Medicine Meets Virtual Reality
J.D. Westwood et al. (Eds.)
IOS Press, 1999

Gaze Patterns in Laparoscopic Surgery

J.A. Ibbotson[1], C.L. MacKenzie[1], Ph.D, C.G.L. Cao[2], M.Sc., A.J. Lomax[1], M.D.
Simon Fraser University[1], and University of Toronto[2]

By understanding surgeons' patterns of gaze, and what visual information is being obtained during a procedure, one can improve the operation via new techniques or instrumentation. Part of a larger project on Remote Manipulation in Endoscopic Surgery, we analyzed eye patterns of surgeons from videotape annotation. Three categories of eye patterns were defined: 1) eyes on (gaze on monitor); 2) eyes down (gaze on external operative space); 3) eyes off (gaze away from monitor/hands). In the context of hierarchical decomposition of procedures we compared eye patterns and sequential dependencies (gaze as a function of previous gaze) by procedure, surgical steps and tasks. Timelines showed transitions in eye patterns during the procedure. We determined what visual information is available and what visual information is needed by the surgeons. By comparing these, we suggest technology that can provide these needs.

1. Introduction

Endoscopic surgery places the surgeon in a unique position where he/she must deal with both indirect vision and indirect manipulation. This type of surgery brings about its own set of constraints and difficulties. Indirect vision situations are seen when the performer is unable to view the task space directly; rather, they must look elsewhere to receive feedback on the progress of the task. Endoscopic surgery is a remote vision task as the surgeon views the progress of the tools' end effectors on a 2-D monitor, conventionally placed away from the task space. The surgeon must use the visual information received from the monitor to assess the progress of the task. This is done by watching the end effectors of the tools manipulate the desired tissues remotely. This can lead to errors, and increase the time it takes to complete the manipulation task.

In endoscopic surgery the surgeon is manipulating long shafted tools through cannulas, the ports of entry into the abdomen of the patient. This is remote manipulation as the surgeon is distanced from the target tissues located within the abdominal cavity. Since there is no direct contact between the surgeon's hands and the tissues there can be no sensory feedback from the receptors in the skin and therefore no haptic feedback from these receptors. There is haptic feedback from the tool regarding forces opposing the movement of the end effector. Because haptic information is filtered/reduced/delayed, the visual information is of utmost importance. Since this information is indirect as well, further translational steps must occur before the surgeon can use the available visual information. Because the monitor is displaced in a different plane from the task space the surgeon must make also a transformation of the visual information seen on the monitor to the task space which is under the control of the tools in the hands. [1]

By gaining a deeper understanding of not only the patterns of gaze throughout a procedure, but also what visual information is being obtained, one can then look at ways of improving the operation via new techniques or instrumentation to facilitate the gathering of this vital information. We hypothesized that changes in eye patterns would correspond with our previously defined surgical steps and tasks for the procedures. [2,3] These follow logical transitions in the surgeries where a new task is being undertaken. Patterns were expected to vary across specific surgical steps, and tasks consistently for each procedure. We also were interested in seeing what information was being gathered during prolonged periods in one pattern or during the quick glances up and down that seemed to be occurring regularly.

2. Method

This study was a part of a larger project on Remote Manipulation in Endoscopic Surgery. We analyzed eye patterns of surgeons performing sixteen laparoscopic procedures (nine Nissen Fundoplications, four Inguinal Hernia Repairs and three Cholecystectomies) in teaching hospitals in Greater Vancouver. Split screen videotaping was used to provide two views of the surgery: the endoscopic camera's view of the internal abdominal space was inset over our video camera's view of the operating room. The software used for video annotation was MacSHAPA, which displays time data taken from video in a spreadsheet. Analysis included operating room (O.R.) events, surgical events, surgical steps, subtasks, suturing, suturing motions, knotting, knotting motions, cutting suture and transcription of surgeons' conversations separated by topic (teaching, observation/complaints, and new tools).

The eye pattern data, the focus of this report, were also obtained through analysis of the individual procedures. We did not record quantitatively surgeon's head and eye movements directly (gaze equals eye position plus head position). [4,5] We identified the direction of gaze qualitatively by watching the videotape, frame by frame. Based on viewing the videotapes, eye patterns were separated into three categories of gaze: 1) eyes on (gaze on the monitor in the operating room, observing endoscopic camera view); 2) eyes down (gaze on external operative space, where hands and tool handles are located); and, 3) eyes off (gaze up and away from monitor/hands). If the eyes were not visible due to an obstruction or poor video quality, this video segment was labeled, "can't see eyes". The operational definitions of eye patterns provided the onset of each pattern, with the offset being the onset of the following pattern.

