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Eye Motion Parameters Correlate with Level of Experience in Video-Assisted Surgery: Objective Testing of Three Tasks

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ABSTRACT

***Background*: Laparoscopic skills vary with experience and training; however, objective measures to ascertain the level of training have not yet been established. New technology allows noninterfering measurement of eye motion parameters that correlate with attention and distraction during visually oriented tasks. Our objective was to apply this new technology in the setting of video-assisted surgery to evaluate eye motion parameters among surgeons of varying experience.**

***Materials and Methods*: Subjects with various levels of laparoscopic experience (novice, intermediate, and expert) were fitted with a noninvasive, Food and Drug Administration approved, eye motion monitoring device. The device was used to measure and record parameters of eye motion, including saccadic rate (SR), standardized peak velocity (PV), standardized saccadic amplitude (SA), and the duration of gaze fixation (FD), during the performance of 3 basic laparoscopic tasks on a laparoscopic training station.**

***Results*: A total of 24 subjects (3 groups of 8 each) participated in this study. Experience level was found to have a main significant effect on SR ($P = 0.047$) and PV ($P = 0.028$). Two-way ANOVA demonstrated that experience level approached significance for SA ($P = 0.058$) and FD ($P = 0.055$).**

***Conclusion*: The advancement of laparoscopic techniques and instrumentation relies, in part, on expanding the current understanding of operator/instrument interactions. This places an increasing demand on objective methods of monitoring such interactions during laparoscopy. Our study demonstrates a significant difference in eye motion parameters in surgeons with differing levels of experience. Further testing is needed in actual clinical settings to determine the importance of eye motion during surgery.**

INTRODUCTION

As the number and types of operations performed laparoscopically increases, there is a mounting need to develop objective measures of competence and skill.[1] Traditional methods of assessment have relied on observation and subjective evaluation by more experienced individuals.[2] New technologies have paved the way for the development of novel assessment methods that focus on dividing laparoscopic tasks into discrete and measurable components, and providing objective parameters for evaluating and assessing laparoscopic skills.

Performing minimally invasive surgery challenges the surgeon to interpret the 3-dimensional position and motion of surgical instruments by means of 2-dimensional visual information. Thus, laparoscopic tasks can be di-

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vided into two interrelated yet distinct interactions: the surgeon/instrument and surgeon/monitor interfaces. Recently, virtual reality simulators, videoscopic box trainers, and intraoperative instrument monitoring devices have been used to objectively measure and evaluate surgeon/instrument interactions.[3,4] In one study, Rosen and colleagues employed a mechanical system comprised of linear and rotary potentiometers attached to videoscopic instruments to track their positions and orientations intraoperatively.[5,6] The authors found that there were significant differences between expert and novice videoscopic surgeons in many of the measured parameters, including force/torque magnitudes applied during tissue manipulation and dissection, instrument tip displacements, and time spent in the idle state. This notion—that measured surgeon/instrument parameters vary based on the level of training—forms the basis for many of the current methods used to teach and evaluate videoscopic surgeons during training.

Less is known about the surgeon/monitor interface, where 2-dimensional visual information is collected and processed by the surgeon during laparoscopy. A growing number of studies address various types of viewing technologies, such as 3-dimensional monitors and head-mounted displays, but most focus on improving the delivery of visual information.[7–9] Little is known about the actual consumption of visual information during surgery. Recent developments in eye motion monitoring systems that pose minimal interference to the surgeon have made studying this component of laparoscopic surgery more feasible.

Based on the numerous reports of experience-related differences in measured surgeon/instrument interactions, we hypothesized that there would be similar differences in measured parameters at the surgeon/monitor interface. To test this hypothesis, we used a head-mounted eye motion monitoring device to noninvasively measure eye motion parameters relating to saccadic activity (the movement of the eyes as they shift from one point of gaze to another). We compared the eye motion parameters of subjects with different levels of laparoscopic experience during the performance of basic tasks on a laparoscopic box trainer.

MATERIALS AND METHODS

Volunteers with various levels of experience in laparoscopy participated. Subjects were classified based on self-report as either novice (no previous laparoscopic experience; this group included nonmedical hospital staff and medical students with no previous operative experience), intermediate (< 100 total laparoscopic cases performed), or expert (fellowship training in advanced laparoscopic surgery).

