THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2009

A STUDY ON STEVENS' POWER LAW APPLIED ON THE HUMAN PERCEPTION OF A RUNNING VEHICLE TRANSMITTED VIBRATIONS

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ABSTRACT

This paper studies the way humans perceive vibrations induced by a running vehicle, starting from Stevens' Power Law. The measurable physical magnitude was the acceleration transmitted to the hand-arm system. The measurements were made with MEASTRO 01dB. A new four components model was developed, based on the results of this experiment. The conceptual model presented included an increase in discomfort with vibration magnitude as well as an increase of discomfort with duration of exposure.

KEYWORDS: Human vibrations, Stevens' Power Law, Subjective signal.

1. Introduction

Humans interact with other humans and with the environment through senses (visual, auditory, tactilite, olfactory and gustatory). This interaction takes place on two levels: firstly, on a physical level (eyes, ears, etc.) and secondly, on a perceptual (cognition) level (the way in which the brain processes the information).

In this paper we will refer to the way humans perceive vibrations induced by a running vehicle, starting from the Stevens' Power Law (Stevens, 1957). This phenomenon takes into account two aspects: the perception magnitude and the comfort.

These phenomenons regarding the human perception of vibrations are both subjective: cannot be measured objectively in the same manner as physical vibration magnitude (in m/s^2).

In order to present these phenomenons, a group of 4 drivers were exposed to various vibration magnitudes of a running vehicle and then their opinion was recorded on a standard scale.

The measurable physical magnitude was the acceleration transmitted to the hand-arm system. The measurements were made with MEASTRO 01dB.

2. Stevens' Power Law

Through a series of experiments, Stevens found that a consistent relationship existed between the subjective magnitude of a signal (ψ) and the physical magnitude of the same signal (φ) for a wide range of input stimuli. The relationship is known as Stevens' Power Law and is given by:

$$\psi = k\varphi^{\beta} \tag{1}$$

where ψ is the perceived magnitude, k is a scaling constant, φ is the physical magnitude and β is the stimulus dependent exponent. Values of β for different input stimuli are given in below in Table 1.

Howarth and Griffin (1988) calculated the value of β from Stevens' Power Law from the bandwidth measurements 0.04 to 0.4 m/s^2 r.m.s (figure 1). Figure 1 presents the calculated values for β for the subjective magnitude of whole-body vibration in the vertical (z-axis) and lateral (y-axis) directions for nine frequencies of sinusoidal motion.

The vibration magnitude varied from 0.04 m/s^2 to 0.4 m/s^2. The results from their experiment did show a significant variation of β

Table 1: Selected representative exponents of the power functions relating subjective magnitude to stimulus magnitude (Stevens, 1957).

Stimulus	Measured exponent β	Stimulus condition
Loudness	0.67	Sound pressure of a 3 kHz tone
Vibration	0.95	Amplitude of 60 Hz on a finger
Vibration	0.60	Amplitude of 250 Hz on a finger
Brightness	0.50	Brief flash
Visual length	1.00	Projected line
Visual area	0.70	Projected square
Taste	1.40	Salt
Taste	0.80	Saccharine
Smell	0.60	Heptane
Cold	1.00	Metal contact on arm
Warmth	1.60	Metal contact on arm
Tactile roughness	1.50	Rubbing emery cloths
Tactile hardness	0.80	Squeezing rubber
Pressure on palm	1.10	Static force on skin
Heaviness	1.45	Lifted weights
Vocal effort	1.10	Vocal sound pressure
Duration	1.10	White noise
Angular acceleration	1.40	5-second rotation

