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A CONTRIBUTION TO THE STUDY OF HUMAN SENSITIVITY TO RANDOM VIBRATIONS IN CARS WITH PAIRED COMPARISONS

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1. INTRODUCTION

Our purpose is to determine a target for vibration discomfort of a new seat. The method proposed here allows to draw for a specific car seat under development, a scale of discomfort for different domains of frequency, with the associated measurement procedure to put the new seat on this scale.

We used a single floor input, five existing seats, and 30 persons. We designed the experiment in order to draw comparisons of the different seats in the same vibrational environment *at floor level*. The paired comparisons protocol was used, with predefined subjective variables. We obtained one preference matrix for each subjective variable and the associated seat score. A regression model was derived for score prediction from adequate filtering of the RMS values of the seat dynamic response.

2. PAIRED COMPARISONS FOR VIBRATION DISCOMFORT

2.1 Feasibility of paired comparisons

Paired comparisons have been used intensively in the last twenty years in food industry, and more recently in psychoacoustics. We also have some examples of this test protocol being used for vibration discomfort [1], [3], [5]. The main advantage is the simplicity of use for non-expert subjects.

A first step was to verify the ability of non-expert subjects to express a difference of feeling for a number of subjective variables, namely *strength*, *movements*, *tiredness*, *disturbance*, *trembling*, *tingling*, and *difference*. We constructed three different sample signals, designed to be as « contrasted » as possible for the listed variables. We chose to filter a band-limited white noise (0.8 Hz - 30 Hz), 120 seconds long with three different frequency weighting functions : A) $K_1.W_b$ weigthing function (as defined in [4]) B) K_2 (flat) , and C) K_3/W_b (inverse Wb), with K_i adjusted for the same RMS value of 2 m/s^2. These three signals were grouped into two pairs : pair 1 (B-A) and pair 2 (C-B). With this choice, the flat signal (B) is « heared » twice, but with the longest separation time.

2.2 Preliminary vocabulary study

Signals are used as acceleration references at floor level for the test rig. One single seat was used, with 12 male and 10 female subjects.
The first level of analysis of the results is to draw a histogram for each preference variable. The *difference* between the samples is non zero for 95% of the responses.

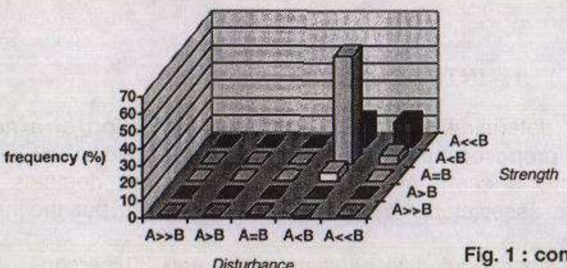

Fig. 1 : contingency diagram of *disturbance* and *strength*

The second result is obtained from the contingency diagrams, one of which is given on Fig. 1. It shows quite clearly that *disturbance* and *strength* are semantically redundant. The same tendancy is observed for *tiredness*, also redundant with *strength* and *disturbance*. On the other hand, *trembling* and *tingling* appear to be also very correlated, whereas *movements* remains alone. We then obtain three groups of semantically independant variables, namely *movements*, *trembling*, and *disturbance*. *Difference* remains a useful « utility » variable.

3. APPLICATION TO TARGET SELECTION

3.1 Construction of the signal samples

Ideally each subject should be submitted to the signals measured on all seats with a subject of equivalent mechanical impedance. However, from previous work [4], it is possible to reduce the number of signals needed, according to population characteristics. The shift in the signal level from one person to another is no longer a problem in a relative assessment as soon as the hierarchy remains the same. As a result, we defined two populations according to gender and weight : A) males up to 40^{th} centile

and females up to 60th centile, and B) all other subjects. The acceleration spectra for the five seats at subject level, using one single floor signal, were measured for a reduced number of subjects.
The collected signals, with a duration of 90 seconds each, could not be used directly in the experiments, because of the total duration implied (this could involve a biasing tiredness of the subjects). After estimating the PSD of the measured signal, this spectrum is square-rooted to define a filter (in the frequency domain) applied to a white noise of the desired duration (20 seconds). The residual discrepancies between the original spectrum and the synthetic one are less than 0.2 dB.

