Determination of the Human index force perception threshold

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***Abstract*— This paper presents an experiment measuring the force perception threshold of the human index, by studying the psychometric function of the feedback of seven subjects over their haptic sensation. This is achieved by a slow increase of the contact between a controlled pendulum and the human index. The range was chosen according to other studies, starting with an initial force of 20 mN. Two sorts of tuning were implemented in the controller, a coarse tuning which gave a threshold of 100 mN and a fine tuning which gave a threshold of 50 mN. The results obtained are of the same order, but appeared to be higher than those compiled in other works.**

I. INTRODUCTION

The questions about finger perception are various. The minimal threshold of perception of a force[1][2], presented in this paper, but also sensitivity to vibrations [3], the two-points discrimination are studies that represent key parameters in many applications or domains such as braille or tactile screens which represent a huge market. Neuroprosthetics researchers require as well such studies in order to progress further in the development of artificial limbs [4].
This present study aims at defining the human index threshold, which fits into the psychophysic domain, as it deals with the interaction between mental states and physical events and processes [5]. Here an absolute threshold is evaluated, as the subject will tell if she/he felt something or not. This was achieved by using an haptic paddle (and its related software), an academic device with which experiments were performed on 7 subjects with a defined protocol. The results were then analyzed through a psychometric function, which models the relationship between a given feature, here the perception of force, and forced-choices responses of the subjects. Then, the results were compared with other studies in which different methods and protocols were used through a t-test with a mean of 30 mN, as in King, 2010 [2].

II. EXPERIMENT

A. Equipment

The haptic paddle provided in Haptics: Human-Robot Interfaces course was used to conduct the experiment.It is a one degree of freedom haptic device controlled by a STM microcontroller with an ARM processor. It is motorized by one Maxon RE 25 DC motor with a cable transmission, and a maximum torque allowed of 0.0323 N.m, which corresponds to a peak force of 6.46 N on the paddle's arm according to the paddle's specifications[6]. The haptic paddle has one rotational DoF which, since the only measured feature is the tangential force, is sufficient for this experiment.

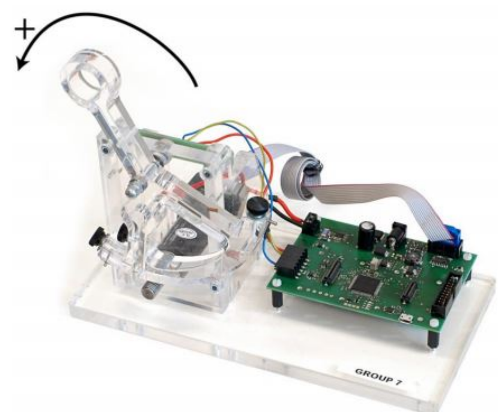


Fig. 1: Image of haptic device used[1]

B. Haptic force simulation

The aim is to apply a force on the subject fingertip. Since the haptic paddle is motorized by torque, a transformation is necessary to allow force control. Figure 3 shows a schematic of the paddle. With respect to the laws of conservation of force and momentum, the force that is applied on the subject fingertip is $-F_{ext}$. This force can be computed using the law of conservation of kinetic momentum in the static case. This yields :

$$\sum M = 0 \tag{1}$$

$$R.T_m - m_p.g.l.sin(\Phi_p) - r_{p1}.F_f - r_{p2}.F_{ext} = 0 \tag{2}$$

Where:

- T_m is the motor torque applied
- F_f is the force of friction due to the cable transmission
- R is the gear ratio motor paddle with $R = \frac{r_{p1}}{r_m}$

Equation 2 results in the following relation:

$$T_m = \frac{r_{p2}}{R}.F_{ext} + \frac{1}{R}.m_p.g.l.sin(\Phi_p) + r_m.F_f \tag{3}$$

Equation 3 shows that friction and gravity must be taken into account while implementing the control of the paddle, hence their compensation. Indeed, the compensation of the effect of friction and gravity allows the direct control of the motor torque by the force wanted to be tested.

