DISORIENTATION IN MINIMAL ACCESS SURGERY: A CASE STUDY

Caroline G.L. Cao & Paul Milgram
Ergonomics in Teleoperation and Control (ETC) Laboratory
Department of Mechanical & Industrial Engineering
University of Toronto
Email: ccao@etclab.mie.utoronto.ca, milgram@etclab.mie.utoronto.ca

Navigating through minimal access surgical environments such as the human colon can be difficult, even for expert gastroenterologists. "Getting lost" is a common experience for endoscopists, especially within the tortuous sigmoid colon where salient landmarks are not generally available. This paper presents the concept of "getting lost" in endoscoppy as a loss of both global and local spatial orientation. For the endoscopist performing a colonoscopy, the consequence of local disorientation is an inability to continue the procedure, or possibly even injury to the patient, while consequences of global disorientation can be mistaking the location of a lesion, and/or incomplete examination, resulting in misdiagnosis. This study provides important insights into the physical and cognitive constraints of the task of navigating in colonoscopy, contributing to disorientation in the colon. The implications of our findings for the design of navigational aids and training tools are also discussed.

INTRODUCTION

In minimal access, or endoscopic, surgery, the surgeon operates with an indirect and restricted view of the surgical site, as provided by an endoscope and displayed on a TV monitor. During the course of a surgical procedure, the endoscope may be moved, and/or rotated, to focus on or zoom in on a particular structure, or zoom out to another location in the surgical field. As the view from the endoscope is not always at an optimal viewing angle, changes in the camera viewing perspective may require the surgeon to perform visuomotor transformations to match the mapping of the displayed image onto the frame of reference of her manually controlled surgical instruments at the working surgical site. Mismatches in the spatial orientation between the visual display space and the physical workspace are known to impede surgical performance, however (Holden & Flach, 1999). One of the most problematic consequences of this mismatch is disorientation on the part of the surgeon. This problem is especially exaggerated when flexible, as opposed to rigid, endoscopes are used. Thus, endoscopic manipulation often requires that the surgeon acquire a high degree of hand-eye co-ordination, as well as a good sense of spatial orientation or spatial awareness.

In colonoscopy for adult patients, a flexible scope of 140-180 cm in length is used to visualise the wall of the colon, in order to diagnose possible lesions and treat diseases of the colon. During the procedure, the patient is usually semi-sedated. The endoscopist passes the endoscope through the anus of the patient, into the rectum, running along the length of the large intestine, and stopping at the ceacum (see Figure 1). The endoscopist advances the scope along the colon by pushing the shaft of the scope into the patient, while negotiating the many twists and turns in the colon by turning the tip of the scope using the two wheels at the handle of the scope.

When navigating from one location in the anatomy to another, the surgeon may lose sight of a landmark, making it difficult to maintain a sense of spatial orientation. 'Getting lost' is a common experience for endoscopists. In one study, for example, when the position of the end of the scope within the colon was verified using fluoroscopy, an experienced endoscopist was wrong in almost half the cases (Cotton & Williams, 1990, p.182). In general, there are two classes of being lost: 1) not knowing where you are in the colon, and 2) not knowing in which direction to go next in order to advance in the colon. Both of these classes of disorientation, *global* and *local* respectively, have implications for diagnosis and completion of the procedure.

This paper reports on a case study of navigation in colonoscopy, part of a larger study of navigation and orientation issues in minimal access surgery. The objectives of this observational study were to identify whether disorientation actually occurs, what is its nature, and to determine its causes in terms of the surgeon's cognitive map and spatial knowledge of the colon. In addition our aim is to identify the constraints that may impose an increased cognitive demand on the surgeon, as well as to identify expert strategies used to overcome these constraints. Implications for the design of navigational aids in colonoscopy are also discussed.

