# Effects of Haptic Feedback and Stereoscopy on a Surgical Training Task in Virtual Reality

**Bliss M. Altenhoff**
Department of Psychology
Clemson University
blissw@clemson.edu

**Ashley S. Sewall**
Department of Psychology
Clemson University
aastafford@gmail.com

**Blair Shannon**
Department of Psychology
Clemson University
cshanno@clemson.edu

**Andrew T. Duchowski**
School of Computing
Clemson University
duchowski@clemson.edu

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## INTRODUCTION

Minimally invasive surgical techniques offer patients the promise of smaller incisions, less pain, and shorter recovery times [4]. New technologies have allowed this rise in minimally invasive surgery making efficient and effective training of the surgical task vital to the continued success of this technique. Due to the challenging visual conditions and the unintuitive nature of tool manipulation when performing laparoscopic surgery, tremendous training of these skills is required and is often performed through simulators. In fact, there are more surgical training simulators available for laparoscopic training than any other type of medical training task [10].

Research aimed at improving surgical proficiency in training tasks has focused on the addition of haptic information to reduce problems associated with tool manipulation and with the addition of stereoscopic information to displays to mitigate visual challenges. The current experiment is one in a series of experiments that seek to extend these areas of research and to test the effectiveness of adding haptic and stereoscopic information to surgical tasks in virtual reality. The current experiment focuses on the effect of stereoscopy on a simple surgical training task (FLS Peg Transfer Task) presented in virtual reality. It is hoped that a second study will be implemented in the future to examine the effect of haptic feedback on this same task. It is believed that both the addition of haptic and stereoscopic information will reduce task completion time and improve task accuracy. Though, it is currently unknown if there will be an added benefit of concurrently providing the participant with both haptic and stereoscopic information on task performance, another step in this series of experiments will be to examine the effect of both these feedback types on this training task. The current work seeks to better understand the perceptual information necessary to successful training of minimally invasive surgical techniques with specific emphasis on the impact of stereoscopy.

## BACKGROUND

### Haptic feedback

Though only stereoscopy will be examined in the current experiment it is important to understand the theoretical background of all relevant perceptual sources of information added to the surgical training task which include both haptic and stereoscopy. We here present first the literature as it pertains to haptic feedback with a final focus on stereoscopy.

Minimally invasive surgical techniques allow for reduced pain and recovery time for patients. With extensive patient benefits, the successful training of these minimally invasive surgical techniques is being examined. Due to the nature of the surgical task, training on actual patients would not be acceptable and though cadavers are an option this is often an expensive option allowing the training surgeon minimal errors before being rendered useless [10]. Additionally, mannequins are occasionally used for training but the lack of physiological realism makes this yet again a sub-par alternative. However, medical simulators are becoming an increasingly accepted tool for the extensive training necessary to prepare surgeons. Medical simulators provide a safe, yet realistic environment in which the surgeon can train with the freedom to make mistakes.

One drawback to the use of medical simulators is that the manipulation of tissue using these simulators is indirect with impoverished visual information through the camera [17] and unnatural eye-hand coordination [6]. This creates a very unrealistic and challenging situation for the training surgeon to face. However, the addition of tactile and force information, more broadly known as haptic feedback, can mitigate these challenges [30, 19]. It is important to the success of the training that the task environment is similar to the surgical environment and one way this can be accomplished is through the appropriate use of haptic feedback [31].

Haptics are defined as “the combination of tactile perception (through sensory skin receptors) and kinesthetic perception (through muscle, tendons, and joint sensory receptors)” [31]. There are then two main categories of haptics: tactile feedback and force/torque feedback. The tactile component of haptic feedback is what is sensed by the receptors (hot, cold, pain, etc.) while the force component refers to motion and rotation information available [10]. Primarily, haptic devices available focus on the force/torque component of haptic feedback though both play a role in the surgical task [10].

