Surgical Team and Team Assessment: Psychomotor Evidence

by

Wenjing He

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Surgery
University of Alberta

ABSTRACT

Effective teamwork is critical to the success of surgery. In the operating room (OR), a surgical team is generally composed of surgeons, nurses and an anesthesiologist. Of all the factors that might affect patient safety and the success of the surgery, collaboration among team members is considered to be essential. Improvement of team performance in the OR should therefore lead to safer surgery. When applied to a laparoscopic procedure, where surgery is performed through insertion of specialized long-shafted instruments and a fiber-optic video camera (laparoscope) to provide visualization inside the abdominal cavity, the team collaboration between primary surgeon and assistant becomes more important. In laparoscopic surgery, the primary surgeon’s vision is guided by the assistant who maneuvers the laparoscope. If the intended surgical site is not optimally displayed, it might affect the primary surgeon’s decision-making process. However, few studies have been done into studying the teamwork between the primary surgeon and assistant.

Although every educator knows the importance of surgical team training, we lack technologies in assessing team performance which are the primary barrier for high quality team study. Without a clear assessment of team performance, it is hard to construct an effective education program for team training. To date, the most common technologies and tools for assessing team performance are based on the subjective feedback from senior surgeons or knowledge testing of individuals in a team. However, these subjective assessment methods are limited in reflecting team

performance as they are based on self-filled out test or the subjective feedback from other observers, which may raise bias for team assessment. The purpose of this thesis research is to find objective assessment of team performance through psychomotor evidence.

In order to achieve the general research goals, a simulated operating theater was set up in the Surgical Simulation Research Lab (SSRL) at the Department of Surgery, University of Alberta; the operating environment included all the necessary surgical devices for laparoscopic surgery. In such an environment, surgeons were recruited to participate in a simulated laparoscopic surgery, acting as a primary surgeon and an assistant without harming patients. While they performed, their team performance was recorded using a video camera; their eye motion was recorded using cutting-edge technology - remote eye trackers. Then data analysis was carried out, including *video analysis* on team collaborative behaviour; spatiotemporal analysis of *eye tracking* trajectories; and synchronization analysis of *pupil response* from both team members.

Video analysis showed that elite performance teams had less movement desynchronization than poor performance teams. Dual eye gaze analysis revealed that elite teams had more overlapping of eye gaze than the poor teams; and also, a higher chance of visiting the same visual spots and a shorter phase delay of eye gaze were observed in the elite teams than in the poor teams. Dual pupil analysis showed that the elite performance teams have higher pupil dilation similarity than the lower-performance teams; and that medium collaboration teams have higher pupil similarity than in the least collaborative teams.

Findings from the video and eye tracking signals enable us to look deeply into behaviours and cognition that constructs team collaboration. For example, the overlapping between two people's eye motion trajectories can be used to describe team's shared visual attention; the synchronization of pupil dilation can provide rich information for us to describe whether two people detect the change of task load and react simultaneously over time. All this knowledge will provide the foundation for us to develop an advanced methodology for the objective evaluation of team cognition. The thesis concludes with a summary of findings and the contribution to teamwork assessment. I believe the future of assessing teamwork should be more objective and quantitative based on this thesis research.

PREFACE

This thesis is an original work by Wenjing He. Some of the work referred to, and presented in this dissertation, has been published, will be published, or is currently under peer-review. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Health Research Ethics Board, “Analysis of Dual Gaze: An Indicator for Team Readiness between Two Operators in Performing a Laparoscopic Procedure”, ID Pro00040616, June 17, 2013.

A version of Chapter 4 has been published as “He W, Zheng B. Collaborative performance in laparoscopic teams: behavioural evidence from simulation. Surg. Endosc. 2016 Oct;30(10):4569-74.” I was responsible for the literature review, design of the experiment, data collection and analysis and composition of the manuscript. Zheng B. was the supervisory author responsible for revision of the manuscript.

Chapter 5 is based on the work of spatiotemporal eye gaze data analysis to better understand team cognition. This project was presented at the conference International Conference on Smart Multimedia (ICSM) 2018. Spatio-Temporal Eye Gaze Data Analysis to Better Understand Team Cognition: First International Conference, ICSM 2018, Toulon, France, August 24–26, 2018, DOI: 10.1007/978-3-030-04375-9_4

A version of Chapter 6 is being submitted for publication as W. He, X. Jiang, B. Zheng. “Synchronization of pupil dilations reveals team performance. I was responsible for the design of the experiment, data analysis and writing of the article; X. Jiang helped with data analysis and revision of the manuscript; B. Zheng was the supervisory author who assisted with the revision of the manuscript.

ACKNOWLEDGEMENTS

Above all else, I would like to thank my family for always being there to support and encourage me. Thank you, my husband - Yanjun, for accompanying me to Canada to start my PhD study in September 2014, your company, love, encouragement and patience are appreciated more than you know.

I am really thankful for being given the opportunity to share the PhD journey with my son, Leon, who was born in November 2015. You are a buddy who not only grows with my thesis project, but also makes my life full of happiness, joy and laughter.

I am extremely grateful to my mom/mother in law's continuous support for our family, without your support it would have been impossible to complete my PhD study without maternity leave or any other leave from work.