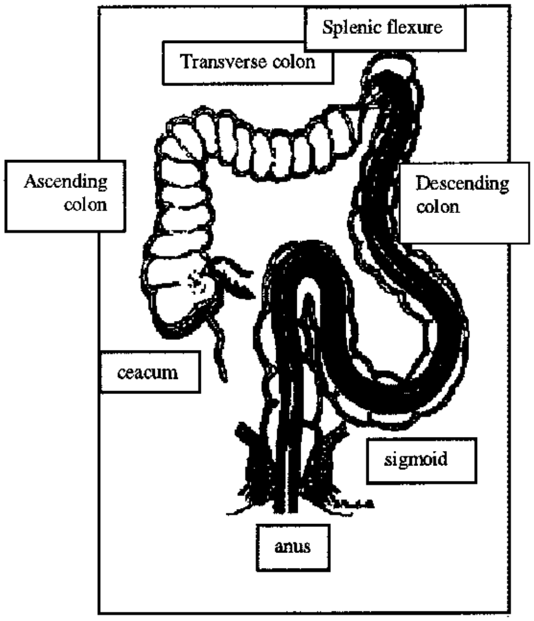

Figure 1. A schematic of the colon, showing the configuration of the colonoscope with the end of the scope at the splenic flexure.

METHODOLOGY

As expert knowledge is often tacit and automatic, one way to elicit expert knowledge that is otherwise not easily articulated explicitly is during actual task performance (see Cooke, 1994). In this study, the ideal situation for this was during patient examination. Verbal reports from semi-structured interviews, on-line talk-aloud protocols and verbal interactions during the examination of patients were collected (recorded by hand-written notes, audiotapes, and videotapes) and analysed to infer the knowledge and skills required for colonoscopy.

Subjects

Our subjects were expert gastroenterologists, general surgeons who also performed colonoscopies, gastroenterology fellows, and residents in the hospitals belonging to the University Health Network in Toronto. We report here the general procedure of our study, followed by a summary of the general findings obtained from one set of expert gastroenterologists.

Procedure

Semi-structured interviews. Each subject went through an initial interview about the procedure of colonoscopy, the general types of difficulties encountered during the colonoscopy procedure, and strategies used for successful navigation through the colon, etc. The interviews were recorded on audiotape for subsequent transcription and analysis.

Intra-operative observations and verbal protocols. After the initial interviews, observation of three separate clinical sessions was conducted with each subject, within the natural setting of an actual colonoscopy procedure. During patient examination, the endoscopists were encouraged to speak aloud everything that he/she was thinking and doing, whenever possible, as though carrying on an internal conversation, presumably similar to a teaching session with a novice resident. An external microphone was placed in the room to record all verbalising for subsequent transcription and analysis. Simultaneously, the endoscopic image of the colon (i.e. the same view as displayed to the endoscopist) was recorded in parallel on a VCR.

Analysis. Verbal protocols were transcribed and annotated using MacSHAPA (Sanderson, 1994), a software package for annotation and analysis of observational data. Eleven variables of interest relating to spatial orientation and strategies were coded for the interviews and the colonoscopy procedures. A qualitative protocol analysis was performed. Here, we describe the findings relating to the phenomenon of disorientation in the colon. These were identified by the variables: 'landmark', 'loops and 'strategies'.

FINDINGS AND DISCUSSION

Factors contributing to disorientation

Landmarks. In the interview, the expert endoscopists described several causes for uncertainty of localisation. It was a commonly acknowledged fact among their peers that no one can be "100% certain" of where in the colon they are viewing during most of the colonoscopy procedure. The endoscopic anatomy of the colon is variable from patient to patient and there are few landmarks in the colon that could indicate to the endoscopist the exact location along the length of the colon. When salient landmarks of the colon are displayed on the screen, the endoscopist can be confident of the location, but this generally requires confirmation with the next landmark encountered.

During the colonoscopy procedure, the appearance of the inner colon wall is unremarkable for the most part. The few landmarks expected were not always present or recognisable. For example, one of the landmarks expected at the splenic flexure is a blue shadow, which, when observed, is supposed to indicate the presence of the spleen showing through the adjacent wall of the colon. This is not always reliable, however, because the colon may be lodged in a position not adjacent to the spleen, or the spleen may be lower or higher in a particular patient. Another landmark is the triangular lumen of the transverse colon; however, whenever the colon is distended with too much air, this triangular shape is no longer noticeable.