There is evidence to suggest that haptic feedback does improve performance in both the minimally invasive surgical task and basic laparoscopic training tasks. In a report examining the application of haptic feedback to robotic surgery, surgeons were asked to perform a suture knot tying task using the Da Vinci robotic system both with and without the use of haptic feedback [4]. In this experiment there was an optimal force that the surgeon should use to perform the task without tearing the knot. These surgeons more consistently used an optimal amount of force for completing the knot tying task when they were aided by haptic information than without this information. In another study, the use of force feedback was examined in the context of performance of basic laparoscopic skills [9]. In Chmarra et al., participants performed three basic laparoscopic tasks with and without natural force feedback and concluded that force feedback does influence the performance of basic laparoscopic skills, particularly when pulling or pushing was needed to accomplish the task. These studies provide examples of the usefulness of haptic information when performing both training and surgical tasks.

Additionally, results suggest that receiving haptic feedback in a virtual training environment may be critical during early training phases for psychomotor skill acquisition. Due to the indirect contact with the tissue, future surgeons have to learn new things about force feedback before they can safely conduct actual surgery. For example, during surgery the operator may perceive forces 0.2-4.5 times the force generated. Realistic simulators with haptic feedback are thought to lead to better overall performance, faster learning, and high transfer of skill to operating on actual tissue [29]. Some warn that learning tasks in VR without realistic haptic feedback may result in negative learning effects when these tasks are completed on actual tissue, where appropriate application of force plays an important role in surgical performance [9].

Research demonstrates that experienced surgeons demonstrate the skills to accurately produce and perceive haptic forces, although it is unlikely that they were specifically trained how to attune to those forces [25, 26]. Training devices are currently being developed that are specifically devoted to training haptic skills. Trainees have shown significant improvement even after only a brief training period, demonstrating that it is a learnable skill [17]. Although few experiments have investigated the effect of haptic feedback in a virtual environment (VE) simulator, the majority of research supports the idea that haptic feedback should be incorporated into VE training based on findings on the importance of haptics in minimally invasive surgery [27].

### Stereoscopic feedback

VE's are a common means of training for situations that are dangerous, expensive, rare, or remote, such as laparoscopic surgery training [5, 12, 23]. A main advantage of virtual environments is that they provide a controlled scenario so users can repeatedly and safely interact with situations. However, distance estimates are typically found to be less accurate in virtual environments than in real environments. Based on experiences with rescue robots at the World Trade Center during the aftermath of September 11, 2001, Murphy [21] concluded that one of the biggest problems with using teleoperated cameras is the lack of depth perception and ability to accurately perceive sizes of elements in the remote environment. Tittle, Roesler, and Woods [26] have termed these difficulties "the remote perception problem." Robot operators at the September 11th clean up also had difficulty identifying objects and determining whether the robots could pass over obstacles and through apertures[8].

VE's can be displayed with or without stereoscopic viewing. Stereopsis is the three-dimensional effect that people perceive due to slightly different images falling on each of our eyes because of their different locations in space, which is known as binocular disparity [31]. Egocentric distance estimation can be categorized in three distinct regions: vista space, 30 meters from one's body and beyond, action space, maximum arm's reach to 30 meters, and near-field, 0 meters to maximum arm's reach [11]. Users have shown to consistently underestimate distances between themselves and other objects in a VE, whether or not it allows for stereoscopic viewing. Specifically, estimates of egocentric distances in action space (1m - 30m) can be underestimated by as much as 50% [1, 20, 22, 24, 25, 30]. Although less research has been done on distance estimates in near-field than action space, when directly compared in IVE and real world viewing conditions, both verbal and reach estimates show distance compression when made to near-field targets. For the reaches, underestimation was shown to increase as target distance increased. Although the underestimations were not as exaggerated as in the IVE compared to the real world viewing (less than 5% distance compression), estimates were very dissimilar from veridical (~20% underestimation) [22].

Research has shown that adding stereoscopic viewing during laparoscopic surgery does improve performance on laparoscopic training tasks and robotic laparoscopic surgery for both novice and experienced surgeons [15]. Completing training tasks such as needle threading, needle capping, bead transfer, and knot tying, surgeon performance time decreased by 34-46% completing the tasks in three-dimensional viewing, and surgeons completed 44% to 66% fewer errors [7]. Surgeons performing suturing drills with the daVinci Surgical Robot System were 35% faster and reduced errors by 60% when performing surgery with three-dimensional viewing compared to two-dimensional viewing [2].

