Assisting Hand Skill Transfer of Tracheal Intubation Using Outer-Covering Haptic Display

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ABSTRACT

In this paper, we propose a novel haptic display called Outer-Covering Haptic Display (OCHD) that supports effective training of hand skills that require strength. Adopting tracheal intubation training as an example, we show the difficulty of teaching a novice to manipulate a laryngoscope. Although previous training systems tackled the issue by presenting force to the learner's palm by directly actuating the laryngoscope, this approach is sometimes ineffective because learners typically have difficulty sensing the haptic feedback from the laryngoscope when they are holding it tightly. Thus, we propose a different approach (OCHD) that effectively guides the novice's hand by presenting force to the back of his/her hand as if an expert is holding it. A preliminary experiment showed that OCHD effectively guides users with less actuator drive force than cases where a laryngoscope is directly actuated.

Author Keywords

Tracheal intubation, haptic display, skill transfer.

ACM Classification Keywords

H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces-Haptic I/O.

General Terms

Human Factors, Experimentation

INTRODUCTION

Tracheal intubation is a medical procedure where a practitioner opens a patient's buccal capsule with an instrument called a laryngoscope (Fig. 1, left) and places a plastic tube into the trachea to secure an open airway for forced respiration (Fig. 1, right). This procedure "requires accurate manipulation of the laryngoscope blade [6]". If the laryngoscope is not properly manipulated, it not only results in incorrect intubation but it may also injure the patient's buccal cavity or break the patient's front tooth. Although recent development of mannequin simulators has enabled realistic training, the success rate of inexperienced paramedics remains low [9]. Therefore, we need an efficient way to impart the hand skills for manipulating the laryngoscope.

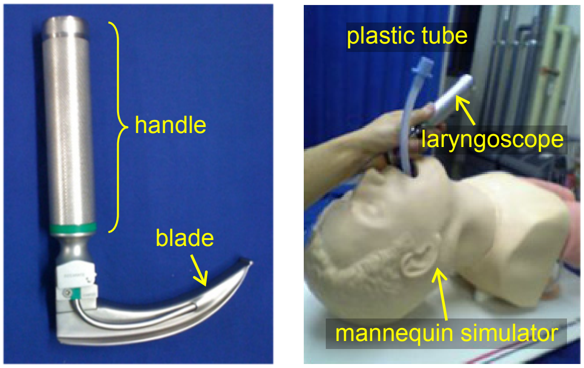

Figure 1. Laryngoscope (left) and tracheal intubation using a simulator (right).

Assisting skill transfers have been actively studied in the domain of virtual reality. Most previous studies have operated a tool with haptic displays so that learners can directly sense the guiding force from the tool itself [10]. However, this approach is not practical when applied to learning skills that require strength such as tracheal intubation. Since learners have to hold the laryngoscope tightly, it becomes harder to sense the haptic feedback from the laryngoscope itself.

Thus, instead of presenting force to the palms of learners by actuating the laryngoscope, we present force to the back of the hand as if an instructor were holding it. In this way, experts should be able to effectively guide the learner's hand with less drive force of the actuator compared to the case where the laryngoscope is directly actuated. The aim of this paper is to introduce a new haptic display called Outer-Covering Haptic Display (OCHD) that actualizes our idea and show its potential in a preliminary experiment.

In the remainder of this paper, we first explain the theoretical background of our approach and review related studies. Next, we introduce our new haptic display, and using it, we describe an experiment that assesses its potential. Finally, we conclude with a discussion about some remaining issues and future work.

BACKGROUND

Various approaches have been proposed to support tracheal intubation training. Video laryngoscope is one of the most common. A small video camera attached to the blade enables learners to easily observe the trachea, increasing the intubation success rate [4]. Noh et al. developed a mannequin simulator equipped with various force sensors [7] with which learners can sense if their laryngoscope is applying improper pressure inside the buccal capsule. Mayrose et al. developed a virtual reality simulator that provides learners the illusion of actually conducting a tracheal intubation [6]. Although these systems aid the learner's assessment of the current status, they do not straightforwardly instruct them how to move their hands.