I owe my deepest gratitude to my supervisors. Dr. Zheng, Dr. Birch and Dr. Basu for providing support and guidance, attending 6-month reviews of progress and providing the resources necessary for completing this work. Without your enthusiasm, encouragement, support and continuous optimism throughout my graduate studies, this thesis would hardly have been completed.

I would like to express my sincere gratitude to my supervisor, Dr. Zheng, for his excellent guidance, persistent encouragement and endless support throughout my time as his student. I have been very lucky to have a supervisor who cared so much about my work, and who responded to my questions and queries so promptly.

With your guidance, my experience over the past four years in SSRL was enriched with opportunities for professional development and personal growth. I really enjoyed the time I spent with you. Your encouragement and positive attitude towards research and life have impacted me tremendously over the past years.

And finally, last but not least, I am forever thankful to my colleagues at the Surgical Simulation Research Lab, and for creating a cordial and supportive working environment… Especially, Xianta, for helping with my thesis writing and data analysis, it was fantastic sharing a laboratory with all of you during last four and a half years. Thanks for all your encouragement!

Thanks to Li Ka Shing Sino-Canadian Exchange Program and Graduate Assistantship's financial support for my PhD program at the University of Alberta. These generous sponsorships over the past years have made my PhD study possible and also have changed my life profoundly.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

OR	Operating Room
SSRL	Surgical Simulation Research Lab
CRM	Crew Resource Management
MIS	Minimally Invasive Surgery
BDI	Bile Duct Injury
HROs	High Reliability Organizations
OTAS	Observational Teamwork Assessment of Surgeons
KSAs	Specific knowledge, skills, and attitudes
2D	Two-dimensional
EEG	*Electroencephalography*
NS	*Neurophysiologic synchronies*

fNIRS	*Functional Near-infrared Spectroscopy*
INS	Interpersonal Neural Synchronization
fMRI	Functional Magnetic Resonance Imaging
CMD	Command (File Name Extension)
CRA	Cross Recurrence Analysis
CRP	Cross Recurrence Plot

GLOSSARY OF TERMS

Team Cohesiveness: Cohesiveness is the attraction of the members to the team: A social glue that binds the team members together as a unit. Without cohesiveness, it is extremely difficult for a team to attain the other components of a developed team.

High Reliability Organization: The organizations that conduct operations with minimal error, over an extended time, and consistently make decisions that result in high quality and high reliability.

Laparoscopic surgery: also called minimally invasive surgery (MIS)/ keyhole surgery, is a modern surgical technique in which operations are performed through small incisions.

Dyad team: a team formed by two team members.

Movement desynchronization: during laparoscopic surgery, the surgeon performs the surgery by watching the images of a patient's organ on the monitor, the assistant's role is to hold the camera and provide the view of the surgical site. The moment a surgical instrument or surgical site is out of view is considered as movement desynchronization.

Eye tracker: a sensor technology that enables a device to know exactly where your eyes are focused. Eye tracking is the process of measuring where one is looking at (the point of eye gaze) or the motion of an eye relative to the head, it could also record the pupil dilation over time. Eye tracking data is collected using either a remote or head-mounted 'eye tracker' connected to a computer.

Dual eye tracking: tracking eye movement of two people simultaneously using two separate eye trackers.

Median filter: a nonlinear digital filtering technique, often used to remove noise from an image or signal. Such noise reduction is a typical pre-processing step to improve the results of later processing (for example, edge detection on an image). Median filtering is very widely used in digital image processing because, under certain conditions, it preserves edges while removing noise, also having applications in signal processing.

CHAPTER ONE: INTRODUCTION

Chapter one provides the context and background for this thesis research. My personal thoughts on the importance of teamwork in surgery will be presented first, and secondly, the methods of measurements of teamwork, followed by research objectives and thesis organization.

Operating theaters are often high-stress environments where team members must work as a team to provide patient-centered care. In the OR, a surgical team is generally made up of interdisciplinary individuals (surgeons, nurses, an anesthesiologist and other specialists). In all the factors that might affect patient safety and the success of the surgery, effective teamwork among team members is considered as an important component as it minimizes the occurrence of adverse events [1].

A laparoscopic procedure is performed through insertion of specialized long-shafted instruments and a fiber-optic video camera (laparoscope) to provide visualization for the surgeon inside the abdominal cavity. The team collaboration between primary surgeon and assistant becomes more important, as the primary surgeon's visualization of the surgical site is guided by the assistant who maneuvers the laparoscope. If the intended surgical site is not optimally displayed, it might affect the primary surgeon's decision-making process and team performance. Typically, surgical residents start their training as assistants to senior surgeons in the OR. When a laparoscopic procedure is assisted by an inexperienced resident, the visual contact with the instruments can be easily lost, and the coordination between the surgeon and the assistant can be a problem which may increase surgical risks [2].