Using eye tracking, previous research has demonstrated that this technology can track eye vergence as participants view an image with and without stereoscopic vision and with and without motion parallax. Only in conditions when participants viewed the display with stereoscopic vision (with or without motion parallax) did their gaze depth reflect changes in eye vergence to view parts of the display at closer and farther images. With stereoscopic viewing, as the stimulus depth increased and decreased, eye tracking techniques showed that gaze depth increased and decreased accordingly. However, without stereoscopic viewing, gaze depth remained constant at a fixed depth [14]. Eye tracking should be used in the current study to further investigate to see how these results apply to our visual stimulus.

It is hypothesized that both haptic feedback and stereoscopic feedback would reduce performance time and improve accuracy on a virtual peg transfer task. It is also expected that during stereoscopic viewing, participant eye vergence will adjust to the appropriate depth of the peg. However, due to technical challenges, the current study will only examine the effects of stereoscopic feedback without haptic feedback. Therefore, it is hypothesized that stereoscopic feedback will reduce performance time and improve accuracy on a virtual peg transfer task.

## METHOD

### Participants

Twelve Clemson University, right-handed, undergraduate students from the ages of 18-25 were recruited for participation in this experiment. Visual acuity under normal room lighting, as measured using a Bailey-Lovie chart, was tested prior to experiment participation. Each participant had 20/40 or better binocular visual acuity and had no known visual pathologies. Participants wearing glasses were excluded from data collection. Additionally, due to the dexterity required to perform the surgical task participants with wrist injuries were not be allowed to participate. After informed consent was obtained, participants were seated in a comfortable chair throughout the experiment 6 ft from an 82 inch television screen and 60 cm from a Mirametrix eye tracker. Participants were seated at a table and asked to keep their head stable throughout the experiment. At this point the Mirametrix eye tracker was calibrated to each participant and eye movements were tracked throughout the rest of data collection.

### Apparatus

#### *Mirametrix Eye tracker*

**Figure 1. The S2 Eye Tracker manufactured by Mirametrix**

The eye tracker used is the S2 Eye Tracker manufactured by Mirametrix. The gaze accuracy for the eye tracker as reported by the manufacturer is 0.5 to 1 degrees with a drift of less than .3 degrees. It records at a frequency of 60 Hz. We used the built-in calibration software for both 2D and 3D calibration. It uses the bright pupil tracking methodology.

#### *Razer Hydra Motion Controller*

**Figure 2. The Razer Hydra used to manipulate objects in the virtual task.**

The participants used the Razer Hydra motion controller-manufactured by Razer USA to interact with the virtual environment. It supports a full 6 degrees of freedom, tracking the position of the tip in x, y, and z space, as well as the pitch, roll, and yaw of the stylus. The apparent mass of the tip of the stylus due to the resistance of the joints is 45 grams.

#### *Nvidia 3D Vision Pro*

For displaying the environment in three dimensions, we used the Nvidia 3D Vision Pro to calculate and display accurate screen parallax with shutter glasses in a time multiplex display. The display ran at 120 Hz and each eye perceived 60 Hz. The Display being used was an 82 inch Mitsubishi WD-82737 with a screen resolution of 1920 x 1080 pixels.

#### *Peg Transfer Task*

The Fundamentals of Laparoscopic Surgery (FLS) program is a validated method regularly used to effectively train residents certain laparoscopic skills before they practice on actual animal or human tissues. For example, the program includes five tasks that students must master: peg transfer, pattern cut, endoloop, extracorporeal suture, and intracorporeal suture tasks [13, 16]. For the current experiment, the peg transfer task was replicated in a VE constructed with the Unity 3D game engine for participants to complete by moving a disk across 5 different pegs. Participants used a Razor Hydra motion controller to manipulate the disk under two viewing conditions.