Several studies support hand skill teaching using haptic displays. Teo proposed a pen-like haptic display to assist the skill transfer of Chinese calligraphy [10]. This system records an expert's movements, and the recorded pen movements give learners proper feedback to stay on track, allowing them to effectively learn the correct hand movements for Chinese calligraphy.

In fact, to assist hand skill transfer, haptic displays commonly operate a tool using actuators, enabling learners to directly sense the guiding force from the tool itself. However, this method may not be practical when applied to learning skills that require strength (i.e., when learners need to hold the tool tightly) because the guiding force inevitably increases, which typically increases the tool's size and cost. The key theory that supports this assumption is Weber's Law.

Weber's Law states that the change in a stimulus that is "just noticeable" is a constant ratio of the original stimulus [11]. For example, one must shout to be heard in a noisy environment but a whisper works in a quiet room. This law can be applied to a variety of sensory modalities including strength. Consequently, we predict that the size of a just noticeable guiding force increases as the learner holds the tool tighter.

Unfortunately, tracheal intubation requires practitioners to apply relatively strong force (about 40 N at the peak) and torque (about 4 Nm at the peak) to the laryngoscope [3], forcing the handle to be held tightly. According to Weber's Law, the actuators to manipulate the laryngoscope should have a much stronger drive force. As the required drive force of the actuators becomes stronger, the required motor performance becomes higher and the rigidity of the structure needs to be stronger, making the actuator heavier, more costly, and more dangerous to be used near humans.

To resolve this issue, we focus on previous works that apply stimulus to a person's outer skin to guide movement rather than moving the instrument itself. For example, Bark et al. proposed "a wearable haptic feedback device that imparts rotational skin stretch to provide feedback regarding movement of a virtual object [1]." Kuniyasu et al. also proposed a wearable haptic device that applies skin deformation to a person's forearm and found that it can give illusory external force to users [5].

Spurred by these previous studies, we developed the idea of applying guiding force to the back of a learner's hand. Since no other force is applied at its back, we expect that learners will be sensitive to relatively weak stimulus no matter how strong they hold the laryngoscope. However, note that the validity of our idea is unknown since palms are more sensitive than the back of the hand [2], it is not clear whether our idea is valid.

This study is important in two ways. First, it demonstrates the effectiveness of applying haptic sensations to the back of a person's hand when the learning skill requires strength. Second, it adds to our understanding of the use of a stimulus on the back of the hand. To the best of our knowledge, no studies have compared the stimulus threshold between the palm and the back of the hand when holding a tool with particular grasping powers.

OUTER-COVERING HAPTIC DISPLAY

OCHD applies haptic sensations to the back of a learner's hand. Fig. 2 shows OCHD's latest structure. Its main components are aluminum frames, silicon effectors, and silicon bands. It weighs about 80 g, which is much lighter than a typical laryngoscope that weighs about 500 g. The effectors attached to the frames are square, 1 cm on a side and 2-mm thick, and the distance between them is 1 cm. Since the effectors reduce the contact area, we expect them to effectively apply pressure to the learner's skin as well as enhancing the haptic sensation by deforming the skin [5].

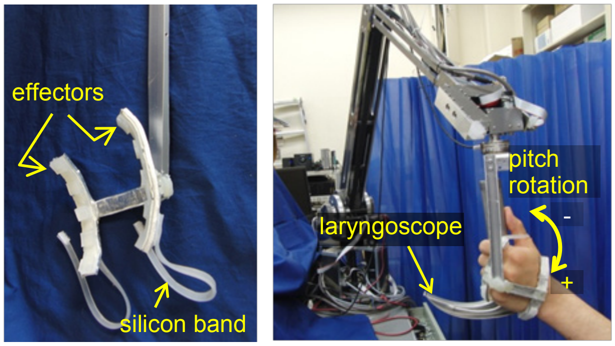

Figure 2. Left photo shows OCHD and right photo shows OCHD actuated by 6-DOF manipulator.

PRELIMINARY EVALUATION

We experimentally investigated the effect of OCHD for applying haptic sensations to subjects. We aimed to confirm that OCHD requires less drive force to make the subjects detect the haptic sensation around the pitch axis compared to the case where the laryngoscope was directly actuated. Our hypothesis argues that for the latter case, as the subject increases his grasp of the laryngoscope handle, a proportionally stronger drive force is required. In the former case, on the other hand, the required drive force will not change so much regardless of the grasping power. Note that since we only used one motor for this experiment, we considered the “drive force” equivalent to the motor torque that drove the apparatus.