I, as a young physician who has recently finished a three-year residency training in general surgery, understand the challenges facing every member working in a surgical team. I remember when I practiced as a surgical assistant for the first time. My principle role was to hold the camera for the primary surgeon in laparoscopic surgery. My orientation was often lost in the abdominal cavity and I could not navigate well to display the operating site for the primary surgeon. At that time, I was not only stressed by my unsatisfactory performance, but also my own performance was affecting the primary surgeon's performance. I believe one could imagine how annoyed the primary surgeon would be when s/he tries to focus on the surgical site, but the assistant cannot display the site correctly for the surgeon. As the need for a correct view is raised by the primary surgeon, it would cause more stress for the assistant. However, as a novice, the assistant has limited mental ability to deal with refining the movement to perfectly display the view for the surgical site and the continuous requests from the primary surgeon. As a result, the stress from internal and external sources could destroy the assistant's confidence for completing the task. In my experience, the development process of a high-performance team is not a result of coincidence but is due to team members' hard work, commitment and some struggle.

What are the several factors that contribute to successful teamwork? I think there are several factors contribute to a good team through literature review. First and foremost, team collaboration is an important attribute of a good team; the higher amount of collaborative behaviour is related to better team performance [3]. Team collaborative behaviour is observable in a team setting. Take team's collaborative behaviour in thread cutting task as an example, the assistant surgeon started to move the scissors as the primary surgeon started to grab the thread is a team collaborative behaviour [4, 5]. Secondly, communication has been identified as an important factor contributing to team collaboration in healthcare, and communication failures could lead to medical errors and defect patient safety [6-9]. The communication of OR teams is complex, Lingard et al.'s research thoroughly studied the communication patterns in the OR team, and a number of communicative events were observed with regard to time (i.e. room turnover), resources (i.e. equipment location), safety and sterility and situation control [10]. In aviation industry, communication has been incorporated in training curriculum since 1990s [11]. However, the role of communication in healthcare teams has not been fully investigated, and communication has not yet been fully incorporated into team training. Secondary to collaboration and communication, team leadership is another critical skill that contributes to a good team. A team leader helps with goal setting, sets priorities selection and role assignments within a team. The importance of team leadership has been addressed especially during uncertain and time-pressured conditions [12]. Relocation of intrateam resources is another factor that contributes to a good team [13, 14]. A team member should not only able to anticipate another team member's needs but also have a backup plan when one team member shows weakness and would be able to help or fill out the role. Besides these factors, I believe team size is a factor that contribute to a good team based on my previous study. A suitable amount of team members should be controlled in a good team, as adding extra team member would degrade team performance [15]. A good team should also be formed by trained team members, as dedicated team members could result in better team performance than team members have never been worked together [16].

Why I address the importance of team work? I interviewed an expert surgeon regarding the importance of team work, he commented that, "teamwork is very important in surgery, especially in laparoscopic surgery. I performed better with the intern who has been working with me for a long time than with an expert we have never worked before. I believe effective teamwork can shorten the procedure time and cost". This point of view is also supported by that although individuals have extensive task-relevant expertise, they are still vulnerable to poor team performance if teamwork is inadequate [17-19]. The value of dedicated surgical teams has been shown in significantly decreasing operative time, improving patient safety and reducing the cost to the healthcare system [16].

Formatted: Pattern: Clear

Formatted: Pattern: Clear

Formatted: Pattern: Clear

Team training is truly needed for surgical procedures, especially in laparoscopic surgery. This view is also supported by a Consensus Conference on the Development of Training and Practice Standards in Advanced MIS in 2007, where the surgeons addressed that surgeons should be trained in a team [20]. It has been shown that the improvement of team-working ability with training correlate with reduced technical errors [21] and perioperative mortality [22]. Currently, various simulation models have been used for training in laparoscopic skills, however, available training programs for laparoscopic surgeons are still mainly designed for individuals and the skills are evaluated on an individual basis [23, 24]. In the few team-training models, outcomes are typically assessed through the metrics of performance or a list of observable skills [23-26]. In fact, the deficiency in tools for objective team assessment has been a major barrier in promoting surgical team training [27-29]. To understand team performance and to develop team training, reliable and valid measures of team performance are necessary.

1.1 HOW TO MEASURE TEAMWORK IN SURGERY?

When it comes to the assessment of surgical teamwork, I find the current assessment tools are usually built on paper assessments on team members' knowledge or feedback from senior surgeons, which are quite subjective and not able to reflect the actual shared mental model among team members.

Traditionally, team knowledge elicitation has been used to examine the knowledge of the team members, for example, through interviews/surveys [30]. Several teamwork assessment tools have been developed over the past decades for a range of healthcare professionals [31]. The most commonly used tool for surgical teamwork assessment is Observational Teamwork Assessment of Surgeons (OTAS), which is based on the observation of teamwork behaviour. The score is rated by the observer in regard to the five components of teamwork: cooperation, leadership, coordination, awareness and communication [32]. The current assessment tools are mainly characterized by individuals' observation based on paper assessments or individuals' subjective endpoint feedback, which are non-continuous and slow. Well-designed team training includes team competencies; and employs measurement and feedback [33].

1.2 WHAT ARE THE GAPS IN OUR KNOWLEDGE?

The gap in our knowledge is between the need of implementing high quality of team training program and the lack of valid and reliable tool to measure team performance in surgical setting. If we intend to enhance our understanding of surgical team performance and the role of team cognition to effective team performance, we need to develop a more valid and objective tool to measure team cognition [34, 35].

