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EXPERIMENTAL SET-UP FOR THE MEASUREMENT OF THE PERCEIVED INTENSITY OF VIBRATIONS

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Abstract: A new experimental set up for the measurement of the perceived intensity of vibrations transmitted to a finger is presented. The related measurement procedure includes two independent tests for a jury of subjects, whose results are jointly processed to attain the corresponding scale. The requirements and the features of experimental set up realized for producing and controlling the vibration stimuli are discussed in detail. The user interfaces implemented for gather the perception responses of the subjects are also discussed and illustrated.

Keywords Perceptual measurement, hand transmitted vibration, dynamic measurement, ergonomics.

1. INTRODUCTION

The measurement of perceived features is of great importance in the user-oriented development of products and services. Key perceived features include sound or noise emission, vibrations, tactile and haptic properties. When dealing with vibrations the first concern is the safety of the user, which demands the evaluation of the impact of the mechanical action on user's health. On the other hand perceived vibrations can also affect user perception of the product, since they affects comfort, annoyance and other characteristics, not directly connected with health but still contributing to the overall quality of the living and working environment [1, 2].

When measuring a perceived property a jury of people is involved and a test modality is required to gather the results from each subject. Such measurements are critical from a theoretical and metrological standpoints and research in this area is needed [3-6]. The proper definition of a measurement scale, the design of the experiment, the selection of the test method, the processing of the results may affect the reliability of the results. In particular our interest is focused on the measurement foundations of the measurement of perceived quantities [3,7]. In this sense the authors have already carried out some research proposing a metrological validation of the measurement procedure used in the measurement of quantities related to sound perception, such as noise annoyance or perceived sound intensity [8-10].

In this paper we propose a similar approach applied to the measurement of vibration intensity as a function of frequency. In particular we will focus on:

- validation of the measurement procedures
- construction of measurement scales

The first point requires that each subject in the panel evaluates his/her perception by using at least two independent test methods, with different test modalities and informative levels. A proper comparison procedure has to be set up, so that, if the data demonstrate coherence, the validity of the measurement result is confirmed [8, 9].

As regards the measurement scale, when dealing with a new perceived quantity it is recommendable to proceed from a measurement scale with low information content, to a more informative measurement scale up to the ratio scale [10, 11]. This last point is particularly critical when an empirical addition operation is not present, as often happens for perceptual features [12, 13].

In order to achieve these two goals, we are using a double test approach. Each subject of the panel has to evaluate the perceived intensity of the same vibration stimuli with two different procedures: one focused on differences the other on ratios. In the paper we present the hardware and software set up for both the methods, with particular attention to the test modalities and user interfaces. Then we introduce the test procedure and present some preliminary but significant results.

2. TEST METHODS

We implemented two test procedures to construct a measurement scale of perceived vibration intensity: in the first test, called *interval test* the subject attention is focused on differences between stimuli; in the second test, called *magnitude estimation test*, the subject attention is focused on the ratio between stimuli.

The set of stimuli consists of six sinusoidal vibrations with fixed, in the first, or variable, in the second case, amplitudes and different frequencies between 70 Hz and 210 Hz. The frequencies were selected in order to have the possibility, within a limited number of samples, to investigate the spectral range of maximum sensitivity as reported in literature [2]. The same set of stimuli is presented to the subject in the two test procedures, but when dealing with intervals the subject will have the whole set available, while when evaluating ratios he/she will perceive only a couple of them at a time, so the perceptual space is completely different.

