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Surgeon's vigilance in the operating room

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Patient safety

Abstract

OBJECTIVE: Surgeons' vigilance regarding patient condition was assessed using eye-tracking techniques during a simulated laparoscopic procedure.

METHODS: Surgeons were required to perform a partial cholecystectomy in a virtual reality trainer (SurgicalSim; METI Inc, Sarasota, FL) while wearing a lightweight head-mounted eye-tracker (Locarna systems Inc, Victoria, British Columbia, Canada). Half of the patients were preprogrammed to present a mildly unstable cardiac condition during the procedure. Surgical performance (evaluated by task time, instrument trajectory, and errors), mental workload (by the National Aeronautics and Space Administration Task Load Index), and eye movement were recorded and compared between 13 experienced and 10 novice surgeons.

RESULTS: Experienced surgeons took longer to complete the task and also made more errors. The overall workload reported by surgeons was similar, but expert surgeons reported a higher level of frustration and a lower level of physical demands. Surgeon workload was greater when operating on the unstable patient than on the stable patient. Novices performed faster but focused more of their attention on the surgical task. In contrast, experts glanced more frequently at the anesthetic monitor.

CONCLUSIONS: This study shows the usefulness of using eye-tracking technology to measure a surgeon's vigilance during an operation. Eye-tracking observations can lead to inferences about a surgeon's behavior for patient safety. The unsatisfactory performance of expert surgeons on the VR simulator suggests that the fidelity of the virtual simulator needs to improve to enable surgeons to transfer their clinical skills. This, in turn, suggests using caution when having clinical experts as instructors to teach skills with virtual simulators.

While performing a laparoscopic operation, surgeons are required to regularly check the status of the patient undergoing the procedure. A rising CO_2 level, for example, during the laparoscopy may cause cardiac arrhythmias and respiratory problems such as acidosis.[1] Delays in detecting worrisome changes may result in serious harm to the patient.[1,2] Therefore, the study of a surgeon's vigilance (ie, the ability to maintain attention and alertness over the course of a laparoscopic operation) is important when determining ways to improve patient safety.[3–5]

To date, there are few articles on the study of a surgeon's vigilance in the operating room. There are articles describ-

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ing the vigilance of anesthesiologists and other health care providers, but these studies often use methods that are subjective and lack consistency.[6–9] In this project, we introduce the eye-tracking technology to study the vigilance of surgeons while performing a simulated laparoscopic operation.

Psychological studies on human eye motions have documented that the point of gaze is tightly bound to the individual's attention when compound tasks are being performed.[10] Although a surgeon can attend to something else outside his/her point of gaze (covert attention), a shift of eye gaze (saccades) is invariably accompanied by a shift of attention.[11,12] Therefore, tracking a surgeon's eye movements during an operation indirectly provides information as to a surgeon's cognition of the task and even the surgeon's expertise to perform that task. Recently, in a study analyzing eye metrics (including blinking, fixation, pupil dilation, and convergence), scientists successfully classified 21 surgeons as expert or nonexpert with high accuracy in a simulated environment (90%–93% accuracy) and in a live-operating environment (81%–82% accuracy).[13] These results show that a surgeon's eye movements contain rich information regarding his/her confidence and expertise in performing a surgical procedure.

In this project, we have recorded surgeons' eye movements while they were performing a laparoscopic procedure on a simulated patient. The patient was preprogrammed to display either a stable or a mildly unstable cardiac condition during the procedure. We had 2 specific research objectives. The first objective was to investigate whether vigilance is a function of surgeon experience in performing a laparoscopic procedure. The second objective was to examine whether a surgeon's vigilance was affected by a patient's preoperative condition.

We hypothesized that (1) the frequency that a surgeon checked a monitor for the patient's vital signs was a function of his/her level of surgical experience and (2) the frequency that a surgeon checked the anesthetic monitor would be affected by the preoperative condition of the patient. We predicted that experienced laparoscopic surgeons would check a patient's vital signs more often than novice surgeons and that operating on a patient with an unstable cardiac condition would cause surgeons to check a patient's vital signs more often than when they were operating on a stable patient.