1.3 HOW WILL THIS STUDY AIM TO FILL THOSE GAPS?

To fill this gap, I used video analysis to find behavioural evidence associated with team performance. Besides video, I also considered that eye tracking can be a promising tool for monitoring team performance. In detail, while they perform, their team performance was video recorded using a video camera; their eye motions were recorded using cutting-edge remote eye trackers. Data analysis was carried out based on videos and eye tracking evidence, including video analysis of team collaborative behaviour; spatiotemporal analysis on eye tracking trajectories; and synchronization of pupil response from both team members.

Firstly, a conventional approach would be used to identify team collaborative behaviour captured by the video and to correlate this behaviour with team performance. Moments of de-synchronized movement, where the camera holder was not displaying the operational site and surgical instrument for the primary surgeon well, were identified from each surgical procedure. It is hypothesized that elite performance teams would have more synchronized movements than poor performance teams. And fewer desynchronization movements would result in improved task performance, measured by task time and errors.

Secondly, dual eye trackers were used to monitor team members' eye gaze behaviour associated with team performance. Specifically, the synchronization of eye movement trajectories was measured via gaze overlapping, recurrence rate and delay. Gaze overlapping was calculated when two team members were looking at the same surgical site at the same time; Cross Recurrence Analysis (CRA), a spatiotemporal analysis, was used to analyze the gaze trajectory data for the recurrence rate and gaze delay. The measurements would be cross correlation and phase delay. I hypothesized that elite performance teams would display more synchronization on eye-movement trajectories between two team members, in which higher gaze overlapping rate, higher recurrence rate and a shorter delay of the eye gaze signals would occur.

Lastly, team members' pupil dilation was investigated to find evidence of cognition synchronization during the procedure. Both team members' pupil response to a specific surgical task was analyzed over the surgical procedure. It is hypothesized that elite performance teams would have more synchronized pupil dilation than poor performance teams, which means elite performance teams would have more synchronized cognitive response to the surgical task than poor performance teams.

1.4 THESIS ORGANIZATION

The thesis is divided into seven chapters. The first part provides a literature review on the topic of team performance and team cognition (Chapter 2). The review helps to clarify the current state of team cognition assessment and further issue that need to be addressed. Chapter 3 describes the experimental set up of the thesis projects. Chapter 4 presents the behavioural evidence of collaboration pattern between the primary surgeon and the assistant through video. In Chapter 5, I will show how dual eye gaze trajectories analysis reveals team cognition. Lastly, I will correlate team performance utilizing team's joint pupil dilation (Chapter 6), then followed by conclusions, discussions and future directions (Chapter 7), and references in the end.

CHAPTER TWO: LITERATURE REVIEW

In this chapter, there is a literature review on the topic of team performance and team cognition. The characteristics of high reliability organizations (HROs) and the importance of teamwork during surgery are presented first, followed by the ambiguity in the OR, then the increases of team loads with the introduction of MIS. The chapter also reviews the literature discussing factors affecting team efficiency, current assessment tools for teamwork and possible technologies that could be used for teamwork assessment.

2.1 THE IMPORTANCE OF TEAMWORK DURING SURGERY

Salas et al. define a team as “a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal, objective or mission, who have each been assigned specific roles or functions to perform, and who have limited life span of membership” [36]. The collaboration among team members from diverse disciplines requires comprehensive coordination and cooperation [37], and every individual has his/her own critical tasks to perform. Based on the above definition alone, it is easy to tell the critical role of teamwork for the delivery of health care. Healthcare workers are interdependent (e.g. a surgeon cannot operate until a patient is anesthetized) while functioning in specific roles (e.g. surgeon, assistant, nurse, anesthesiologist, etc.) and sharing the common goal of care. To work effectively together, team members must possess “specific knowledge, skills, and attitudes (KSAs) such as skill in monitoring each other’s performance, knowledge of their own and teammates' task responsibilities, and a positive disposition toward working in a team" [38].

Globally, the volume of surgical service is getting larger and continuing to increase in all countries. It is stated that approximately 313 million surgeries were performed worldwide in 2012, which was a 34% increase over the volume in 2004 [39]. Not only is the volume of the surgical procedures increasing, but also the complexity of technologies is getting more complicated. Technology innovation keeps transforming healthcare [40], the ORs in hospitals are becoming more complicated and stressful environments to work in. In general, a surgical team is comprised of surgeons, nurses and an anesthesiologist [15]. Most of the surgeries require team collaboration, and surgical teams in the OR that consist of professionals from different disciplines especially further complicate the teamwork. OR teams' effectiveness in working together would even affect surgeons' technical performance – the actual surgical procedure [41]. Many researchers have reported that the errors of team collaboration are hazardous to patient safety [42, 43]. Better performance OR teams would minimize human errors and maximize surgical outcomes; poor performance teams would lead to more adverse events and worse outcomes. Despite the importance of teamwork in health care, the current clinical teams are continuing to function as discrete and separate collections of professionals, which is partially due to the fact that team members are rarely trained together [38].