C. Experimental setup

The experiment uses a basic setup composed of the haptic paddle, an arm support and a computer with a graphic interface for the subject to submit the answers. The combination paddle/arm support is responsible for applying force stimulus on the fingertip of the subject while guaranteeing the

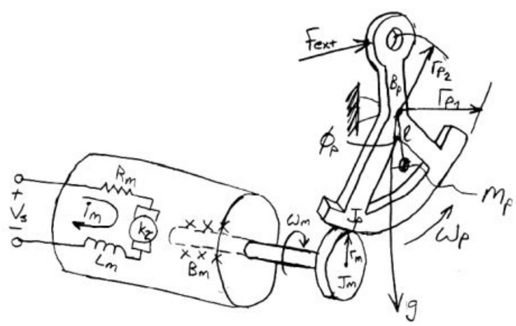


Fig. 2: Hand drawn schematic of the haptic paddle

best conditions for experimentation. Indeed, the arm support serves the purpose of keeping the participant's hand rested while being in a fixed position with respect to the paddle, with the finger always placed on the same position on this latter.

The GUI automates the experiment, so it can go much faster. It also reduces significantly the chances of an outside stimulus or information to the subject, compared to a setup where the participant is faced to an experimenter asking for his answers and recording the data which might influence the results.

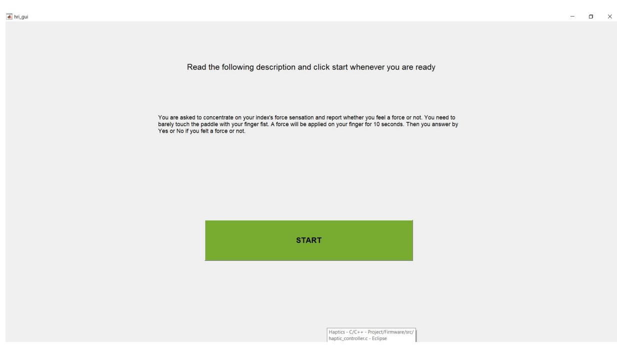


Fig. 3: The graphical used interface implemented for this experiment

D. Adaptive staircase thresholding method

The experiment takes form of a two-alternative forced choice protocol, where a force is applied on the tip of the index finger of the subject and this latter is asked to report if he felt the stimulus or not. In order to improve the fidelity of the experiment and test as much stimulus intensities as possible, an adaptive staircase thresholding method was used. This protocol adapts the force stimulus applied on the subject's finger depending on his answers.

A 2-Up 1-Down approach was adopted so that the stimulus is increased by a fraction of its value every time the participant reports a "no" answer, and is decreased by the same factor after two "yes" answers. This was also the result of tests during the design of the experiment which showed that when the stimulus intensity remains low throughout most of the experiment, the proportion of yes answers is low which doesn't yield significant results. This method increases the force applied rapidly if the subject doesn't feel the low stimulus intensities.

Moreover, in order to counter balance this rapid increase of force, two experiments were conducted where for one the stimulus was increased by 0.25 times its intensity, and for the other 0.1 times. With this protocol, the experiment yields two sets of results. The first is a coarse result where the stimulus is in a large interval of intensities. The second is a fine result where the interval of forces is smaller and the threshold yielded reflects the reality with higher fidelity.

Also, the placebo effect influences considerably the subjects answers. In order to test this influence and have data on its significance, a false stimulus was implemented. With a probability of 0.96, a stimulus intensity of 0 is applied, and the participant is asked whether he felt a force or not.

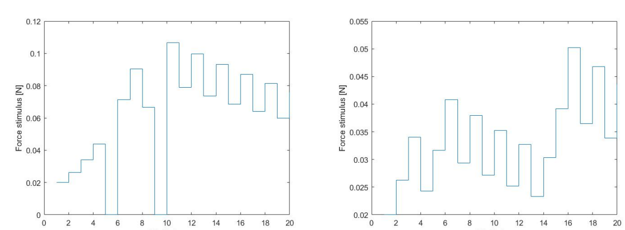
E. Experimental procedure

This experiment was performed on seven healthy right-handed subjects, 5 males and 2 females. An experimenter first explains the goal of the experiment and its protocol. The subject then places his arm on the support and is asked to barely touch the side of the paddle's arm with the tip of his index finger. When the subject is ready, he clicks on the start button in the GUI, a low reference force stimulus is applied that the participant shouldn't feel. In order to confirm this, the experimenter asks the subject if he feels a force before starting. If all the conditions are met, the experiment starts. When the subject is ready, he clicks on the go button, which applies a force stimulus on the finger in addition to the reference for a duration of 10 seconds. The stimulus intensity difference between the actual one applied and the reference one starts at 20 mN. The participant is then asked to report on the GUI if he felt a force on his finger or not by clicking on one of the yes or no buttons. Then, the same protocol is done again for a total of 20 trials. The same experiment is done again with lower variations of the stimulus. At the end, the data collected is stored in a text file for analysis.