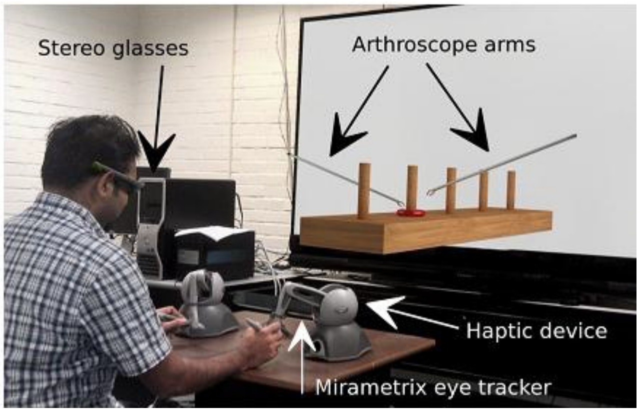

**Figure 3. Depiction of peg transfer task setup with two controllers, stereo glasses, Mirametrix eye tracker, and view of pegs, disk, and arthroscope arms**

### Experimental Design

The current experiment features a within subjects design with two experimental conditions: stereoscopic feedback, and no stereoscopic feedback. Each participant experienced both conditions though the order in which the participant experienced each condition was counterbalanced across all participants. These data were analyzed using a 2 x 5 repeated measures *ANOVA* to determine the effects of stereoscopic feedback on task performance: time and accuracy (measured by the number of times the disk was dropped).

### Procedure

*Video Gaming Survey*

After visual acuity was measured and participants were seated, participants completed a short survey on the video gaming experience. There is some evidence to suggest that video gaming experience may predict performance on laparoscopic surgical tasks [3]. For this reason information about participants gaming habits was collected.

*Virtual Peg Transfer Task*

Participants were instructed to take a few moments to familiarize themselves with the Hydra controllers and the virtual environment. For this purpose, participants completed a practice phase in which they were asked to learn how the controllers affected the arthroscope position in space and to practice using the tools to lift the ring and transfer it in the air. After this practice session, the virtual peg task was shown on the screen. Participants received the following instructions:

> "This peg transfer exercise requires you to lift the disk shown on the screen with the stylus in your right hand, transfer the disk to your left hand while it is still in the air, and move it to the peg on the screen. Once you have control of the disk with the stylus in your left hand, you may then place the disk on the peg. You will need to perform this task quickly but accurately. Timing for this task will begin when you grasp the first disk and will end when you have successfully released the disk onto the peg. Once you successfully drop the disk on the peg, the peg will change locations and you will repeat the task. You will do this a total of five times."

Performance on the virtual peg transfer task was measured by the time to complete the task and the accuracy with which the task was completed. Time to complete the task was measured from the time the disk was first grasped to the time the disk successfully fell over the peg for each trial. Task accuracy was determined by the number of times the participant dropped the disk.

*Stereoscopic Feedback*

In the stereoscopic feedback condition the participant received depth information from the television display on which the virtual peg task was being displayed. In this condition, participants wore Active 3D Shutter glasses with the Nvidia 3d Vision Pro that displayed this depth information. The virtual pegs were displayed three dimensionally. Once again, the participant received the general instructions above with the addition of the following:

> "As you perform the peg task you will need to wear these 3D glasses. Please take a moment to put these glasses on and look at the screen in front of you. As you can see, everything on the screen now appears to be popping out toward you, as if you were watching a movie in 3D. Please complete the peg task with these glasses on."

*No Stereoscopic Feedback Condition*

This condition served as a baseline condition to which performance in the stereoscopic feedback condition could be compared. In this condition, participants received no stereoscopic feedback on the television screen. By measuring performance in this condition we were able to examine the distinct effects of our manipulation on time and accuracy.

### RESULTS

The accuracy data was split into two files: time to complete each trial and errors committed during each trial. A 2 (stereoscopic viewing vs. non-stereoscopic viewing) x 5 (peg positions) *ANOVA* was conducted on errors and time separately.

*Errors*

A 2 x 5 repeated measures *ANOVA* revealed that number of errors committed while completing the peg transfer task were significantly higher in the stereoscopic viewing condition compared to viewing without stereoscopic feedback $F(1,44) = 6.134$, $p < .05$, with an average of 2.47 errors committed in the stereo viewing condition, and only 1.53 committed in the non-stereo viewing condition (Figure 4).