2.2 LESSONS LEARNT FROM HROS

HROs are those with a high potential of failures causing accidents and catastrophes [44]. For example, failures in the airline industry and nuclear plant could result in dreadful consequences. However, if we are looking back, the actual recurrence of the adverse event is low in HROs. The commitment to safety is a main characteristic of HROs, they often use failure as an input for learning, constantly looking for weaknesses in the system and taking steps to make improvement [45]. To reduce human error, many HROs have emphasized team training. For example, in the early 1990s, Crew Recourse Management (CRM) has been applied in the aviation industry to improve cockpit crew teamwork as part of a strategy to improve aviation safety [46]. CRM training had resulted in heightened safety-related attitudes; improved communication, coordination, and decision-making behaviour; and enhanced error-management skills [47]. The effect of team training in promoting team performance has been shown in aviation, nuclear power and military [41, 48].

Adapting and applying the lessons learnt from HROs could be a way to increase the quality and safety of healthcare. Numerous researchers have reported that the errors of teamwork in healthcare are hazardous to patient safety [42, 43], the OR has also been described as an HRO [38, 49]. It is considered that teamwork is an essential component in achieving higher reliability in healthcare [38]. A positive relationship has been shown between team training and team performance by a meta-analysis done by Salas et al., therefore team training could be enhance team outcomes [50]. One important lesson we have learnt is initiatives need to be taken to transform a healthcare organization into a high reliability healthcare organization through team training, as the current health care organizations do not have standard team training and assessment of teamwork for surgeons. The effect of team training in improving team performance has also been demonstrated in healthcare teams [41].

2.3. Teamwork in MIS

The development of technologies has caused a dramatic increase in surgical technology and innovation over the last two decades. The introduction of Laparoscopic procedures has brought substantial progress in modern world due to its cosmetic effects and shorter recovery time which is beneficial to patients and hospitals [51]. Typical of surgical innovations that have occurred in the last two decades is the development of MIS. When MIS is performed in the abdominal/pelvis area, such a procedure is often called laparoscopic surgery, also known as keyhole surgery. Laparoscopic surgery is performed through small incisions with the aid of a camera (which is called "laparoscope"). In general, the laparoscopic procedure requires cooperation and coordination between at least two team members. One surgeon performs as the primary surgeon, and the other as the laparoscopic camera holder. Typically, surgeons stand face to face, in order to manipulate the instruments and camera. No less than two monitors are used to display the laparoscopic video, and each surgeon faces an angled monitor which is in front of them (Figure 2.1).

Figure 2.1 The surgery requires a primary surgeon, standing on the right side of the patient, and an assistant, standing opposite. Typical laparoscopy setup is composed of a camera providing video images from inside the patient's abdomen on both monitors, allowing the surgeon and assistant to view the procedure. Copyright by the Paras HMRI hospital.

From the reading till now, you may think laparoscopic surgery is such an exciting advanced surgery with so many benefits. But was the adoption of laparoscopic surgery smooth? At the beginning of the 1990s, laparoscopic surgery was inhibited by the surgical community due to the slow development of laparoscopic technologies. In 1993, a study published in Annals of Surgery that evaluated 42,474 cases of cholecystectomy concluded that open cholecystectomy was safer than laparoscopic surgery with regard to less bile duct injury (BDI) rate (0.2% vs. 2%) [52]. Other studies did in the mid-2000s determined the laparoscopic BDI rate had plateaued to about 0.5% [53-56]. In the modern era, smaller case studies with thousands of patients suggested that the incidence of BDI are comparable between laparoscopic and open cholecystectomy [57, 58].

Why did laparoscopic surgery yield more complications than open surgery at the beginning of adoption? The truth is laparoscopic procedures are far more difficult to learn than open surgery procedures, not to say mastering advanced laparoscopic surgeries is even more difficult. Both physical and mental demands are increased in laparoscopic surgery due to 1) the limited motion (degrees of freedom) of the straight laparoscopic instruments (the long shaft instruments are limited in motion by the fixation from the abdominal wall trocars); 2) the unstable video camera platform, two-dimensional (2D) display of the images on the screens. Frequently, the inexperienced laparoscopic camera holder moves or rotates the camera out of the surgical site or off the horizon, which is not only physically demanding but also mentally demanding; 3) the loss of depth perception and spatial orientation due to 2D display are the main challenges for a novice to overcome. R. Berguer et al. used a multi-channel bio-signal measurement system to test surgeons' mental workload while performing laparoscopic procedures, it showed that performing laparoscopic surgery causes more stress than open surgery [59]. Additionally, surgeons stand awkwardly while performing the operations. These factors hinder surgeons' learning and performing advanced laparoscopic surgeries, and also significantly lengthen the learning curves of novices.

There is a promising automated robotic camera that has been developed by Mohsen et al. (2016) to automatically track the robotic tools and automatically manipulate the camera to achieve the best field of view [60]. The authors believe the team collaboration between the primary surgeon and the assistant, adding additional mental workload for the primary surgeon, and also the variation of the camera assistant's skill affect the procedure significantly. So, they developed the self-guided robotic camera. However, the robotic camera that has been developed by Mohsen is only for visualizing a single operating site. More technologies that make the robotic camera display surgical site in real time accurately in the future is still challenging for engineers. Nonetheless, this thesis research project is still valuable for teamwork assessment in laparoscopic surgery, especially between the primary surgeon and the assistant.

