# Training Effects of a Visual Aid on Haptic Sensitivity in a Needle Insertion Task

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**Abstract**

This paper describes an experiment conducted to measure human's haptic sensitivity and the effects of haptic training with and without visual aid on a needle insertion task. The haptic training protocol consisted of a needle insertion task using dual-layer silicon samples. A visual aid was provided as a multimodal cue for haptic perception. Results show that for a novices' group, training with a visual aid inhibited haptic perception. Hence, haptic skills must be trained differently from visuo-motor skills.

**Keywords:** haptic perception, haptic training, needle insertion, visual aid.

**Index Terms:** H.5.2 [Information interfaces and presentation]: User Interfaces — Graphical user interfaces (GUI) —Training, help, and documentation—Ergonomics; H.1.2 [Information Systems]: User/Machine Systems—Human factors.

## 1 Introduction

Clinicians such as surgeons, nurses, radiologists or anesthesiologists rely mainly on their haptic sense during many of the examinations and procedures they carry out on a daily basis (Figure 1). Some of these procedures, such as the administration of drugs in anesthesiology or cell extraction during biopsies require percutaneous needle insertions that require a high level of haptic "sensitivity". Indeed, clinicians need to reach a target in the human body using the needle sometimes with the support of image-based technology, but usually without a real-time visual feedback during the needle insertion. Previous task analyses in interventional radiology [1] have shown that this kind of procedures depends on the clinician's knowledge of anatomy, spatial representation of the patient's body and haptic perception.

Clinicians have to train their skills to be able to perform to the given standard needed for their task. This training is usually done by several years of practice under the supervision of a more skilled clinician until their performance is rated as proficient by the experienced clinician [1].

Several studies [2], [3] have shown that surgeons are better at haptic perception tasks (measured in force and time needed to perform the task) than subjects without any previous training. In all cases, visual cues can improve the haptic perception task performance by diminishing the error rate [3][4].

The visual cue given to the subject can be of different types. For instance, Zhou et al. [3][4] used endoscopic images to inform the subjects about the position of the tool and the amount of force applied; whereas Gerovich [2] used a virtual environment where the user could see the different layers of tissue being penetrated and the real-time position of the needle in a needle-insertion task. In this paper, the research question is: can haptic sensitivity be improved in a needle insertion task using visual cues?

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Figure 1. Needle insertion in a lung biopsy procedure

## 2 Objectives and hypotheses

The goal of this study is to compare the haptic sensitivity of experts and novices during needle insertion in a dual layer silicon sample. The objective is also to quantify the effects of training with and without a visual aid for the novices in order to see if their haptic perception could be improved. The measured factors are the accuracy in reaching the second layer, the task completion time and the amount of force applied during the needle insertion.

Two participants' profiles were investigated according to their levels of expertise: (i) Experts, defined as clinicians with previous needle handling experience, and (ii) Novices, participants without any type of needle handling experience.

The following hypotheses were made:

**H1:** The experts will present better accuracy in reaching the second layer,

**H2**: The experts will apply higher forces in the needle insertion procedure during the experiment,

**H3**: Training will improve novices' haptic perception performances:

- after training without the visual aid,
- after training with the visual aid in two case scenarios:
  - With the visual aid turned on during the experiment,
  - With the visual aid turned off during the experiment.

## 3 Methodology

The previous hypotheses were tested in a controlled experiment. A visual aid was designed to provide information about the force applied by the users in real-time during the needle insertion.

### 3.1 Simulated task

The task was designed to simulate needle handling during a biopsy procedure. Tissue layers were simulated using silicon samples (Figure 2). The subjects were instructed to perforate the silicone using a 22° bevel needle (Figure 4) until they reached the middle layer of the dual-layered gel samples. This task was performed with or without a visual aid which displayed on screen the force applied on the needle in real-time (Figure 3). As the visual display was used to convey the force information to subjects during task performance, the force-vs-time graphical design presented the most direct representation of the force information, without requiring subjects to perform additional mental transformation to understand the information.

