



A laboratory study on anticipatory movement in laparoscopic surgery: a behavioral indicator for team collaboration

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Abstract

Background: To assess team collaboration in the context of laparoscopic surgery, laparoscopic cutting tasks performed by single operators and dyad teams were observed. Our previous work suggested that the anticipatory movement performed by a teammate may lead to a shorter total task time than for a single bimanual operator. This report further explores this phenomenon by quantifying the frequency of anticipatory movements and discussing their significance to team collaboration.

Methods: Subjects were required to reach, grasp, and cut a piece of thread using a laparoscopic grasper and scissors. The task was performed by either 8 individual subjects bimanually or 16 paired subjects unimanually (using their preferred hands). The performances were video recorded. The total task time, the time used for thread grasping and cutting, and the number of anticipatory movements were computed and compared between the single operator and the dyad team group. In this report, anticipatory movement is defined as movements of the scissors before the completion of grasping and holding the thread.

Results: Shorter durations of total task time were shown for the dyad than for the bimanual group. Anticipatory movements were counted significantly more often when the scissors were controlled by a teammate on the dyad team (96%) than when they were controlled by the preferred hand of the operator (45%). The number of anticipatory movements increased with practice, but no significant difference was shown among practice phases.

Conclusion: Higher frequency of anticipatory movement was observed in the dyad team, which led to superior performance for team collaboration, as compared with that of the single operator. Performance of anticipatory movements in the dyad team was explained by a shared mental model, which postulates combined capacity for information processing among team members. Results

have implications for surgical education, team training, and error prevention in the performance of laparoscopic surgery.

Key words: Anticipatory — Attention — Endoscopy (training) — Ergonomics — Mental workload — Team performance

Complex laparoscopic tasks require surgeons to collaborate with nurses and assistants to form a surgical team. In contrast to open surgery, it is impossible for the surgeon to perform a laparoscopic surgery without assistants. The outcome of the surgery is markedly tied to the quality of such cooperation. Therefore, effectiveness and efficiency of surgical teamwork needs to be explored in the context of laparoscopic surgery.

A small number of studies investigating surgical teams have focused on team structure [21], communication patterns [14, 15], and cost efficiency [13]. Recently, some sophisticated observational systems have been introduced into the surgical theater for observation of real-time interactions among surgical team members [9, 21]. However, few studies have focused on the psychomotor aspects of team collaboration, and even fewer have developed a practical, objective assessment tool to evaluate the effectiveness and efficiency of surgical teams in the operating room [11, 21].

A comprehensive assessment of laparoscopic teamwork should examine the activities performed by all team members rather than the surgeon alone [3]. The activities of a team can be divided into two categories: task-related or team-related activities. *Task-related activity* refers to interactions with tasks, tools, and the environment. It includes the efforts primarily performed by individuals. In contrast, *team-related activity* refers to interpersonal interaction among team members for exchange of information, synchronization of actions, and development and maintenance of work flow.

In some circumstances, team-related activities may be initiated before they are requested by other team members. In this situation, maximum anticipatory movements will be observed. Normally, the anticipatory movements are performed when the performer possesses comprehensive knowledge of a surgical task and the ability to predict the upcoming action by a team partner, a behavior often seen in an experienced surgical trainee. Because of its significance to team collaboration, anticipatory movement has been recognized as a behavioral marker of a team's maturation and the quality of teamwork [1, 12, 17].

In this study, anticipatory movement was investigated in a laboratory setting. Two university students were required to perform a laparoscopic cutting task in a dyad team. One participant (the surgeon) was required to reach, grasp, and lift a thread from a synthetic organ using a laparoscopic grasper. The other participant (the surgical assistant) was required to reach and cut the thread beneath the grasper using a pair of laparoscopic scissors, much as an assistant might do in the operating room. Anticipatory movement in this case was described as scissors movement before the completion of thread holding.