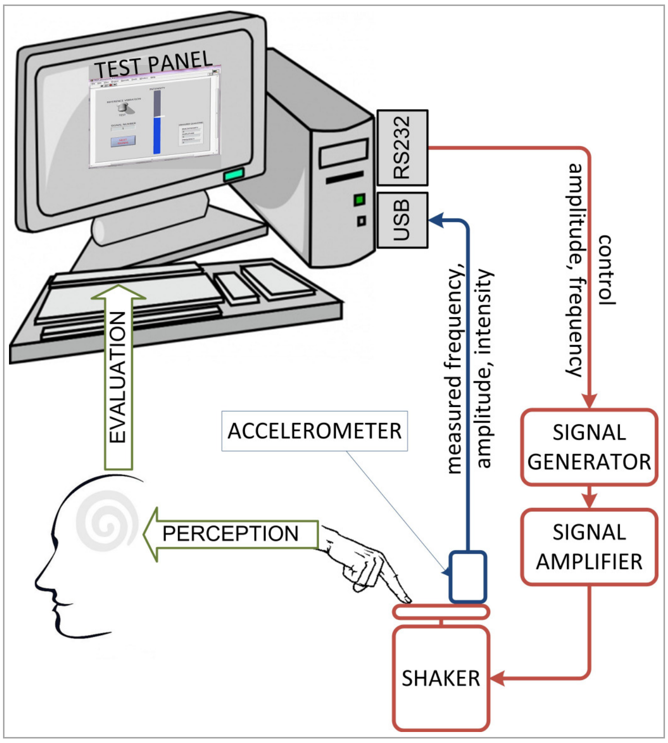

Fig.1: Test hardware configuration

2.1 Magnitude estimation test

The test is designed in such a way that each subject refers to the same fixed reference vibration, called *anchor* stimulus. The reference was selected among the same six stimuli and it is the one with the medium frequency (140Hz) in the set. Note that this frequency is not the most sensible one according to the literature, but it presents an intermediate behaviour.

As already depicted the goal in this test is to establish an equal ratio of the perceived vibration intensity between a fixed anchor at constant amplitude and frequency, and a second stimulus at different frequency, that the subject can adjust in its amplitude by moving a slider. Of course the initial amplitude of the stimulus under test will be set to a random value far different form the reference one, so that the user has to widely move the slider to find the required condition. Beside that among the six stimuli to be evaluated the subject will find also a stimulus at the same frequency of the anchor so it will be possible to evaluate the ability of the subject to determine a one to one ratio for the perception of the same vibration frequency.

2.2 Interval estimation test

In the interval test, subject has to evaluate the vibration intensity of six vibration stimuli at constant amplitude but different frequencies and without a reference. Subject's attention is focused on the perceived intensity differences. The subject is asked to place the six references on a graduated segment, with a distance between them proportional to the perceived intensity difference. The goal is to establish a perceived intensity interval scale.

The amplitude of the vibration stimuli here is set to the same level of the fixed amplitude of the anchor stimulus in the magnitude estimation test, so that we have a common stimulus amplitude between the two test methods.

2.3 Some discussion about the test methods

We can make some considerations regarding the two test methods.

Independency: the two tests even if they involve the same set of stimuli are completely different as test organisation and the final goal. In particular as regards the test organisation let's consider the perception space: the subject has the possibility to evaluate only two stimuli at a time in the magnitude estimation test even if he/she is required to obtain the same perception ratio with different couples of stimuli at different times. In the Interval estimation test he/she has the possibility to appreciate all the stimuli in the desired order with the repetitions and the sequence of presentations he/she prefers, to evaluate the differences in perception. Besides that the stimuli to be evaluated in the former case has a variable amplitude that is actively adjusted by the subject to obtain an equal perceived amplitude with a standard reference, while in the second case the stimuli present constant amplitude and they are just aligned by the subject on an interval scale and not varied in their amplitude.

It emerges that we have designed two different and independent test, or measurement, methods and we will have the opportunity to compare the results. In fact, as we will discuss in detail later, it will be possible to consider the order of the samples in the interval and magnitude test to validate an ordinal scale, while the differences in the magnitude results should present a relation with the differences in perception in the interval test.