3.2 Test protocol

The purpose is to use one single test environment for all vibration signals, in order to minimize the influence of external causes (such as noise, smell, view, posture, accessibility, seat materials and contact, or vibrations in other directions). A non-filtering seat was built, with a transfer function modulus between 0.95 and 1.15 over the [0-30Hz] range for all people.
The test protocol was designed to enable non-expert subjects to feel comfortable with the vocabulary used. The questionaire contains four variables : *difference*, *disturbance*, *movements* and *trembling*. *Disturbance* is defined as a general feeling, purely hedonnic and subjective, and as such does not have to be related to any other variable. *Movements* and *trembling* are predefined with two white signals of twenty seconds each were used, one with a flat PSD from 1 to 8 Hz to define *movements*, the other from 8 to 18 Hz to define *trembling*, both with the same RMS value of 2 m/s^2. The subject is then submitted to all five seat signals in a row, in order to get a first glimpse over the range of signals he will have to judge. Then the actual paired comparison scheme starts. The Ross series [6] with 5 objects were used, with no repeats, no A-A pairs, and no reverse order effect test (for test duration), resulting in the following pattern : [1 2;5 3;4 1;3 2;4 5;1 3;2 4;5 1;3 4;2 5]. To collect the responses, a PC-based system was used, to avoid the large amount of paper manipulation generated by paired comparison schemes, and prevent the subject from being confused during the test.

4. ANALYSIS OF RESULTS

4.1 Consistency of judgements

The averaged histogram of *difference* (over all pairs, for 30 subjects) gives evidence of a perceived contrast (Fig. 2). This variable does not appear to be strongly correlated to the absolute value of any of the other three variables (the maximum correlation of 0.85 is obtained for pair n° 5, opposing the two seats with maximum difference of RMS value).

As was already noted in [4], the discomfort of the second stimulus is overestimated. This is clearly shown by the averaged histogram of the variable *disturbance* (Fig. 2), which is strongly dissymetrical, and whose results are therefore not usable. The histograms for the two other variables still show an order effect, but clearly less important ; they remain sufficiently reliable for further processing. A second indicator about judgements is the coefficient of agreement between subjects defined in (1) [2], with values between $-\frac{1}{n}$ and 1 (for all identical judgements).

$$(1)\ u = \frac{2\sum_{i\neq j} C^2_{\alpha_{ij}}}{C^2_n . C^2_t} - 1\text{, where } C^p_n = \frac{n!}{p!(n-p)!}.$$

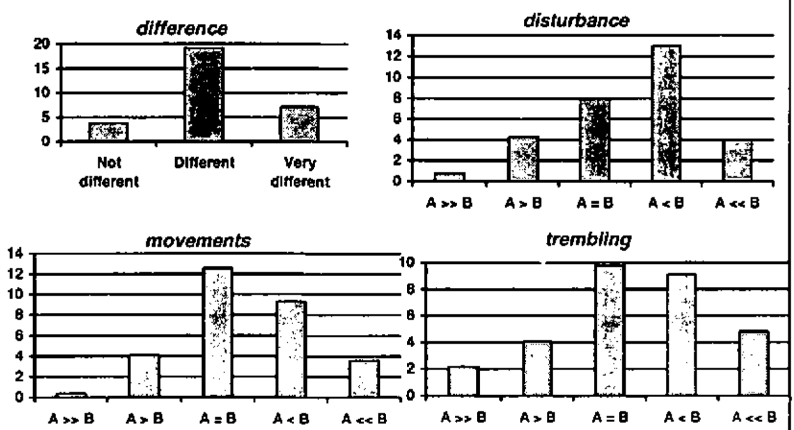

Fig. 2 : averaged histograms (10 pairs, 30 subjects) for the four variables.

(1) does not allow ties in judgements. Therefore we repeatedly replaced all zeros randomly by 1 or -1 in the matrix of judgements. The averaged u converges to provide the values in Table 1.

Table 1

	All subjects	Population A	Population B
disturbance	0.177	0.183	0.221
movements	0.195	0.237	0.132
trembling	0.278	0.287	0.303

Except for population B with *movements*, the coefficient of agreement increases for the sub-populations compared to the entire population. Whereas higher values of u indicate a good consistency *between* subjects, they do not give an idea of *self consistence* of each subject.