As a control, the same laparoscopic thread-cutting task was performed by a single operator bimanually with one hand on the grasper and the other hand on the scissors. When performed by a single operator, meaningful scissors movements were seldom made before the thread was held. In fact, the reaching, grasping, and cutting task in the bimanual setting usually was performed in a sequential fashion, with the operator reaching and grasping with the grasper, then reaching and cutting with the scissors. This contrasted with the concurrent movements of the grasper and scissors observed in the team performance. In the dyad team, the scissors holder started to move the scissors as the grasper holder started to grasp the thread. We therefore expected that the dyad team would have a shorter task time than a single operator performing bimanually. Finally, we investigated the change in the number of anticipatory movements over the course of 20 trials, thus studying the effects of practice on building efficient team collaboration.

In short, two hypotheses were tested in this study of a laparoscopic cutting task. First, we hypothesized that the overall performance of a dyad team would be superior to that of a single operator because anticipatory movement performed by the second team member would shorten the total task time. Second, we expected that when practicing in a dyad team, team members would develop strategies for sharing information and mutual support. As a result, we hypothesized that the anticipatory movement would be observed more frequently in the later trials than in the early trials.

Methods

Subjects

University students completely naïve to laparoscopic techniques and the study goal were recruited. As a result, 16 subjects (9 males and 7

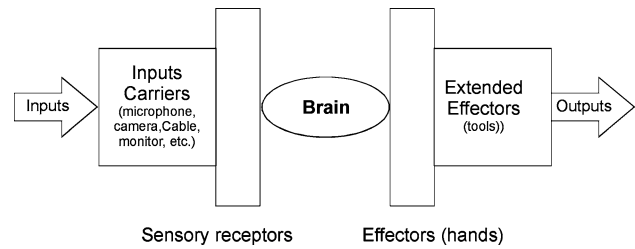


Fig. 1. Model of human information processing for remote manipulation such as a laparoscopic surgery. Input information in remote manipulation is delivered by artificial devices, and the movements are performed with extended effectors such as tools.

females) ages 19 to 29 years (mean, 22.4 years) formed eight dyad teams. The partners within each team did not know each other before the study. Each participant was randomly assigned either to use a laparoscopic grasper to reach and grasp the thread or to use laparoscopic scissors to cut the thread.

Another eight participants were assigned to the single-operator bimanual group (2 males and 6 females). These participants ranged in age from 20 to 30 years (mean, 23 years). All were right-handed with normal or corrected-to-normal vision. Each participant provided informed consent and received an honorarium for his or her participation.

Apparatus

Tasks were performed in an endoscopic training box (35 × 30 × 20 cm) placed on a wooden table 72 cm above the floor (Fig. 1A). The training box had ports of entry for a 0° laparoscope (Olympus A5254 Laparoscope, Olympus, Heidelberg, Germany), a laparoscopic grasper (Karl Storz Endoscopy, Mississauga, Ontario), and scissors (Ethicon Endo-Surgery, Cincinnati, OH, USA). The entry ports of the instruments formed an isosceles triangle on the cover of the training box. The grasper (left side) and the scissors (right) were separated by 18 cm. The laparoscope is placed vertically at distant 20 cm to the grasper or the scissors. The lens of the laparoscope was 9 cm from the work plane, providing a 2X magnification. The work plane in the current experiment was laid horizontally on the bottom of the training box. This positioning is uncommon in laparoscopic surgery. However it has been used in experimental setups [10, 22].

Placed at the bottom of the training box was a synthetic ear (Sandyllion Stick Design, Guangzhou, China) simulating human tissue. In the middle of the ear, an embedded fishing line (Maxima Mfg., Geretsried, Germany) protruded from the synthetic tissue. The task was to grasp the visible portion of the thread. The length of the visible part was about 1 cm, constant over all trials. The work plane was illuminated by a Xenon light source (ORC Lighting, Azusa, CA, USA). The image was collected by a Sony color video camera (DXC-C1 Video Camera; Sony, Tokyo, Japan) and displayed on a 19-in. color monitor (995E CRT Monitor; LG Electronics, Seoul, Korea). The viewing distance from the participant's eyes to the work plane was about 85 cm. Synchronized to the display monitor, the image of the work plane was recorded via VCR (SLV-660 HF VHS Player; Sony) on VHS cassettes (FujiFilm Pro120; FujiFilm, Tokyo, Japan).