3. Data Analysis

We had two approaches to the data analysis. The first approach was to look at the different procedures and levels of the hierarchical decomposition and note if systematic eye patterns occurred. A second way of looking at the data was to plot it to see where the interesting eye pattern events were occurring. An example of this may be noting where the longest gaze pattern duration occurred. It is interesting to note where in the procedure this was occurring and try to understand the reason behind it.

Previously, we outlined the hierarchical decomposition of the operating room (O.R.) videotapes. [3] This provides a structure for the analysis of the eye patterns by outlining definite steps, tasks and subtasks that may provide a narrower context than the procedural level in which to look at the frequencies and duration of patterns. At the highest level the trends seen across procedures were analyzed to see if any differences could be seen across the three procedures, i.e., Fundoplications, Inguinal Hernia Repairs and Cholecystectomies. A similar approach was undertaken at the surgical step level and then at the more specific task levels of suturing and knotting. We hypothesized that eye patterns would coincide with our hierarchical decomposition levels. Here we could see if there were any meaningful patterns occurring during certain surgical events in the procedure.

The frequencies and duration of the eye patterns, by procedures and surgical steps, were determined, and averaged by procedure. This provides a summary of the pattern, frequency, total time of pattern and average time of pattern over the entire procedure. To normalize the data for comparison purposes, the frequencies for each pattern were converted to a percentage of the total number of gaze patterns. The total time for each pattern was normalized to a percent of operative time. Operative time was defined as the time from first tool insertion to completion of all surgical activity, indicated by removal of all tools. For each procedure the frequencies and the durations were then split up into the specific surgical steps.

4. Results

The results include overall eye patterns for each procedure, then eye patterns as a function of hierarchical decomposition into steps for each procedure. Then sequential orders of gaze patterns are examined. Following this, timelines of the eye patterns are examined to see the temporally ordered events as they happened within the surgeries. For the sake of brevity only detailed results relating to the Fundoplication procedure are included in this paper.

4.1 *Eye Patterns by Procedure*

The overall eye pattern data are provided in Table 1, for each procedure. The frequency column gives the count of each eye movement pattern throughout the operative time. The percent of the total movements normalizes the counts into percents for easy comparisons. There were about the same number of occurrences of eyes on and eyes down gaze patterns. The total time of each pattern is shown as well as the total time as a percent of operative time. The average time of the pattern is calculated by taking the total time of the pattern and dividing it by the frequency. From examining Table 1, we can see that the eye patterns were similar, both in frequency and proportional duration across the three procedures. In contrast to the similar number of occurrences of eyes on and eyes down gaze patterns, a much greater proportion of operative time was spent with eyes on than eyes down.

4.2 *Eye Patterns as a Function of Surgical Steps*

The eye patterns separated into surgical steps for the Fundoplication procedure only are shown in Table 2. Each procedure has a different set of surgical steps. Clearly the longest step was to expose the crura and GE junction, then the fundus wrap. Table 2 shows that, regardless of surgical steps, the frequency and duration of the three gaze patterns followed the same patterns as seen in Table 1.

Table 1. Eye Patterns for Each Surgical Procedure

Pattern	Frequency	% total movements	Total time of pattern (min.)	% of operative time	Average time of pattern (sec.)	Operative time (min.) [Total time for procedure (min.)]
Fundoplication (n=9)						
eyes on	216	44	71.10	82	19.75	87.04
eyes down	209	42	8.58	10	2.46	
eyes off	69	14	7.36	8	6.40	
TOTAL	494					[105.38]
Inguinal Hernia Repair (n=4)						
eyes on	58	41	37.17	84	38.45	44.25
eyes down	63	45	2.98	7	2.84	
eyes off	20	14	4.10	9	12.30	
TOTAL	141					[55.14]
can't see eyes			0.73			
Cholecystectomies (n=3)						
eyes on	71	42	22.88	78	19.34	29.18
eyes down	67	40	3.80	13	3.40	
eyes off	31	18	2.50	9	4.84	
TOTAL	169					[48.20]
can't see eyes			4.24			

Table 2. Eye Patterns for Fundoplications (n=9), by Surgical Step

Pattern	Frequency	% total movements	Total time of pattern (min.)	% of step duration	Average time of pattern (sec.)	Step duration (min.)
divide peritoneum (DP)						
eyes on	17	45	3.90	72	13.76	**5.41**
eyes down	17	45	0.69	13	2.44	
eyes off	4	10	0.82	15	12.30	
TOTAL	38					
expose crura and GE junction (GE)						
eyes on	47	46	27.12	89	34.62	**30.49**
eyes down	44	43	2.02	7	2.75	
eyes off	12	11	1.35	4	6.75	
TOTAL	103					
divide short gastrics (SG)						
eyes on	12	43	18.14	88	90.70	**20.70**
eyes down	13	46	2.19	10	10.11	
eyes off	3	11	0.37	2	7.40	
TOTAL	28					
repair crura (RC)						
eyes on	12	43	5.45	87	27.25	**6.30**
eyes down	13	46	0.49	8	2.26	
eyes off	3	11	0.36	5	7.20	
TOTAL	28					
wrap fundus (WF)						
eyes on	80	41	20.32	80	15.24	**25.53**
eyes down	81	41	2.14	8	1.59	
eyes off	36	18	3.07	12	5.12	
TOTAL	197					

