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Analysis of eye gaze: Do novice surgeons look at the same location as expert surgeons during a laparoscopic operation?

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Abstract
Introduction Eye-gaze technology can be used to track the gaze of surgeons on the surgical monitor. We examine the gaze of surgeons performing a task in the operating room and later watching the operative video in a lab. We also examined gaze of video watching by surgical residents.
Methods Data collection required two phases. Phase 1 involved recording the real-time eye gaze of expert surgeons while they were performing laparoscopic procedures in the operating room. The videos were used for phase 2. Phase 2 involved showing the recorded videos to the same expert surgeons, and while they were watching the videos (self-watching), their eye gaze was recorded. Junior residents (PGY 1-3) also were asked to watch the videos (other-watching) and their eye gaze was recorded. Dual eye-gaze similarity in self-watching was computed by the level of gaze overlay and compared with other-watching.
Results Sixteen cases of laparoscopic cholecystectomy were recorded in the operating room. When experts watched the videos, there was a 55 % overlap of eye gaze; yet when novices watched, only a 43.8 % overlap ($p < 0.001$) was shown.
Conclusions These findings show that there is a significant difference in gaze patterns between novice and expert surgeons while watching surgical videos. Expert gaze recording from the operating room can be used to make teaching videos for gaze training to expedite learning curves of novice surgeons.

Keywords Eye tracking · Eye gaze · Simulation · Competency assessment · Teaching videos · Minimally invasive surgery · Laparoscopy · Surgical education

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Eye tracking technology has been used as early as 1960 for image perception in radiology. Kundel and Nodine developed the concept of foveal fixation clusters while analyzing the visual search during the interpretation of plain radiographs. They suggested foveal fixation clusters of a duration more than 100 min and used the centroid of a fixation cluster to describe the center of focal attention surrounded by a 5° visual field for the region of interest [1]. It was well understood that the main function of the oculomotor system was to keep the center of gaze very close to the point of greatest interest being temporally and spatially coupled to the task at hand [2] and that analysis of saccades could reveal much about the underlying cognitive mechanisms that guided them. The areas of interest for a basic simulated laparoscopic task had been previously assessed [3]. Dempere-Marco et al. [4] from Imperial College have shown how novices can be trained to follow expert visual assessment strategies in reading CT lung images, with significantly improved performance.

Eye-tracking technology was used recently for the assessment of surgical skills [5]. It also has been shown that gaze-trained learners do better than motion trained and discovery learning groups [6]. The purpose of this study was to determine whether eye-tracking technology can be used to detect differences in the eye-gaze patterns between experts and residents while watching videos. We decided to examine the similarity in the eye tracking of surgeons and junior residents while watching the same video. To fulfill the goal, we obtained the eye gaze of surgeons performing in the operating room. We also wanted to test whether gaze overlay was a function of surgical complexity.

We hypothesized that self-watching videos (by expert surgeons) would achieve higher overlay gaze than the video watched by others (junior residents). We further hypothesized that while watching complex surgical tasks, such as dissecting the cystic duct and artery, surgeons would achieve a higher level of overlap than watching a relatively easy surgical task, such as removing the gallbladder from the liver. The later was used to test whether or not gaze overlap was a function of surgical complexity.

Fig. 1 Operating room setup for phase 1 recording. The eye-tracker was placed on top of a mayo stand covered with a sterile drape

Fig. 2 Live recording in the operating room

Study design and methods

This study was performed in an operating room at the University of British Columbia Hospital and at the Centre of Excellence for Simulation Education and Innovation (CESEI) laboratory. We obtained ethics review board approval to conduct the study. Expert surgeons and novices (postgraduate year 1-2) were enrolled in the study. The letter of enrollment was distributed among residents and staff. The participation in the study was voluntary. Expert surgeons were recruited from the Minimally Invasive Surgical Service at Vancouver General Hospital.

Technology used and equipment setup

A Tobii X50 eye-tracker was used to capture surgeon eye gaze in the operating room as well as in the laboratory. It was accurate to 1° visual angle. The eye-tracker was placed on a Mayo Stand covered by a sterile drape under the main display monitor. This was the monitor that the surgeon was looking at during the operation, and it was positioned at arm's length from the surgeon as per manufacturer's guidelines (Figs. 1, 2). Eye calibration was performed before changing the display back to the laparoscopic image used for the surgical procedure. The same eye-tracker was used in the lab for the phase II study.

The eye-tracking computer used ClearView 2.7 eye-gaze analysis software (Tobii Technology, Sweden). The data were exported as spreadsheet and analyzed using Microsoft Excel.

Procedure

The study was divided into two phases. Phase I was conducted in the operating room during a real laparoscopic operation. Phase II was conducted in the laboratory at CESEI.

During phase I, we recorded surgeon eye-gaze on the monitor where the real-time image was displayed during a laparoscopic procedure. We selected laparoscopic cholecystectomy for this study because of the relatively stationary position of the surgeon during this operation. We divided the whole operation into two distinct portions in terms of complexity. The more complex portion was dissection of the triangle of Calot, and the less complex part was removing the gallbladder from the liver bed.

