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Collaborative performance in laparoscopic teams: behavioral evidences from simulation

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Abstract
Objectives To examine the frequency of movement de-synchronization between a surgeon and assistant in a laparoscopic simulation task, and test whether it can be a valid behavior marker for team performance.
Methods Fourteen subjects formed a total of 22 dyad teams. Each team performed a laparoscopic task where the camera driver navigated a laparoscope for the operator to transport a plastic cylinder between targets. Key movement landmarks were annotated from recorded surgical videos and were used to identify team behaviors and performance. Task completion time, number of movement de-synchronization, and errors (cylinder drops) were compared over 3 performance groups (elite, intermediate, poor) and 2 types of movements (on-site manipulation vs. position-shifting.
Results Task completion time of elite teams was shorter than intermediate and poor teams (33.3 vs. 66.8 vs. 141.2 s, $P < 0.001$). Elite teams made fewer errors (0.1 vs. 0.5 vs. 0.9, $P = 0.063$) and recorded fewer numbers of de-synchronization than poor teams (2.9 vs. 3.0 vs. 4.9, $P = 0.009$). We also found that the on-site manipulation took longer task time (113.5 vs. 51.2 s, $P < 0.001$) and recorded fewer de-synchronization (0.6 vs. 5.3, $P < 0.001$) than position-shifting tasks. However, there is no significance in the measure of errors ($P = 0.029$). Interaction effects were revealed between performance groups and two movement types in task time ($P = 0.010$) and movement de-synchronization ($P = 0.003$).
Conclusions Video analysis is a useful tool for identifying team behaviors during surgery. Movement de-synchronization between surgeons and assistant reveals team cooperation in laparoscopic procedure. The evidence where de-synchronization occurred frequently during the position-shifting tasks rather than during the on-site manipulation suggests team collaborative behaviors can be affected by different task requirements.

Keywords Team collaboration · Collaborative behaviors · Video analysis · Laparoscopic surgery · Surgical simulation

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In laparoscopic surgery, the vision of the primary surgeon is controlled by an assistant who maneuvers the laparoscope. This highlights the importance of team collaboration between surgeon and assistant. Typically, surgical residents start their training as assistants to senior surgeons in the operating room. When a laparoscopic procedure is assisted with an inexperienced resident, the visual contact with the instruments can be easily lost, and the coordination between surgeons and assist can be a problem which may increase surgical risks [1]. Currently, various simulation models have been used for training of laparoscopic skills, however, available training programs for laparoscopic surgeons are still mainly designed for individuals, and the skills are evaluated on an individual basis [2, 3]. In the few team training models, outcomes are typically assessed through the metrics of performance or a list of observable skills [2–5]. In fact, the deficiency in tools for objective team assessment has been a major barrier in promoting surgical team training [6–8].

In 2007, leading laparoscopic surgeons in Canada participated in a consensus conference; they argued that surgeons should be trained in teams to maintain the quality of laparoscopic surgery [9]. To ensure effectiveness of team training, we should develop an evaluation system to assess team behaviors. However, our knowledge on team collaborative behaviors remains rudimentary. Reports on behavioral evidence between surgeons in laparoscopic surgery are seldom found.

Our earlier studies using video analysis on laparoscopic cutting tasks revealed that anticipatory movement performed by a team member is a valid behavioral marker for superior team performance. Following these laboratory studies, field studies in the operating room confirmed that experienced nurses and surgical assistants were able to perform more anticipatory movement during the laparoscopic surgery [10, 11]. In addition, dedicated teams may have decreased the operation time when cases were complicated; in other words, it can translate to improved patient care and decreased costs for healthcare institution [12].

In this study, we will further use video analysis technology to investigate team behaviors between surgeon and assistant during a more realistic laparoscopic task, i.e., navigating the camera for the surgeon to transport an object to a defined location. This time we will identify whether there is any movement de-synchronization between two peoples in a team. De-synchronized movement is defined as the discordant movement of the surgeon and assistant. For example, should the object, tooltip or target fall outside camera view during object transportation or object loading, a de-synchronization event would be recorded. We asked a surgeon and assistant to perform together in a simulated laparoscopic training setting to record their movement de-synchronization, examine their behavioral changes, and to further correlate movement de-synchronization with task performance.

We hypothesized that elite teams would demonstrate fewer movement de-synchronization events compared to poor teams, and fewer movement de-synchronization would result in improved task performance, measured by task time and errors made.