Since our study is still in its early stage, we only tested the effect of OCHD on the pitch rotation. In the future, we will test its effect on all 3-rotational axes and three directions.

Design

This experiment, which measured the minimum motor torque (stimulation threshold) for subjects to detect the haptic sensation around the pitch axis, was conducted using a 2x3x2 within-subjects design. The independent variables were *haptic display* {OCHD, laryngoscope}, *grasping power* {1 kgf, 2 kgf, 3 kgf}, and *rotation direction* {plus, minus}. For the *grasping power*, half of the participants conducted the tasks in an incremental order (1 kgf → 2 kgf → 3 kgf) and the other half in a decremental order (3 kgf → 2 kgf → 1 kgf). For the *rotation direction*, the plus and minus directions of the pitch rotation were randomly presented several times to each subject. The orders of the *haptic display* and *grasping power* were counterbalanced across subjects.

Apparatus

Figure 3 shows the experiment’s apparatuses. For the OCHD condition, the subjects wore it on their left hands and grasped the aluminum pipe. OCHD was driven by a motor. But the pipe was structurally disconnected from the motor, and thus the haptic sensation was only applied through the OCHD (Fig. 3 left). In the laryngoscope condition, since the subject grasped the same aluminum pipe structurally connected to the motor (Fig. 3 right), the haptic sensation was only given through the pipe.

The aluminum pipe was embedded with two pressure sensors inside (Fig. 4 left). The subject’s grasping power was measured as the sum of two pressure sensor values. To make the influence of the effectors equivalent for both OCHD and the aluminum pipe, we wrapped the pipe with a silicon sheet and attached silicon effectors in the same way as for OCHD (Fig. 4 right).

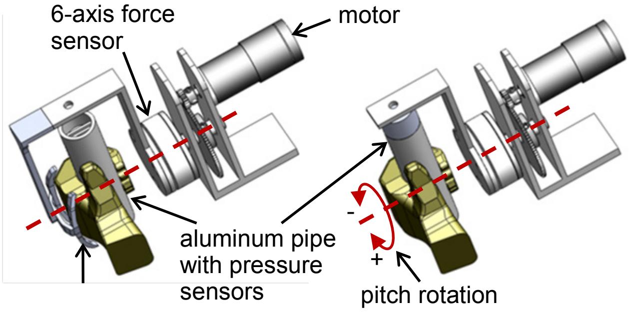

Figure 3. Apparatuses for OCHD condition (left) and laryngoscope condition (right).

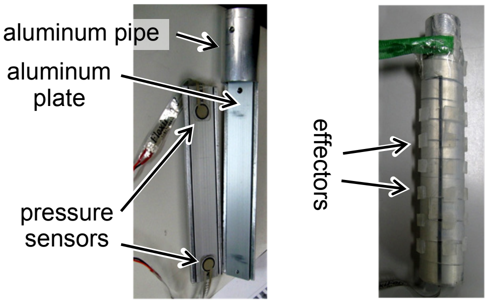

Figure 4. Internal structure (left) and outside view (right) of laryngoscope model pipe.

Participants and Procedures

Eight males from 21-29 years participated in this experiment.

At the beginning of each task, they grasped the pipe with a designated grasping power. Then the stimulation threshold was measured using the simple up-and-down method [8].

For this experiment, the subjects were notified that they would be presented with the pitch rotation (it was specifically explained to the subjects). However, the plus and minus directions, presented several times, were randomly mixed, and the subjects were not notified which direction they would be presented each time. In this way, the stimulation threshold (i.e., minimum motor torque) was measured six times for both directions. For each direction, the average of six measured values was used as each subject’s stimulation threshold.