2.4 Test set up

The hand fingers are normally used to perceive and investigate external stimuli, but fingers are also normally used to press and make force, hence an accidental stimulus modification becomes highly probable. In particular during the interval test the subject has to perceive six different stimuli at the same physical amplitude in order to be able to evaluate difference in perception only due to the different frequencies of the stimuli. Beside that we have to consider the load effect of the finger on the shaker that can alter its acceleration output while the waveform in input is the same. So we have adjusted the amplitude of the six vibration waveforms (stimuli) in order to have equal acceleration on the actuator with the finger in position. Nevertheless, since the experimental set up is based on an open loop shaker, we have experienced some acceleration variations with subjects' finger pressure or finger position on the shaker plate. In order to obtain reliable results, during the test we have recorded not only the perceived quantity produced by the subject, but also the physical acceleration measured on the shaker plate were the finger is positioned.

In the magnitude test such an approach is not required since the subject actively varies the vibration amplitude, but we have maintained the same approach to obtain perceptual and physical results from each test.

We have considered also that body posture strictly influences finger pressure and then accidental stimulus modification may happen due to the weight of hand and arm that may load the actuator. These factors may affect the reproducibility of the test, so we have designed a test procedure that provides a control on subject's position and finger pressure.

Finally another influence quantity is the acoustical noise produced by the shaker: of course it does not modify directly the intensity of vibration but it affects subject's perception, in particular subject response may be affected by the perception of the different noise frequencies during the test, so that responses may be related to the frequency content of the noise more than to the perceived intensity of vibration.

3. HARDWARE SET UP

The hardware setup is the same for the two methodologies; they mainly differ in the test panel software.

The hardware setup design has considered the instrumentation, measuring and actuator chain, and the minimization of above mentioned unwanted influence quantities.

The system presents an active channel that produces the vibration stimuli and a measurement channel that records the stimuli produced and the subject response. The following figure 1 sketches the actuation and the measurement chains, respectively in red and blue.

The test panel control software sends via RS232 the required amplitude and frequency to the signal generator, the power amplifier provides the waveform with the power required to move the shaker plate with the desired amplitude and frequency. The frequencies involved are presented in table 1.

Stimulus	1	2	3	4	5	6
Frequency [Hz]	220	100	140	170	70	90

Tab.1: Subject posture with forearm and wrist support

As previously depicted the shaker operates in open loop, so on the same shaker plate were the subject will touch with the finger, we have positioned an accelerometer, to measure the physical acceleration of the stimulus. The acceleration signal is acquired through an USB data acquisition board. The processing of this measurement signal give us a physical characterization of the vibration intensity under judgment, moreover it is possible to verify the efficiency of actuator chain.

The signal processing provides the overall rms acceleration together with its principal frequency component and amplitude. The test control software records on a file these quantities jointly with the subject perceived intensity evaluation.

During both the tests the subject seats in front of the personal computer monitor, presenting the test interface on the screen; with the right hand he/she uses the mouse to control the test, while the left forearm and wrist are positioned on a support to relief the weight, and the left index finger is in touch with the vibrating plate. With this setup, after a preliminary adjustment of the waveform levels at different frequencies, and with the proper positioning of the subject, we were able to limit the variation of the physical amplitude below the ± 5%.

4. MEASUREMENT PROCEDURE

When dealing with perception tests a strict measurement procedure is needed to obtain reliable results limiting variations due to repeatability and reproducibility effects [22]. Our test procedure requires:

- the presence of one subject only together with the instructor in the test room, to avoid pre-training on the subjects
- a standard presentation to each subject giving a clear definition of the quantity of interest, perceived vibration intensity in this case, and not related quantities such as the frequency of the stimulus, and the illustration of the test functionalities
- some functional instructions such as the finger to be positioned, and the recommendation regarding the low pressure on the plate
- the set-up of the proper position of the subject's arm on the fixture, as presented in figure 2, with the left forearm and wrist to rest horizontally, without adapting their height by moving the shoulder, with the finger reaching its position on the plate with all the arm in rest on the fixture
- the subject has to wear a worker acoustic earmuff so that he/she is able to concentrate on vibration perception without considering any acoustical distraction
- the execution of the two tests one after the other starting with the magnitude estimation test.

