Surgical knot training in ophthalmic surgery: Skill assessment with eye-tracking

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INTRODUCTION

Suturing is a fundamental task in ophthalmic surgery. Focused training is necessary to master technical (tissue handling, knot tying) and cognitive (appropriate selection of instruments, forward planning) skills and develop a high level of hand-eye coordination required for ophthalmic microsurgical procedures. Formulating novel objective measures of operational performance will be beneficial for training in ophthalmic microsurgery.

Capturing eye movements and points of focus while performing surgical tasks can provide meaningful information to assess the operator's technical and cognitive skills and overall performance. The locations of gaze focus and spatial distribution of fixations embed valuable information for assessing the use of instruments, the sequence and quality in executing subtasks, and possibly the level of hand-eye coordination the operator demonstrates. This study explores eye-tracking for developing performance metrics for suturing tasks in ophthalmic surgery and preliminary analysis focuses on the total duration of executing a surgical suture and its subtasks. It also introduces the spatial distribution of fixations as a feature to characterize the level of surgical expertise.

Eye-tracking has been used as a tool for skill analysis in a variety of different surgical applications. Copogna et al. [1], compared anesthesiologists of different expertise levels performing an epidural block. Attentional heat-maps and gaze plots showed different gaze dispersion between the groups. Causer et al., showed that quiet eye training significantly improved learning of surgical knot tying compared to a traditional technical approach [2]. In [3], expert and novice neurosurgeons performing under a surgical microscope were examined, concluding that experts spend more time fixating on the region of interest before performing an action. Lee et al., used eye-tracking data to identify gaze patterns and blind spots in a real-time EGD [4].

While efforts have been made to analyze gaze patterns [3],[4], it has yet to be developed a metric that can be used to statistically compare the spatial distributions of gaze focus points, a rather useful tool to evaluate the skill level of groups with different expertise.

MATERIALS AND METHODS

This study was conducted in the Royal College of Ophthalmologists (London, UK) during the training course "Introduction to Ophthalmic Surgery". It includes two one-hour long training sessions for practicing surgical knots. Prior to practicing, participants were educated through lectures, videos, and live demonstrations. In the first session, attendees were instructed to practice the surgical knot on a standard suture training board, where on average they completed five knots and continued with more demonstrations before the second practice session.

Equipment

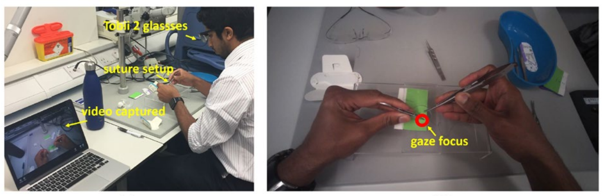
For capturing eye movements, the Tobii Pro Glasses 2 (Stockholm, SWE) was used and deployed as shown in Fig. 1(a). Tobii glasses use near-infrared illumination to create reflection patterns on the cornea and pupil of the subject's eye, while image sensors are used to capture images of the eyes with the reflection patterns. Image-processing and a physiological 3D model of the eye are then used to estimate the point of gaze within the field of view (FoV) provided by a camera at the front side of the glasses. Time-stamped gaze focus points (pixel coordinates) are synchronized with the FoV video recording and overlayed (red circle) as shown in Fig.1(b).

Participants

We recruited 20 volunteers, 9 *experts* – faculty members delivering the course and 11 *novices* – trainees attending the course, in the early stage of their residency training. Of the 11 novices, we selected 6 from the first session and 5 from the second one, to compare novices that had more time to practice. All participants were asked to execute a single surgical knot on the training board, whilst wearing the eye-tracking glasses. After obtaining basic familiarity with the task, we recorded one video from each participant, and calibration took place before every recording.

Dataset and Annotation

A surgical knot consists of two major subtasks, as shown in Fig. 2. These are needle passing and knot tying, where typically surgeons tie three knots to secure the suture. By reviewing the videos, we annotated the start and end moments of each subtask, as shown in Fig. 2.



(a) (b)

Figure. 1. (a) Experimental setup, (b) Snapshot of a video showing the wearer's field of view along with gaze focus point.