4.3 *Sequential Dependencies of Gaze Patterns*

To focus on transitions from one pattern to another, we examined the frequencies of gaze patterns as a function of previous gaze, shown in Table 3. The "total" column represents the sum of specific eye transitions over the five Fundoplications performed by one surgeon. The eyes down pattern most frequently followed eyes on, and the eyes on pattern most frequently followed eyes down. The eyes off pattern followed both eyes on and eyes down.

Table 3. Gaze as a Function of Previous Gaze for Fundoplications by One Surgeon

	TO	FROM eyes off	TOTAL	eyes down	TOTAL	eyes on	TOTAL
12-Mar-96	eyes off	*		28		26	
30-Apr-96		*		33		32	
2-July-96		*		33		34	
24-June-97		*		26		62	
15-July-97		*	0	39	159	37	191
12-Mar-96	eyes down	29		*		137	
30-Apr-96		33		*		170	
2-July-96		38		*		164	
24-June-97		50		*		130	
15-July-97		53	203	*	0	187	788
12-Mar-96	eyes on	24		139		*	
30-Apr-96		32		169		*	
2-July-96		30		167		*	
24-June-97		38		154		*	
15-July-97		23	147	201	830	*	0

4.4 *Sequential Dependencies of Gaze Pattern as a Function of Surgical Steps*

We then looked at the gaze pattern transitions as a function of their individual surgical steps. An example of the breakdown of these steps for one Fundoplication procedure is found in Table 4. We can see whether the patterns are different across the surgical steps. The two most difficult steps, exposing the crura and wrapping the fundus show a greater number of transitions from eyes on to eyes down and eyes down to eyes on as reported in the previous section.

Table 4. Gaze as a Function of Previous Gaze for One Fundoplication

Surgical Step	TO	FROM eyes off	eyes down	eyes on
divide peritoneum	eyes off	*	1	*
expose crura&GE junction		*	7	4
divide short gastrics		*	*	*
repair crura		*	6	1.
wrap fundus		*	12	18
divide peritoneum	eyes down	*	*	9
expose crura&GE junction		4	*	34
divide short gastrics		*	*	*
repair crura		5	0	13
wrap fundus		16	*	70
divide peritoneum	eyes on	1	9	*
expose crura&GE junction		7	30	*
divide short gastrics		*	*	*
repair crura		1	13	*
wrap fundus		14	73	*

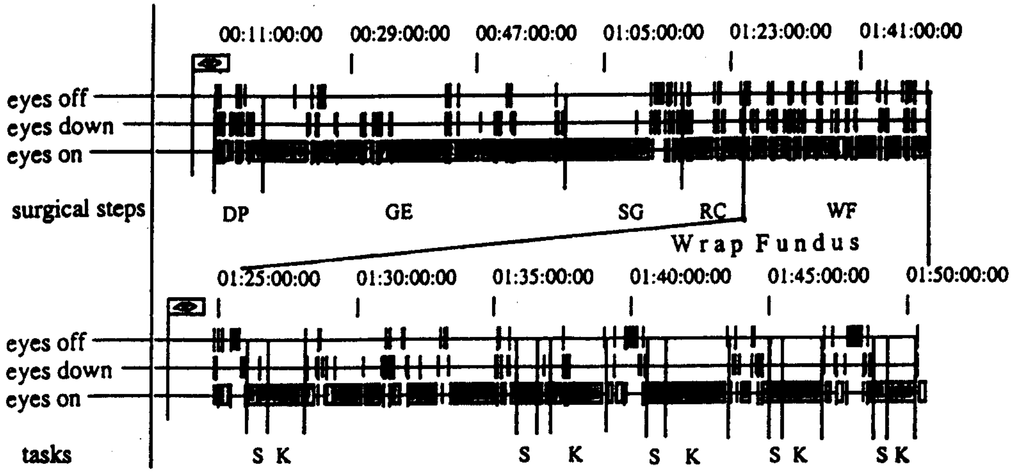

Figure 1. Timeline of eye patterns for one fundoplication procedure. Note the step, wrap fundus, is expanded below with different time scale. See text.