There was not a significant effect of peg position on errors, $F(4,44) = 1.85$, $p = .136$, nor was there was a significant 3 way interaction, $F(4,44) = .478$, $p = .752$.

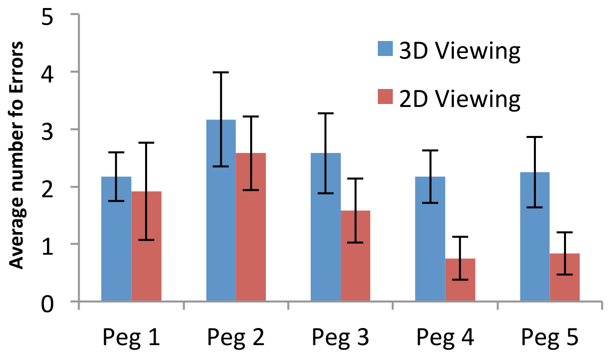

**Figure 4. Average number of errors committed in stereoscopic (3D) and no stereoscopic (2D) viewing conditions**

### *Time*

A separate 2 x 5 repeated measures *ANOVA* on task completion time revealed that there was also a significant effect of condition on time, $F(1,11) = 9.299$, $p < .05$. Average completion time in stereoscopic viewing was 68 seconds, compared to 37 seconds without stereoscopic feedback.

As with errors, there was no significant effect of peg position, $F(4,44) = .637$, $p = .639$, nor was there a significant 3 way interaction $F(4,44) = .877$, $p = .485$.

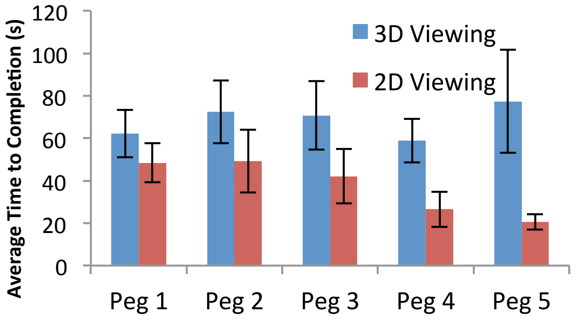

**Figure 5. Average time taken to successfully complete the task in stereoscopic (3D) and no stereoscopic (2D) viewing conditions**

### *Eye Tracking*

This experiment also examined the effect of the stereoscopic condition on participants' vergence. Duchowski et al. [14] highlight the inaccuracy of observers' accommodation and vergence when viewing a display that conveys depth information. In this paper, using the same calibration and analysis tools as Duchowski et al. eye tracking data was collected and analyzed while the participant completed the virtual peg transfer task. Using formulas reported in Wang, Pelfrye, Duchowski, and House [31] participants' gaze depth was estimated from measured gaze disparity. The Mirametrix eye tracker measured the spatial position of the eyes while the participant completed the task. Gaze depth was calculated for each participant at each peg presented. The eye tracker reports the 2D on-screen gaze positions of the two eyes in pixels, $(x_l, y_l)$, $(x_r, y_r)$. Using these gaze coordinates we found the average of the left and right gaze $y$ coordinate, $y_e = (y_l + y_r)/2$.

The distance to the screen varies with the height of the gaze point and was estimated using the equation,

$$D' = \sqrt{D^2 + y_e^2}.$$

Finally with gaze disparity calculated as $\Delta x = x_r - x_l$, gaze depth relative to screen positions was calculated with the following equation: $z = \frac{\Delta x D\prime}{\Delta x - a}$ where $a$ is the separation between the eyes, assumed here to be 6.3 cm, the average of all people [31].

With the observed gaze depth (z) and the stimulus gaze depth (depth of the pegs on the screen) calculated we were able to compare all observers' actual gaze depths with the viewing depth of the stimulus on the screen when under stereoscopic viewing conditions and when stereo was off (see Figures 6 and 7).

