a statistic of the results, we find that the subjects begin to be strongly affected by vibrations with f = 16 Hz or higher and accelerations between 2.8 and 5.8 m/s^2.

The statistical results of the Semmes-Weinstein test (Table 3) show that:

– for t = 10 min irradiation with a = 10.5 m/s^2, the subjects did not feel anything from f = 63 Hz;
– for t = 20 min irradiation with a = 2.8 m/s^2, the subjects did not feel anything from f = 125 Hz;
– for t = 20 min irradiation with a = 5.8 m/s^2, the subjects did not feel anything from f = 16 Hz;
– for t = 20 min irradiation with a = 10.5 m/s^2, the subjects did not feel anything from f = 4 Hz.

Table 3

The statistical results of the Semmes-Weinstein test

Semmes-Weinstein	4 Hz	16 Hz	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz
1.2m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min	20 min	20 min	20 min	20 min	20 min	20 min
2.8m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min	20 min	20 min	20 min			
5.8m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min						
10.5m/s^2	10 min	10 min	10 min				

The statistical results of the Purdue Pegboard test (Tab. 4) show that:
– for t = 10 min irradiation with a = 10.5 m/s^2, the subjects did not feel anything from f = 63 Hz;
– for t = 20 min irradiation with a = 2.8 m/s^2, the subjects did not feel anything from f = 16 Hz;
– for t = 20 min irradiation with a = 5.8 m/s^2, the subjects did not feel anything from f = 16 Hz;
– for t = 20 min irradiation with a = 10.5 m/s^2, the subjects did not feel anything from f = 4 Hz.

Table 4

The statistical results of the Purdue Pegboard test

Purdue Pegboard	4 Hz	16 Hz	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz
1.2 m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min	20 min	20 min	20 min	20 min	20 min	20 min
2.8 m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min						
5.8 m/s^2	10 min	10 min	10 min	10 min	10 min	10 min	10 min
	20 min						
10.5 m/s^2	10 min	10 min	10 min				

4. CONCLUSIONS

It is found that the results of the two tests almost coincide. This means that for a prolonged irradiation, with accelerations exceeding 2.8m/s^2, the subjects lose control of the fingers.

It should be noted that:

– 4 of the subjects complained of fingers numbness even in reference condition, without vibration, for t = 20min. In other words, these subjects had their fingers numb the end of the experiment in which they stood with their hands placed on the vibrating system, without it being turned on.

– absolutely all the subjects complained of pain in their hands even from f = 4 Hz, after 5–7 min of irradiation.

In conclusion, after the test Semmes-Weinstein, it is found that, for a 20 min irradiation period, the emergence of paresthesia starts even at small frequencies, of 4 Hz, for high accelerations, of 10.5 m/s^2, according to a law that can be written as (Fig. 7):

$$f = 17.401 \cdot a^{-0.3817} \qquad (R^2 = 0.9972). \qquad (5)$$

After the Purdue Pegboard test one can also come to the same conclusion, except that, in this test, the subjects had paresthesia symptoms at at even smaller frequencies. In this case, the law of occurrence of the first cases of hand numbness has a much larger error because the test involved a lot more manual work, so it was more difficult (Fig. 8):

$$f = 27.353 \cdot a^{-0.6908} \qquad (R^2 = 0.6971). \tag{6}$$

Therefore it can be concluded that, as far as the vibration perception threshold is concerned and therefore the sensitivity of the mechanoreceptors as well as the development of temporary neurological impairment, the ISO frequency weighting has no value.

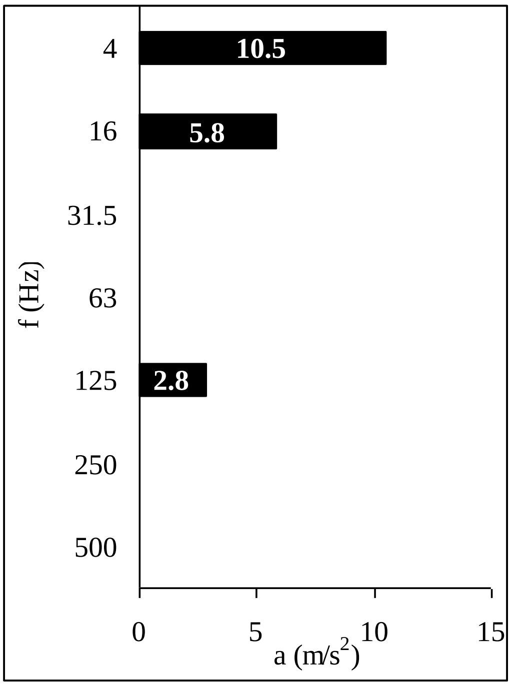

Fig. 7 – Paresthesia emergence (according to the Semmes-Weinstein test) for irradiated subjects
t = 20 min.

