

TOWARD IMPROVED COMMUNICATION IN LAPAROSCOPIC SURGERY: ACCOUNTING FOR MULTIPLE FRAMES OF REFERENCE AND MENTAL ROTATIONS

Cristina Rivera & Caroline G.L. Cao
Department of Mechanical Engineering
Tufts University
Medford, Massachusetts

ABSTRACT

This work is an examination of barriers to communication between the attending and assisting surgeons during laparoscopic surgery, where the same image of the surgical site is viewed from different vantage points with respect to the patient. Part of the problem lies with the multiple frames of reference each surgeon holds, and the mental rotations each must perform to construct a common frame of reference for communication and collaborative work. An experiment was conducted to demonstrate the effects of display-control incongruency on the performance of an aiming task in a simulated laparoscopic environment. Aiming performance was best when the camera was oriented at 0° perspective and worsened as the angle of deviation from 0° increased. Performance was affected to a greater degree by viewing perspectives from the left of the subject than viewing perspectives from the right. Results also suggest that when surgeons are facing each other, as is the case in many laparoscopic surgeries, one surgeon's performance will be worse than the other's. The mismatched display-control perspectives are compounded by ambiguous spatial references in verbal communication. From these findings, a case can be made for the importance of vocabulary that forces a common frame of reference during laparoscopic surgery.

INTRODUCTION

In laparoscopic surgery, the surgeon does not have a direct view of the abdominal cavity, but rather an indirect view provided by a small camera inserted into the area of interest through a small incision. The camera view is displayed on one or more monitors in the operating room. Other incisions allow for the insertion of long tools to perform the surgical tasks. In most cases there are at least two surgeons working in collaboration: the "attending" who takes primary responsibility for the case, and one or more "assisting" surgeons. Sometimes the attending surgeon is an experienced surgeon, while the assisting surgeon is a novice surgeon who requires guidance from the attending throughout the procedure. Effective communication between the attending and the assisting in these scenarios is paramount, both for the training of the novice surgeon, and for the success of the collaboration and the surgery. Verbal instruction is vital because it is the main mechanism attendings have to convey what they would like help with during the procedure. They may gesture with their hands or tools, and/or point to the monitor. However, there are certain instructions that simply must be given verbally. The quality of instruction directly affects the quality of an assisting surgeon's performance. Misunderstandings slow things down because assisting surgeons have to double-check on intentions and required actions.

PROBLEM

In laparoscopic surgery, a common misunderstanding during collaboration relates to the spatial orientation of the

surgical tools or targets. This is because the display space and the workspace are separated. Due to this control-display separation, surgeons must perform mental rotations to match what they see on the screen to what they do at the site. Further, although they often have the same orientations with respect to the monitors, surgeons often have different perspectives with respect to the patient. This means that each surgeon may be required to perform additional mental rotations in order to arrive at a common frame of reference to communicate with one another. Because laparoscopic surgery imposes this higher cognitive workload on the surgeons than open surgery, it can lead to confusion and degradation in communication. While there are other factors, such as authority and stress, affecting communication between surgeons, this paper is limited to how communication is affected by the issues surrounding mental rotations and frames of reference. We describe the first in a series of experiments to investigate this problem.

Frames of reference

The idea that mismatched frames of reference (FOR) degrade navigation performance is one already proven in the field of aviation (for review, see Gugerty and Brooks, 2004; and Aretz, 1991). Since many analogies can be drawn between conventional geographic navigation and navigation within the human body, it is safe to expect that FOR coping strategies in conventional navigation can help us understand FOR problems in surgery.

Logically, pilots use different vocabularies for different FOR. Aretz pointed out in his work on map displays that when pilot's FOR were egocentric, they used clock

directions to describe locations. If, however, they were using a world-centered FOR, which was necessary to communicate effectively with the air traffic controllers, they used compass headings (Aretz, 1991). As long as pilots use these vocabularies, it eliminates the question of which FOR is being employed and therefore the possibility of confusion.

Similarly, laparoscopic procedures involve more than one possible frame of reference (i.e., egocentric, or exocentric). Surgeons also have certain conventions which help eliminate ambiguity. However, visits to the OR and interviews with surgical residents have shown us that they tend to mix these vocabularies with other ways of speaking to indicate directions. For example, “cephalad” and “lateral” are sometimes used to indicate direction toward the head and side of the body, respectively. “Up” and “towards you” (or towards some other object) are also used to indicate these same directions. It is not clear how a surgeon chooses the directional labels.