In phase II, the surgical videos recorded in the operating room (phase 1) were shown to the surgeons a few weeks later in the lab and also to junior residents while their eye gaze was recorded. We compared the overlay of dual gaze during "self-watching" and "other-watching." We also compared the overlay rate between tasks with greater precision requirement (dissecting the cystic duct and artery) and relatively less demanding tasks (removing the gall bladder from the liver). Eye-gaze patterns were considered "overlapped" when the distance between two gaze points was less than 120 pixels, which corresponds to $\sim 3°$ of visual angle. The percentage of overlap time was based on the entire procedure time. Figure 3 shows dual overlay and Fig. 4 shows gaze separation visualization.

Statistics

To test our hypothesis, a within subject ANOVA was employed to compare the gaze overlay difference presented between watching styles (self-watch vs. other-watch) and between surgical steps (dissecting structures in Calot's Triangle vs. removing the gallbladder from the liver). Results were reported as mean $\pm$ standard deviation unless otherwise stated. $p < 0.05$ was considered significant.

Results

We recruited a total of four expert surgeons for the study. We were unable to track the eye gaze of two of the surgeons. This was mostly due to the inability of the surgeons to stay within the required distance as recommended by the manufacturer of the eye-tracker. We excluded those recordings in the beginning of the procedure due to "no capture."

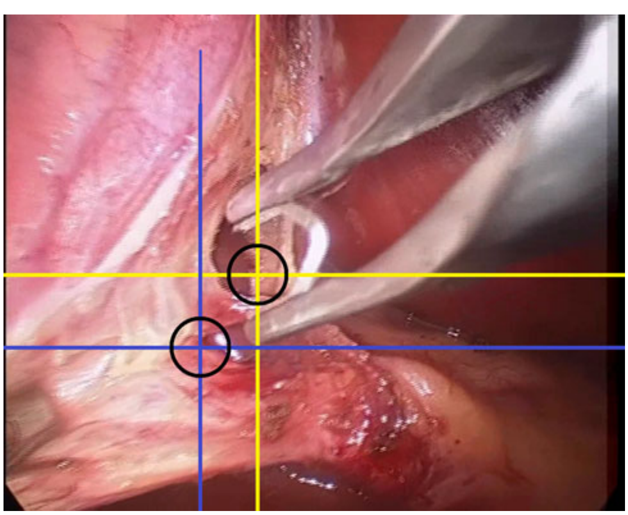

Fig. 3 Dual overlaid screenshot with operator's point of gaze (*blue*) and third-party watcher's gaze (*yellow*). The 3° visual angle *circle* ($\sim$120 pixels) is shown in *black*

We successfully recorded 16 laparoscopic cholecystectomy cases from the operating room performed by two expert surgeons. Expert surgeons showed a 55 % overlap ($n = 16$; standard deviation (SD) 10.3 %) of eye-gaze pattern from phase 1 to phase 2 (doing vs. self-watching). When the video was watched by junior residents, only a 43.8 % overlap ($n = 20$; SD 8.6 %) was shown, which was significantly less compared with the self-watching by the expert surgeons ($p = 0.001$).

While watching surgical tasks requiring a higher level of precision, all participants had a higher percentage (48.5 %) of gaze overlay than while they were watching relatively easier tasks (37.9 %, $p = 0.011$).

Discussion

We have demonstrated successfully in this study that there is a significant difference in the eye-gaze pattern between expert and novice surgeons. Novice surgeons had eye-gaze patterns that often wandered from key areas of the operative field, whereas expert surgeons demonstrated closer eye-gaze patterns that focused on these key target areas.

Although only 55 % of gaze overlap was noted, several factors may contribute to the low overlap. During video watching, surgeons (including experts) tended not to perform proactive eye gaze as they did in performing the task; they tended to shorten the fixation time on the surgical site during watching compared with performing the task. We have made a similar observation in a simulated surgery laboratory setting using a training box to measure the eye-gaze overlap between performing a task and watching the task video [7], where we reported an eye-gaze overlap of 68 % at 2.5° of visual angle overlap. This result shows that even in a simple laboratory setting, the maximum overlap to be expected is less than 70 %.

Beside the behavioral differences between doing and watching, there is an important technical factor that may account for the low overlap rate. We realized that although surgeons might be gazing on the same anatomic structure, the gaze could fail to be calculated as overlapping. In this study, we used an overlap area of 120 pixels, corresponding to approximately 3° of visual field. In this more dynamic surgical setting, where the point of view of the camera is changing as well as the surgical scene and the tools in the scene, it is not surprising that the overlap observed (55 %) was less than noted in the laboratory task (68 %).