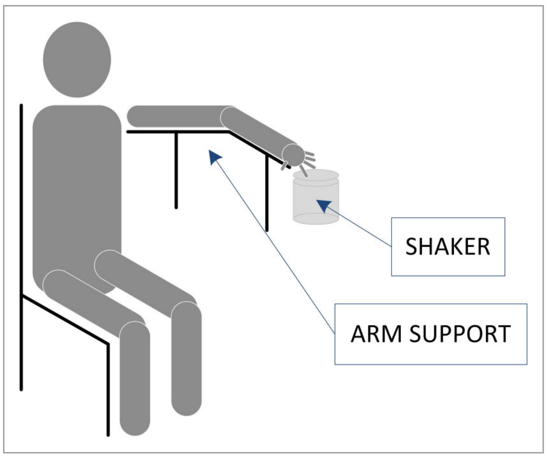

Fig.2: Subject posture with forearm and wrist support

4. USER INTERFACE

The test panel interfaces were developed in LabView ®, permitting us to have a unique program that controls the vibration stimuli production, measures the actual vibration stimuli and records the judge evaluation.

In the magnitude estimation test, two vibrating stimuli are presented at a time: one is the reference anchor , fixed for the entire test; the other is the current stimulus under test. The subject is asked to vary the intensity of the stimulus under test, by using a slider, until he perceives both stimuli of equal intensity.

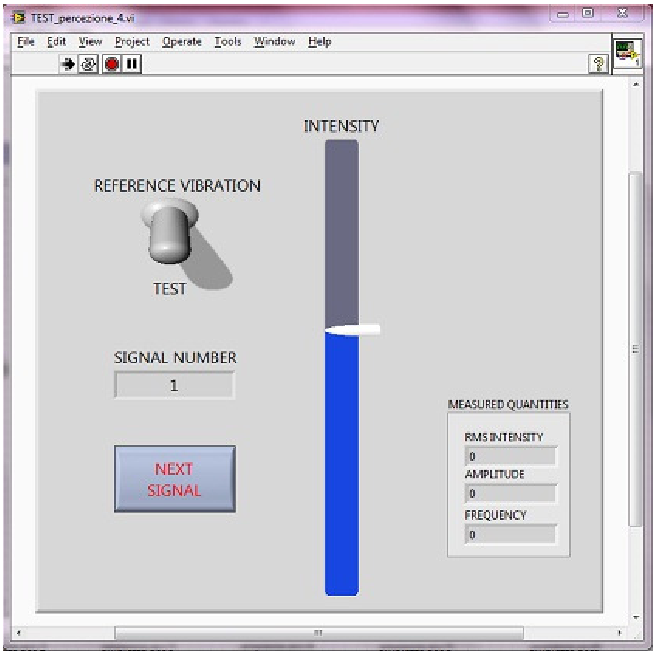

Fig.3: Magnitude estimation test interface

In the interface, shown in figure 3, subject has a toggle switch to reproduce the two stimuli as many times as he requires, and a slider to vary the intensity of the second vibration. When the subject is satisfied of the perceived equality that he/she has obtained, with the pressure of the 'Next Signal' button he/she proceeds to the next couple of stimuli to be compared until the full set of 6 couples is completed. The order of presentation of the couples is fixed as presented in table 1.

When magnitude test is completed the subject proceeds to the interval test, where he/she is asked to order the same set of six vibrating stimuli which present now the same fixed intensity but different frequencies.

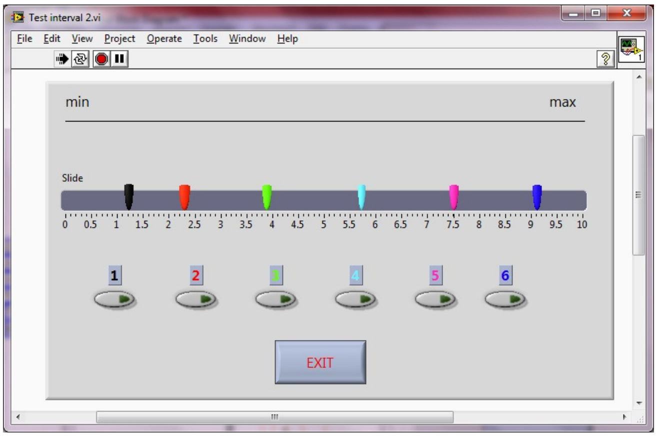

Fig.4: Interval estimation test interface

In the interface, shown in figure 4, subject has a set of ix sliders representing the six signals to order. We ask the subject to give a distance between sliders considering their perceived intensity difference. On the bottom there are six buttons to reproduce the stimuli as many times as he/she requires. The test finishes when the subject has disposed along the slide all six sliders according to his/her perception.