Inspired from the literature [1],[2], we then calculated **i)** the total duration of the entire suturing task, which commences with the needle passing and ends with suture cutting; **ii)** the duration of the needle passing subtask, as well as **iii)** the duration of tying the first knot. These time-based metrics were further used for statistical analysis.

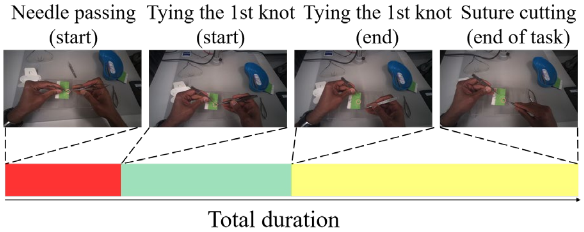


Figure. 2. Annotation of a surgical suture task from our dataset.

In order to aggregate gaze focus points in a single image, we should assume that the subject's FoV doesn't change. During knot tying head movements were limited, in contrast with the needle passing phase, hence we assume that the FoV remained mostly the same. This allowed us to investigate the spatial distribution of gaze samples and fixations during that phase. Gaze samples are classified as part of a fixation, if the velocity of directional shifts of the eye is below 30 visual degrees per second. The distribution of fixations is illustrated as a heatmap plot (see Fig. 3) in which warmer colors signify a larger concentration of fixations observed on that point. From Fig. 3, it is evident that differences in the spatial distribution of fixations between the expertise groups exist. Experts' fixations are clustered together in smaller areas than novices' ones. To quantify the spatial distribution of fixations during the knot tying phase., we introduce *fixation sparsity*, as the ratio of the total number of color-valued pixels (locations that we obtain fixations) in the heatmap divided by the image resolution, 1080×1920.

RESULTS

The four variables, total duration of the task, needle passing duration, first knot tying duration, and fixation sparsity were analyzed using the Mann-Whitney U-test with p = 0.05 significance level (two-tailed). Results are summarized in Table 1, where one can observe significant differences between the groups of experts and novices. No significant differences (p > 0.05) between novices from the first session and the second one were found.

Table. 1. Mann-Whitney U-test results with p = 0.05 significance level (two-tailed).

Dependent Variable	Median/Min/Max		p-value
	Experts ($n_e = 9$)	Novices ($n_n = 11$)	
Total duration	70.12/46.36/83.32s	98.08/55.6/191.2s	0.001
Needle passing duration	19.04/35/18.96s	30.12/15.36/79s	0.04
1st Knot tying duration	12.68/5.6/18.96s	16.44/13.7/40.24s	0.006
Fixation sparsity	0.0362/0.0215/ 0.0486	0.0516/0.0216/ 0.0697	0.008

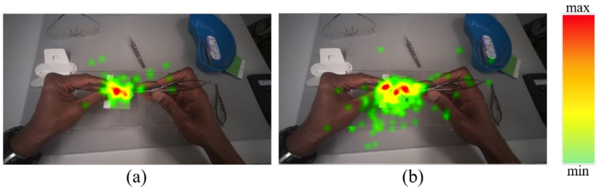


Figure. 3. Example of the spatial distribution of fixations during knot tying (a) expert surgeon, (b) novice surgeon.

CONCLUSION AND DISCUSSION

In this work, we compared expert and novice surgeons based on their duration in executing a surgical knot as well as its different subtasks. Overall, expert surgeons were found to be significantly faster than their novice counterparts. Our analysis on the spatial distribution of fixations concluded that experts focus their gaze almost entirely on areas of interest (e.g., suture, tools) when tying the knots, resulting in the distribution, being concentrated in the area around the suture (see Fig. 3a). On the contrary, novices' distribution is more dispersed, with fixations occurring across a larger area (see Fig. 3b). A possible explanation is that novices need to visually verify that they are using the appropriate instruments. We also found that when tightening the knot, novices focus their gaze on the tools pulling the thread, rather than on the suture. Analyzing the fixation distribution can indicate areas of high/low interest, and patterns associated with levels of expertise, contributing towards novel metrics for skill assessment in ophthalmic surgery. These interesting observations can potentially lead to objective metrics for assessing the level of hand-eye coordination. Future work will focus on developing novel eye-tracking features and examining their correlation with standardized manual assessment, as well as on algorithms for predicting surgical skills.

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