III. RESULTS

A. Data analysis

The first step of data analysis is to study the variation of the force stimulus during the experiment according to the staircase method.



(a) First experiment (b) Second experiment

Fig. 4: Plot of an example of force variation across trials

Figure 4 shows an example of the variation of the force stimulus across the 20 trials of one subject during the two experiments. Plot 4a shows that the force increases gradually until it stabilizes around 80 mN which is predictable since the first experiment yields coarse results. Also, the two downward peaks to 0 are an example of fake stimulus. Plot 4b has the same characteristics as the first one, with an increasing force stimulus this time with a lower factor, the stimulus stabilizes after a number of trials and averages at 35 mN in this case, which also respects the fact that the second experiment yields fine results.

In order to extract meaningful information from the dataset, a number of operations were done to filter the data and classify it. First, data related to fake stimulus was removed, this will be studied later on this paper. A Matlab script was implemented to sort data and count the number of positive answers for each force stimulus. The new dataset yields the plot in figure 5, it gives meaningful information about the force threshold but it is hard to extract visual information from the plot. This is due to the fact that a staircase method is used which results in different values of force stimulus across experiments. The filtered dataset still contains a lot of different stimulus intensities associating a number of positives to each one, some of these intensities appear much frequently than others.

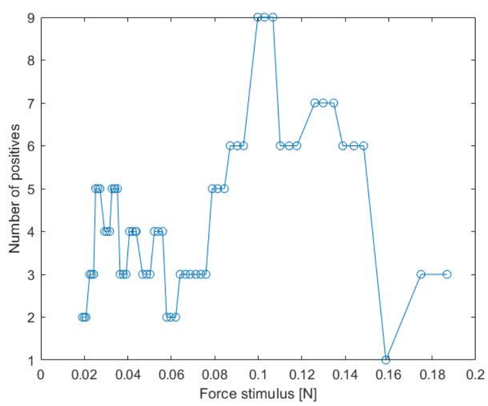
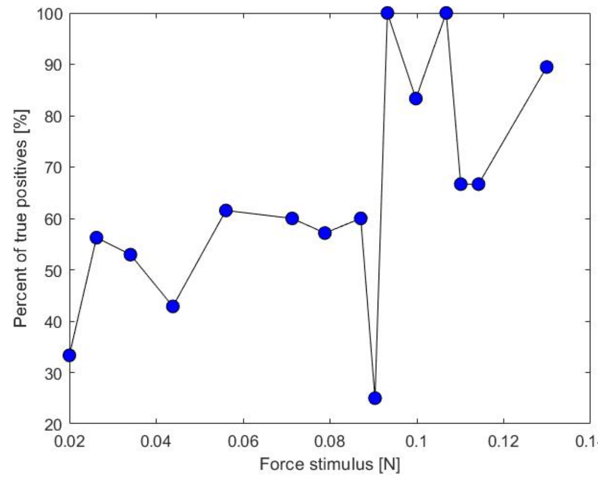


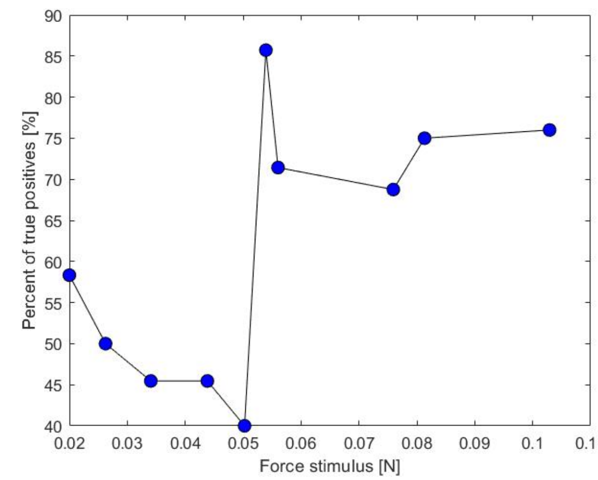
Fig. 5: Plot of number of positives depending on the force stimulus

One solution for this problem is to consider intervals of the stimulus intensity at once. This means that, instead of considering the proportion of positives for each force stimulus independently, we combine all positive answers in an interval of the stimulus. In order to implement this, a number of the most frequent values of force stimulus is selected so that only the most meaningful data is kept untouched, this number is chosen in the way that influences the least the dataset. The numbers of positives for the rest of the force values is then assigned to the closest of these most frequent stimulus intensities.