Methods

Environment and apparatus

The study was conducted at the Centre of Excellence for Surgical Education and Innovation at the University of British Columbia, an America College of Surgeons accredited level 1 education center in western Canada.[14] The experimental apparatus shown in Figure 1 consisted of 3 components, (1) a personal computer–based virtual simulator (SurgicalSim VR; METI Inc, Sarasota, FL), which created the simulated environment to perform a laparoscopic cholecystectomy; (2) a simulated patient whose vital signs were preprogrammed and controlled by a Mac operating system–based system (Emergency Care Simulator, METI Inc) during the operation, and (3) a lightweight head-mounted eye-tracker (PT-Mini; Locarna System Inc, Victoria, British Columbia, Canada) for monitoring the surgeon's eye motion pattern.

Figure 1 Experimental setup.

Participants

General surgery residents, minimally invasive surgery fellows, and attending surgeons of various experience levels were recruited from the Department of Surgery at the University of British Columbia for this study.

Procedure and measures

Participants were briefed on the nature of the study and gave consent to participate in the study. Participants were then asked to complete a background survey to measure their experience in performing laparoscopic surgery. The survey included a list of 12 surgical procedures in which participants were asked to indicate how many of each procedure they had completed as the primary surgeon and as the first assistant. The frequency of performing each procedure was rated using a 5-point scale. The participant was also required to report their training level (ie, junior, middle, senior resident, fellows, or attending) and estimate the number of years he/she had performed laparoscopic procedures using a 5-point scale. The raw surgical experience score was then normalized by dividing the raw score by the highest points that could be earned within a team, which was 130 points in this study.

Before starting the operation, surgeons were first calibrated on the Locarna eye-tracker. Then, they were given a written description of the patient history. Two patients were included with different histories. The first (stable) patient had a healthy history, whereas the second patient had a history of mild cardiac disorder (ie, unstable blood pressure). In the operation, the anesthetic simulator produced relatively stable vital signs and breathing rate for the stable patient. In contrast, for the second patient, the life signs cycled through stable, abnormal, and recovery at roughly 30-second intervals. Participants were required to perform a single trial on each condition in a counterbalanced order.

During the operation, the surgeon's eye motions were recorded and analyzed using measures of the percentage of time of eye gazing on the surgical and anesthetic monitors, the number of saccades (rapid eye) movements to the anesthetic monitor, and the eye fixation time on the anesthetic monitor. To avoid bias in eye measures, participants were not informed of these eye measures during the data-collection phase.

The SurgicalSim VR recorded the entire video of each surgical procedure. It reported surgical performance by measuring the following: (1) total procedure time (seconds), (2) instrument tip trajectory (centimeters), (3) time the electrocautery was in the air (seconds), (4) number of excessive traction movements on tissues, (5) number of times the electrocautery touched the opposite instrument, (6) number of times the electrocautery touched nontarget tissue, and (7) weighted sum of errors made during the operation. To achieve high scores, surgeons needed to perform the procedure quickly, precisely, and cautiously.

Once the operation was completed, the National Aeronautics and Space Administration Task Load Index (NASA TLX) form was used to measure the workload of the surgeon. The NASA TLX requires participants to rate their perceived levels of mental, physical, and time demands associated with a task on a scale of 20 points as well as their effort, performance, and frustration during that task. NASA TLX has been used extensively in a variety of projects for assessing the mental workload experienced while performing both open and laparoscopic operations.[15–17]

Data analyses

The participants were divided into 2 groups by their reported surgical experience. The novice group included junior residents (postgraduate year [PGY] 1 to PGY 3). The expert group included senior residents (PGY 4 and up), fellows, and attending surgeons. Demographics and surgical experience scores were compared between these 2 groups. Task performance, eye motion measures, and the NASA TLX measures were analyzed using a 2 (group) × 2 (patient condition) mixed analysis of variance model to examine the differences between 2 groups of surgeons and 2 different patient conditions.