Shepard and Hurwitz pointed out that the “perceptual availability” of FOR vary (1985). For example, humans are accustomed to functioning in a gravitational field which always helps them distinguish up from down. This distinction is available whether they hold an egocentric or exocentric reference frame. In this way, the perceptual availability of the egocentric and exocentric FOR are similar. This contrasts with the left-right directions, which vary depending on the reference frame (e.g. Do you mean my right or your right?) (Shepard & Hurwitz, 1985). Similarly, the “availability” of the frame of reference (e.g., what makes the most sense to the speaker) may determine a surgeon’s choice of words. The fact that humans can hold different frames of reference simultaneously can exacerbate the problem (Lemay, 2004).

Mental rotations

Contrary to the direct viewing available in open surgery, laparoscopic surgeons must deal with the frequent mismatch between the orientation of the view of the surgical site and the orientation of the physical surgical site with respect to the surgeon. The need to perform mental rotations in laparoscopic surgery is due primarily to the use of a laparoscope. When inserted into the abdominal cavity, it can be angled and rotated, with the insertion point acting as a fulcrum. The camera is often moved several times during a procedure. Therefore, surgeons must sometimes deal with a rotated view on the monitor, as well as non-canonical view when the camera is moved about its fulcrum.

It is useful then to review what is already known about visuomotor transformations in the context of surgery. We know that individuals vary in their natural spatial ability. Keehner et al. found that having less natural spatial ability affected novice laparoscopic surgeons more than experts (Keehner et al, 2004). Since experienced surgeons perform more automatically, they may have forgotten what it was like to perform surgery when they relied more on their natural spatial talents. In other words, it is harder for the teachers to tailor the instructions when they can’t remember the difficulties in learning as a student. Several studies have been conducted to better understand the visual spatial talents of

surgeons. A study by Risucci suggested that these talents were higher among surgeons than the average population (2002). Further, Keehner presented results which suggested that once individuals self selected into a career in surgery, there was no difference in spatial ability between experienced and novice laparoscopic surgeons (2004).

Cooper’s work on mental rotations showed that if an object was presented in an unexpected way, people do one of two things: 1) Rotate it in their heads to the familiar way or 2) Rotate the world around it until it matches their familiar orientation (1976). The question that follows from this is exactly how the mental process works for surgeons. It is possible that surgeons perform mental rotations in one of three ways: 1) They train themselves to be in a state of permanent mental rotation while performing surgical tasks; 2) They discretely perform rotations as needed; 3) They perform mental rotations as a combination of the first two – dual processing. Dual processing theory may be the most probable explanation for the problems associated with performing complex mental rotations (Barrett et al. 2004). The interplay between the automatic and the controlled process may be the source of confusion when surgeons are performing mental rotations and trying to maintain the correct frame of reference at the same time.

Research in aviation provides insight into how human operators deal with mental rotation tasks. Certain aircraft provide pilots with the ability to select the orientation of the map displayed to them (e.g. track up vs. north up) as they fly. The problem with this, Aretz stated, is that after they have chosen an alignment, a stressful situation could cause them to forget this alignment and set a course in the wrong direction, believing the map to still be in the previous alignment (1991). If we think of the laparoscopic monitor as analogous to the map and a rotation of the camera as the selection of map orientation, we can expect a novice surgeon may forget this rotation and move his tool toward the wrong tissue or organ. This problem can manifest itself in other ways as well. For example, if a teaching surgeon indicated a particular perspective, and that perspective required a mental rotation in order for the student to understand what to do, the student would make the rotation. If while the student was in the process of making this rotation, he became distracted, he may forget which perspective he was trying to match. The student may then be forced to revert back to some more comfortable orientation while deciding how to proceed. In order to avoid re-orienting each time, he may store up each rotation in memory and call it up each time the frame of reference is changed. The question becomes what are these surgeons mental processes and how do they affect communication.

It was hypothesized that mental rotations in laparoscopic surgery degrade surgical skills performance and communication. In particular, we hypothesized that performance varies depending on the perspective and rotation of the laparoscope. To test this hypothesis, an experiment was conducted.

METHODS

Subjects. Thirty undergraduate students from Tufts University participated this study. None had any previous experience with laparoscopic surgery.