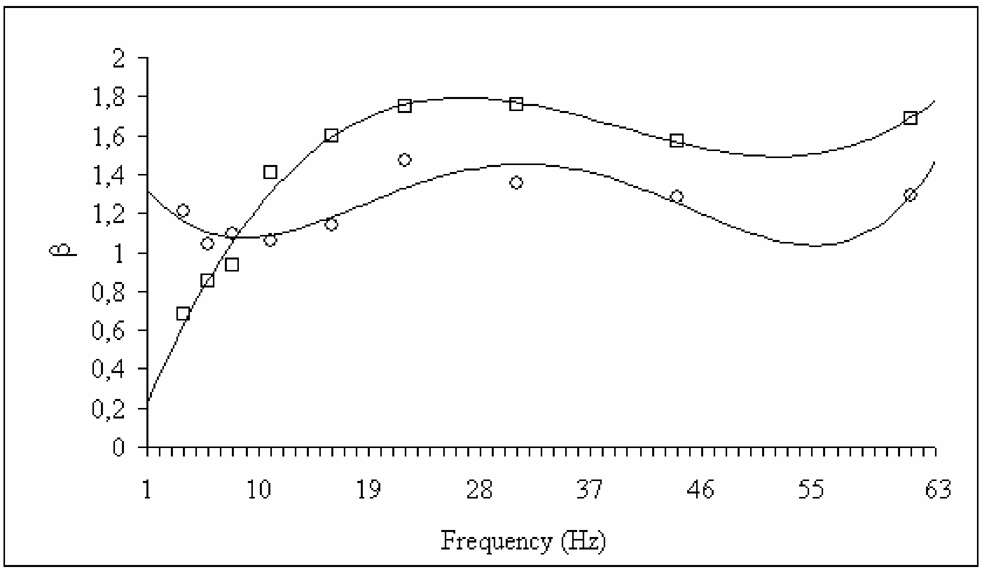


Fig. 1 Calculated value of β from Stevens' Power Law, as determined by experimentation for whole-body vibration in the magnitude range 0.04 to 0.4 m/s^2 r.m.s. (Howarth and Griffin, 1988). (O) Acceleration measured on z-axis, (€) Acceleration measured on y-axis

with frequency for the lateral vibration, but not for the vertical vibration.

3. Measurements and discussions

In this paper, hand-arm vibrations were studied on a group of 4 drivers, of approximately same driving experience, the same age (30-35 years old) and the same body weight (80-90 kg). They drove the same vehicle and followed the same route for the same time period, trying, this way to obtain almost similar experiments. The acceleration measurements were made by mounting the triaxial accelerometers.

A linear model was developed, based on the results of this experiment. The model comprises four components (by token of Mansfield and all, 2007): static discomfort (a constant for the seat), fatigue discomfort (a component which depends on time), vibration discomfort (a component which depends on the

