Dynamic Investigation Test-rig on hAptics (DITA)

2013 J. Phys.: Conf. Ser. 459 012032

(http://iopscience.iop.org/1742-6596/459/1/012032)

Dynamic Investigation Test-rig on hAptics (DITA)

F Cannella[1], L Scalise[2], E Olivieri[1], M Memeo[2] and D G Caldwell[1]

[1] Department of Advanced Robotics, Istituto Italiano di Tecnologia, via Morego, 30, 16163 Genova, ITALY

[2] Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica delle Marche, Via Brecce Bianche, 60131, Ancona, ITALY

E-mail: ferdinando.cannella@iit.it

Abstract. Research on tactile sensitivity has been conducted since the last century and many devices have been proposed to study in detail this sense through experimental tests. The sense of touch is essential in every-day life of human beings, but it can also play a fundamental role for the assessment of some neurological disabilities and pathologies. In fact, the level of tactile perception can provide information on the health state of the nervous system. In this paper, authors propose the design and development of a novel test apparatus, named DITA (Dynamic Investigation Test-rig on hAptics), aiming to provide the measurement of the tactile sensitivity trough the determination of the Just Noticeable Difference (JND) curve of a subject. The paper reports the solution adopted for the system design and the results obtained on the set of experiments carried out on volunteers.

1. Introduction

The importance of the sense of touch for human beings is universally known; everybody knows that all the physical interactions of humans with the environment generate touch sensations which are of utmost importance for the subject interactions. Up to now the evaluation of somatic sensation measurement devices used in screening exam, such as groove, Von Frey filaments or Semmes-Weinstein monofilaments, 2 or 3 points discriminator, tuning forks, are quite simple and are mostly operated by means of light touch, pain, vibration or warmth&cold sensation, directed to the human skin [1]. Even if widely used with positive results [2–6], they present a relevant limit: when used in clinical environment on patients, the variety of nervous system disorders or injuries can cause impaired tactile sensibility. Moreover, the literature shows the dependence of the test protocol on the results obtained, in fact different procedures lead to different conclusions about the prevalence of severe neuropathy, with differences ranging from 3.4% to 29.3% [7].

The aforementioned aspects led to the request of the design and development of a novel test apparatus to have a standard scale on which objectively evaluate the assessment of peripheral neuropathies. The high resolution of cutaneous sensation allows to monitor every small difference between measurements; by analyzing stimuli comparison the novel apparatus should be able to measure the acuity of the patient's sense of touch and to compare it with the standard cutaneous sensations levels.

From the previously reported observations, this paper founds its main scope which is to design and build a novel measurement system, that has been called DITA (Dynamic Investigation Test-Rig on hAptics) and is aiming to the measurement of tactile sensitivity.

The concept is based on known experimental tests widely used in haptic, the task is a well-known psychophysical method for eliciting responses from a person about his or her experiences of a stimulus where the experimental paradigms classify it as simple forced choice (also named as yes-no task) [8]. From these data the subject performance and the Just Noticeable Difference (JND) were determined. The JND, also known as the difference threshold, is the minimum difference in stimulation that a person can detect 50 percent of the times [9]. As a consequence, the objective sensitivity scale obtained from this apparatus will provide quantitative data to help the current peripheral neuropathy screening procedures, [10, 11]; 40 subjects have been tested measuring their tactile sensitivity.

2. Materials and methods

The DITA measurement system is reported in figure 1 and it is possible to observe how the fingers of the subject can be moved on a stimulus with or without array. The tactile peripherals (array and stimuli) are shown in figure 2; their values are listened in table 1 and table 2.