Methods

Participants

A total of 14 subjects (including surgical residents, international surgeons, and university students with no prior surgical experience) formed 22 dyad teams. A pretest questionnaire was given to obtain demographic data as well as the participants' training level and surgical experience. To assess the surgical experience score, each individual was asked to report the number of 12 basic laparoscopic cases performed or assisted up to the date of study [5]. The self-reported case volume was adjusted by the year in surgical training to create a general score to descript individual surgical experience. Score below 20 refers to novice, most general surgery residents can achieve a score ranging from 20 to 60 points depending on their year of training. Laparoscopic surgeons can easily earn 60–80 points in their experience [5, 13, 14]. When two members were assigned to a dyad team, the team score was calculated by averaging individuals' surgical experience scores in the team. Methods used in the experiment were subjected to Health Research Ethical Board of University of Alberta. Consent was obtained from each participant before entering the study.

Apparatus

The experimental apparatus (Fig. 1) includes 3 main components: (1) a standard laparoscopic towel (Stryker Endoscopy, San Jose, California, USA), including laparoscope, camera, light source and video monitor) was used to set up laparoscopic training environment. In the centre, a custom-made laparoscopic training box measuring $30 \times 30 \times 20$ cm^3 was placed. On the bottom of this wooden box, a 2×2 cm home position was labeled. Five 2 cm pins, coded in different color (blue, red, orange, pink, and yellow), were located on two sidewalls with different distance to the home position (Fig. 2). The training box has ports on the other two sidewalls allowing for insertion of a

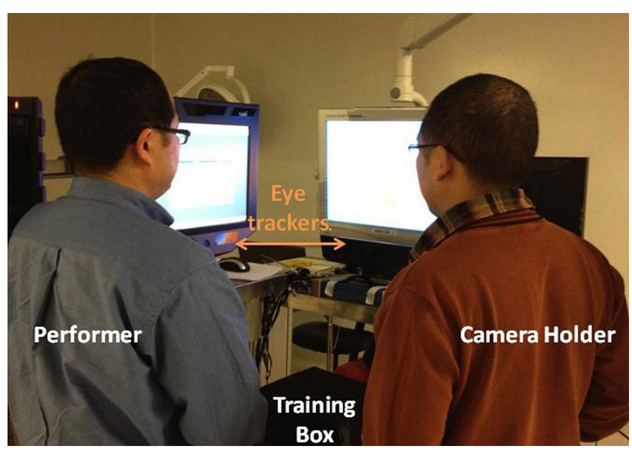

Fig. 1 Two subjects working in a laparoscopic team in front of two separate surgical monitors, the camera holder manipulates the laparoscope to track the object for the primary performer to complete the object transportation task inside a training box. Two separate eye trackers are attached below each monitor, capturing eye motion of two team members

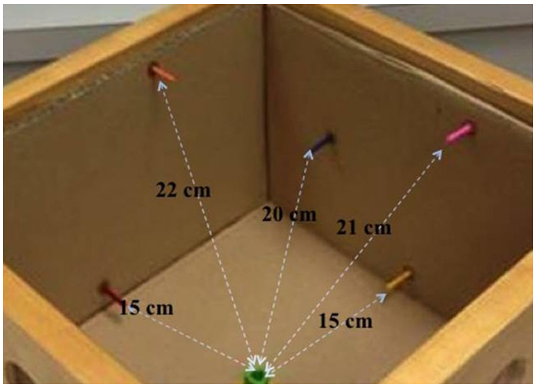

Fig. 2 Five pins in different color are located within a wooden training box

0-degree laparoscope (Stryker Endoscopy, San Jose, California, USA) and a laparoscopic grasper (Ethicon Endo-Surgery, Cincinnati, OH, USA). (2) Two 17″ video monitors (Tobii 1750 LCD Monitor, Tobii Technology, Stockholm, Sweden; Stryker OR 1 TV monitor, Stryker Endoscopy, San Jose, California, USA) were mounted in an orthogonal arrangement in front of each team members to display the video image captured by a laparoscope. (3) Two high-resolution remote eye trackers (Tobii 1750 and Tobii X50, Tobii Technology, Stockholm, Sweden) were attached to different monitors. Each eye tracker can remotely track one operator's eye motions unobtrusively within a comfortable viewing distance (75 cm).