RESULTS

Figure 5 compares the average stimulation threshold of two haptic display conditions for each grasping power. A 3-way repeated measures ANOVA was used to determine the significant effects of rotation direction, haptic display, and grasping power. The main effects of all factors were found to be significant: (F(1, 84)=5.7, p<.05), (F(1, 84)=116.51, p<.001) and (F(2, 84)=34.23, p<.001). We observed significant interaction between the *haptic display* and *grasping power* (F(2, 84)=25.62, p<.001) but not between the *direction* and *haptic display* (F(1, 84)=1.99, p=.16). Also the simple main effect of the *grasping power* at laryngoscope condition was significant (F(2, 84)=59.17, p<.001) but not at OCHD condition (F(2, 84)=.68, p=.51). For both the plus and minus directions, a Bonferroni post-hoc test showed significant difference between the laryngoscope and OCHD conditions for grasping power of 1 kgf (plus: F(1, 84)=26.56, p<.001, minus: F(1, 84)=11.88, p<.01) and 2 kgf (plus: F(1, 84)=73.19, p<.001, minus: F(1, 84)=56.55, p<.001). We could not find a significant difference for 0 kgf grasping power (plus: F(1, 84)=1.54, p=.22, minus: F(1, 84)=.27, p=.6).

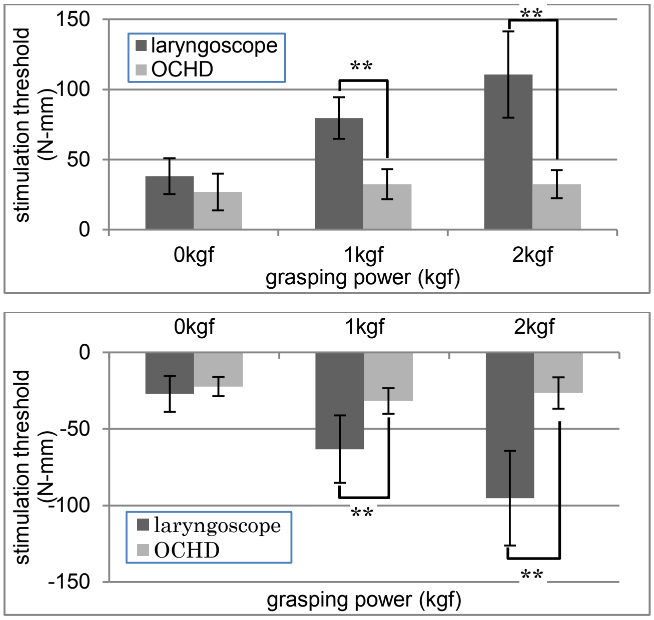

Figure 5. Average stimulation threshold for plus (above) and minus (below) directions: "" denotes significant difference at p<.01 level.**

DISCUSSION

From this experiment, we could prove that the OHCD condition was superior to the laryngoscope condition in terms of the stimulation threshold. For the laryngoscope condition, the stimulation threshold significantly increased as the grasping power became stronger. In contrast, for the OCHD condition, the stimulation threshold remained almost the same regardless of the grasping power. These results suggest that Weber's law only affected the laryngoscope condition but not the OCHD condition. Thus we think that the OCHD is a promising tool for learners to acquire hand skills in tracheal intubation.

Since the palm of the hand is more sensitive than its back, one might predicted that for 0 kgf grasping power, the stimulation threshold would be lower for the laryngoscope case. Surprisingly, however, we did not find any significant difference between the two cases. Since the number of effectors contacting the subject hands is fewer for the OCHD condition than the laryngoscope condition, we speculate that each OCHD effector yields more pressure and skin deformation to the hands than for the laryngoscope case, resulting in a similar stimulation threshold for the OCHD condition. This result also strengthens the effectiveness of our approach.

OCHD's advantage is not only its insusceptibility to Weber's law. Since it does not require tools to be directly actuated by the system, we expected to apply our idea for hand skills of such tools as endoscopes and medical ultrasonic probes. For this purpose, we need to refine OCHD's structure so that it applies to versatile applications.

CONCLUSION AND FUTURE WORK

To assist transferring hand skills for tracheal intubation, this paper proposed an Outer-Covering Haptic Display (OCHD) and proved that, although only for the pitch rotation, the display effectively reduces the stimulation threshold compared to the case where the laryngoscope was driven by a motor. Our future work includes improving the OCHD so that it can support 6-DOF. Then we will experimentally assess the effect of our system on actual tracheal intubation training.

ACKNOWLEDGMENTS

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