Medicine Meets Virtual Reality 18
J.D. Westwood et al. (Eds.)
IOS Press, 2011

doi:10.3233/978-1-60750-706-2-658

Quantifying Surgeons' Vigilance during Laparoscopic Operations Using Eyegaze Tracking

Geoffrey TIEN [a,1], Bin ZHENG [b] and M. Stella ATKINS [a]
[a] *School of Computing Science, Simon Fraser University, Canada*
[b] *Department of Surgery, University of British Columbia, Canada*

Abstract. The vigilance of surgeons while operating is an important consideration for patient safety. Using a lightweight mobile eyegaze tracker, we can objectively observe and quantify a surgeon's vigilance measured as the frequency and duration of time spent gazing at an anaesthesia monitor displaying various patient vital signs. Expert surgeons and training surgical residents had their eyegaze recorded while performing a mock partial cholecystectomy on a computer simulator. Results show that experts glanced at the patient vital signs more than the residents, indicating a higher level of surgical vigilance.

Keywords. Laparoscopic surgery simulator, Head-mounted eyegaze tracker

Introduction

Vigilance is the state of being watchful to avoid danger. In an operating room (OR) setting, surgical vigilance can be extended to encompass awareness of potential dangers to a patient. A high level of mental judgment ability inclusive of awareness of patient condition is an important part of ensuring patient safety [1,5,6]. When observing surgical performance in the OR, it is noticeable that the senior surgeon usually keenly detects signs that may concern patient safety. But little is known whether vigilance is associated with a surgeon's competency in performing the surgical procedure. The first goal of this study is to examine the relationship between vigilance and surgical skills.

To achieve this first goal, we asked surgeons with a wide range of surgical experience to perform a laparoscopic procedure in a simulated environment. We chose laparoscopy due to a simple fact that a sufficient level of vigilance can be more difficult to maintain in a laparoscopic setting where only a part of the surgical field is visible by a video display from an endoscope, and additional mental processing is needed to maintain orientation of the patient anatomy, further compounded by the increased difficulty of precisely controlling the laparoscopic instruments compared to open surgery.

A problem with observing the vigilance of surgeons is the lack of a method of measuring this skill. To this end we propose to use eyegaze tracking as an approach to objec-

[1]Corresponding Author: Geoffrey Tien, School of Computing Science, Simon Fraser University, 8888 University Drive, Burnaby, B.C. Canada; E-mail: gtien@cs.sfu.ca.

tively quantify surgical vigilance. Our second goal is to prove the value of using eyetracking in a surgical context, based on our earlier work showing how the eyegaze of novices and experts differ in a virtual laparoscopic training environment [3]. We hypothesize that as surgical experience increases, cognitive effort in performing the primary surgical task will decrease, hence freeing attentional resources to observe the patient condition. In this study we aim to track surgeons' eye movements during a mock laparoscopic procedure and to use this as a measure of awareness of changes in a patient's condition displayed on a simulated anaesthesia monitor.

1. Method

1.1. Apparatus

The study was conducted in the surgical skills training lab at the Centre of Excellence for Surgical Education and Innovation (CESEI) of the University of British Columbia (UBC). Two high-fidelity simulators were used to create patient scenarios.

The first, a SurgicalSim VR manufactured by Medical Education Technologies, Inc. (METI) provided the main visual and tactile interface of the apparatus. This PC-based simulator includes a set of slender tools and a foot pedal to mimic the form and function of laparoscopic instruments, and a 17" LCD monitor as the simulated laparoscopic display. SurgicalSim was used to create a virtual surgical training environment for our participants to perform a partial cholecystectomy.

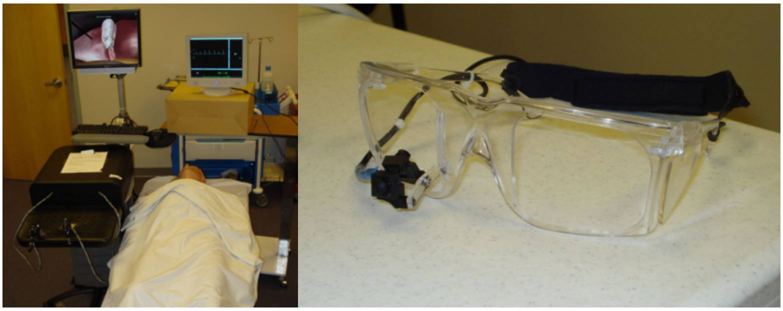
A separate MacOS-based METI Emergency Care Simulator (ECS) includes a life-sized pneumatically controlled mannequin, whose simulated vital signs such as heart rate (with audible beep), blood pressure, and blood oxygen saturation were displayed on a 15" LCD monitor placed to the right side of the main SurgicalSim VR display.