Therefore another usefull indicator is the number of circular triads c which is calculated from the preferences a_i with (2) [2]

$$(2)\quad c = \frac{t}{24}.(t^2-1) - \frac{1}{2}.\sum_i \left(a_i - \frac{t-1}{2}\right)^2$$

where t is the number of objects.
The preference value a_{ij} for pair i,j is calculated from (3)

$$(3)\quad a_{ij} = \frac{1}{n}\left(\alpha_{\gg} + \alpha_{>} + \frac{1}{2}\alpha_{=}\right)$$

where $\alpha_{\bullet}$ is the number of reponses with value $\bullet$ in the judgements for pair i,j. Again in our case a random choice is needed to cope with ties, and c converges to the average number of circular triads for each variable, in Table 2, from which *disturbance* appears again to be the most inconsistent variable.

	c
disturbance	2.7
movements	2.0
trembling	1.6

Table 2

4.2 Scores and scaling

The determination of scores for each seat is done only for *movements* and *trembling*. The score for object i is obtained by summation over all preferences a_{ij} given by (4) :

$$(4)\quad A_i = \sum_{j \neq i} a_{ij}$$

The least significant difference between scores is given by (5) [2]

$$(5)\quad D = 1.96 \times \sqrt{\frac{n.t}{2}} + \frac{1}{2} \text{ (with p=0.05)},$$

where n is the number of subjects.

The A_i and D have been normalized by $\frac{1}{10}n.(t-1)$ to fit between 0 and 10.

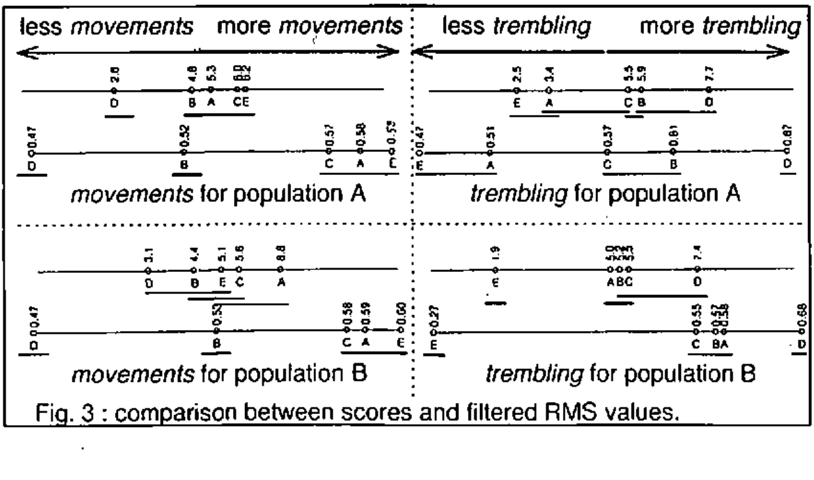

Fig. 3 : comparison between scores and filtered RMS values.

4.3 Synthesis of results

Fig. 3 gives an overview of all results, with scores for the two descriptive variables *movements* and *trembling* from the paired comparison tests (top scale) and corresponding RMS acceleration σ from measurements (in m/s^2, filtered between 2 Hz and 6 Hz, for *movements*, 6 Hz and 25 Hz for *trembling*). Any two scores (or σ) not underlined by the same line may be considered distinguishably different. These lines are obtained from the calculated D (5) for the scores, and from the 95 % confidence interval for the RMS values. The hierarchy is correctly reproduced for both variables except for the *movements* of seat E in population B. *Trembling* appears to be an excellent indicator for the 6-25 Hz hierarchy over both populations.

Table 3

	a	b	R2	F (critical : 10.1)
movements **(pop. A)**	27.1	-9.8	0.89	25.5
movements **(pop. B)**	22.1	-7.2	0.75	9.2
trembling **(pop. A)**	26.0	-9.7	0.98	214.1
trembling **(pop. B)**	12.9	-1.8	0.95	58.7

Table 3 summarizes, for each variable and population, the regression model for score prediction ($score=a.\sigma+b$ where σ is the associated band-limited RMS value), the prediction coefficient R2, and the F statistics, all showing that the only unacceptable model is *movements* with population B. These results will be used for future seats to put them on the subjective scales without repeating any of the experiments. To collect the dynamic responses in the same measurement conditions will be sufficient.

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