Apparatus. A *Simulab* endoscopic training box was used to simulate the abdominal cavity of a patient. The task space consisted of a 4x4 inch wooden block with six nails of varying vertical heights arranged in a circle equidistant apart. The nails were numbered 1-6. On the underside of the block, wires connected each of the nails to an RCX module. Wires were also attached to the grasping part of an *Endo Clinch II* laparoscopic grasper and connected to the RCX. In this way, a circuit was completed each time the subject touched the grasper tip to a nail. An RCX program was created to record the time of contact (i.e., states of open or closed circuit). A 0° endoscope was used to project the image of the task space to a TV monitor that was at the subject’s eye level.

Tasks. Using the grasper, subjects were asked to touch the nails in sequence as quickly and accurately as possible, under various viewing conditions.

Experimental Design. A between-subjects design was used, with 3 groups, each with 2 opposing camera perspectives (see Figure 1) and 6 camera rotations. Each group consisted of 10 subjects; each subject performed the aiming task three times under each viewing condition. The camera perspectives were counter-balanced, while the camera rotation conditions were randomized.

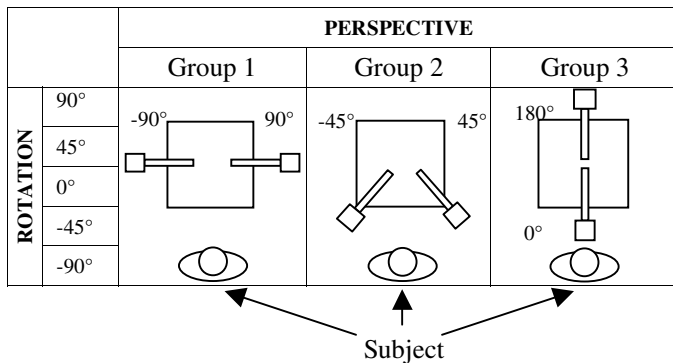


Figure 1. Camera perspectives.

Dependent Measures. Dwell time, movement time, and total time were measured. Dwell time was the amount of time subjects spent in contact with the nails; movement time was the amount of time they spent traveling between nails; and total time was the sum of the dwell and movement times, or the task completion time.

Analysis. ANOVAs were performed using SPSS software for the three groups of subjects with an alpha value of 0.05. Analyses were done on dwell, movement, and total times, respectively.

RESULTS AND DISCUSSION

There were significant main effects for perspective (Dwell time: $p < .001$, Movement time: $p < .001$ Total time: $p < .001$) (see Figure 2).

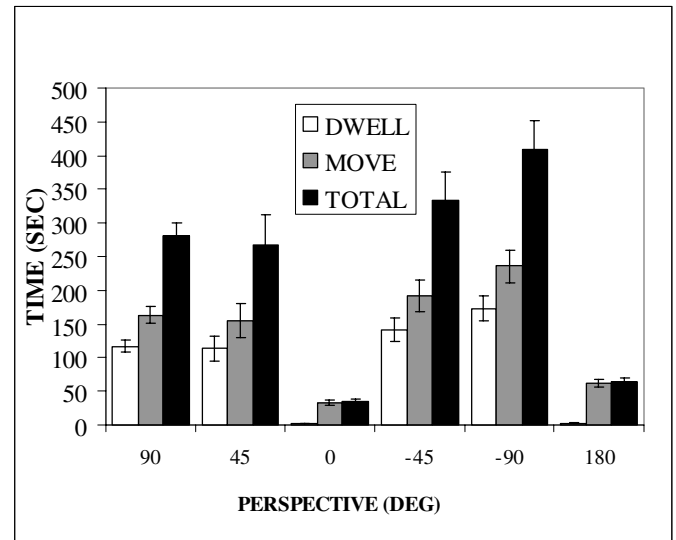


Figure 2. Dwell, movement, and total times as a function of camera perspectives.

Significant main effects were also found for rotation (Dwell: $p < .001$, Movement: $p < .001$, Total: $p < .001$). There were significant interaction effects for the two dependent variables (Dwell: $p < .001$, Movement: $p < .001$, Total: $p < .001$).

As expected, subjects performed best when the camera perspective was at 0° or 180° on dwell, movement, and total time. For all three time classifications, post-hoc tests showed no differences between a 45° and a -45° perspective, collapsed over camera rotations. However, there was a difference between the 90° and -90° perspectives (Dwell: $p = .01$, Movement: $p = .02$, Total: $p = .02$) and 0° and 180° perspectives (Dwell: $p = .04$, Movement: $p < .001$, Total: $p < .001$). Post-hoc tests revealed only one difference for rotation angles, collapsed over perspectives. The movement time was longer when the camera was rotated at -90° vs. 45°.