Figure 2. The dual layer silicon sample

The gel samples were made using Room Temperature Vulcanizing silicone EC00 following the procedure described in [5]. The silicon compliance was controlled by changing the dilution required for the samples creation and measured by doing a mechanical compression test with an Instron compression tester.

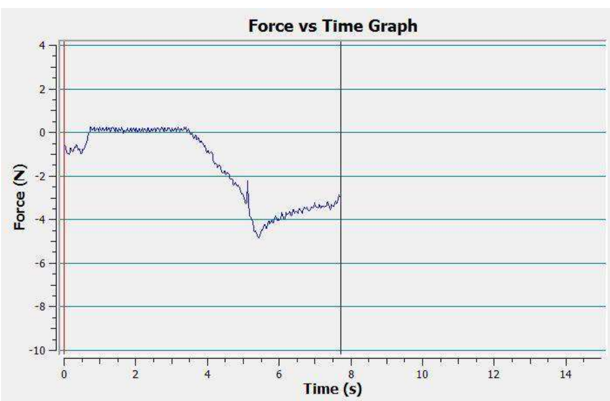


Figure 3. The visual aid based on the “WYSIWYF” paradigm: real-time plot of the force applied by the needle vs. the time

The top silicon layer was softer than the bottom layer. The difference in compliance between each two layers was always greater than the Just Noticeable Difference in compliance (JND): the “sensitivity” of the human haptic system to discriminate between different compliances [6] reported for similar silicon samples [7]. The difference between the two layers was regulated to create two values of constant difference in compliance to allow a different level of haptic perception during the trials.

The participants were instructed to halt penetration as soon as they reached the middle layer just before penetrating the second layer. This simulates a needle insertion task in biopsy when the desired target tissue is reached.

### 3.2 Apparatus

To comply with a common needle insertion task, a 22$^o$ bevel-tip needle was used. An ATI Nano 17 force sensor which has 6 DoF (3 force and 3 torque) was mounted to the handle of the needle. This permits to measure the instantaneous force that was felt by the user during the needle insertion. The sensor had an ergonomic grasping device for ease of access of the haptic needle (Figure 4).

The position of the needle was tracked using 5 OptiTrack infrared cameras (NaturalPoint Inc.). The cameras were positioned to cover the volume of movement used by the participant during his examination of the samples. A total of 4 markers were added to the handler of the haptic needle (Figure 4) to allow the visual tracking of the needle.

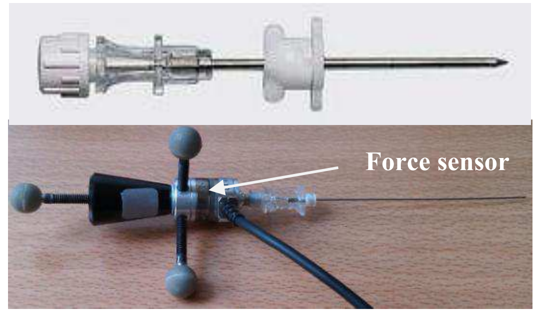


Figure 4. Biopsy (Top) and instrumented (Bottom) needles for position and force/torque measurement

To prevent participants from learning the physical position of the tissue samples and their compliance difference, a Lazy Susan with eight different heights was used (Figure 5). This allowed a fast sample changing and height variation during the experiment. The device was placed in a box (Figure 5) that had a 0.6cm hole cut into the top surface. This hole served as a guide for the needle insertion. This prevented the participants from seeing the position of the target sample, forcing them to rely only on their haptic perception (during the trials without a visual aid).

For the trials with a visual aid, the force profile was computed and displayed to the users. For that purpose, a 15 inches computer screen was placed in front of the participants so that they could match their haptic perception with the force profile displayed on the monitor (Figure 5). Data collection was managed by a real-time program in C++ using Nokia Qt GUI system.