FIG. 1. A study subject performs a laparoscopic task with the eye motion monitoring device in place.

Eye motion monitor

The Cyclops Eye Trak saccadometer (Bertec Corporation, Columbus, Ohio) was used to noninvasively measure the eye motion of each subject during the performance of three basic laparoscopic tasks (Fig. 1). This instrument uses infrared oculography technology to track corneal movement and eye-blinks by illuminating the surface of the eye with infrared light and measuring the amount that is reflected back. The device is positioned on the forehead of the subject and held in place with a headband strap. The eye motion sensors rest on the bridge of the nose, similarly to a pair of glasses. Data are continuously transferred from the device to a laptop computer via an infrared link. Real-time outputs of eye motion parameters are displayed and stored on the computer.

Laparoscopic box trainer

All videoscopic tasks were carried out on a basic closed-box training station (Stryker Surgical, Kalamazoo, Michigan) (Table 1). We have previously reported the use of this box trainer as an effective method for developing and assessing laparoscopic skills.[10]

Data processing and statistics

For each subject, during each task, two categories of eye motion parameters were simultaneously recorded. The first set was time-independent and included total number of saccades, saccadic amplitude (in arbitrary units), peak velocity per saccade (in arbitrary units/second), duration of each saccade (in seconds), and duration of gaze fixation preceding a given saccade (in seconds). The second set of data was time-dependent and used a 3-

TABLE 1. DESCRIPTION OF LAPAROSCOPIC BOX TRAINER TASKS

Loops	A 5 x 5 inch board with 5 loops screwed into the surface is used. The leading tip of a 5-mm cord is passed through successive loops, following a winding path. The task is complete when the tip of the cord is passed and pulled through the final loop.
Rope	A 100-cm segment of rope marked with 1-cm black bands at 10-cm intervals is used. The rope is run from one end to the other, touching only the black bands.
Beans	A bean is passed through a small opening located at the apex of a convex-top container. The task is complete when 10 beans have been successfully transferred into the container.

second window centered on a given timepoint to determine saccadic rate (saccades/minute). The window was advanced and rates were recalculated 25 times per second. Thus, saccadic rate was recorded as number of saccades per 3-second window, which was converted to number of saccades per minute for data evaluation.

The measurement of saccadic amplitude and peak velocity in arbitrary units introduced the possibility of intersubject variability in these measurements. Therefore, these values were standardized to reflect deviation from the mean in units of standard deviation (SD).[11] The resultant dimensionless standardized values were averaged and compared between subjects and groups, as described below.

The null hypothesis was that there would be no difference in the eye motion parameters between groups of subjects with varying levels of videoscopic experience. All eye motion parameters were averaged per subject (3 groups of 8 subjects each) and per task (loops, rope, and beans). Based on these means, the main effect of experience level on the dependent variable (the eye motion parameter being measured) was determined using two-way analysis of variance (ANOVA). One-way ANOVA was used to compare mean overall times required to complete individual tasks. Equal group sizes allowed for pairwise comparisons to be carried out using the Tukey honestly significant difference (HSD) post-hoc criteria. Differences were considered significant and the null hypothesis was rejected when $P \leq 0.05$.

RESULTS

A total of 24 subjects participated. Subjects were separated into one of three experience level groups based on self-reported information: 8 subjects were classified as novice, 8 as intermediate, and 8 as expert. All subjects successfully performed the three tasks. In all cases, the effect of experience level on the group mean times to complete individual tasks and all tasks combined was highly significant ($P < 0.01$) (Table 2). For mean times across all tasks, the post-hoc pairwise comparisons showed that both intermediate and expert group means were significantly lower than the novice group mean ($P < 0.01$ for both). The difference between intermediate and expert group means was not statistically significant.

As described above, each value recorded for the time-dependent variable, saccadic rate, represented the number of saccades during a 3-second window centered on a given time point. All reported values were converted to saccades/min for analysis. Two-way ANOVA yielded a main effect for level of experience ($F_{2,21} = 3.54$, $P = 0.047$), such that the average saccadic rate was significantly lower for the expert group (25.50 ± 8.91) than for the novice group (35.98 ± 10.24) (Fig. 2). The average saccadic rate for the intermediate group (33.96 ± 6.92) was between those of the novice and expert groups, but not significantly different from either on post-hoc analysis.