Figure 3 shows the graphs of movement time for individual camera perspectives as a function of camera rotations. Only movement times are shown here, although similar patterns were found for dwell time and total time.

When the camera was at 0°, directed at the workspace from the subject’s viewing perspective, the performance was most stable, even across rotations. As the camera was deviated from this canonical perspective, performance began to fluctuate. At 45° and 90° perspectives, performance was similar across rotations, suggesting that these two angles were perceptually equivalent. As the camera is moved further to the right of the subject, at 180°, performance worsens. Performance at -45° and 180° are mirror images of one another. This would seem to suggest that camera deviations to the left of the subject are more detrimental to performance than deviations to the right. Deviation of 45° to the left is equivalent to the distortion caused by 180° to the right.

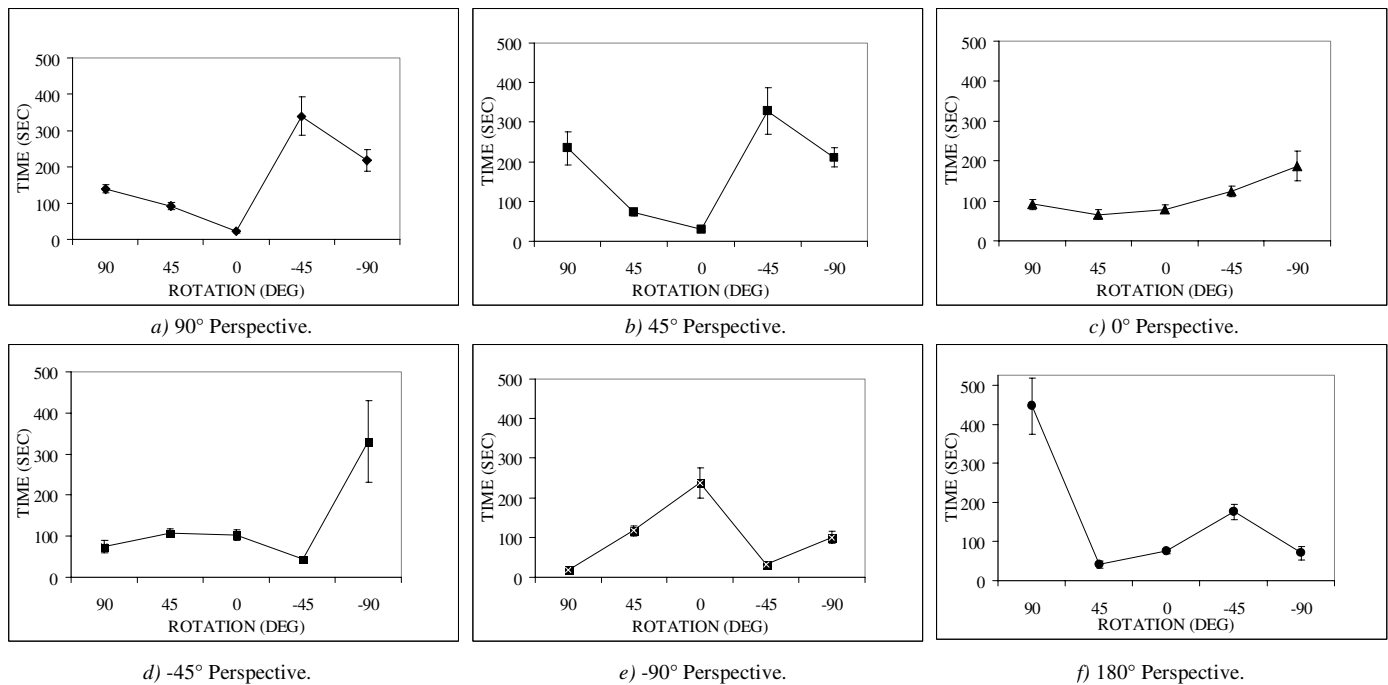


Figure 3. Movement time as a function of camera rotations for different camera perspectives.

If we think of the perspectives in pairs of opposing angles, the results become extremely useful. In the case of 90° and -90°, they represent perspectives of two different surgeons standing on opposite sides of the patient (see Figure 4). Similarly for 0° and 180°, the camera may be directed along the patient’s medial-lateral axis as in Figure 5.