It is important to note that the ECS and SurgicalSim VR systems were placed closed to each other creating a sensation for the participant that they were operating on one single patient; however, the ECS and SurgicalSim VR do not communicate with one another.

Finally, eyegaze tracking was accomplished by a head-mounted PT-Mini system manufactured by Locarna Systems, Inc. The PT-Mini headgear consists of two linked video cameras—one aimed at the wearer's eye, and one facing forward to capture the scene relative to the wearer's head. The two video feeds were saved to a portable notebook computer for post-processing. The components of the experimental apparatus are shown in Figure 1.

1.2. Task

The experimental task required a surgeon to hold a grasper and a monocautery hook to dissect the gall bladder from the liver. A foot pedal placed on the ground controlled cautery. For each participant, the partial cholecystectomy exercise was performed on the SurgicalSim VR under two different patient conditions. One patient presented a stable heartbeat controlled by ECS, while the other patient's heartbeat became slightly erratic at set intervals. Because ECS and SurgicalSim VR are unlinked, changes in patient condition on ECS do not alter the scene on SurgicalSim VR.



(a) (b)

Figure 1. (a) METI SurgicalSim VR and ECS, (b) Locarna PT-Mini headgear.

1.3. Participants

Participants included surgical residents, laparoscopic fellows, and attending surgeons from the surgery department at UBC. A pre-test questionnaire was administered to gather demographic data and to measure their laparoscopic surgical experience score as detailed by Zheng et al [6].

1.4. Procedure

After signing their consent to participate and completing the pre-test, each participant was allowed to complete the simulated partial cholecystectomy once without the patient vitals to learn the characteristics of operating the SurgicalSim VR. Each participant then put on the Locarna headgear and was guided through a short calibration procedure to ensure that his eye could be reliably tracked across the scene camera's field of view. Participants then performed the partial cholecystectomy task once for each of the two patient conditions, for a total of 2 trials. The patient histories were presented on a printed sheet of paper before each trial. The order of the patient conditions was counterbalanced across participants.

1.5. Data processing and analysis

Eyegaze was recorded over the duration of each trial of the cholecystectomy task and analyzed using Locarna's Pictus Eyegaze Calculation software. Eyegaze fixation detection was done using a dispersion threshold algorithm with a minimum duration of 100 ms and a maximum dispersion of 40 pixels relative to the captured video scene frame. Results were analyzed in a 2×2 ANOVA using statistical software from SPSS Inc., where $P<0.05$ is considered significant.

2. Results

16 surgeons and medical students participated in this study. Based on the pre-test questionnaire, the participants were divided into 8 novices (3 female, aged 25-49, mean age 32) and 8 experts (all male, aged 34-57, mean age 39), based on their years of training

Table 1. Number of glances made to the vitals display.

Novice	Stable	Unstable	Expert	Stable	Unstable
Mean, std.dev	1.3 ± 1.8	2.1 ± 3.4	Mean, std.dev	1.3 ± 3.5	3.4 ± 6.1
Min, median, max	0, 0.5, 5	0, 0, 9	Min, median, max	0, 0, 10	0, 1, 18

Table 2. Eyegaze fixation times on the surgical and vitals displays.

	Stable			Unstable		
	Total time (s)	Surgical (% total)	Vitals (% total)	Total time (s)	Surgical (% total)	Vitals (% total)
Novice						
Mean	162	151 (94.4)	0.9 (0.4)	176	169 (95.9)	1.6 (0.8)
Std.dev	48.8	42.8	1.6	62.4	59.1	3.0
Min	72	70	0.0	78	77	0.0
Median	168	157	0.2	177	168	0.0
Max	219	212	4.5	262	254	8.6
Expert						
Mean	186	176 (94.5)	0.8 (0.3)	201	185 (92.9)	3.2 (1.1)
Std.dev	49.6	41.5	2.3	66.0	52.0	7.8
Min	143	128	0.0	114	104	0.0
Median	174	167	0.0	208	200	0.3
Max	303	269	6.5	318	243	22.5

and their surgical experience scores. Novices had around 6 months of laparoscopic training, whereas experts had at least 2 years training and had performed many laparoscopic cases as the primary surgeon. Aggregated eyegaze saccade results appear in Table 1, and the eyegaze fixation results are shown in Table 2, where the first column for each condition describes the total recording time; the second and third columns describe only the time captured in fixations.