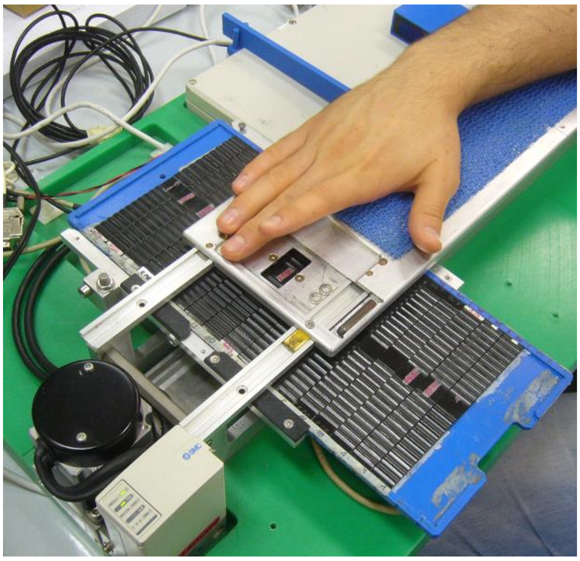

Figure 1. Dynamic Investigation Test-rig on hAptics (DITA).

Subjects' right arm rests on a metallic support where there is a non-slip surface placed (it is the blue part under the forearm); for exploring the gratings one movement along only one direction is allowed. In this work the gratings are the tactile cues and they are 17, as shown in the table 2; each of them has two elements (called stimuli) separated by a flat part, as shown in figure 2. One of the stimuli is called "reference stimuli", its wavelength is 5.09 mm and it is the same for all the gratings, the other one is called "main stimuli" and the wavelength changes depending on the grating, as shown in the table 2. The test procedure is the following: the subject slides the index fingertip along the grating beginning from the 1st stimulus and then on the 2nd stimulus. Finally the subject has to indicate which stimulus is perceived as the one with the higher spatial frequency.

In order to have a scale for determining the level of the peripheral neuropathy, 5 arrays shown in the (figure 2) are used in the experimental tests as an artificial tactile handicap. These arrays have the following pins distribution: 7x7, 9x9, 11x11, 13x13, 17x17 (respectively numbered as array number 1 up to 5) and the bare finger which corresponds to the array number 6, as shown in the table 1. A higher number of pins means that touch sensitivity is similar to the bare fingertip, while a lower number of pins means that the skin will be stimulated in fewer point than the bare fingertip thus the touch will be impaired.

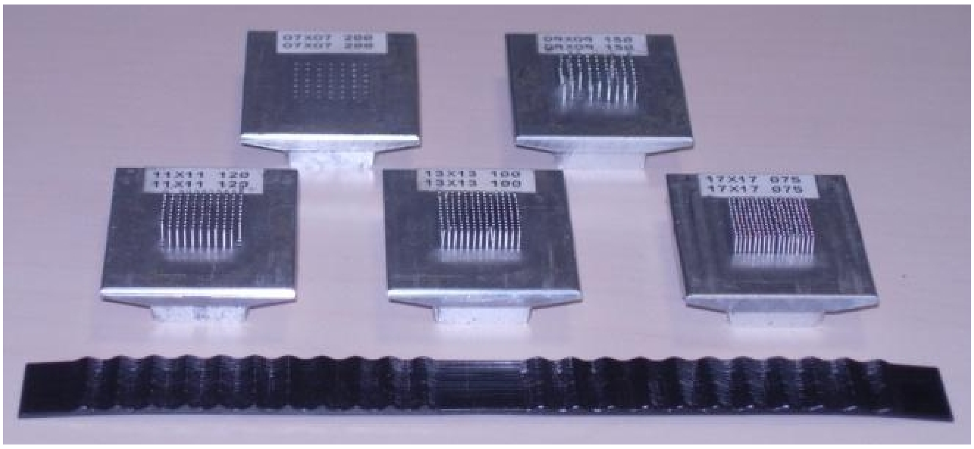

Figure 2. Tested arrays with different spatial resolution, it increases from the top left to the bottom right. On the bottom of the picture a grating is also shown.

Table 1. Array list: first column is the identification number, second is the resolutions (number of pin) and the third is the interaxis distance between pins.