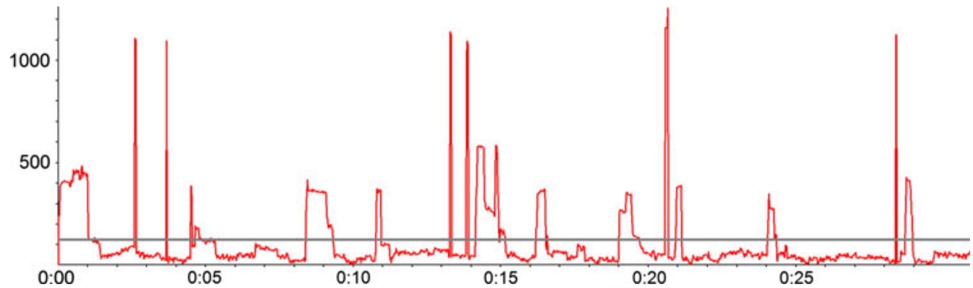

Fig. 4 Gaze overlap visualization, time on *x*-axis and pixels by which the gaze points differ on *y*-axis. The *horizontal line* is our cutoff of 120 pixels

During surgical procedures, surgeons need to scan over multiple places besides display monitors. When their eyes were focused on the surgical monitor, which were the moments for which we calculated gaze overlap, surgeons might have different strategies for directing their vision. What we found here was that the expert surgeons developed an ability to scan over surgical sites using a replicable strategy over different trials. In contrast, novice surgeons did not develop a stable strategy and had a lower chance to copy the expert's visual strategy. We are excited that the dual gaze technology used in this study is able to reveal such a difference between novice and expert. This technology opens an opportunity for us to scrutinize the learning process of a surgeon in an objective way. We will be keen to check whether the gap in gaze overlap will be reduced once novices have learned more about the surgery and improved their surgical skills. On this issue, the difference between novice and expert, although small, is quite significant for surgical education.

We also demonstrated that gaze overlay is affected by the complexity of the surgical procedure. The dissection of the cystic artery and cystic duct required closer observation to identify critical structures and to prevent major complications, such as injuring the common bile duct. This close and careful observation by the operating surgeon as well as by observers of the surgical video (both expert and novices) showed higher gaze concordance than the less complex part of dissecting the gallbladder off of the liver.

Gaze training has been shown to expedite the learning curve compared with movement training and discovery learning groups as mentioned above. Gaze-trained participants had more attentional spare resources to complete the eye-hand coordination task under multitasking pressures [6]. The gaze-trained group watched videos displaying the eye tracking of the experts. The experts' eye tracking was obtained while they were actively performing a task. In reality, it is difficult to obtain such eye-tracking video during a real operation. An obvious method to circumvent these difficulties is to have expert surgeons review recorded videos of operations and record their eye gaze patterns at that time. However, we have demonstrated in our study that this eye-tracking data may not be accurate and hence not ideally suited for teaching videos. Eye-gaze patterns obtained from the expert surgeon should be recorded during the actual operation and then superimposed on the recorded surgical video. This would provide additional information to novice surgeons as to where the expert surgeon is focusing his/her attention during each step of the operation.

Eye-gaze technology is a way to provide an objective assessment of surgical trainees instead of the usual subjective assessments that are currently available. Even with only two expert surgeons, we were able to demonstrate a statistically significant difference between expert surgeons and surgical trainees. The next step will be to use eye-tracking technology in the operating room to assess how trainees at different levels of training perform. In this way, this technology can be a very useful adjunct to monitoring surgical performance.

At present, the Global Operative Assessment of Laparoscopic Skills (GOALS) is one of the best methods for assessing laparoscopic surgical skills. It includes a five-item global rating scale (depth perception, bimanual dexterity, efficiency, tissue handling, and autonomy), a ten-item task specific checklist, and two 10-cm visual analogue scores (this is similar to OSATS Objective Structured Assessment of Technical Skills) [8, 9]. The use of eye tracking for surgical skills assessment is a potentially new way of obtaining objective data as opposed to the mostly subjective data that is obtained from current assessment methods. Wilson et al. used eye tracking and gaze analysis on a laparoscopic simulator and noted "…that experienced surgeons spent significantly more time fixating the target locations than novices who split their time between focusing on the targets and tracking the tools" [10]. Our study also has demonstrated a statistically significant difference between expert and novice eye-gaze patterns while viewing videos from real operations. Eye-metrics together with eye tracking while watching surgical videos can be used as adjuncts to assessing surgical skill and level of competence.

Our next step is to have a novice surgeon perform a laparoscopic task in the operating room while being supervised by an expert surgeon and record the eye-gaze patterns of both surgeons while they are watching on the monitor. We will then analyze how novice surgeons differ from expert surgeons during a real operation and how these differences can be used to assess surgical performance and competence.

Conclusions

This study has demonstrated that there is a significant difference in eye-gaze patterns between novice and expert surgeons while watching a laparoscopic operation. Eye-tracking technology potentially can be used to expedite the learning curve for laparoscopic operations by teaching surgeons-in-training to follow the eye-gaze patterns of expert surgeons.

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