Table 1 Demographics of participant surgeons

	Expert (n = 13)	Novice (n = 10)	*P* value
Training level	PGY 4–6 residents, fellows, surgeons	PGY 1–3 residents	
Age	38 ± 9	31 ± 8	.07
Years of performing laparoscopic procedure	2~15	0~3	
Surgical experience score	64 ± 20	26 ± 8	<.001

Results

A total of 10 novice and 13 expert surgeons were recruited to the study. The demographics of the 2 groups of participants are displayed in Table 1. Surgeons in the expert group had significantly higher experience scores than surgeons in the novice group.

To our surprise, expert surgeons took longer to complete the laparoscopic procedure than novices (200 ± 71 seconds vs 184 ± 49 seconds, $P = .48$), and expert surgeons made more errors per case with the virtual simulation model (14 ± 11 vs 10 ± 6 total counts of errors, $P = .26$). However, the differences were not significant. Changes in patient condition did not significantly alter surgeon performance.

Although the overall level of workload reported by surgeons in both groups was similar (53 ± 15 vs 52 ± 16, $P = .96$), surgeons in the expert group reported a higher level of frustration (46 ± 20 vs 33 ± 17, $P = .07$) and a lower level of physical demands (36 ± 18 vs 54 ± 20, $P = .03$) than novices while performing tasks under simulated conditions. Surgeons reported a higher level of overall workload when they were operating on the unstable patient than on the stable patient (54 ± 16 vs 54 ± 15, $P = .01$).

Novices performed the task faster but concentrated intently on the surgical task. On average, novices performed 1.6 times per case of saccade eye movement to the anesthetic monitor. In contrast, expert surgeons scanned the vital signs of the patient more often (2.7 times/case, $P = .50$). When examining the impact of patient condition on surgeon vigilance, experts and novices scanned differently to the anesthetic monitor (Fig. 2). Experts increased their frequency of checking the anesthetic monitor from 2.5 times for the stable patient to 2.9 times for the unstable patient. Novices increased from 1.1 times with the stable patient to 2.1 times with the unstable patient.

Comments

The results of this study indicate that expert surgeons visually scanned more than novices to the patient's condi-

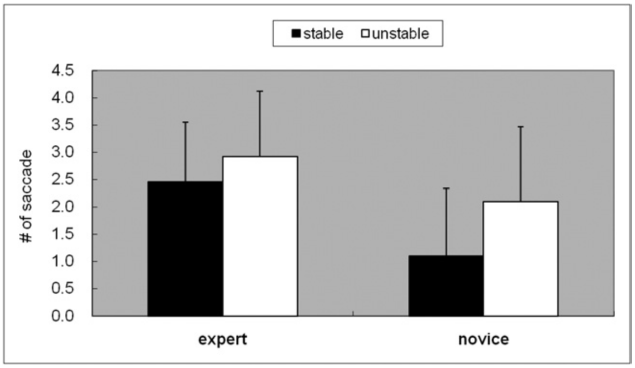

Figure 2 Surgeons scanned anesthestic monitor differently when operating on the stable and unstable patients.

tion during the operation. This is consistent with results from our previous study.[18] While performing a laparoscopic procedure, novices tend to focus their eyes to a limited area of the operative field, usually the tips of the instruments they are using. They seldom move their eyes around the surgical environment for other visual input.[18] As skills improve, surgeons start to acquire relevant information from the surgical targets and environment.[19] As we have shown here, the visual researching area of an expert surgeon can expand beyond the surgical monitor to other places around the operating room. They acquire information related to the patient and the operation.