Number	Resolution	Pin distance (mm)
1	7x7	2.00
2	9x9	1.50
3	11x11	1.20
4	13x13	1.00
5	17x13	0.75
6	Bare finger	No pins

3. Results

The experimental test was undertaken on 40 subjects (1 was subsequently discharged), aged 24 ±5 years; all subjects were right handed, in good physical conditions and were recruited among the student population. The testing procedure is described in details in a previous paper [10]. To improve subjects' attention on the tactile sensation, they were visually and acoustically isolated from the laboratory environment.

The analysis has been conducted with two different examinations: the first is focused on subjects' answers depending on each grating (as first or second position) and the second depends on stimulus wavelength according to the different arrays used.

Figure 3 illustrates the correlation between the correct answers and the grating stimuli difference, listed in the table 2: larger is the difference, higher is the guess rate. In fact, the best performance is where the main stimulus is 3.77 mm (–1.32 mm of difference) or 6.41 mm (+1.32 mm of difference) and worst one where the main stimulus is close to the reference (±0.33 mm). This relationship can be associated to the tactile sensitivity of the subjects. The first group of gratings has negative wavelength difference (the second stimulus explored has higher spatial frequency), that seems more perceivable. A particular mention is given for the "fake" grating where the difference is 0 mm: the two stimuli have the same wavelength, as shown in the table 2, because this grating is used for determining the "neutral" value of the subjects. Normally both the answers are given with the same rate: 50%. The non respect of this condition could be due to some tactile issues.

The percentage of correct answers related to the difference between the grating stimuli represents the psychometric function: this function typology describes the relationship between the subjective responses and a parameter of a physical stimulus. In the case of plotted stimulus wavelength, the psychometric curves have a standard profile, as shown in the figure 4. When the stimulus wavelength is near the longest value (6.41 mm) or the shortest one (3.77 mm), the correct answer percentage is near to 100. In between, around 5.09 mm, there is a transition value which represents the just noticeable difference (JND). This value is the minimum level of stimulation that a person can detect 50 percent of the time [12].

Starting from these data, it was set a global threshold referred to the highest detectable percentage (at 80%) and JND for each subject. The results are evaluated depending on two different parameters: the difference between grating stimuli, as shown in the figure 3, and the stimulus wavelength, as shown in the figure 4.

