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Vibro-Band – Supporting Needle Placement for Physicians with Vibrations

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Abstract

Medical images and navigation systems support physicians during needle-based interventions. As the information is primarily displayed on monitors, the physician's attention is drawn away from the patient's body. To address this issue, we explore the additional use of a vibration wristband that directs the movements for needle-based operations via different vibration patterns on the operator's arm. We conducted a first user study comparing the combination of tactile and visual guidance versus visual-only feedback with 12 participants to investigate the general feasibility. Our results show that task times, usability scores, cognitive load, and accuracy are comparable for both conditions suggesting that vibration feedback is generally suitable for medical navigation tasks and warranting further iteration and research in this direction.

Author Keywords

Vibration; Tactile; Task Load; Needle-Based Intervention; SUS; Wrist-band; User Study

ACM Classification Keywords

H.5.m [Information Interfaces and Presentation (e.g. HCI)]: Miscellaneous; H.5.2 [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces; J.3 [Life and Medical Sciences]: Medical Information Systems

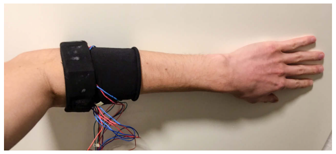

Figure 1: The vibro-band

Introduction

Advancements in imaging technology enable physicians nowadays to gather detailed information to precisely plan their steps ahead of the intervention. With the help of modern navigation systems, which present information on monitors, surgeons can now safely perform difficult surgeries, which used to be too risky or impossible [14]. But the navigational information on the monitor competes with the patient for the physician's visual attention and the amount of information is cognitively demanding. As our skin is highly sensitive to tactile stimuli, it seems feasible to employ tactile feedback as an additional complementary modality. The aim of the work presented in this paper is to allow physicians to focus their visual attention on the patient while the navigational information is presented via the skin. However, potential side-effects and problems such as interfering with the precise motions required for conducting interventions need to be investigated before any further developments.

With vibro-band, a "wrist band" with eight vibration motors, tactile information for placing a needle, e.g., for biopsies, can be presented on the physician's arm, while the physician can concentrate the visual attention on the patient and the insertion point. To the best of our knowledge vibration has not been used in this setting before. In this work, we present a first investigation towards the feasibility of the approach. We investigate: (1) if participants can integrate the tactile navigation information with the visual navigation information for needle placement, (2) if they can correctly identify the vibrating motor, (3) if vibrations disrupt their performance for fine motor skills. We conducted a user study with two conditions: visual-only versus vibro-band and visual feedback combined. The results show that there were no significant differences in needle placement performance. Participants were successful in correctly identifying directions and fine motor skills were not affected. Our results suggest that tactile feedback is applicable in this use context, which opens the research space for further investigations.

Related Work

The support of navigation in surgery [14] is a relevant topic at the intersection of human-computer interaction (HCI) and medical research.

Various approaches have been developed to support surgical navigation. Different devices have been evaluated to realize overlaying the navigational information onto the view of the operator by using augmented (AR) or mixed reality (MR), e.g., head-mounted displays (HMDs), tablet computers [3, 16, 13] or projection [4]. Other works provide navigational information within the operator's field of view by utilizing instrument-mounted displays (IMDs) [8, 12] or by feeding the information directly into video streams [6]. Audio, i.e., sonification of navigational information, has also been tried as an alternative modality [5].

Monitor-based solutions generally suffer from the problem that the surgeon has to split visual attention between the patient and the location of the display. HMDs can be uncomfortable and taxing to wear for the operator, and HMDs and IMDs add additional weight and can suffer from problems with glasses, tracking systems, or difficult lighting conditions. The latter is also a problem for projections.

Tactile stimuli have been successfully investigated as an alternative modality for conveying information outside the OR. Examples for wristband or watch-like devices are the Skin Drag Display by Ion et al. [10], BrushTouch by Strasnick et al. [15], or HaptiColor by Carcedo et al. [2]. The prototype of Ion et al. drags a tactor across the skin, creating a tactile stimulus as well as a stretching stimulus, leading to better shape recognition. BrushTouch substituted the common vibration motors with brushes and showed that certain cues can be more accurately recognized with brushes than with vibrations. The goal of the HaptiColor wristband is to "show"

Prototype Specification

- 8 vibration motors
  - 8 x 3.4 mm & 8 g
  - vibration amplitude (3 V): 0.75 g
  - speed (3 V): 12000 rpm
- Arduino Due
- soft & stretchable material to fit different arm diameters

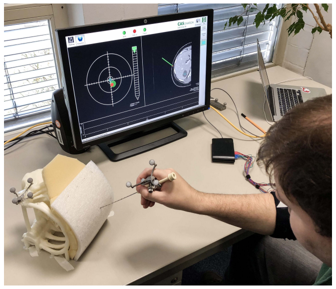

Figure 2: Study setup with monitor, model and vibro-band on the right arm.

colors to colorblind people with a combination of vibration location and intensity. This method of conveying information is also called “tactile display”. A review on tactile displays was done by Jones and Sarter [11].