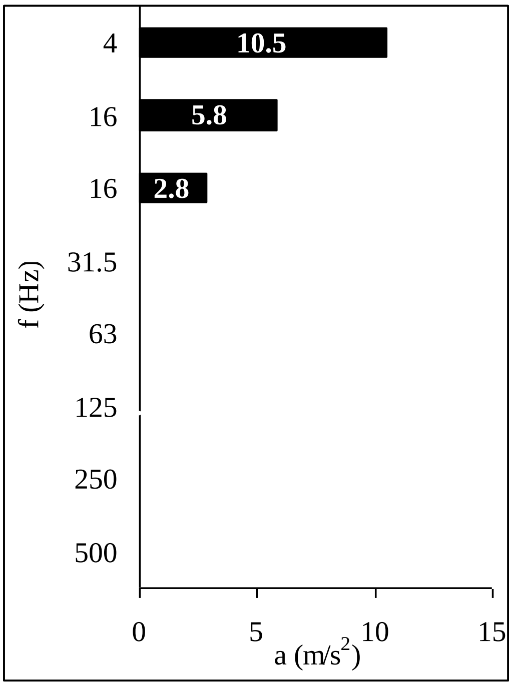

Fig. 8 – Paresthesia emergence (according to the Purdue Pegboard test) for irradiated subjects
t = 20 min.

There was an increased sensitivity of the subjects starting from low frequencies, which increases as a function of “power” and in no case as a “linear” function.

The statistical analyzes demonstrated relatively small differences between subjects for each of the two tests, but anyhow they were incidental or having no variation depending on the acceleration or on the vibration frequency.

Although the vibration experiments were extremely tediously for the subjects none of the tests can be probative. First of all the differences between subjects must be taken into consideration from all points of view. It is difficult to quantify people's reaction to some type of stress. It requires further investigation and more sensitive or appropriate tests must be discovered.

At the end of the study, a few points remain to be investigated: How to quantify the significant differences in responses between subjects? How these injuries lead/or not to permanent injury on long term? The subjects with the strongest short-term response are they most likely to develop permanent damage, as in the noise case, or the two phenomenae are independent?

REFERENCES

1. AASERUD O., JUNTUNEN J., MATIKAINEN E., *Vibration sensitivity thresholds: methodological considerations*, Acta Neurologica Scandinavica, **82**, *4*, pp. 277-283, 2009.
2. AATOLA S., FIIRKKILI M, PYYKKÖ I., KORHONEN O., STARCK J., *Measuring method for vibration perception threshold of fingers and its application to vibration exposed workers*, International Archives of Occupational and Environmental Health, **62**, *3*, pp. 239-242, 1990.
3. BANISTER P.A., SMITH F.V., *Vibration-induced white finger and manipulated dexterity*, British Journal of Industrial Medicine, **29**, pp. 264-267, 1972.

4. BORG K., *Increase of vibration threshold during wrist flexion in patients with carpal tunnel syndrome*, Pain , **26**, *2*, pp. 211-219, 1986.
5. BURRIS A., *Testosterone therapy is associated with reduced tactile sensitivity in human males*, Hormones and Behavior, **25**, *2*, pp. 195-205, 1991.
6. BURSTROM L., LUNDSTROM R., HAGBERG M., NILSSON T., *Vibrotactile Perception and Effects of Short-Term Exposure to Hand-Arm Vibration*, Annals of Occupational Hygiene, **53**, *5*, pp. 539-547, 2009.
7. EKENVALL L., GEMNE G., TEGNER R., *Correspondence between neurological symptoms and outcome of quantitative sensory testing in the hand-arm vibration syndrome,* Occupational and Environmental Medicine, **46**, *8*, pp. 570-574, 1989.
8. LUNDSTRÖM R., STRÖMBERG T., LUNDBORG G., *Vibrotactile perception threshold measurements for diagnosis of sensory neuropathy*, Int Arch Occup Environ Health, **64**, pp. 201-207, 1992.
9. MAEDA S., *Necessary Research for Standardization of Subjective Scaling of Whole-Body Vibration*, Industrial Health, **43**, *3*, pp. 390-401, 2005.
10. MALCHAIRE J, PIETTE A., RODRIGUEZ DIAZ L.S., *Temporary threshold shift of the vibration perception threshold following a short duration exposure to vibration,* Annals of Occupational Hygiene, **42**, *2*, pp. 121-1227, 1998.
11. MALCHAIRE, J., PIETTE, A., BELEM, T., LUNDSTROM, R., *Neurological and Functional Effects of Short Term Exposure to Hand-Arm Vibration*, Biomed 2 project no. BMH4-CT98-3251, 2011.
12. TIFFIN J., ASHER E.J., *The Purdue Pegboard: norms and studies of reliability and validity,* Journal of Applied Psychology, **32**, pp. 234-247, 1948.
13. WANG Y., M.J. TURNER, HEWITT W.T., *Creating a Novel Multiple-Frequency Based Vibration Built Upon Human Perception Analysis*, 2006.
14. WU J.Z., KRAJNAK K., WELCOME D.E., DONG R.G., *Analysis of the dynamic strains in a fingertip exposed to vibrations: Correlation to the mechanical stimuli on mechanoreceptors*, Journal of Biomechanics, **39**, *13*, pp. 2445-2456, 2006.
15. WU J.Z., KRAJNAK K., WELCOME D.E., DONG R.G., *Analysis of the biodynamic interaction between the fingertip and probe in the vibrotactile tests: The influences of the probe/fingertip contact orientation and static indentation*, Journal of Biomechanics, **42**, *2*, pp. 116-124, 2009.
16. * * *, *Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration*, ISO 5349-1, 2001.

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