Figure 6 shows the results for the two experiments after data filtering and merging. The plots show clearly a sigmoid shape as predicted, that allows a first approximate extraction



(a) First experiment



(b) Second experiment

Fig. 6: Plot of the proportion of true positives depending on force stimulus for the two experiments

of the threshold. Indeed, figure 6a shows that the approximate threshold given by the first experiment is around 90 mN, which is three times higher than the threshold found in the literature. Concerning the second experiment, figure 6b shows that threshold of force detection is around 55 mN, which is 1.8 times higher than the known threshold. The result of the fine experiment is, hence, comparable to the results in the literature.

B. Psychometric analysis

The dataset being filtered and adapted, a psychometric approach is possible in order to pinpoint the exact resulted threshold for both experiments. The Weibull psychometric function was used to fit the data. The Weibull cumulative distribution is a standard psychometric function that fits data from a 2AFC experiment[8]. It has the general form:

$$y = 1 - (1 - g).e^{-(\frac{k.x}{t})^b} \tag{4}$$

Where:

- $k = -log(\frac{1-a}{1-g})^{\frac{1}{b}}$
- g is the probability of an answer, in this case of 2AFC this probability is 0.5.
- t is the threshold.
- a is the proportion of true positives that defines the threshold, in this case of 2-Up 1-Down staircase, a represents the proportion at which there is an equal probability of getting a yes or a no answer. This gives $a^2 = 0.5$, which results in $a = 0.5^{\frac{1}{2}} = 0.707$, so the proportion of true positives that defines the threshold is 71%.
- b determines the slope of the function.

The only parameters that have to be determined are the threshold t and the slope b. The log likelihood measure is a way to evaluate the goodness of data fitting. This measure was used to determine the best t and b that allow the Weibull function to best fit the data. The habitual form of the log likelihood measure is :

$$logLikelihood = \sum r_i.log(W_i) + (1 - r_i).log(1 - W_i) \quad (5)$$

Where:

- r_i is the subject's answer for the force stimulus i, $r_i = 1$ if the answer is yes, $r_i = 0$ if it's no.
- W_i is the value given by the Weibull function evaluated on the force stimulus i.

Since the dataset had been adapted to make the data visually meaningful, equation 5 was also adapted to yield the log likelihood of the dataset. Indeed, in this case, r_i does not represent the answer of the subject on a specific trial, but rather the number of true positives for a specific force stimulus i. Hence, the adapted form of the log likelihood measure is:

$$logLikelihood = \sum r_i.log(W_i) + (n_i - r_i).log(1 - W_i) \quad (6)$$

Where:

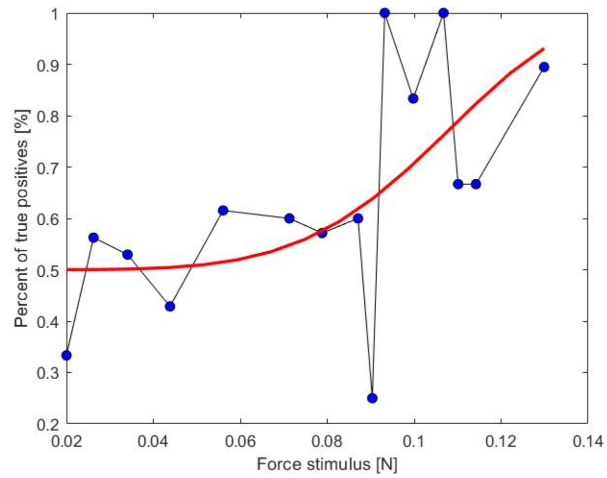
- r_i is the number of true positives for the force stimulus i.
- n_i is the total number of answers for stimulus i.