TABLE 2. COMPARISON OF TIMES REQUIRED TO COMPLETE TASKS

	Loops	*Rope*	*Beans*	*All tasks*
Novice	211 ± 111	148 ± 53	143 ± 68	167 ± 84
Intermediate	97 ± 21	56 ± 9	75 ± 28	76 ± 27
Expert	70 ± 22	55 ± 12	59 ± 16	61 ± 18
P value	<0.01[a]	<0.01[b]	<0.01[c]	<0.01[d]

[a] *P* value based on one-way ANOVA, $F_{2,21} = 10.14$.
[b] *P* value based on one-way ANOVA, $F_{2,21} = 22.52$.
[c] *P* value based on one-way ANOVA, $F_{2,21} = 8.38$.
[d] *P* value represents main effect for group based on two-way ANOVA, $F_{2,21} = 21.10$.
Times are expressed in seconds as mean ± standard deviation.

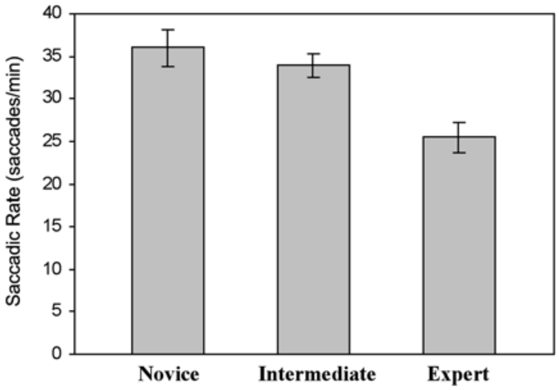

FIG. 2. The mean saccadic rates across all three tasks are shown for each group. The main effect for group ($F_{2,21} = 3.54$, $P = 0.047$) was determined by two-way ANOVA. Post-hoc pairwise comparisons showed that the intermediate group was not significantly different from either novice or expert groups.

For standardized peak velocity, the main effect of experience level yielded an F ratio of $F_{2,21} = 4.28$, $P = 0.028$, indicating that the mean standardized peak velocity was significantly greater for the expert group (0.791 ± 0.013) than for the novice group (0.737 ± 0.008). The mean standardized peak velocity for the intermediate group (0.759 ± 0.009) was between those of the novice and expert groups, but not significantly different from either on post-hoc analysis (Fig. 3). The results for mean standardized saccadic amplitudes demonstrated a similar trend for means; however, the main effect of experience level only approached significance ($F_{2,21} = 3.27$, $P = 0.058$) and post-hoc pairwise analysis was not significant (Fig. 4). The overall mean standardized saccadic amplitudes were 0.667 ± 0.014 for the novice group, 0.713 ± 0.014 for the intermediate group, and 0.738 ± 0.021 for the expert group.

The mean duration of gaze fixation, in seconds, across all three tasks was 0.562 ± 0.039 sec for the novice group, 0.544 ± 0.023 sec for the intermediate group, and 0.804 ± 0.087 sec for the expert group. Two-way ANOVA showed that the main effect of experience level on mean fixation duration was borderline significant ($F_{2,21} = 3.34$, $P = 0.055$) (Fig. 5). Post-hoc analysis did not reveal significant pairwise differences.

DISCUSSION

The results of this pilot study demonstrate that previous laparoscopic experience has a significant effect on eye motion parameters measured during the performance of basic tasks on a laparoscopic box training station.