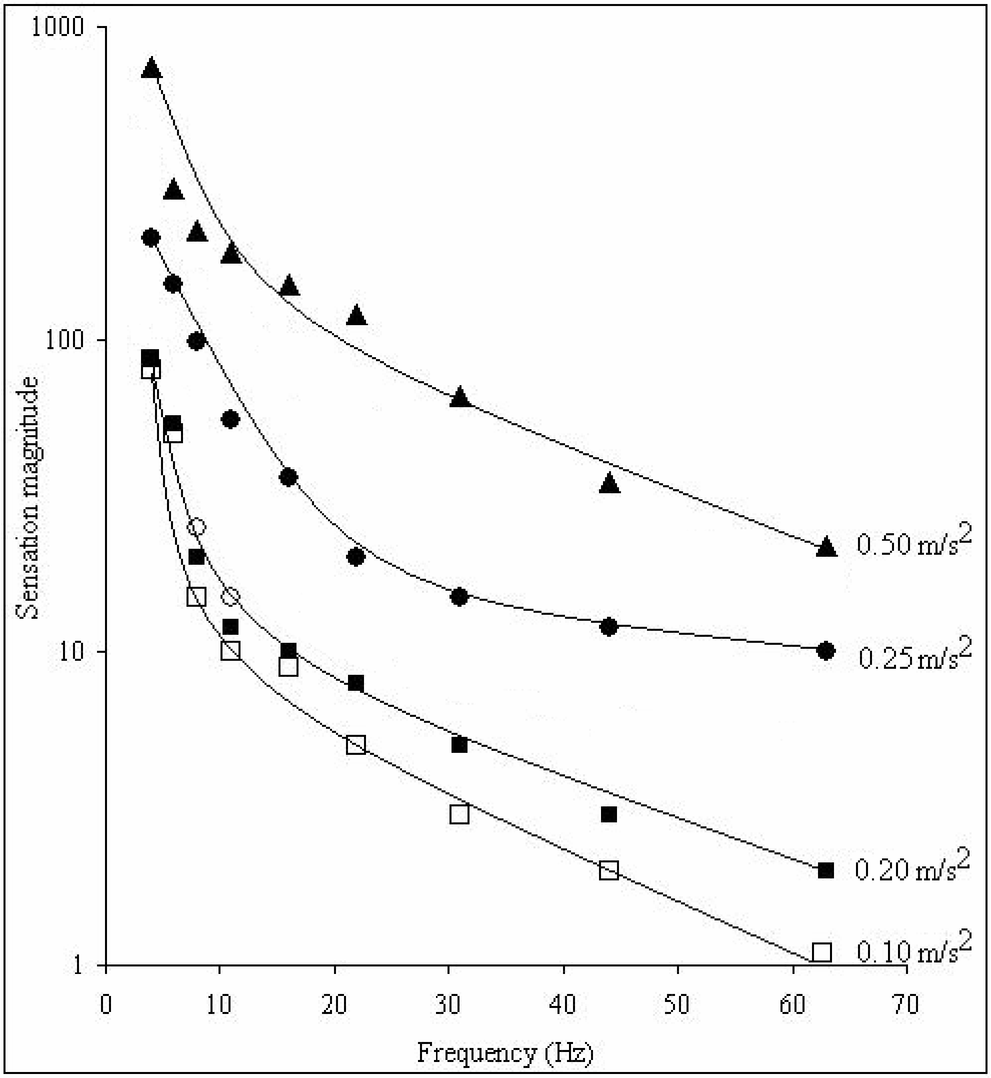


Fig. 3 Horizontal perceived acceleration magnitude corresponding to four acceleration magnitudes (0.10 to 0.50 m/s^2).

vibration magnitude) and interaction (a component of interaction between the vibration exposure and duration). These can be expressed as:

$$\psi = s_s + f_t \cdot t + d_v \cdot a + i_{tv} \cdot t \cdot a \qquad (2)$$

where ψ is the rating of discomfort, s_s is the static discomfort constant, f_t is a fatigue constant, d_v is the vibration discomfort constant, i_{tv} is an interaction variable, t is the time (min) and a is the r.s.s. acceleration. Fitting to the data obtained in this experiment: $s=1.84\psi$, $f_t=0.018\psi$ (min), $d_v=0.480\psi$(s²/m), $i_{tv}=0.010\psi$(s²/min·m).

The acceleration r.m.s measured were 0,10m/s^2, 0,20m/s^2, 0,25m/s^{2}and respectively 0,50m/s^2 at the frequency: 4 Hz, 6 Hz, 8 Hz, 11 Hz, 16 Hz, 31 Hz, 44 Hz and 63 Hz. The sensation magnitude was represented in figure 3.

In figure 3, it can be seen that the shape of the curve corresponding to a given acceleration magnitude varies with frequency, and that the effect of frequency decreases as the acceleration magnitude increases. R-squared values are: R^2=0,9843 (for 0,50m/s^2), R^2=0,9758 (for 0,25m/s^2), R^2=0,9788 (for 0,20m/s^2) and R^2=0,9855 (for 0,10m/s^2)

The conceptual model presented included an increase in discomfort with vibration magnitude as well as an increase in discomfort with duration of exposure.