5. SOME PRELIMIANRY RESULTS

At the time we were presenting the final paper we had proposed the two test to a jury of 19 subjects, most of them student s of the faculty of biomedical engineering, about 23 years old. In the following we present some results considering all the subjects without adopting any exclusion policy such as coherence between the order in the perceived intensity obtained in the two tests, or consistency of the subject's results with the overall jury.

Figure 5 presents the mean perceived intensity for the magnitude (a) and interval (b)estimation tests. Bars indicate the standard deviation of the mean. In general standard deviation of the mean is 3÷10% for the magnitude estimation test and 5÷13% for the interval estimation, without considering the lowest stimulus, positioned at the minimum value, that in our interface corresponds to zero.

Since we are considering here a set of about 20 subjects this result is appreciable and it includes not only the variability due to the measurement system itself but also the one connected with differences in subjective perception among the jury. Note also that in the magnitude estimation test (figure 5a) subjects has to evaluate the perceived intensity of a stimulus with the same frequency (140Hz). In this case the stimulus under test and the anchor has the same frequency so the evaluation is particularly facilitated and this is evident in the limited variability for the stimulus at 140Hz as compared to the others.

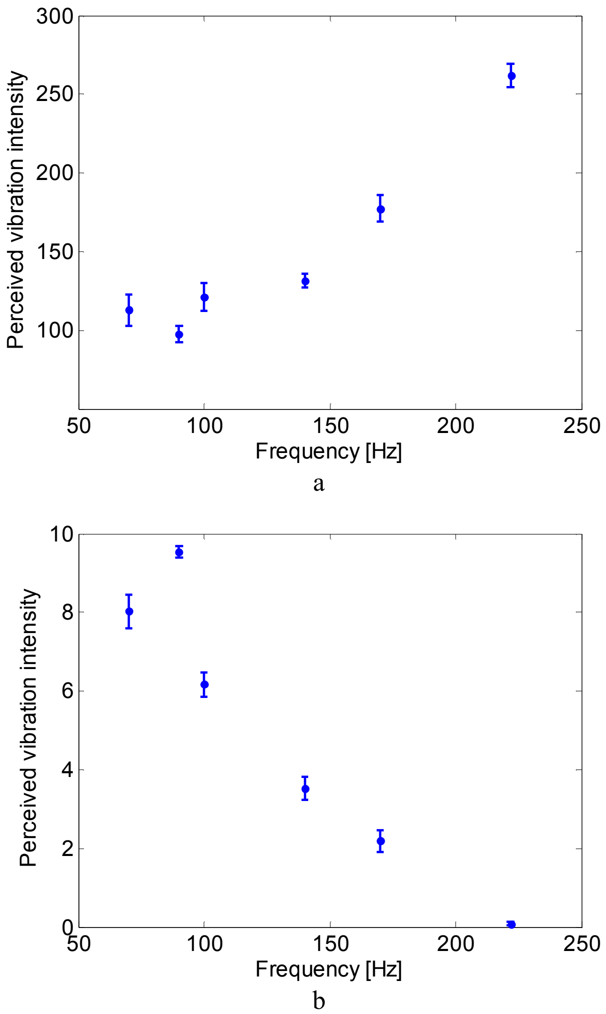

Fig.5: Preliminary results from the magnitude (a) and interval (b) estimation tests. Points show mean values, while bars indicate one standard deviation of the mean.