Task and procedure

Each dyad team was asked to perform object transportation tasks. A practice trial was given to subjects before the recorded trial. The task requires one team member (camera driver) to navigate the laparoscope to locate five different colored pins for his/her teammate to grasp and transport a plastic cylinder (2 cm long, 1.5 cm wide) among five pins. The sequence of the transportation was randomly assigned by the experimenter by giving the color code of the pin before the grasper leaves the home position. To locate the pins, object and home position, the camera driver must manipulate the laparoscope forwards, backwards, clockwise and counterclockwise to keep the object and the instrument at the center of view. The camera driver must also adjust the focus of camera to provide a clearer image.

Video analysis

The task scene was captured through laparoscope. Videos were analyzed frame by frame by the experimenter using VirtualDub 1.9.11 (Free Software Foundation, Inc. Cambridge, MA 02139, USA) to obtain the task performance variables.

For each trial, a number of events were identified with specific operational definitions. The subtasks include (1) object loading—the grasper with object touches the pin with the object, and subsequently releases the object onto the pin (Fig. 3A) (2) homing—after release, the grasper and tool returns back to home position (Fig. 3B) (3) reaching—the tool and grasper leave home position and reach back toward the object, (4) object pickup—grasper touches the object and object breaks off contact from the pin and (5) object transportation—after object breaks off contact from the pin, the grasper transports object toward another pin. We further combined the subtasks into two types of movements: Subtask A and D are called "on-site manipulation" and Subtask B, C, E are called "position-shifting movement." By clearly defining each subtask, the durations of each event were obtained for further analysis. The task performance variables include time to complete a task, number of de-synchronization (object/tool out of view in 1 cm margin of the video when placing object on pin or transportation from pin to home/ home to pin/ pin to pin) and errors (drops object or putting object on the ground to make adjustment during tasks) recorded at each subtask.

Statistical analysis

To test our hypothesis, subjects were divided into three performance group based on their performance time. A histogram of total time was first created, then the percentiles (25, 25–75, 75) were used to divide the subjects into 3 performance groups (Elite, $n = 5$; Intermediate, $n = 12$; and Poor, $n = 5$).

Statistical model

Dependent measures, including task time, errors and de-synchronization, were analyzed using a 3 (Performer groups: elite, intermediate, poor) $\times$ 2 (movement types: on-site vs. position-shifting) between-subject ANOVA. Statistical analysis was performed using SPPSS 16.0 (SPSS Inc., Chicago, IL, USA). Means and standard errors are reported for significant effects, with an a priori a level of 0.05.

Results

Table 1 shows demographic of participants in three different team groups. Age reported in Table 1 is the average age over two team members in a dyad team. Surgical experiment score did not vary significantly among three different team groups ($P = 0.094$).

Table 2 shows the group effect of performers and movement types on task time, errors and de-