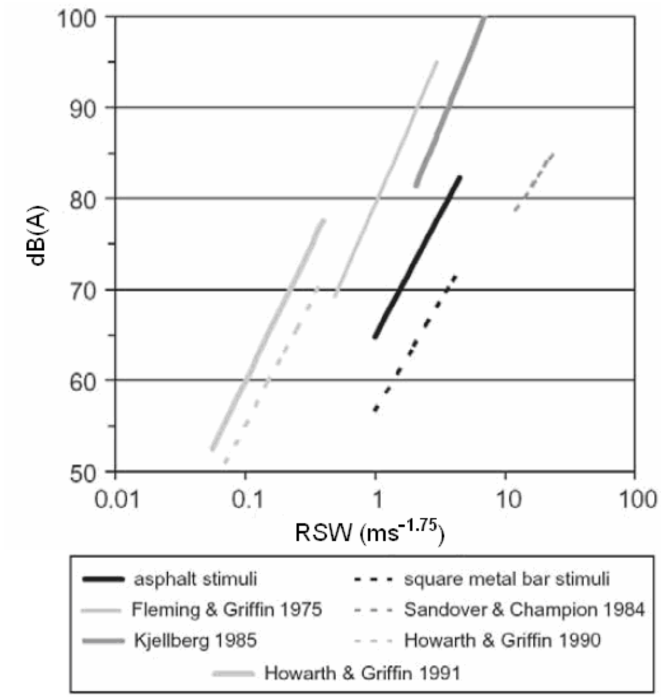


Fig. 4 Equivalence between sound (dBA) and vibration (RSW) for steering wheel rotational vibration (asphalt stimuli and square metal bar stimuli) and whole-body vibration stimuli (other lines) for a number of different studies as discussed in the test above (Giacomin and Fustes, 2005).

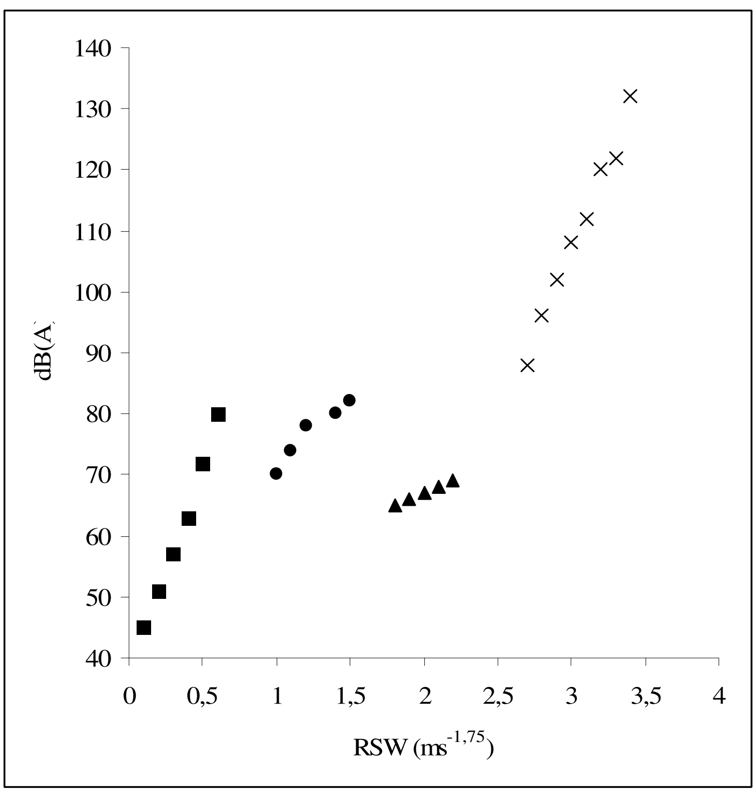


Fig. 5 Equivalence between sound (dBA) and vibration (RSW) for steering wheel rotational vibration for the four drivers

4. Interaction between the sensations induced by vibration and by sound

There is a vast majority of published works that refer to the sensations induced by vibrations, by noise and their interaction (Rimell and Hollier 1998, Hollier and Rimell and al.1999, Rimell and Hollier 1999, Rimell and Owen 2000) (figure 4). Giacomin and Fustes (2005) who studied the equivalence between the sensation induced by a rotational steering wheel vibration and sound give a good example. The authors calculated the equivalence between sound pressure level (SPL) and rotational steering wheel vibration (RSW) showing that for the smooth and coarse asphalt the SPL (in dBA) can be given by:

$$SPL = 26{,}8 \cdot lg(RSW) + 64{,}8 \text{ [dBA]} \quad (3)$$
(for the smooth asphalt)

$$SPL = 26{,}8 \cdot lg(RSW) + 64{,}8 \text{ [dBA]} \quad (4)$$
(for the coarse asphalt)

Taking into account such a model, the equivalence between the sensation induced by the rotational steering wheel vibrations and sound for the 4 drivers is presented in figure 5.From figure 5 it can be seen that the slopes of all of the results are not similar:

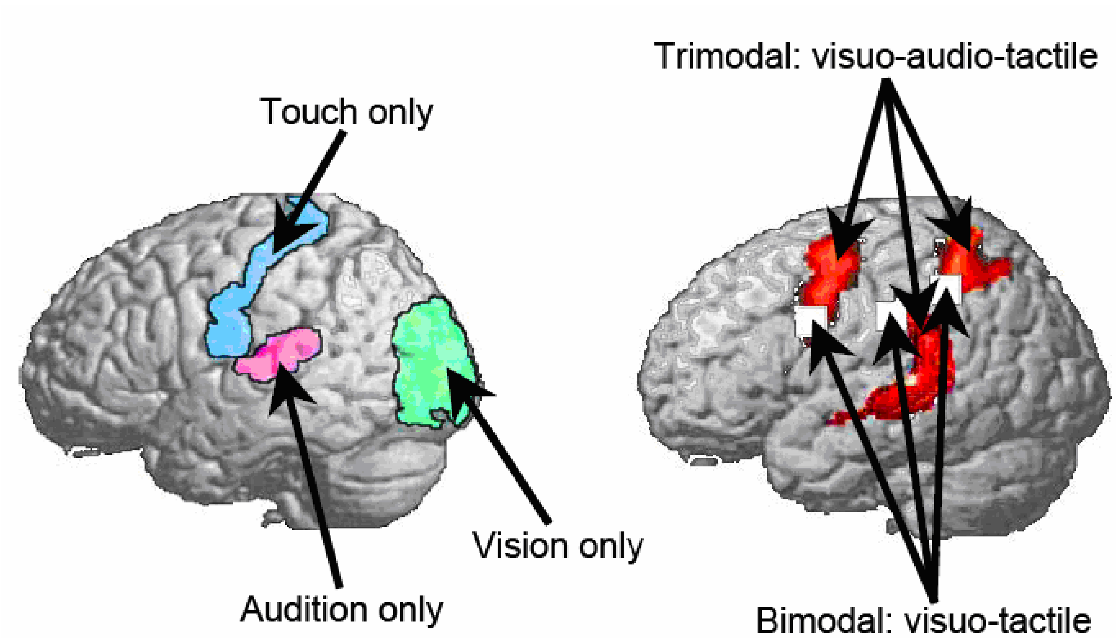
$$SPL = 69{,}714 \cdot lg(RSW) + 36{,}933 \text{ [dBA] with } R^2 = 0{,}992 \quad (5)$$

$$SPL = 22{,}326 \cdot lg(RSW) + 49{,}116 \text{ [dBA] with } R^2 = 0{,}9238 \quad (6)$$

$$SPL = 10{,}8 \cdot lg(RSW) + 45{,}46 \text{ [dBA] with } R^2 = 0{,}9352 \quad (7)$$

$$SPL = 59{,}048 \cdot lg(RSW) + 70{,}095 \text{ [dBA] with } R^2 = 0{,}9894 \quad (8)$$

The observed differences may be attributed, in part, to the different experimental configurations used.



(a) Unimodal areas (b) Multimodal areas

Fig. 6 Unimodal and multimodal brain areas, adapted from (Macaluso *and al.* 2005) and (Macaluso and Driver 2001). These diagrams show areas of the brain used for touch, vision and audition when processing single stimuli (a) and when two or three modalities are simultaneously excited (b).

5. Conclusions

Human perception of vibration is a subjective measure of the sensation these vibrations input to the body. Even if the 4 drivers used for this experiment have approximately the same age, the same physical characteristics and the measurement conditions were almost identical, the results were different. Every person has a different experience when subjected to the same stress factors.

In figure 3 it can be seen that Stevens' Power Law can be applied successfully to the measurements premises adopted for these experiments. The allowable errors for this measures range between 1,45% and 2,42 %.

Because it is difficult to find real life situations with only one stress factor it is necessarily to study all of them together.

Figure 6 presents the way in which the human brain records 3 different sensations (visual, audio and touch) separately (a) and simultaneous (b): visuo-tactile and visuo-audio-tactile.

From a biological perspective, these interactions are not yet fully understood. There were different trials to obtain a mathematical pattern (model) which could render the way in which the human subject reacts when it is subjected to more than one stress factor.

The purpose for further experimentation in this field, is to develop mathematical models of the temperature and noise influence on the human perception of vibration

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