Task and procedure

The subjects started with the tips of the grasper and scissors on the start plates located below the synthetic organ. On a verbal signal, they began the task of reaching, grasping, and cutting the thread. When the task was complete, the tips of the tools were replaced on the start plates.

Three practice trials were given to each subject or dyad team. All the subjects were right-handed. Thus for the given task, the subjects in the bimanual group held the grasper in the left hand and the scissors in the right hand. In the dyad group, each tool was held in the participants' preferred hands. A total of 20 trials were performed, and the movements were video recorded for further analyses.

Table 1. Occurrence of anticipatory movements^a

Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Team 1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 4	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 5	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 6	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 7	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Team 8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 4	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 5	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 6	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 7	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single operator 8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

^a A total of 20 trials for each subject were divided into four practice phases with five trials for each. Each dot represents an anticipatory movement of the scissors before the completion of thread holding

Video analysis

Details for selecting significant events and computing movement durations in video analysis have been reported elsewhere [23]. The total task time, grasper time, scissors time, and number of anticipatory movements were obtained for each trial. Total task time was defined as the time from lifting of the grasper off the start plate until cutting of the thread. Grasper time was calculated as the time from lifting of the grasper off the start plate until the jaws were firmly closed around the thread. Scissors time was measured from the time the thread was held to the time the thread was cut. For cases in which the scissors were lifted off the start plate before the thread was held by the grasper, an anticipatory movement was counted.

Despite the label “anticipatory movements,” we are aware that not all the scissors movements recorded during the thread grasping were intentional or volitional. For example, in the single operator bimanual setting, the scissors may have displayed some unintended movements together with the intended movements of the grasper on the “go” signal. Strictly speaking, this type of scissors movement would not be designated as an anticipatory movement because it was unintentional and provided no meaningful assistance for completion of the task. Such a movement may have been the result of bimanual spatial interference [7]. Obviously, this type of scissors movement in the bimanual group is different from the anticipatory scissors movement observed in the dyad team group. In the team setting, the scissors were moving toward the target and intended to cut once the thread was held. It was difficult for us to separate the types of scissors’ movements using merely video recording technology, and even harder for us to judge the intention of the participants when they moved the scissors. As a trade-off, we counted all scissors’ movements before completion of the thread grasp.

Statistical analysis

To examine the learning effects over the practice, 20 trials for each subject were divided into four blocks with five trials for each. Dependent measures were analyzed with a two groups (dyad team vs single operator bimanual) × four blocks mixed designed analyses of variance (ANOVAs) with a repeated measure on the second factor. Means and standard errors are reported for significant effects, with an a priori α level of 0.05.

Results

In the dyad team, the scissors were moved much more often (154 trials, or 96% of 160 trials) before the thread

was held with the grasper, as compared with bimanual performance by a single operator (72 trials, or 45% of 160 trials). The difference between the dyad team and the single operator group was significant ($p < 0.001$) (Table 1).

Averaging over the two groups shows that the percentage of anticipatory movements performed increased slightly as practice went on (65%, 69%, 75%, 74%). However, the difference among training phases was not significant ($p = 0.393$). When performed by a single operator, the number of advanced scissors movements fluctuated over the four blocks of training phases (43%, 40%, 50%, 48%). The tendency for an increasing number of anticipatory scissors movements was more apparent in the dyad team group (88%, 98%, 100%, 100%).

For temporal measure, there were significant differences between the dyad team and the single operator group in the total task time ($p = 0.044$) and grasp time ($p = 0.004$). Explicitly, the dyad team used less time (12.1 ± 10.0 s) to complete the task than the single operator (18.3 ± 12.8 s). The shorter total time in the team condition was composed of a shorter grasper time (5.1 ± 2.8 s) than in the bimanual condition (8.1 ± 6.6 s). The scissors movement time was less for the team (7.0 ± 9.5 s) than for the single operator (10.2 ± 9.1 s).