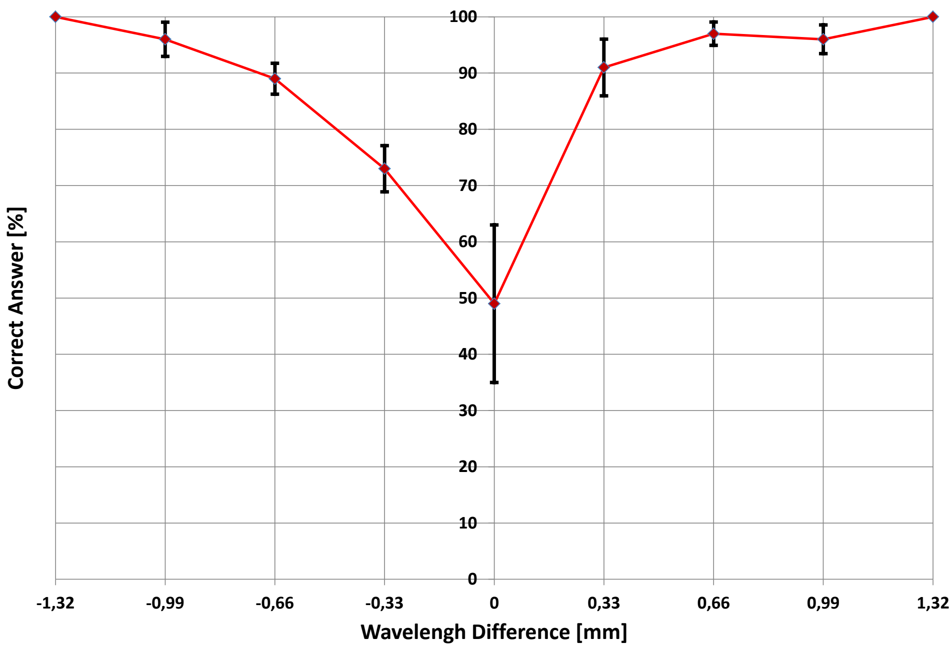

Figure 3. Correct answer depending on grating *perceptilility*, expressed as the difference between the wavelengths of the two stimuli of gratings.

The analysis conducted with the JND psychometric curves of figure 4 is different from the previous one. In this case subject classification is double because they are divided into six groups according to the different arrays and the psychometric curves are drawn for each group depending on stimulus wavelength. In statistics, the method used to investigate differences between groups and the differences variation among and between groups is the ANOVA analysis [13].

In this case the difference among groups is described with the six arrays used instead the difference between groups is dependent from the stimuli wavelength. This analysis uses the F-test with the hypothesis that the means (in this case the JND values) of these six groups are equal [13]. In JND analysis, ANOVA results show that JND values have a statistically significant difference, with accuracy of 5% ($F\text{-}test = 4.87$, $\rho = 0.001$). JND values found, for each array

Table 2. Gratings with main and reference stimuli wavelength and their difference.

Stimulus 1 (mm)	Stimulus 2 (mm)	Difference (mm)
6.41	5.09	−1.32
5.09	3.77	−1.32
6.08	5.09	−0.99
5.09	4.10	−0.99
5.75	5.09	−0.66
5.09	4.43	−0.66
5.42	5.09	−0.33
5.09	4.76	−0.33
5.09	5.09	0
5.09	5.42	0.33
4.76	5.09	0.33
5.09	5.75	0.66
4.43	5.09	0.66
5.09	6.08	0.99
4.10	5.09	0.99
5.09	6.41	1.32
3.77	5.09	1.32

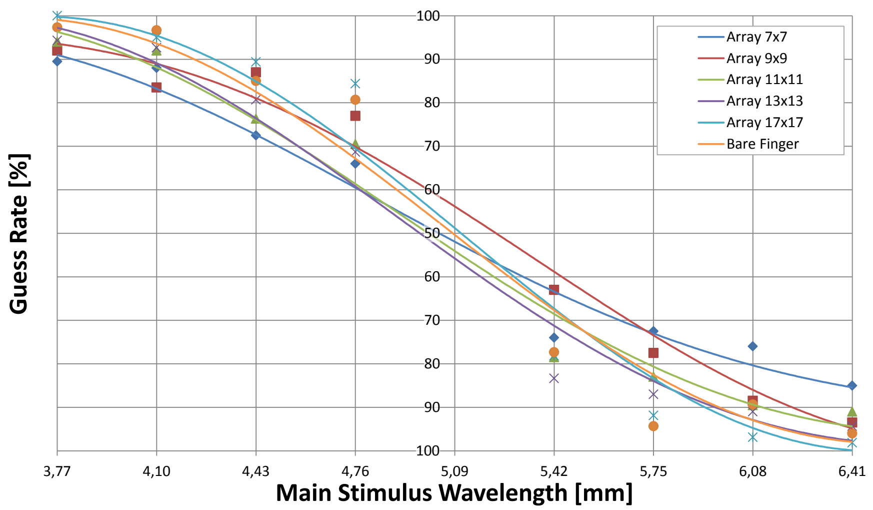

Figure 4. Psychometric curve (JND) for each array. On the x axis there is the main stimulus of the grating, in the ordinate the corresponding percentile guess rate. From 5.42 value (on x-axis), the JND values have been inverted to show the slope of the passage around the 50%.

are: *7x7* 0.49 mm, *9x9* 0.48 mm, *11x11* 0.41 mm, *13x13* 0.38 mm, *17x17* 0.34 mm, *Bare Finger* 0.33 mm.