Vibration or similar mechanical methods have been used to guide and train movements. An example is the work by van der Linden et al. [17] to guide violin bowing or by Hong et al. [9] to guide visual impaired people on 2D interfaces.

Prototype Development

The prototype presented in this paper is a vibration wristband (called “vibro-band”, see Fig. 1).As placing it at the wrist, where the tactile sensitivity would be higher [11], would interfere with the sterilization requirements, we attached it below the elbow. The wristband features eight evenly distributed pockets, where the eight vibration motors are placed. Informal interviews during a workshop with physicians at a local hospital indicated that surgeons prefer wearing the vibro-band on the dominant arm, usually the arm performing the needle placement. Overall, the participating physicians valued the concept and encouraged to go ahead with a first study.

Based on the workshop insights, the tactile sensation of the vibro-band was designed to create a stimuli into the opposite direction of where the needle has to go, i.e., “pushing” the arm with the vibrations toward the correct position. This is similar to the approach by van den Linden [17]. The process of placing the needle *on* the phantom was split into two steps: first, aligning the tip for the entry point and second, aligning the handle for the insertion angle. To differentiate these steps, two vibration patterns were used consecutively. For the needle tip we used a repeating on-off pattern, i.e., 100 ms vibration alternated with 50 ms breaks. The pattern for the handle was a continuous vibration. If the tip was correctly placed, the pattern changed automatically to guide the handle placement. If the handle was also correctly placed to the surface (cf. Procedure), the vibration stopped completely.

User Study

Our study aimed at a first evaluation of feasibility because vibration is an unusual way of presenting information for a task that requires fine motor skills. We investigate whether the vibro-band interferes with the placing process and if participants understand this way of information presentation the context of a needle-placement task.

Procedure

The study had three parts: first, needle positioning with and without the additional help of the vibro-band, second, a shape cutting test, and third, a vibration-recognition test. We used a CAS-One optical surgical navigation system[1] to evaluate the vibro-band for needle positioning, which provides an application with a 2D cross-hair visualization (see monitor at the setup on Fig. 2). The application is similar to state-of-the-art systems. It can track a needle and a 3D-printed phantom by tracking the attached reflective markers (see setup in Fig. 2).

For the first part, participants were given the task to place the needle correctly *on* the phantom, i.e., place the tip on the target insertion point and adjust the needle’s angle to match the given trajectory. This was done under two conditions, executed in counterbalanced order: (1) using only a 2D cross-hair visualization and (2) using vibro-band with additional help of the cross-hair visualization.

For the vibro-band condition, the participants were instructed to focus on the information provided by the vibration and on the phantom rather then focusing on the monitor. The placement task was repeated four times for each condition and the needle was put down on a table after each trial. After each condition, the participants had to fill in the NASA

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[1] http://cascination.com/

	Time in seconds
	Monitor
Run 1	23.90 ± 12.11
Run 2	19.45 ± 7.26
Run 3	18.23 ± 10.39
Run 4	16.29 ± 7.38
Average	**19.47** ± **6.88**

Table 1: Average task completion for visual-only condition $\pm SD$ times per run

	Time in seconds
	Vibro-band
Run 1	24.03 ± 11.60
Run 2	21.48 ± 17.32
Run 3	15.60 ± 5.76
Run 4	16.21 ± 6.68
Average	**19.33** ± **6.81**

Table 2: Average task completion for vibro-band condtion $\pm SD$ times per run

TLX [7] and the System Usability Scale (SUS) [1] questionnaires. Additionally, task completion times were measured and we recorded the user interaction including the screen, the phantom, and the participant.

For the second part, the participants had to cut out a paper shape with scissors. They had to do it one time without vibration and a second time with the vibro-band turning individual motors randomly on and off to determine possible effects on performance. This is important as the vibro-band is worn on the dominant arm. If the vibrations disrupted the movements this would exclude any use during an ongoing intervention.

For the third part, the participants' task was to identify the direction correctly. Each of the eight motors vibrated consecutively in random order and the participants had to report which one was active. The aim of this task was to measure if the spatial resolution of eight motors is acceptable. The participants were not told that each motor was active once.