In our investigation, whenever a salient landmark was encountered, the endoscopist would first name the location within the colon, and then request verification from the nurse or the fellow. This may have been done partly to ensure that they did not in fact see what they *expected* to see, and partly to teach the fellow or resident to recognise the landmarks corresponding to anatomical locations.

Loops. The most difficult thing about colonoscopy, according to the endoscopists, is working the controls on the colonoscope to negotiate the corners and tight turns in the colon (the colonoscope is essentially a 4 degree-of-freedom (dof) control device, comprising one longitudinal dof (in-out), two rotational dofs (pitch and yaw) controlled by the two wheels at the handle, and one rotational dof (roll) controlled by rotating the entire scope). The mechanical properties of the flexible scope in combination with the floppy colon render the task of navigating and wayfinding through the colon technically very difficult. Whenever the colon is collapsed, furthermore, the lumen is not easy to detect (the *lumen* is the actual cavity, or opening, inside the colon through which the colonoscope must pass. If the lumen is not visible, however, the colonoscopist can not easily know in which direction to head). In many instances, the end of the scope can end up pushing against the wall of the colon, or in a fold of the colon wall, thus making it difficult to see which way to turn the scope in order to advance. The danger of pushing ahead without an adequate view of the opening in the colon involves the risk of perforating the colon.

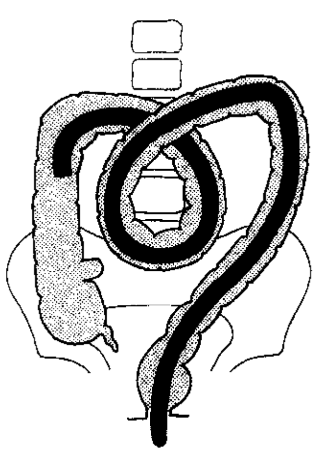

Figure 2. Loop in the transverse colon.

Since the colon is a flexible and highly tortuous elastic tube, its diameter can easily be stretched when insufflated with air, while its length is easily stretched with the push and pull of the scope. At times, in fact, loops can form, essentially anywhere along the length of the scope, both inside and outside of the colon (see Figure 2). When this happens, the scope barely advances within the colon, even as more and more of the scope is fed into the body. In fact, the loop formed in the scope and colon tends to enlarge with more pushing, while the end of the scope remains in place. Clearly, the formation of loops can make it difficult to advance. It can also inflict a great deal of pain and discomfort on the patient. If such pushing persists unchecked, the endoscopist may end up perforating the colon from shear force in the loop.

Therefore, learning efficient techniques for negotiating the colon requires a good understanding of how different parts of the colon behave mechanically in response to the manipulation of the scope. This in turn requires that the endoscopist recognise the location in the colon, the possible configurations of loops formed by the scope in the floppy segments of the colon, and the appropriate manoeuvres for straightening such loops.

Strategies. The experienced endoscopist possesses a large repertoire of tricks for dealing with loops in the colon. Depending on the possible configuration of the loop, different manoeuvres can be performed with the scope to get out of the loop and, when one trick doesn't work, another is usually attempted. The key to successful navigation is to minimise the likelihood of formation of loops, and to quickly straighten the loops if and when they are formed.

Even though very little pre-planning took place before the procedure, the endoscopist has a good idea of what to expect in terms of the general physical layout of the colon (e.g. that there is a sharp corner at the splenic flexure). Therefore, certain prescribed actions can be carried out, such as sliding the scope along the greater curve when making the tight turn at the splenic flexure. Thus, unnecessary manipulation of the scope can be avoided, reducing the chances of forming loops in the sigmoid colon. The majority of the time during the procedure, however, endoscopists respond to what is displayed in the endoscopic image, and the haptic feedback from the colonoscope. Therefore, once a loop is formed, it is important for the endoscopist to realise quickly that a loop has formed, to be able to deduce the likely configuration of the loop, and to successfully execute the appropriate manoeuvre for getting out of the loop. The ultimate trick, in an extremely difficult situation, is to use fluoroscopy -- an x-ray of the colonoscope which reveals the configuration of the loop as well as the location of the end of the scope. The problem with this "solution", however, is that exposing the patient unnecessarily to excessive radiation is highly discouraged.