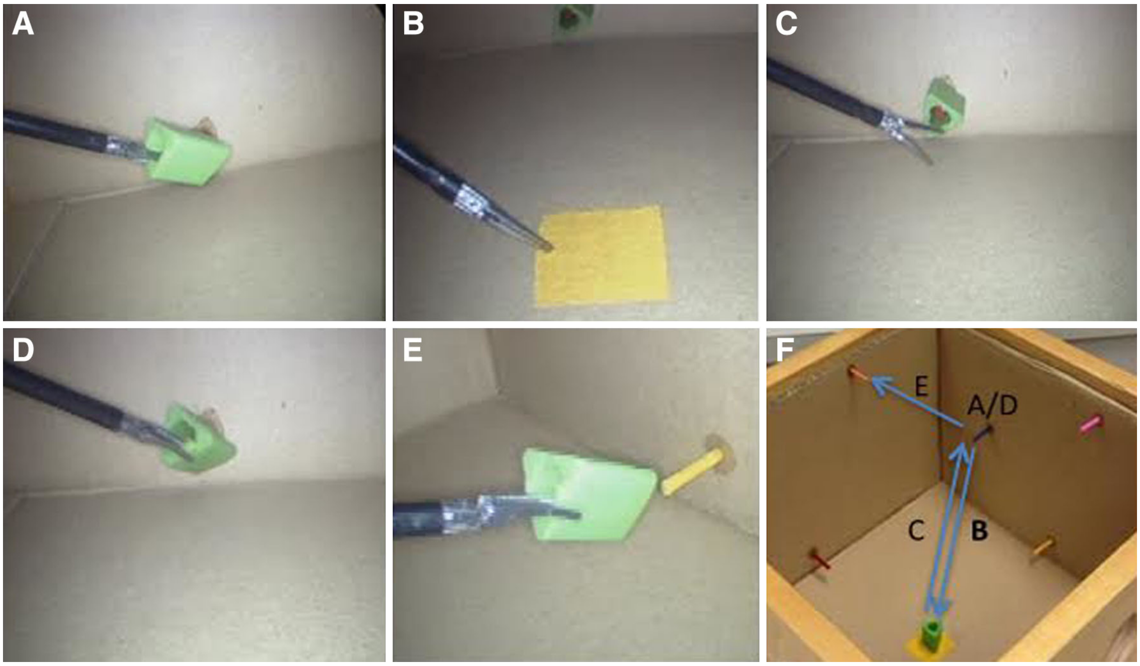

Fig. 3 Series of snapshots from task video showing subtasks. Subtask 1, loading object on a pin (**A**); Subtask 2, bring the grasper back to the home plate (**B**); Subtask 3, reaching to the object (**C**); Subtask 4, picking up the object from a pin (**D**); and Subtask 5, transporting the object to next pin (**E**); A still picture illustrate two types of movement: subtask **A** and **D** are on-site manipulation; Subtask **B**, **C**, **E** are position-shifting movement

Table 1 Demographic of 3 different team groups

Group	*N*	Age (mean ± SD)	Sex ratio (M:F)	R: L handed	Surgical experience (mean ± SD)
Elite	5	30.0 (6.6)	5:5	10:0	16.3 (0.8)
Intermediate	12	31.0 (4.9)	19:5	23:1	17.0 (0.9)
Poor	5	26.1 (1.1)	6:4	7:3	16.1 (0.3)
P value	–	0.189	–	–	0.094

synchronization. Significances were found among performer groups for task time ($P < 0.001$) and de-synchronization ($P = 0.009$), but not for errors ($P = 0.063$). Explicitly, the elite teams required less time (33.3 ± 15.8 s) to complete the task in comparison with intermediate teams (66.8 ± 60.1 s) and poor teams (141.2 ± 127.6 s). Post hoc multiple comparisons (Bonferroni) revealed the differences between elite and poor performers ($P < 0.001$), intermediate and poor performers ($P < 0.001$), but not between elite and intermediate performers ($P = 0.113$). Elite teams made fewer errors (0.1 ± 0.4) than intermediate (0.5 ± 1.4) and poor teams

Table 2 Comparison of task performance over 3 different performance groups and 2 movement types

Variables/mean ± SD	Performance group				Movement type		
	Elite	Intermediate	Poor	*P*	On-site	Shifting	P
Task time (s)	33.3 ± 15.8	66.8 ± 60.1	141.2 ± 127.6	<0.001	113.5 ± 114.8	51.2 ± 38.7	<0.001
Errors	0.1 ± 0.4	0.5 ± 1.4	0.9 ± 1.5	0.063	0.9 ± 1.5	0.2 ± 0.7	0.029
De-synchronization	2.9 ± 2.3	3.0 ± 2.8	4.9 ± 4.8	0.009	0.6 ± 0.9	5.3 ± 3.0	<0.001

(0.9 ± 1.5). Lastly, more numbers of de-synchronization were found in poor teams (4.9 ± 4.8) than intermediate (3.0 ± 2.8) and elite teams (2.9 ± 2.3). Post hoc multiple comparison revealed the differences of de-synchronization presented between elite and poor performers ($P = 0.005$), intermediate and poor ($P = 0.001$), but not between elite and intermediate performers.

Movement type group effects were showed in task time ($P < 0.001$), errors (0.029) and de-synchronization ($P < 0.001$). Specifically, on-site movement took longer time (113.5 ± 114.8) than position-shifting movement (51.2 ± 38.7). More errors were made during on-site manipulation (0.9 ± 1.5) than position-shifting movement (0.2 ± 0.7). Also, there were fewer occurrences of de-synchronization events in on-site manipulation (0.6 ± 0.9) than position-shifting movement (5.3 ± 3.0).

Interaction effects were revealed between performance group and movement type in task time ($P = 0.010$) and de-synchronization ($P = 0.003$), not in errors ($P = 0.722$). As shown in Fig. 4, the elite team used shorter time to complete the position-shifting movement compared against intermediate and poor teams. The differences between the three performer groups were more prominent when they performed on-site manipulation (Fig. 4A).

The three teams perform a similar amount of de-synchronization during on-site manipulation but differences became significant when they performed position-shifting movement. While the elite and intermediate team increased the number of de-synchronization events in a moderate manner, the poor team had increased much more dramatically (Fig. 4B).