The mean saccadic rate was found to vary inversely with experience level. Experts were able to execute the laparoscopic tasks with fewer eye movements per unit of time. Since a decreasing number of saccades would be expected to result in longer latency periods (periods during which the eyes are not moving), finding that mean durations of gaze fixation tended to be longer in the expert group was not surprising. Overall, these results suggest that subjects with greater experience tend to move their eyes less and spend more time fixed on a given point. In contrast, subjects with no previous experience move their eyes more frequently and tend to spend less time looking a particular point. One possible explanation for these results is that novice subjects frequently reposition their gaze to maintain focus on objects as they change position on the monitor, while experienced subjects avoid excessive eye movements by better utilizing their peripheral vision to carry out laparoscopic tasks. However, objects in the box trainer are freely mobile and easily repositioned. Therefore, it is also possible that expert subjects reduce eye motion not by relying on their peripheral vision, but by bringing the point of action to the center of their gaze. Also, less experienced subjects may try to minimize the manipulation of objects in 3-dimensional space by opting to simply move their eyes along the 2-dimensional video display. Lacking the experience to know where on the screen to look, this behavior may lead to the increased saccadic rates and shorter fixation durations observed for novice subjects. From our data, we are unable to determine the position and movement of objects in the box trainer. Future studies to account for these variables are needed to more clearly explain the observed differences in saccadic rate and fixation duration.

It is more difficult to draw conclusions from the standardized peak velocity and standardized saccadic amplitude data. Owing to a number of uncontrollable variables

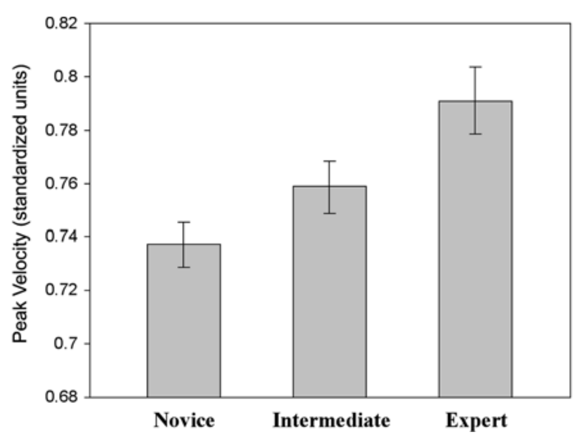

FIG. 3. The mean standardized peak velocities across all three tasks are shown for each group. Main effect for group ($F_{2,21} = 4.28$, $P = 0.028$) was determined by two-way ANOVA. Post-hoc pairwise comparisons revealed a significant difference ($P = 0.022$) between novice and expert groups only. Bars represent standard errors of the mean.

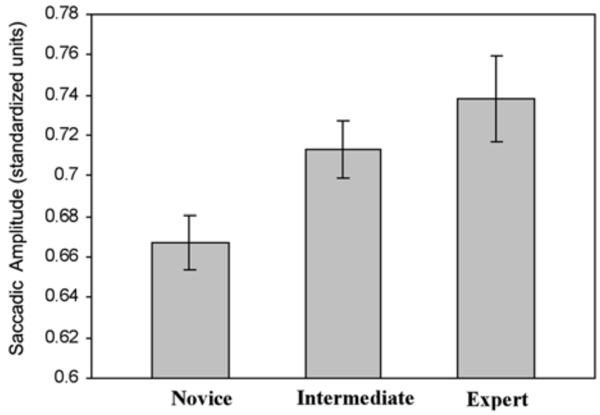

FIG. 4. The mean standardized saccadic amplitudes across all three tasks are shown for each group. Main effect for group ($F_{2,21} = 3.27$, $P = 0.058$) was determined by two-way ANOVA. Post-hoc pairwise comparisons were not significant. Bars represent standard errors of the mean.

between subjects, such as interpupillary distance, arm length, height, and subject-to-display distance, we were unable to accurately convert saccadic amplitudes and peak velocities into units of discrete distance. Instead, we used these parameters as measured by the saccadometer, in arbitrary units. Each recorded value was standardized based on the mean for a given task and for a given individual. The resultant dimensionless measures do not indicate magnitude of amplitude or velocity; rather, they represent the deviation from a given subject's mean value in terms of SD. Using this method, we found that mean standardized peak saccadic velocities varied significantly between groups with different levels of experience.

Peak saccadic velocity is representative of two measured eye motion parameters: saccadic amplitude and saccadic duration. Our results indicate that experience level does not have a significant effect on saccadic duration (data not shown), but does have a nearly significant effect on standardized saccadic amplitude. Furthermore, a similar pattern of increasing mean values across groups (expert > intermediate > novice) for both standardized saccadic amplitude and standardized peak velocity leads us to conclude that much of the significant variation in standardized peak velocities is due to variations in standardized saccadic amplitude, not saccadic duration.