The results presented in Figure 2 show that the change in patient condition affected surgeon behavior when scanning the patient's vital signs. This behavior is an essential human factor for the safe performance of a surgical procedure. In 1995, an in-depth interview was conducted in Ottawa with 33 surgeons involved in high-risk surgery to determine what was believed to be important for surgical excellence.[20] These highly proficient surgeons rated mental readiness as the most important factor above 2 other elements: technical skill and physical readiness. Where the surgeon's eyes are looking was identified as a vital determinant between successful and unsatisfactory surgical performance. The results presented in this study show promise for using eye-tracking technology to measure a surgeon's cognition during an operation.

The unsatisfactory performance of expert surgeons on the virtual simulator suggests that surgeons had difficulty transferring their clinical skills to the virtual simulator. Current versions of the virtual simulator may not provide sufficient fidelity to allow surgeons to transfer their skills, especially when tasks are compound (like suturing).[21,22] This, in turn, suggests using caution when having clinical experts as instructors teaching skills with virtual simulators.

There are limitations related to the design of this study. Several surgeons who participated in the study commented that a patient's vital signs are routinely monitored by the anesthesiologist in the operating room rather than by an operating surgeon. Junior surgeons may trust the work done by the anesthesiologist and are therefore not paying attention to the vital signs of patient.

To improve the fidelity of our next study, we will examine the surgeon's eye scans on the panels of surgical devices located inside the laparoscopic tower placed in front of the surgeon. While performing a laparoscopic procedure, surgeons are required to regularly check the status of several laparoscopic devices, such as the insufflator for maintaining pneumoperitoneum, the illuminator for lighting the scope, and various kinds of electrosurgical devices for dissecting tissue and stopping bleeding.[1,2] Failure to adjust a parameter promptly may result in problems during the operation such as a reduced intra-abdominal workspace or damage to the patient's tissues around the surgical site.[1,2] In addition, we will replace the virtual simulator with an animate model that will allow surgeons to transfer their clinical skills easier because it will more closely resemble the operating room environment.

Conclusions

This study shows the usefulness of using eye-tracking technology to measure a surgeon's vigilance during an operation. Eye-tracking observations can lead to inferences about a surgeon's behavior for patient safety. The unsatisfactory performance of expert surgeons on the VR simulator suggests that the fidelity of the virtual simulator needs to improve to allow surgeons to transfer their skills from the real operating room environment. This, in turn, suggests using caution when having clinical experts as instructors to teach skills with virtual simulators.

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Discussion

James Peck, M.D. (Portland, OR): Dr. Zheng and colleagues compared 13 experienced surgeons and 10 novices using “eye metrics” during a simulated laparoscopic cholecystectomy. Experienced surgeons more frequently checked the anesthetic monitor for vital signs. They did so not only in unstable patients with a cardiac history but also in stable patients. Unstable patients had episodes of tachycardia, hypotension, or hypertension in 30 second cycles. The results confirmed the objectives of the investigators that vigilance is a function of surgeon experience.

Eye-tracking techniques, as an objective assessment of surgical skill, have been well documented in the literature. The point of gaze is tightly bound to the individual’s attention or focus. A shift in the eye gaze, so-called saccades, is invariably associated with a shift in attention. It has been shown that by using eye metrics that expert surgeons are more focused and deliberate to the task at hand than non-experts. The completion of any surgical task requires cognitive skills including a detailed understanding of the anatomy and the ability to progress logically in a sequence steps. The expert surgeon re-evaluates his progress in real time identifying potential pitfalls and assessing possible complications.

Yet, experience alone has been used as a surrogate for expertise. However, many surgeons without years of experience can perform at an expert level. Conversely, it is possible that a high-volume surgeon could be repeatedly executing certain tasks poorly. Eye metrics may be the best available purely objective physiological parameter that can identify surgical expertise. Thus, it has the potential to objectively measure the progression of a resident skill through surgical training. Their performance would then be reinforced by role models during actually patients’ operations. Moreover, eye-tracking techniques could be used as a prerequisite for meaningful credentialing of the older surgeon.