Surgical team composition and size are other factors that affect the inter-operative efficiency of MIS. Zheng et al. showed that the composition of the surgical team significantly affects procedure length. Generally, there is a suitable team size for a surgical procedure, for example, an average laparoscopic team size was eight people [61], when the procedure complexity and patient condition are kept constant, adding one team member would prolong the procedure time for about 7 minutes. Another study completed in 2014 also found the similar effect of team size in general surgery cases, adding one team member could prolong the procedure by about half an hour [15]. It has been shown that dedicated laparoscopic teams could achieve better surgical outcomes than newly formed teams, and newly formed teams were more likely to encounter problems in laparoscopic surgery [16, 62]. In order to form a high-performance laparoscopic team, the team should limit unnecessary staff turnover in the OR.

2.4 FACTORS AFFECTING TEAM WORK

2.4.1 Ambiguity in the OR

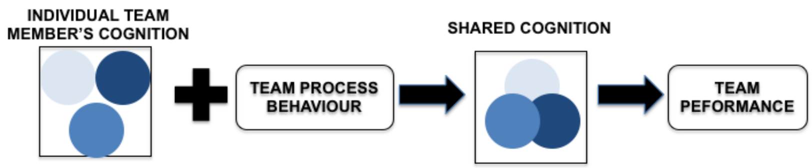
In healthcare, some weakness points exist in the system, for instance, the ambiguities in the working system. The same as the other HROs and intensive care units (ICUs), the OR is a place full of ambiguities. In general, it is the OR manager's responsibility to assign staffs for the operation, know when to prepare patients for surgery, when to move cases and how to prioritize room cleanups [63]. Some of the ambiguities in the OR are caused by the fact that surgical teams are formed shortly before the patient is moved into the OR, which leaves little time for the team members (surgeons, assistants and nurses) to exchange information before the start of the surgery. In addition, patient condition varies from case to case, important information regarding patient condition, special task requirements and instruments used in the surgery might not be efficiently transferred from one team member to another. Besides that, team members' training levels are different, so their surgical skills and experience in dealing with a crisis are varied too. The ambiguity presented in team goals and team coordination has been suggested to be the origin of surgical errors in the OR [64]. Another factor adding to the communication ambiguity is the staff turnover during the surgery [65]. The OR staff turnover is a term that derived from industry and modified to clinical setting. It is generally caused by nurses coming in and out of the OR for work-related breaks. The turnover within the nursing component of the surgical team is often related to a significant decrease in team performance [65].

2.4.2 The importance of shared cognition

S*hared cognition* within a team refers to the collective cognitive activities from individual members, where the collective activity has an impact on the overall team goals and activities [66]. It is "an emergent state that means a team is mentally organized, represented and distributed within a team, which allows team members to anticipate and execute actions" [66, 67]. It emerges from the interplay of individual cognition of each team member and team process behaviour in the pursuit of a common and valued goal [3].

Shared cognition has been the theoretical basis for understanding team performance. There is much previous empirical evidence that suggests that shared cognition will lead to better team performance [68-72]. The possible mechanism of shared cognition in improving team performance is that shared cognition within a team reduces the communication demands of team members in task process, so allowing team members to allocate their mental resources to the tasks at hand [73]; There is much previous empirical evidence that suggests that shared cognition will lead to better team performance [69]. Figure 2.2 shows the relationship between team cognition and team performance [74, 75].

Figure 2.2 Relationship of team cognition with team performance



2.4.3 Increases of team mental loads

Team members must effectively balance between taskwork and teamwork. Taskwork is the performance of specific tasks in achieving team goals, it comes through work-related activities where individuals or teams engage in the tasks while team members function in organization roles; teamwork is the shared behaviour (what team members do), attitudes (what team members feel or believe), cognitions (what team members think or know), which is necessary for teams to accomplish these tasks [76]. Both taskwork and teamwork are critical for team performance. Taskwork is key to team goals, teamwork ensures taskwork is performed effectively.

In general, there are two categories of workload in any given team, one type is called task-related workload, and another is called team-related workload. Task related workload comes from individuals' interaction with tools, tasks and the environment, which broadly corresponds to individuals' efforts to meet task demands [30, 74]; team-related workload comes from interpersonal interaction among team members such as communication in exchanging information, synchronization of actions, decision making, development and maintenance of work flow, which reflects team members' cooperative efforts toward task performance [66, 74].

With the development of technologies, the complexity of surgery technologies increases, and the movement control and information processing of each team member increase too, which means that the human brain will need more resources to process task load. The brain has a limited capacity for information processing [77], so the increase of task loads often means less mental resources are available to manage team loads. Theoretically, performing more complicated procedures, means team performance will be negatively affected by the higher task and team load requirement [78].

In order to optimize team performance, team members should be trained as a team. Team training is valuable in shaping mental models of teamwork [79]. As team members practice together, team loads could be reduced so that each team member can focus on task loads, which maximize team performance.

2.4.4 Insufficient communication

Of the factors that might affect team efficiency, insufficient communication in teams has been recognized as major causes for adverse events [80-82]. In 2008, a root-cause analysis of over 4000 adverse events identified that communication is the most common factor causing adverse events in healthcare [6]. Communication failures can lead to procedure delay and inefficiencies [6]. Common communication failures were mostly related to equipment and keeping team members updated as to the progress of an operation in the OR [6], as communication has an important role in enabling team members' cooperation and coordination [81]. An obligatory Crew Resource Management (CRM) program was developed in the United States in 1995, based on the fact that good communication is able to prevent human error in airline accidents, in addition to technical skills training [11].