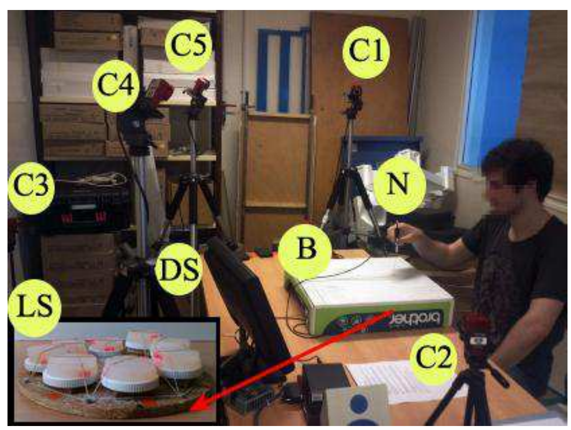


Figure 5. The experimental setup: the tracking cameras (C1-C5), the instrumented needle (N), the Lazy Susan (LS) including the 8 gel samples with different heights placed under the box (B) and the participants’ display screen (DS)

### 3.3 Experimental Design

31 participants were divided into four groups. The first group was composed of 7 experts (EXP) who were clinicians that reported experience with needles (c.f. Table 1).

24 novice subjects were undergraduate engineering students (22-35 years old). They had no previous experience with needle insertion. The novices were divided randomly into 3 groups each composed of 8 participants (C.f. Table 2). All the participants (including the EXP group) performed a pre-test session.

Table 1. Participants marked as experts

| Subjects | Age | Gender | Area of Expertise | Experience (years) |
|---|---|---|---|---|
| 1 | 49 | M | Radiologist | 18 |
| 2 | 40 | M | Nurse | 20 |
| 3 | 40 | M | Radiologist | 11 |
| 4 | 47 | F | Radiologist | 20 |
| 5 | 47 | F | Radiologist | 26 |
| 6 | 44 | M | Radiologist | 13 |
| 7 | 30 | M | Nurse | 7 |

A total of 8 dual layer silicon samples were used per trial. Each subject performed a total of 6 trials: 3 with the visual aid turned on (VA on) and 3 with the visual aid turned off (VA off). The samples were presented randomly to the subjects, while the visual aid condition was counterbalanced.

Table 2. Participants division

| Participants' groups | 1st session: Pre-test | Training Session | 3rd session: Post-test |
|---|---|---|---|
| EXP group (7 experts) | 48 (8 samples x 6 trials) | N/A | N/A |
| T-VA group (8 Novices) | | Visual aid 1h/8 samples x 10 trials | 48 (8 samples x 6 trials) |
| T-NVA group (8 Novices) | | No visual aid 1h/8 samples x 10 trials | |
| CT group (8 Novices) | | No | |

After the pre-test, two novice groups performed a training session: one group with visual aid (T-VA) and the other group without visual aid (T-NVA). The visual aid based on a "What You See Is What You Feel" (WYSIWYF) paradigm consisted of a real-time plot of the force applied by the needle vs. the time. This emphasizes the notion of puncturing and crossing the gel layers by the needle and when the middle layer was reached. After the training, a post-test was carried out, counterbalancing the use of the visual aid. The post-test was also carried out for the control group subjects (CT) but not for the EXP group. This permits to investigate whether the subjects present variations in their haptic perception after a week of their normal activities.

The totality of the experiment was carried out in a 7-day period for each participant. The pre-test was done on Day One (~30min). Training would occur 3 days later (~60min). The post-test was done on Day Seven (~20-30min).