Effects of practice were not shown for any temporal variables (total task time, $p = 0.117$; grasper time, $p = 0.188$; scissors time, $p = 0.162$), nor were there significant group by practice interactions. Hence, our second hypothesis that practice on a team would facilitate task performance through collaborative teamwork was not strongly supported.

Discussion

Laparoscopic surgery presents the surgeon with unique sensory motor challenges. With open surgery, the information processing for movement control is relatively simple and straightforward. Information from the

environment is directly perceived by the surgeon's sensory receptors, and subsequent movements are executed by the surgeon's motor systems. Between perception and movement, there is a central processing unit, the brain, in which information is recognized. A movement blueprint is determined on the basis of the experience, and commands are sent to the motor systems [6] (see Marteniuk [16] for reviews).

When a laparoscopic procedure is performed, the information-processing route is more complex than the one just described. In laparoscopic surgery, the environmental inputs are mediated indirectly by electronic devices (camera, cable, and TV monitor), and movement outputs are performed by long-shafted instruments with paradoxical movements [5, 8, 20] (Fig. 1). To ensure that remote manipulation is performed safely during a laparoscopic procedure, surgeons constantly transform and calibrate information across intermediate interfaces, namely the surgical site, the electronic devices, the eyes, the hands, and the tools. Such high levels of mental transformation lead to higher levels of mental load, and thus fatigue, than with traditional open, tactile surgical procedures [2].

In addition to that, performing bimanual tasks in a laparoscopic procedure can be more challenging for laparoscopic surgeons. Few studies have compared bimanual and unimanual performances in laparoscopic tasks, but it is well documented that the control of bimanual movement is more mentally demanding than unimanual movements in natural manipulation [18, 19]. When a laparoscopic procedure is performed, a practical way to avoid extreme mental stress is to shift attention between the tasks performed by each hand (i.e., concentrating on the task, executing it with one hand, then shifting to the task of the other hand).

This strategy also was used by the subjects in the current study. Single operators divided the bimanual tasks into two subtasks: grasping with one hand, followed by cutting with the other hand. Obviously, some individuals have the capacity to perform different tasks with their two hands simultaneously, but the development of such skills requires intensive training. This particular study did not evaluate the skills of an advanced laparoscopic practitioner, and it might be hypothesized that advanced surgeons would train themselves to a level of independent hand function to achieve operational efficiency.

Advanced laparoscopic procedures require multiple surgical instruments, and therefore more "hands" for the surgery. Because the control of multiple tools may go beyond the capacity of a surgeon, extra "brain power" is needed to manage the larger volume of information that must be processed. In other words, laparoscopic surgeons must share the workload with team members. The advantage of sharing workloads with team members has been suggested in the health settings [4] and further confirmed in laparoscopic surgery [23].

Although adding operators to the task enlarges the capacity for mental process, it also introduces additional workload in cooperation among team members [3]. This includes the need not only to control one's own part of

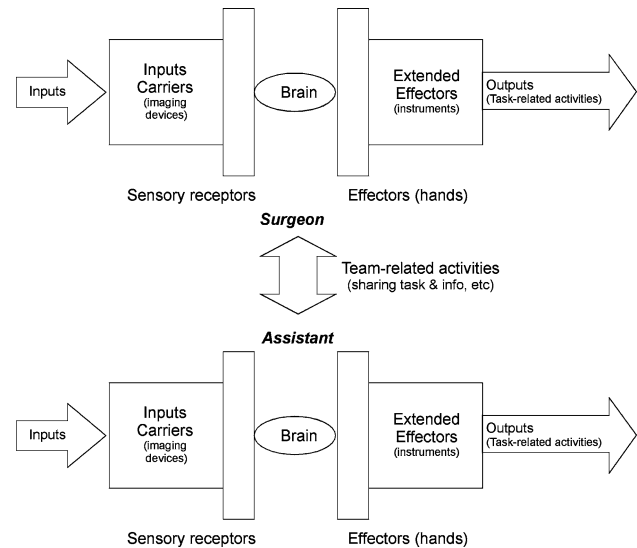


Fig. 2. Model of human information processing among team members for remote manipulation. Although both surgeon and assistant process information and perform task-related activities, they also perform team-related activities such as communication and time-sharing movements. An effective team will develop a coordination to maximize task efficiency and minimize the workload for team-related activities to achieve the task goal.