From my point of view, verbal communication plays an important role at the beginning of a newly formed team. It is also essential during staff turnovers and when a critical situation is happening (which requires decision making and problem solving). However, a mature surgical team could be a silent team, as communication is not required when a team has developed a certain level of team cohesiveness. For example, when a surgical team has worked together for a long time, the role of verbal communication is reduced. This also corresponds to Cannon-Bowers and Salas's assertion in 1990 that "When we observe expert, high performance teams in action, it is clear they can often coordinate their behaviour without the need to communicate" (Cannon-Bowers & Salas, 2001, p. 196) [83]. A possible explanation for this statement is an explanatory mechanism: Expert teams developed compatibility of their team members' cognitive understanding of the procedure and environment, which enables them to work efficiently without the need for overt communication, and as a consequence they can perform tasks more effectively [83, 84].

In sum, shared cognition is an important factor affecting team performance. In order to optimize team performance, team members should be trained as a team in building shared cognition. Our understanding of team cognition should be built on the measurement of shared cognition. In the following part, I will review the possible ways of team cognition assessment.

2.5 Overview of Teamwork Assessment

2.5.1 Traditional assessment

Traditionally, team knowledge elicitation has been well-used to examine the knowledge of the team members, for example, through observation, interviews/surveys and conceptual method (Table 2.1) [30].

Table 2.1 Examples and uses of team knowledge elicitation methods

Elicitation Method	**Examples and Uses**
Observation	Using written, audio or video to provide task performance evidence, for example, OTAS
Interview & surveys	Using structured interviews in the form of written questionnaires to elicit team knowledge. These methods have been chiefly used to measure team mental models
Conceptual Method	Examples include cluster analysis, multidimensional scaling, Pathfinder, and concept mapping. These methods take pairwise estimates of the relatedness of a set of concepts and generate a spatial/graphical representation of the concepts and their relations. The advantage of these methods is to be able to process data and information from several individuals and compare data across individuals.

Assessment of similarity of team knowledge

Table 2.2 shows an example of a traditional 10-item, 4-alternative, multiple-choice test of declarative knowledge. From this form, we can tell the pilot and the navigator share 60% of the knowledge, 40% of the knowledge is correct. Another type of knowledge elicitation method is to assess the similarity of knowledge within a team, the assumption is based on team members being likely to have some knowledge in common no matter that each has a distinctive team role [30]. This has been referred to as consensus, agreement, or overlap among team members by looking at the number or percentage of responses that are the identical between two team members.

Table 2.2 An example of elicitation of factual knowledge for two team members (pilot and navigator) using a 10-item multiple-choice test

Item	Correct Answer	Subject A's Response	Subject B's response
1	a	c	d
2	c	a	c
3	d	b	d
4	a	b	c
5	a	d	d
6	b	c	c
7	d	d	d
8	b	b	b
9	c	c	c
10	d	d	d

In a surgical team, the nurse and surgeon might need to have some knowledge in common. However, it is not necessary for the nurse to understand all of the surgeons' knowledge. As a consequence, the nurse should have some knowledge that is in line with, but not identical to the surgeons. For these knowledge elicitation methods, the researchers need to create specific knowledge test questions, which will require a lot of human resources to be involved. Most importantly, these data are not objective in revealing team cognition as well.

2.5.2 Objective/video analysis of an observable behavioural marker system

Over the past decades, many teamwork assessment tools have been developed and most of them have been tested on the construct and content validity of these assessment tools in the surgical environment. The assessment tools include Observational Teamwork Assessment for Surgery (OTAS); Nontechnical Skills for Surgeons (NOTSS); Oxford Nontechnical Skills (NOTECHS); Anaesthetists' Nontechnical Skills (ANTS); Multisource Feedback (MSF); Case-Based Discussion (CbD); Edinburgh Basic Surgical Training Assessment Form (EBSTAF) and Scrub Practitioners' List of Nontechnical Skills (SPLINTS) (Table 2.3). There are several types of validity involved with the validity testing of the assessment tools, 1) content validity refers to the appropriate content of the assessment tool; 2) face validity: does the test appear to test what it aims to test? 3) construct validity: does the test relate to underlying theoretical concepts? 4) concurrent validity: does it relate to an existing similar measure? 5) convergent validity: the degree of relation between two similar constructs.

Table 2.3 Teamwork assessment tools and the types of validity established in the surgical environment [31].