For the stable patient condition, novices spent approximately the same mean duration of time looking at the anaesthesia monitor (0.9 s) as experts (0.8 s). Novices and experts also glanced at the patient vitals the same number of times during the operation on the stable patient (1.3 times). When operating on the unstable patient, novices spent less time looking at the anaesthesia monitor (1.6 s) compared to experts (3.2s) and did so by looking over less frequently (2.1 times vs. 3.4 times). Also, only 3 novices glanced at the vitals screen of the unstable patient whereas 5 experts checked the patient vitals. However, with our relatively small and variable participant sample, we are unable to associate these results with statistical significance.

3. Discussion

The power of the results obtained in this study is limited somewhat by the small sample size. Secondly, in an OR setting, the anaesthesia monitor is often oriented on a plane not visible to the primary surgeon. Nevertheless, we found that surgeons with extensive laparoscopic OR experience still glanced at the unstable patient's vital signs when the display was made available to see. The situation is different for the stable patient, where only one expert looked at the vital signs. The experts who had performed a high number of OR cases noted that the regular audible beep of the simulated patient's heart rate was sufficient to conclude that the patient was stable, and the operation could proceed as normal. In contrast, novices who had not yet mastered the manual skills for laparoscopic operations likely had most of their mental resources occupied by the primary task, leaving few resources available to monitor the patient condition through auditory or visual channels. Such a compromise of performance easily occurs under high workload [4,2].

Despite extensive OR experience and heightened ability to match the audible heart rate to condition, experts still tended to visually reaffirm their knowledge when the anaesthesia monitor was available, demonstrating that our chosen experimental setup could still distinguish expert and novice behaviours with respect to patient safety. Furthermore, any difference in eye movement characteristics between the two patient conditions within a single group can be safely attributed to noticeable changes in the patient vitals through audio and visual channels; since ECS and SurgicalSim VR are not linked, the actual cholecystectomy task on SurgicalSim VR is identical across both conditions. With these promising early results, we will continue to recruit more participants with the aim of observing statistically significant differences in the eyegaze measures.

Finally, we would like to correlate eyetracking data with surgical performance data and mental workload assessment. Future analysis will include these data dimensions.

4. Conclusion

Awareness of patient condition during laparoscopic surgery is an important skill in a procedure which demands intense focus on a laparoscopic display. Expert surgeons were more aware of changes in patient condition, and were more able to effectively distribute their attention between two surgical and anaesthetic displays compared to novices who concentrated on only the surgical display and were inattentive to the patient condition.

Acknowledgements

The Locarna eyegaze tracker was purchased with funds from the Canadian Natural Sciences and Engineering Research Council grant.

References

[1] R. Aggarwal, J. Leong, D. Leff, O. Warren, G.-Z. Yang, A. Darzi. New technologies for the surgical curriculum, *World Journal of Surgery* **32:2** (2008), 213–216.

[2] K. E. Hsu, F.-Y. Man, R. A. Gizicki, L. S. Feldman, G. M. Fried. Experienced surgeons can do more than one thing at a time: effect of distraction on performance of a simple laparoscopic and cognitive task by experienced and novice surgeons, *Surgical Endoscopy* **22:1** (2007), 196–201.

[3] B. Law, M. S. Atkins, A. Kirkpatrick, A. Lomax, C. L. MacKenzie. Eye gaze patterns differentiate skill in a virtual laparoscopic training environment, *Proceedings of Eye Tracking Research and Applications* (2004), 41–47.

[4] R. G. Loeb. Monitor surveillance and vigilance of anesthesia residents, *Anaesthesiology* **80** (1994), 527–533.

[5] D. Stefanidis, M. Scerbo, J. J. Korndorffer, D. Scott. Redefining simulator proficiency using automaticity theory, *The American Journal of Surgery* **193:4** (2007), 502–506.

[6] B. Zheng, M. A. Cassera, D. V. Martinec, G. O. Spaun, L. L. Swanström. Measuring mental workload during the performance of advanced laparoscopic tasks, *Surgical Endoscopy* **24:1** (2009), 45–50.