4.5 *Eye Patterns as the Surgical Procedure Unfolds*

Timeline graphs were constructed to illustrate the transitions between eye patterns. Figure 1 shows a timeline of the three eye patterns for one Fundoplication procedure as a function of surgical step, as outlined in Table 2. The greater number of eyes on and glances down in the wrap fundus step, expanded below, further shows that during the knotting (K) and suturing (S) tasks, the eyes are constantly on the monitor. The frequent transitions between eyes on and eyes down correspond in large part with the forty-two tool insertions and withdrawals during this surgical step.

5. Discussion

From the eye pattern results a number of conclusions are drawn. The most apparent finding is seen across all three procedures. The interesting result is seen when comparing the frequency of occurrences with percent of operative time spent in each pattern. Even though eyes on has essentially the same number of occurrences as eyes down it makes up about eighty percent of the operative time of the procedures. This can be seen in Table 4. Duration of gaze directed at the monitor, (mean = 30 seconds, range 2 - 600 seconds), was consistently longer than the short glances down, (about two seconds). This makes sense when considering that the surgeon must be looking at the monitor in order to get feedback concerning the tools' end effectors in the internal operative space. When looking at the average time of each pattern we see that the eyes on pattern average is always longer than the other two gaze patterns average time. As for gaze with eyes off the monitor and the task space, these were about fifteen percent of total eye movements, taking up only about nine percent of the total operative time.

The transition tables address issues concerning gaze as a function of previous gaze. A conclusion here centers around the transition to eyes on and eyes down. Over all three procedures it is seen that about eighty percent of the time eyes look down before looking on the monitor and look on the monitor before looking down. The eyes on pattern most frequently occurred before the eyes off pattern. The surgeons are checking the internal status of the abdominal cavity and tools before focusing their attention elsewhere. This leaves the eyes off pattern as only about twenty percent of the occurrences preceding the other patterns.

From the timelines a pattern occurs of frequent glances down and up with the occasional eyes off interspersed between longer eyes on patterns. These quick glances correlated with the insertion of tools and other transitions in the procedures. One way to decrease these movements would be to design tools with multiple end effectors for the task at hand. Surgeons made many quick glances down at their hands throughout, either as a safety check or to recalibrate the visuomotor transformation for remote manipulation. It is interesting to see if there are any consistent patterns occurring over specific procedures or surgical steps. A look at the wrap fundus surgical step of the Fundoplications showed a great deal of eye movement occurring previous to the onset and after the offset of the suture and knot tasks. The tool was being prepared and inserted or removed respectively thus more movements occurred at these times. During specific subtasks like knotting or suturing, eyes usually remained on the monitor as the surgeon concentrated on the goal. In contrast, eye movements occurred while the surgeon was setting up the task space prior to actually suturing.

We determined what visual information is available and what visual information is needed by the surgeons. By comparing these, we can identify technologies that can provide these needs. When eyes are on the monitor, visual information is obtained about: the relationship between the end effectors and the target tissue, location of other internal organs/structures being a safety requirement, and the state of achievement of the goal. When the eyes are looking down the surgeon gets information on: the orientation of the tool handle, checking which tool is in which hand, and locating switches and dials on the tool handle. When eyes are off the surgeon could be resting, passing or receiving tools as well as obtaining other vital information from other O.R. team members.

References

[1] MacKenzie, C.L., Graham, E.D., Cao, C.G.L., and Lomax, A.J. (1999) Virtual Hand Laboratory Meets Endoscopic Surgery. In Proceedings of Medicine Meets Virtual Reality (MMVR:7). Amsterdam: IOS Press, in preparation.

[2] Cao, C.G.L., MacKenzie, C.L., Payandeh, S. (1996). Task and motion analysis in endoscopic surgery. In DSC-VOL58, Proceedings of the ASME Dynamic Systems and Controls Division, 583-590.

[3] Cao, C.G.L., MacKenzie, C.L., Ibbotson, J.A., Turner, L.J., Blair, N.P. and Nagy, A.G. (1999). Hierarchical Decomposition of Laparoscopic Procedures. In Proceedings of Medicine Meets Virtual Reality (MMVR:7). Amsterdam: IOS Press, in preparation.

[4] Jeannerod, M. (1988). The neural and behavioral organization of goal-directed movements. Oxford: Oxford University Press...

[5] Kandel, E.R., Schwartz, J.H., and Jessell, T.M. (Eds.) (1991). Principles of neural science (3rd ed.). Norwalk: Appleton & Lange.

Acknowledgements

The Remote Manipulation in Endoscopic Surgery Project was funded by the British Columbia Health Research Foundation, Canada, to Dr. Christine L. MacKenzie, from 1995 - 1998.