On the surface, our findings suggest that measured eye motion parameters correlate with previous laparoscopic experience and training only when extreme differences in skill exist. For example, the post-hoc pairwise comparisons for saccadic rate and standardized peak saccadic velocity show that both intermediate and expert groups had mean values that were significantly different from novices, but the experts did not significantly differ from the intermediate group. However, this was also true for the mean times required by each group to complete tasks. Since time to complete a task is known to be an effective measure for assessing and comparing laparoscopic task performance, it is possible that our study did not present tasks that adequately challenged subjects with some previous experience.[12] Since all of the subjects in the intermediate group were second or third year surgical residents, most had previously participated in the laparoscopic skills course that is mandatory for second year surgical residents at our institution. All three of the tasks used in this study are also used to test proficiency during that course. Furthermore, due to the novelty of this pilot study, we were unable to perform an accurate prospective power analysis. Thus, it is possible that the study lacked sufficient power to detect small differences. We posit that having a larger sample of subjects performing tasks that are more challenging, and require longer periods of time, will allow for an increased number of eye motion measurements to be obtained and evaluated. This would enhance the overall power of the study and might lead to the detection of significant eye motion differences between surgeons-in-training and experienced surgeons trained in advanced laparoscopic techniques.

In an effort to condense the large sets of data collected for this study, we have illustrated the means ± SEM for each group. However, when the data are examined on an individual basis (data not shown), we find subjects in each group whose eye motion parameters, across all tasks, were representative of subjects in other groups. For example, two subjects in the novice group had eye motion measurements for all tasks that were reflective of the means in the expert group. While these two subjects were generally faster than their group peers at completing each task, they were not as fast as any of the expert subjects. Unfortunately, we were unable to obtain further information on these subjects because our methods required

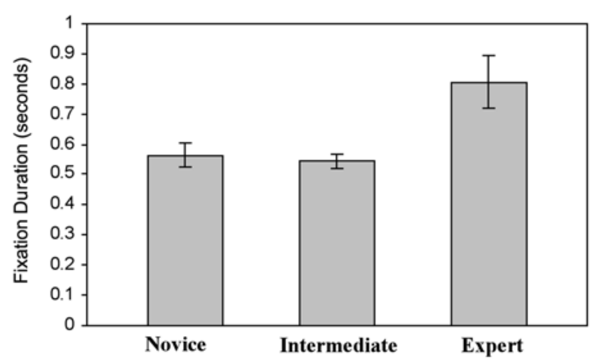

FIG. 5. The mean duration of gaze fixation across all three tasks are shown for each group. Main effect for group ($F_{2,21} = 3.34$, $P = 0.055$) was determined by two-way ANOVA. Post-hoc pairwise comparisons were not significant. Bars represent standard errors of the mean.

that all personal information be excluded from data files. Thus, future studies should be designed to collect more information pertaining to the background and experience of each subject. It would be interesting to assess other measures of surgical skill, such as motion economy or visual-spatial competency, and make parallel comparisons to eye motion measurements on an individual basis.

CONCLUSION

Eye motion parameters vary according to previous laparoscopic experience. Subjects with greater experience demonstrate decreased mean saccadic rates and a tendency for longer fixation of gaze duration compared to novice subjects. Experienced subjects also have greater variation in their peak velocities as evidenced by greater mean standardized values compared to novices. These preliminary data do not establish the measurement of eye motion as a stand-alone means for predicting an individual's level of laparoscopic skill; rather these results open the door for future studies to incorporate these methods for collecting and handling eye motion data. The noninvasive nature of the eye motion monitor makes it ideal for use in the operating room during actual cases. This would make it possible to study eye motion patterns as they relate to surgical outcomes. The static nature of the video display monitor makes laparoscopic cases an ideal setting for eye motion monitoring. For open surgical procedures, the application of such technology may be limited by excessive head motion. However, the additional use of external video monitoring of the surgeon may help account for head motion during data analysis, making it possible to accurately measure eye motion during open cases as well. We believe that the fusion of methods and devices that measure surgeon/instrument interactions with those that measure parameters of the surgeon/monitor interface will provide the optimal and most accurate assessment of laparoscopic skills in the future.

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