At the end, the participants answered a demographic questionnaire collecting data about their age, preferred hand, profession, experience with 3D-tools and with surgical navigation systems. Finally, participants had the chance to verbally provide feedback about the interaction and the device. On average, a study session lasted approx. 35 minutes.

Participants & Design

We performed a within-subject user study with twelve participants (2 female, 10 male) between 19 and 37 years old (M = 26.5, SD = 4.44). Eight of them were students at the University of Bremen, two worked as research assistants, and two worked outside academia. The majority of the participants had a background in computer science (83 %) and 11 out of 12 stated to be right handed. Half the participants had experience with 3D-tools and two of them had used navigation systems for surgeons before.

Results & Discussion

The aim of the study was to conduct a first feasibility evaluation of the prototype. The average task completion times showed no significant differences (p = 0.96) (see Tab. 1 & 2). The results for the questionnaires are presented in Fig. 3 & 4. The differences for NASA TLX (p = 0.14) and SUS (p = 0.19) were also not significant. Therefore, there are no indications that the vibro-band does interfere with the task. The slightly higher workload can be explained by recent research suggesting that both tactile and visual information are processed by the same attentional resources [18]. The analysis of the paper-cuts showed no difference in precision between conditions. There were no noticeable misses in the cut out shape compared to the baseline acquired before, which is evidence that the vibro-band can be worn on the dominant arm without reducing the outcome of fine-motor skill tasks.

Half the participants identified $\geq$75 % of the vibrating motors correctly, while wrongly classified motors were mismatched always by only one motor to the left or right. Therefore the direction was always correct. We received negative and positive qualitative feedback by the participants. Two participants described the vibration patterns as “not intuitive” and one said that it was hard to assess the vibration patterns during tip placement. Two other participants commented that the vibrations would increase the pressure to perform and that more training might be necessary before it will be helpful. Three participants mentioned that the vibrations were helpful. One of them said that the vibrations would guide more subconsciously and another one stated that s/he felt more confident with the vibration guidance. The video analysis indicated that three participants increased their attention towards the model and the needle during the vibro-band condition. The video analysis showed that the participants focusing on the vibrations were stopping earlier when reaching the target, i.e., when the

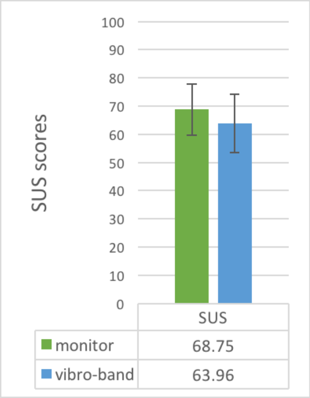

Figure 3: Results for the SUS questionnaire (mean±SD).

Figure 4: Results for the NASA TLX questionnaire (mean±SD).

vibration stopped. Contrary to this, few participants still continued with placing the needle, after the feedback stopped. We expect with further training that the users would have gained trust in the feedback and stop if the feedback suggests that the optimal position is reached. Based on the times taken from the video material, this would have reduced individual task completion times to one half or one third of the time. Based on the CAS-One output, presenting deviation in terms of angle in ° and distance in mm, 25 out of 40 runs with the vibro-band placed the needle with a deviation of less than 1 unit (both angle and distance). In the monitor only condition, 21 were placed with the same accuracy level. Both values were limited at three units.
One limitation of our study is placing the monitor close to the phantom in a location comfortable to look at (cf. Fig. 2). This favors the monitor and might have contributed to the participants mainly focusing on the monitor during both conditions, which in turn might have decreased potential differences between conditions. However, placing the monitor elsewhere might have favored the tactile condition and would have been difficult to control for. Another limitation of our results is conducting the experiment with medical novices. In future studies, we will involve physicians but for this first feasibility study this would not have been practical, given the limited time availability of physicians. The evaluation was designed and explained to the participants in a way that required no prior medical experience.

Conclusion & Future Work

We developed a prototype with eight vibration motors, the so called “vibro-band”, which is worn on the dominant arm, to present physicians with navigational information for needle-based interventions. The results of our user study are promising, as the twelve participants were able to perform fine-motor skill task without interferences and the identification of the vibration direction was good. Additionally equivalent results in terms of time, accuracy, task load and usability were achieved for the needle placement tasks.
For future iterations of the prototype we plan on improving the vibration patterns together with the target group. Additionally we want to run another study with an improved spatial setup and will evaluate if the vibro-band can guide the needle positioning without visual support.

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