the movement, but also to monitor the activities of the other participants in the procedure continuously and to communicate needs and information. A mature team develops strategies to minimize the teamwork burden and maximize the resources for achieving task goals.

Bowers and Salas [3] proposed a *shared mental model* to describe conceptually the information processing of team performance. The shared mental model hypothesizes that team performance is a function of the extent to which team members hold similarly organized expectations surrounding the task or each other. According to this model, when the knowledge of a task, equipment, and environment is well defined and shared by each of the team members, overall team performance is enhanced, as compared with each task being performed by individuals separately. When team members train in such a favorable environment, they are able to develop a shared pattern for effective communication and movement collaboration under a common task goal. In laparoscopic surgery, this optimally translates as a procedure in which the surgeon, assistant, and camera person all are masters of their parts in the procedure, knowing the overall sequence of the operation and making preparation and anticipatory moves in relation to each other (Fig. 2).

In the current experiment, the participants in each dyad team were clearly informed of the task goal, understood their role in the task, and were working in the same environment. They generated excellent time share patterns (e.g., anticipatory), which resulted in a superior task performance, as compared with that of the single bimanual operator. No doubt such mutual support was constructed on the basis of understanding the task goal, the role of each team member, and the working environment. Thus, we suggest using anticipa-

tory movement as a measurable marker for surgical team interaction.

In the current laboratory setting, the role of each team member in the dyad team was clearly defined. In actual surgery, the responsibility and task of the surgeon may not be predetermined. The roles for surgeons actually are subject to change. To enhance the number of cooperative movements such as anticipatory movement, preoperative rehearsal is strongly recommended. Preoperative rehearsal provides an opportunity for surgeons to determine their roles in the team (e.g., leader or assistant), build up effective ways to exchange information, and consciously develop mutual support for other team members. The rehearsal may be conducted with a bench training model or via videos that demonstrate the operative procedure for all surgical team members.

The outcomes for team exercises can be quite dramatic. For example, after a short term of dyad team work, anticipatory movements were observed for 100% of the trials during the late stage of practice, indicating a high level of cooperation being constructed during practice.

We were somewhat surprised that our second hypothesis was not fully supported: the number of anticipatory movements did not significantly increase with increased practice. Perhaps the experimental task was too easy and allowed participants to build up coordination in the early stage of the practice. As a matter of fact, in the first block of trials, the scissors started to move before the thread was held in 88% of the trials, a surprisingly high rate. In the real world of laparoscopic surgery, it is not possible to observe such a high level of cooperative performances within a newly formed team.

A limitation of the current study was that data were collected from a mock laparoscopic task. The results shown in such a laboratory setting may not entirely reflect the movement patterns of a surgical team in the operating room. Our next project is designed to study behaviors of surgeons and nurses during an actual laparoscopic procedure. We will count anticipatory movements performed by team members. The number of anticipatory movements then will be correlated with the outcome of the surgery, as measured by such parameters as operation times and surgical errors. Our goal is to devise an objective assessment tool that can be used to evaluate team quality in the surgical theater.

Conclusion

In performing a laparoscopic reaching, grasping, and cutting task, sharing the task demands between two operators in a dyad team produces significantly better performance than one operator performing the task bimanually. Superior team performance is the result of developing coordination and sharing the workload between team members. Our results support the conclusion that anticipatory movements performed within a team can be used as an indicator for assessing team

collaboration. This study has important implications for the construction of optimal surgical teams and laparoscopic training curricula.

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