Cognitive constraints in colonoscopy

Underlying the technical success of colonoscopy seems to be how well the endoscopists are able to establish a sense of where they are in the colon (i.e., where the end of the scope is within the colon), what potential difficulties are to be encountered ahead, as well as what potential difficulties could arise due to the looping of the scope 'behind' them. It thus requires co-ordination of both visual and haptic information, as well as a good mental model of the patient's colon. Unlike navigating in most large-scale geographical spaces, where the physical environment remains relatively constant during an operation, the colon is a dynamic environment, unpredictably changing with every manipulation of the scope.

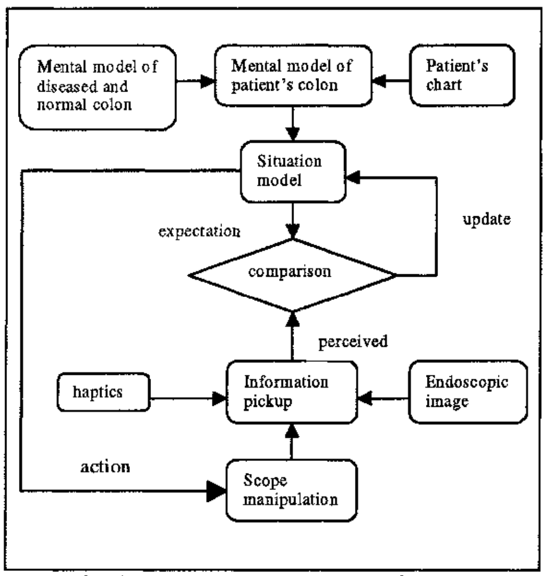

Figure 3. A model of the endoscopist's cognitive constraints in colonoscopy.

In the true spirit of the uncertainty principle in physics, therefore, it is the endoscopist who is effecting changes to the environment that he is in the process of measuring. Conversely, changes in the shape of the colon and scope affect how the scope can be advanced. The endoscopist, therefore, has to constantly update his situation model of the colon (see Figure 3), and formulate actions based on this situation model. Because endoscopists have limited and ambiguous information to specify the environment, they are always making decisions and acting, by trial-and-error, with some degree of uncertainty. The information necessary to make the task less uncertain is hidden from view, within the patient's body.

Implications for design of navigational aid

The key to successful minimal access surgery in general is to provide surgeons with the information necessary to support
spatial awareness in the inner space of the anatomical cavity. In the case of colonoscopy in particular, this means providing the endoscopist the means, preferably to see, and barring that, to infer, the location and configuration of the colonoscope inside the colon at all times. This can serve to minimise uncertainty in deducing the shape of loops formed and in selecting the appropriate strategies for straightening the loops. It can also reduce the load required for mentally mapping the observed video images onto the surgeon's situational model of the surgical space. As well, such information may serve to facilitate advance planning for upcoming difficult spots in the colon.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Stan Hamstra for his help in recruiting subjects for this study. This research was supported in part by an Ontario Graduate Scholarship, and by the Institute of Robotics and Intelligent Systems (IRIS), under project *"Effective Display Systems for Teleoperator Control of Remote Environments"*.

REFERENCES

Cooke, N.J. (1994). Varieties of knowledge elicitation techniques. *Int. J. Human-Computer Studies*, 41, 801-849.

Cotton, P.B. & William, C.B. (1990). *Practical gastrointestinal endoscopy.* Blackwell Scientific Publications, London, UK.

Holden, J.G., Flach, J.M., Donchin, Y. (1999). Perceptual-motor co-ordination in an endoscopic surgery simulation. *Surgical Endoscopy*, 13, 127-132.

Sanderson, P.M. (1994). *MacSHAPA* v. 1.0.2. University of Illinois at Urbana-Champaign.