Discussion

Our research hypothesis was supported by our results, where elite teams performed less amounts of movement de-synchronization when performing tasks than intermediate and poor teams, and they completed tasks with shorter times. Most of the de-synchronization movements occurred during shifting tasks rather than during on-site tasks; this can be explained by the fact that it is more difficult for the camera assistant to track a moving object than a relatively steady task. In order for team members to improve their team performance, they need to develop shared team cognition.

Team cognition refers to the cognitive activities of a team members toward a team goal [15]. It emerges from the interplay of the individual cognition while team members work in a team [16]. Salas and colleagues proposed that a shared mental model is “knowledge structure held by members of a team that enables them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members” [17]. Few programs have assessed the shared cognition built among team members, which is the foundation for constructing an effective team [18]. It has been documented that when team matures, the level of shared team cognition will grow stronger and movement coordination between team members will be more observable [19].

In our study, we did find a positive correlation between movement coordination and team performance. Since the participants in the study were not allowed to verbally communicate, it is quite possible that the team improvement was a result from the development of team cognition toward the team goal, based on their pervious laparoscopic team experience.

In laparoscopic surgery, movement coordination between team members can be identified from surgical videos. Video recordings and video analyses have proved to be a reliable method for observational study such as in this experimental setting [10]. Video analysis provides us a useful tool to examine the coordination patterns of surgeons.

There are several limitations to this study. First, object transportation is too overly simplified to represent true

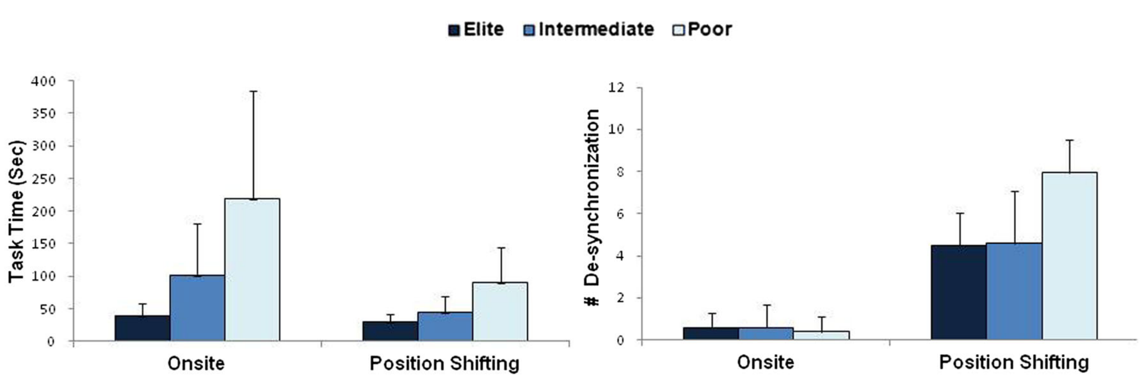

Fig. 4 Interaction effect between different performer teams and type of movements in the measure of task time (**A**), and number of de-synchronization (**B**)

surgical task for laparoscopic procedures. We plan to study team collaboration in a more realistic laparoscopic setting. Second, coordination between surgeon and camera holder, although important, contributes only a small part to teamwork between the entire surgical team. It would be beneficial to study collaborative patterns among all surgical team including additional surgeons, nurses and anesthesiologists. Third, we hope to increase our sample size to investigate whether other types of team collaborative behaviors would be present, ones that would also predict task performance.

While trials have been recorded, we also tracked the eye motions of two team members. In our next paper, we will analyze the dual eye-tracking data to examine the similarities of gaze patterns between two team members. The goal is to identify more psychomotor evidences to describe the team cognition. We expect more distinguishable gaze patterns can be found from different teams based on temporal and spatial features in gaze.

Conclusions

In conclusion, simulation provides a good model for studying surgical team performance. While surgeons perform a team task, video analysis is useful to identify team collaboration behaviors in laparoscopic surgery. Elite teams displayed less number of movement de-synchronization than poor teams. This suggests movement de-synchronization can serve as a behavioral marker when assessing team collaboration quality. The evidences where de-synchronization occurred frequently during the position-shifting tasks rather than during the on-site manipulation suggests team collaborative behaviors can be affected by different task requirements.

Compliance with ethical standards

Disclosures Wenjing He and Bin Zheng have no conflict of interest or financial ties to disclose.

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