# 4 Results

## 4.1 The effects of the training for the novices groups

A Three-way ANOVA was performed to compare the effects of the training on the 3 novices groups:

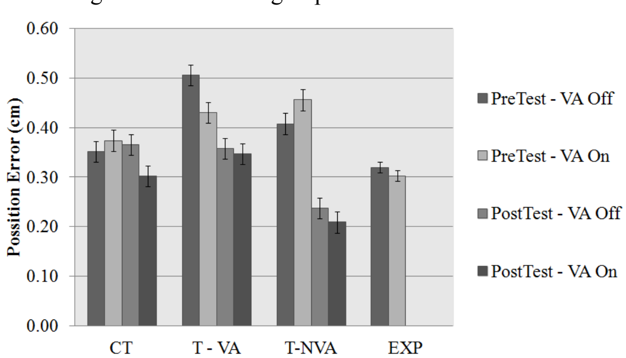


Figure 6. Position accuracy error (Mean and standard deviation)

Position error: The 3-way ANOVA shows that there were two main effects: the type of test ($F_{(1,21)}=7.33$; $p<0.05$), and the type of training ($F_{(2,21)}=12.00$; $p<0.05$). The results show that the trainees improved more their performances when compared to the control group and it is the trainees with no visual aid that performed the best during the post-trials (Figure 6).

The paired tests show that the trainees with no visual aid improved their performance after the training ($t_{(30)}=3.24$; $p<0.05$).

The paired comparisons for the post-test show that the trainees in the T-NVA group were more accurate than the trainees in the T-VA group ($t_{(30)}=2.95$; $p<0.05$) and the control group ($t_{(30)}=2.83$; $p<0.05$). No other significant differences were observed.

Amount of applied force: the ANOVA shows a main effect of the training ($F_{(2,21)}=5.63$; $p<0.05$). The paired comparisons show that the control group participants applied more forces during the pre-test as compared to the trainees groups (CTR/T-VA: $t_{(30)}=2.95$, $p<0.05$; CTR/T-NVA: $t_{(30)}=2.69$, $p<0.05$). For the post-test, the control group applied more forces than the two other groups (CTR/T-VA: $t_{(30)}=2.73$, $p<0.05$; CTR/T-NVA: $t_{(30)}=2.12$, $p<0.05$). The paired tests show that the trainees with no visual aid applied more forces after the training ($t_{(30)}=2.46$; $p<0.05$). No other significant differences were observed (Figure 7).

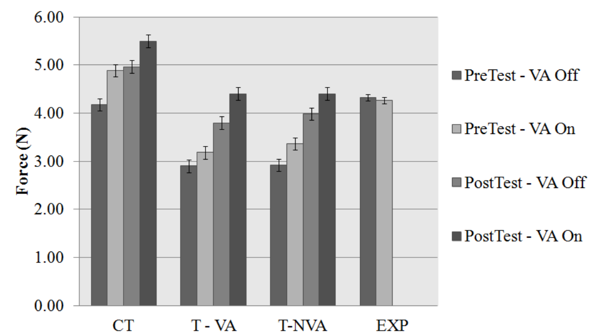


Figure 7. Average applied Force (Mean and standard deviation)

Completion time: The 3-way ANOVA shows no significant differences for the task completion time.

## 4.2 The effects of the expertise level

To compare the experts and the trainee's groups, a set of 12 pair wise tests were done with a Bonferroni adjustment of 0.00416 to avoid inflated type 1 errors. The tests were used to compare the experts' performance (accuracy and forces) in the pre-test with (1) novices' performance in the pre-test and (2) novices' performance in the post-test. The p-values are presented on Table 3.

Table 3: P-values for pair wise tests (* refers to significant values)

| | | | Accuracy | Force |
|---|---|---|---|---|
| **Comparisons** | **Test** | **Visual aid** | P | P |
| **EXP/CTR** | Pre | Off | 0.219 | <0.001* |
| | | On | 0.794 | 0.303 |
| | Post | Off | 0.359 | 0.076 |
| | | On | 0.88 | <0.001* |
| **EXP/T-VA** | Pre | Off | <0.001* | 0.559 |
| | | On | <0.001* | 0.045 |
| | Post | Off | 0.004 | 0.588 |
| | | On | 0.999 | 0.234 |
| **EXP/T-NVA** | Pre | Off | <0.001* | 0.063 |
| | | On | <0.001* | 0.003* |
| | Post | Off | 0.003* | 0.012 |
| | | On | <0.001* | <0.001* |

Accuracy: The results show that the experts had a better accuracy for detecting the second layer than the training groups;

For the post-test, no significant differences were observed between the T-VA group and the experts. This means that the trainees, after the visual training, reached the same level of accuracy than the experts. On the other hand, the trainees in the T-NVA group improved their accuracy as compared to the experts.