There is a completely different behavior for the results of the two tests. In the magnitude estimation test subject have to adjust the intensity of the stimulus under test to perceive it as intense as the anchor, for example at high frequencies when the perception is lower, the subject had to increase the level, so we obtained an upward curve (a). The inverse happens for the interval estimation, where stimuli has constant amplitude and the ones perceived as lower are positioned near the left hand side of the line, corresponding to lower values, so we obtain a downward curve (b).

Of course the two results are correlated as suggest the linear correlation coefficient of about -0.9. To obtain a positive correlation and to be able to compare the two results we have processed the magnitude estimation results, considering first of all their inverse and then normalizing the two set of results considering the anchor signal at 140 Hz, which physical amplitude was set to the same level in both the test methods. With such a normalization a comparison of the two results is now possible as presented in figure 6.

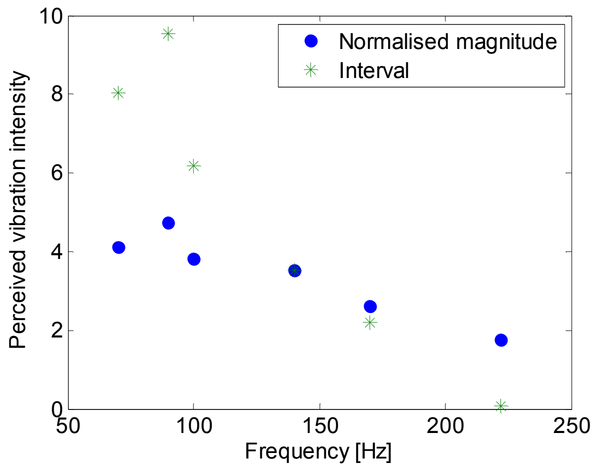

Fig.6: Normalization of the magnitude est. results, compared with the interval est. results.

Now the linear correlation between interval estimation results and the inverse of magnitude estimation results is about +0,97 indicating a strict relationship between the two measurements even if obtained with independent methods.

The linear correlation is clearly visible in figure 7 where the regression line is shown.

Finally we can note that the frequency range in which our jury was most sensible is about 90Hz. Such a result is confirmed by the literature that identifies a zone near 100Hz as the most sensible one.

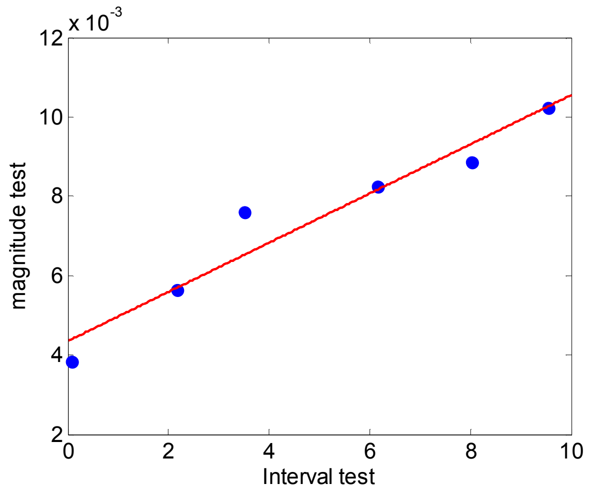

Fig.7: Linear regression of normalized magnitude estimation results vs. interval estimation results.

6. CONCLUSIONS

The measurement of perceived quantities requires a careful metrological approach for obtaining reliable, robust results that can be considered as informative as measurement results from a standard physical measurement process. The procedure here considered is quite complex but allows obtaining significant results.

We have discussed in particular the measurement of the perceived intensity of a vibration. We have investigated the behavior of intensity perception at various frequencies. We have proposed a twofold approach with two independent test set-up, or ‘measurement systems’, then we have compared the results demonstrating a good agreement confirming the possibility to “objectively” measure the perceived intensity of vibration. The standard deviation of the results shows a random variability comparable with that of some physical quantities. This seems to confirm the possibility and usefulness of a metrological approach the perceptual measurement, based on groups of persons that act as “measuring instruments” [3].

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