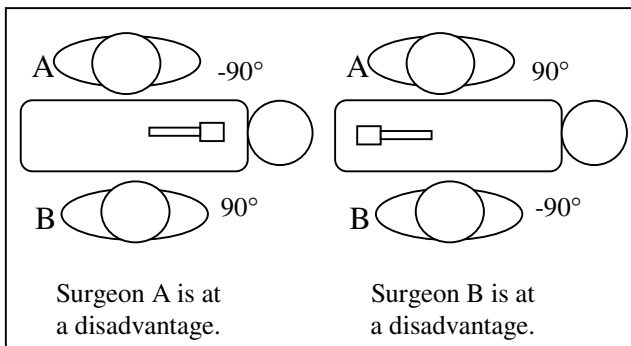


Figure 4. Scenario of 90° and -90° perspectives for two surgeons.

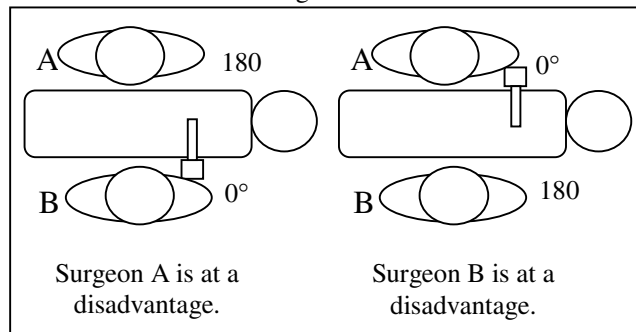


Figure 5. Scenario of 0° and 180° perspectives for two surgeons.

If the surgeon and assisting surgeon stood on opposite sides of a patient in these scenarios, as they do in many cases, our results suggest that one of these surgeons will always be at a disadvantage. This mismatch in performance has implications for communication. If one surgeon has the more intuitive scenario, it may be difficult for him to understand the other surgeon’s situation in order to provide effective directional information. Schober showed that in situations where the people performing a task did not share the same point of view, the person giving instructions tended to give them from the other person’s perspective (1995). It is expected that that this sympathetic behavior is more difficult in the laparoscopic surgery environment.

Thus far, our results support the idea that laparoscopic surgery poses different challenges to different surgeons even as they work on the same case. Add to this disparity differences in experience, spatial ability, and communication styles, and it is easy to see why frustration, misunderstandings, and errors can arise in the operating room. Our next step is to use what we have learned about the differences in perspective to investigate verbal communication of directional information in the surgical environment. We will then impose a standard structure to the vocabulary found in the OR to minimize effort and maximize performance in surgeon’s collaboration. It is expected that the end result of this work will help surgeons communicate more effectively in laparoscopic surgery.

ACKNOWLEDGMENTS

This work was funded by the National Science Foundation under grant #0238284. The authors acknowledge A. Kogan, N. Nolan, and J. Webster for building the testing apparatus and for data collection.

REFERENCES

- Aretz, A.J. (1991). The Design of Electronic Map Displays. *Human Factors*, 33(1) 85-101.
- Barrett, L.F., Tugade M. M., and Engle, R.W. (2004). Individual Differences in Working Memory Capacity and Dual -Process Theories of the Mind. *Psychological Bulletin*, 130(4), 553-73.
- Cooper, L.A. and Podgorny, P. (1976). Mental transformations and visual comparison processes: Effects of complexity and similarity. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 503-14.
- Gugerty, L, and Brooks, J. (2004). Reference-Frame Misalignment and Cardinal Direction Judgements: Group Differences and Strategies. *Journal of Experimental Psychology: Applied*, 10(2), 75-88.
- Keehner, M.M., Tendick, F., Meng, M.V., Anwar, H.P., Hegarty, M., Stoller, M.L., and Duh, Q.Y. (2004). Spatial ability, experience, and skill in laparoscopic surgery. *The American Journal of Surgery*, 188, 71-75.
- Lemay, M., Bertram, C.P., and Stelamach, G.E. (2004). Pointing to an Allocentric and Egocentric Remembered Target. *Motor Control*, 8, 16-32.
- Schober, M.F. (1995). Speakers, Addresses, and Frames of Reference: Whose Effort is Minimized in Conversations About Locations? *Discourse Processes*. 20, 219-47.
- Shepard, R., Hurwitz, S. (1985). Upward direction, mental rotation, and discrimination of left and right turns in maps. *Visual Cognition*, Steven Pinker Ed. pp 161-93 MIT Press.