Applied forces: No significant differences were found between both training groups participants and the experts' group for the average applied forces during both the pre-test and the post-test, except the T-NVA group during the pre-test which applied lower level of forces as compared to the experts (Table 3).

## 5 Discussion

This study presents a new training method for haptic perception in a needle insertion procedure using a visual cue.

The results of the experimental study suggest that when the participants received the visual aid for the first time, they could see the direct link between the force they applied and the graph plotted on the screen. However, they did not seem to understand the relationship between the crossing of the layers and the observed or sensed force since no explanation of how to interpret the visual aid was given during the first trial.

Participants that did not receive training did not improve their results, whereas both training groups improved significantly their results after their training. This result validates the hypothesis of training haptic perception (**H3**).

Time to completion of the task was not taken as a significant variable for the analysis of the test since clinicians do not prioritize the time to completion before the accuracy of the needle insertion task. Nevertheless, the time to completion was smaller for the training with visual aid group compared to the training without the visual aid group. However, the position accuracy performance for the training with visual aid was worse than the training without the visual aid group performance.

Previous researches [2][3] showed that the visuals cues can improve the haptic perception. However, the visual cues used in these studies require subjects to perform additional mental transformation to understand the haptic information. The visual aid proposed in this study as a multimodal system and a direct representation of the force information. The results show that the visual training creates a visual perceptual dependency that can inhibit haptic perceptual sensibility. Hence, the visual training in its actual form decreased the accuracy as compared with the training without the visual aid.

The comparisons between the experts' and the novices' groups confirms that without any training the experts have a better accuracy and apply higher forces than the novices. This validates our hypotheses **H1** and **H2**. As the experts made comments on the setup and compared it to their actual activity during the experiment, the completion time was not considered as a performance measure. After the training, novices achieved a level of performance comparable to that of experts. This confirms that haptic perception can be improved after training.

Finally, participants that did not have visual cue training showed a preference to ignore the visual aid by focusing their attention on the needle and the task. Clinicians also commented that they preferred to perform the tests without the use of the visual aid and they would focus more in the movements of the needle and their haptic perception.

## 6 Improvements and future work

Some modifications to the experimental setup were proposed by the clinicians, such as using a needle that was not as sharp or with a different angle in the needle tip so that the interaction between the silicon layers and the needle would be enhanced and the force perception would be higher. The nurses that had experience on intravenous needle insertion commented that the needle approach used by their area of expertise is an approach of 30° or 40° and not a 90°. This suggested that future needle insertion tests have to be expertise task specific and not only needle insertion related.

The radiologists commented on the elasticity of the silicone samples while trying to compare the samples with skin tissue, saying that their lack of elasticity augmented the pressure felt during the needle insertion. They also reported that the instrumentation of the needles with sensors make it heavier as compared with the actual needles. These changes in the task setup as compared to the radiologists' usual activities, affected undeniably their performances which could be better if the setup was closer to their actual environment.

Overall the trained groups improved their performances at the same levels than the experts. This suggests that haptic sensitivity, even with a less than ideal interface, can be improved with training.

This research shows that the training aid used during this study is not ideal for training haptic skills. Ideally, haptic skills should be trained without modalities that can interfere with haptic perception, such as the actual visual aid. In the future, we plan to investigate other training modalities such as vibrotactile feedback. This kind of information is expected to be more coherent with the haptic perception.

Finally, if an aid is deemed necessary, it should be evaluated for its effectiveness in the actual environment such as the operating room when the visual aid is not necessarily available.

## 7 Acknowledgements

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