It is also possible to use a more powerful test, the Fisher Post Hoc, in order to provide specific information on the causes of the JND difference. This test shows that the significant differences are between arrays 4, 5, 6 and 1, 2, 3. As expected, the arrays 1, 2 and 3 have worse performance than the 4, 5 and 6. No significant differences were found among bare finger and arrays 5 and 4. It is important to note that the standard deviation of JND reaches always the minimum for the array 6 (bare finger).

4. Discussion

From the aforementioned results, it is possible to derive how the accuracy of the DITA is adequate to the scope of the system and this is derivable from figure 3 and from figure 4 for the JND values; the arrays and the gratings can be distinguished (according to the analysis ANOVA).

The authors claim that a tactile sensitivity scale is determined and the subject can be compared with it in order to determine his/her own sensitivity; the overall accuracy of DITA is 9.4% (within the range 3.4-29.3% of the current medical instrumentation [7]), the main improvement is that an objective sensitivity scale is determined and then the subject test results can be stored and recorded accurately. Also, such values of accuracy are considered by the authors adequate for the measurement of the subject sensitivity. This is valuable also with reference to the well know of the scarce repeatability of the sensitivity test conducted with other methodologies.

Thus this device should be adopted to support and improve screening in diagnosis concerning the tactile perception (such as carpal tunnel syndrome, Parkinson disease, muscular dystrophy and so on).

References

[1] Brodal A *Neurological anatomy in relation to clinical medicine* Oxford Medicine Publications ISBN 9780195026948

[2] Bell-Krotoski J and Tomancik E 1987 *J Hand Surg Am* **12** 155–161

[3] Lee S, Kim H, Choi S, Park Y, Kim Y and Cho B 2003 *J. Korean Med. Sci.* **18** 103–107

[4] Keizer D, Fael D, Wierda J M and van Wijhe M 2008 *Clin J Pain* **24** 463–466

[5] Pestronk A, Florence J, Levine T, Al-Lozi M T, Lopate G, Miller T, Ramneantu I, Waheed W and Stambuk M 2004 *Neurology* **62** 461–464

[6] Keizer D, van Wijhe M, Post W J and Wierda J M 2007 *Clin J Pain* **23** 85–90

[7] McGill M, Molyneaux L, Spencer R, Heng L F and Yue D K 1999 *Diabetes Care* **22** 598–602

[8] Smith J 1969 *Journal of Verbal Learning and Verbal Behavior* **8** 633 – 636 ISSN 0022-5371 URL `http://www.sciencedirect.com/science/article/pii/S0022537169801155`

[9] Garcia-Hernandez N, Tsagarakis N and Caldwell D 2011 *Haptics, IEEE Transactions on* **4** 100–110 ISSN 1939-1412

[10] Valente M, Cannella F, Scalise L, Memeo M, Liberini P and Caldwell D 2012 *Haptics: Perception, Devices, Mobility, and Communication* (*Lecture Notes in Computer Science* vol 7282) ed Isokoski P and Springare J (Springer Berlin Heidelberg) pp 589–600 ISBN 978-3-642-31400-1 URL `http://dx.doi.org/10.1007/978-3-642-31401-8_52`

[11] Scalise L, Memeo M, Cannella F, Valente M, Caldwell D G and Tomasini E P 2012 *AIP Conference Proceedings* vol 1457 ed Tomasini E P (AIP) pp 287–293

[12] Savage C *The measurement of sensation: a critique of perceptual psychophysics* ISBN 9780520015272

[13] Mahajan B 2002 *Methods in Biostatistics* (Jaypee Brothers, Medical Publishers) ISBN 9788171795208 URL `http://books.google.it/books?id=y-F1fMHP5hgC`