With all this at hand, a Matlab script was implemented to compute the Weibull function and its log likelihood for different combinations of threshold t and slope b. This allows to find the best combination of these values that results in the best fitting of the data. For the first experiment, the threshold found is 100 mN with a slope of 5 and a log likelihood of -84.89. Concerning the second experiment, the threshold result is 50 mN with a slope of 2 and a log likelihood of -80.68. Thus, the threshold given by the first experiment is 3.3 times higher than the one found in literature, while the threshold found by the second experiment is 1.5 times higher which is close to the known threshold. Figure 7 shows the plots of the fitted data for the first and second experiments.

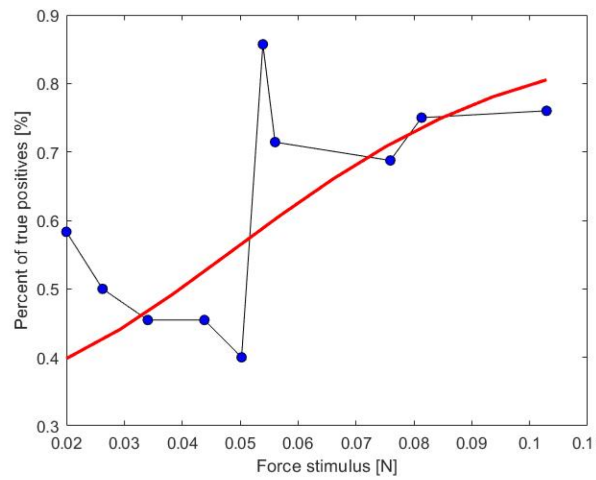
IV. Satistical analysis

A t-test was performed on the two experiences conducted, with respect to the values obtained from other studies. It allows to verify that the data collected are in accordance with other results, by doing a statistic test following a Student's t-distribution under the null hypothesis. As a new device and a new protocol are used, the study is therefore done under different conditions, and the t-test allow to compare the results of this work with existing ones. Comparing with King, 2010 [2] (mean = 33.5 mN and standard deviation = 13.5 mN), and Dosser Hannaford, 2015 (mean = 31 mN and standard deviation = 6.5 mN) [3] the t-tests validate our results by rejecting the null hypothesis at the 1% significance level, for both experiments.Note that those values were taken from the graphs computed in the cited studies.

Another tool to measure the accuracy of the proposed method to compute the threshold is to compute the sensitivity



(a) First experiment



(b) Second experiment

Fig. 7: Plot of the proportion of true positives depending on force stimulus for the two experiments with fitting Weibull psychometric function

and specificity of our data which leads to different measures such as the F-measure.

	Force increment	Force decrement
Positive prediction	TP = 56	FP = 29
Negative prediction	FN = 37	TN = 16

TABLE I: Binary classification test for the first experiment (coarse). TP stands for True Positive, FP for False Positive, FN for False Negative and TN for True negative

	Force increment	Force decrement
Positive prediction	TP = 58	FP = 31
Negative prediction	FN = 32	TN = 17

TABLE II: Binary classification test for the second experiment (fine)

The F-measures of the two experiments are computed as follows:

$$F_{measure} = \frac{2 \cdot TP}{2 \cdot TP + FP + FN} \tag{7}$$

which gives 0.629 for the first experiment and 0.648 for the second, which is acceptable, but subject to amelioration. It has to be noted that despite the protocol, human psychology has to be taken into account, and expectations of the subjects tend to get a higher share of FN or FP.

V. Discussions

The results of this experiment have shown that the human index force threshold is around 50 mN, a result that is statistically comparable with the results found in other works. The separation of experiments between a coarse and a fine tuning of the force stimulus showed that results of this kind of experiment are highly influenced by the way the force stimulus is varied across trials. Also, the values of the log likelihood were quite low, which leads to think that the dataset yielded by this experiment isn't good enough to result in a better fitting by a psychometric function. Moreover, the thresholds found in this experiment are higher than the ones found in literature, this can be explained by the choices adopted during the experiment design. Indeed, the 2-Up 1-Down staircase method chosen for varying the force stimulus might have provided more results for high stimulus intensities and not enough for the low ones which would result normally in a higher result for the threshold. Although, statistical tests showed that the results of this experiment are comparable to those of other experiments, but the accuracy evaluated by the F-measure suggests some improvements can be looked for. This could come from a different protocol, or more measurements.

For future work, increasing the size of the sample of participants as well as the number of trials might result in better results. Also, it might be a good idea to study the influence of how the force is varied across trials on the perceptual force threshold of the human index finger.

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