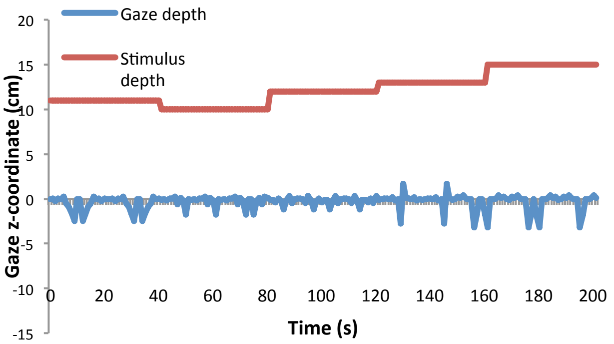

**Figure 6. Observed gaze depth when participants completed task under stereoscopic conditions**

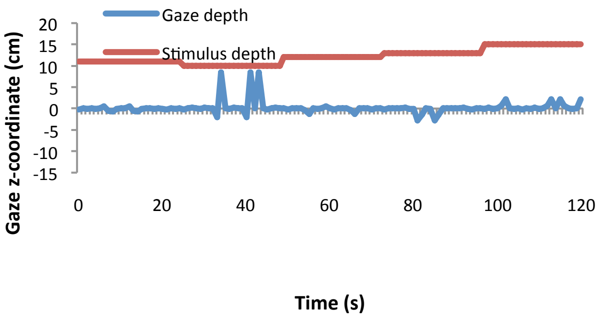

**Figure 7. Observed gaze depth when participants completed task under non-stereoscopic conditions**

A gaze depth of 0 indicates that observers' gazes fell at the screen plane. A negative gaze depth indicates a gaze behind the screen and a positive gaze depth in front of the screen. The gaze depth results of this study indicate that observers' gaze depths were primarily at the screen plane, though we see momentary gazes both in front of and behind the screen.

## DISCUSSION

Results revealed that in the current study, participant performance on our replication of the FLS peg transfer task was better without stereoscopic viewing than with stereoscopic viewing. These results were unexpected and do not agree with any known previous findings [2, 7, 15]. We have examined our eye tracking data as a possible reason for these unanticipated findings. The eye tracking data shows that for both the stereoscopic and non-stereoscopic conditions participants' vergence was at the plain of the display. In the non-stereoscopic condition this gaze depth makes sense and is expected; however, from the findings of Duchowski, et al [14], it was expected that the addition of the third dimension would have improved vergence. We expected to see a gaze depth that more closely resembled the stimulus depth when participants completed the task in the 3D viewing condition. This lack of stereoscopic advantage in gaze depth may be explained by the 3D technology used. It's possible that the Nvidia 3D Vision Pro does not appropriately render stereoscopic feedback for all users. In fact, several participants complained that they were experiencing double vision while wearing the 3D goggles. It is reasonable to conclude that if the 3D technology was not behaving appropriately task difficulty may have been unintentionally increased, thereby increasing both time to complete the task and the number of errors made by participants (Figures 4 and 5). Future research should replicate the current procedure with different 3D technology and evaluate the effectiveness of the 3D technology by asking participants about their perception of depth.

Additionally, because most people today only have experience with 2D virtual interfaces (or very limited interaction with 3D), it may also be possible that successfully manipulating objects in a 3D VE with great precision is a skill acquired only through practice. Much of the existing literature examining effects of stereoscopic viewing on laparoscopic performance use existing surgeons as participants [2, 7], and our novice participants were only given a brief practice phase to see how to control the arthroscopes in the VE.

It is a limitation of this experiment that haptic feedback was not successfully added to the virtual peg task. The addition of haptic feedback to virtual tasks has proven to be an effective strategy for improving the realism of the task and therefore surgical performance [e.g. 30, 19]. Future work should add haptic feedback to the design of this experiment. Finally, there is significant variability in this study due to our limited sample size. This experiment should be run with more participants to truly evaluate the effect of stereoscopy on performance of the virtual peg task.

Performing minimally invasive surgery is a highly skilled task that could greatly benefit from advances in technology, particularly stereoscopic viewing and haptic feedback. Further research is needed to determine to extent to which these technologies benefit the surgeon. It is important that we have a full understanding of what technologies can help surgeons and why they are effective before they are implemented in the operating room.

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