Names of the assessment tools	Domains	Scoring system	Validity
Observational Teamwork Assessment for Surgery (OTAS)	Communication, cooperation, coordination, shared leadership, and team monitoring & situation awareness	7-point Likert scale and generic checklist	Construct [85] and content [86]
Nontechnical Skills for Surgeons (NOTSS)	Situation awareness, decision-making, communication & teamwork, and leadership	4-point numeric scale	Face [87], content [87] [88], concurrent [89], and construct [87, 88]
Oxford Nontechnical	Leadership & management, teamwork	4-point numeric scale	Concurrent [90], convergent [90],

Skills (NOTECHS)	& cooperation, problem-solving & decision-making, and situation awareness		face [90], content [90], and construct [90]
Anaesthetists' Nontechnical Skills (ANTS)	Task management, team-working, situation awareness, and decision-making	5-point numeric scale	Content [91]
Multisource Feedback (MSF)	Clinical care, good medical practice, learning & teaching, and teamwork & communication	3-point Likert scale and 3-point Global Summary Score	Content [92], face [92], and concurrent [93]
Case-Based Discussion (CbD)	Medical record keeping, clinical assessment, diagnostic skills, patient management, leadership, clinical	3-point Likert scale and 5-point Global Summary Score	None

	judgement, communication & team-working skills, and reflection		
Edinburgh Basic Surgical Training Assessment Form (EBSTAF)	Communication, knowledge, clinical skills, teamwork, and technical skills	3-point Likert scale	Construct [94] and concurrent [95]
Scrub Practitioners' List of Nontechnical Skills (SPLINTS)	Communication & teamwork, situation awareness, and task management	4-point Likert scale	Content [96]

Observational Teamwork Assessment of Surgeons (OTAS)

Here, I will specifically introduce you to OTAS, as it is the most frequently used tool for teamwork in the OR. OTAS is a psychometrically robust (i.e. reliable and valid) tool that captures comprehensively the quality of team working and team interactions in the OR. This assessment method consists of five behaviour patterns of team members in the OR, which includes communication, coordination, cooperation and back up behaviour, leadership, and team monitoring and situational awareness. These behaviour patterns are assessed via real-time observation in the OR (or relevant video recording wherever available). Each behaviour is scored on a seven-point scale (0-6). On this scale: The highest score (6) indicates significant enhancement to teamwork via exhibition of the behaviour of interest; The scale midpoint (3) indicates average performance of a behaviour pattern, which neither enhances nor hinders teamwork; The lowest score (0) indicates severe hindrance to teamwork via lack of the behaviour of interest [27].

Although OTAS looks like a robust tool for surgical teamwork, some potential problems exist. To perform OTAS assessment, assessors need to have a structured training period [97]. However, the length of surgical procedures varies, it is said that the average length of a surgical procedure is at least two hours [98]. In regard to long surgical procedures, we could not manage any observer fatigue without biasing assessments. In addition, the assessment cannot continuously reveal team coordination overtime, and which is time consuming.

Table 2.4 The five behavioural dimensions of teamwork of OTAS

Observable behaviour	Definition
Communication	Quality and quantity of information exchanged among members of the team
Coordination	Management and timing of activities and tasks
Cooperation and back up behaviour	Assistance provided among team members, supporting others and correcting errors
Leadership	Provision of directions, assertiveness and support among team members
Team monitoring and situational awareness	Team observation and awareness of ongoing processes

2.5.3 Technologies for Teamwork assessment

Video analysis

Video analysis is analyzing task performance by recorded trials. For example, Zheng et al. performed a quantitative observational study in assessing team quality in the OR [99]. Through video analysis, the authors took the evidence whether the surgical nurse followed instruction correctly or incorrectly. They found that in the procedure assisted by the senior nurse, more anticipatory movements were observed. In other words, anticipatory movements are often observed in experienced nurses. The authors proposed that the anticipatory movement could be a behavioural indicator for team synchronization. The definition of anticipatory movement is performing the assistive action to a team partner without following a verbal instruction. In this situation, the team member who performed the anticipatory movement should be in a position to predict the soon-to-follow behaviour by his/her team partner. In addition, the amount of anticipatory movement increases over a period of training [100], which could explain why dedicated teams have decreased the operation time when cases were complicated; in other words, collaborative behaviour in a team can translate to better team performance [16].

More studies have been done using anticipatory movement as a behavioural indicator for team collaboration [4, 5]. The analysis of videos showed a higher frequency of anticipatory movement in a team setting than a single operator [5, 101]. For instance, in a thread cutting task performed by a team, one as grasper holder holding the thread and the other as scissors holder, it showed that the scissors holder started to move the scissors as the grasper holder started to grab the thread, however, this phenomenon is not observed in a single operator. It has also been shown that the anticipatory movement between the surgeon and surgical fellow changes when comparing the amount of anticipatory movement in a newly formed team when it first works together to after 10 weeks of training [100]. Field studies in the OR confirmed that experienced nurses and surgical assistants were able to perform more anticipatory movement during the laparoscopic surgery [102, 103]. In addition, dedicated teams may have decreased operation time when cases are complicated; in other words, it can translate to improved patient care and decreased costs for healthcare institution[16].

In this thesis, I will further explore the behaviour marker in assessing laparoscopic team collaboration quality through video analysis.

Eye tracking

Eye movement research has recorded significant advances in past decades. Eye tracking, as the name suggests, tracks the eye's movement. In general, there are two types of eye trackers, one is head mounted eye tracker (Figure 2.3A), another type is remote eye tracker (Figure 2.3B). Eye tracking has a long history in being used to study cognition, because eye movements can reveal attention - the location of eye gaze is tightly bound to the individual's attention or focus. A shift in the eye gaze, so-called saccades, is invariably associated with a shift in attention, which provides a window to cognitive processes. Many eye movement measures have been developed to reveal individual's cognition, for example, time-based measures (average fixation duration, etc.), count-based measures (fixation count, etc.), and saccade measures (saccade length, etc.) [104-107].

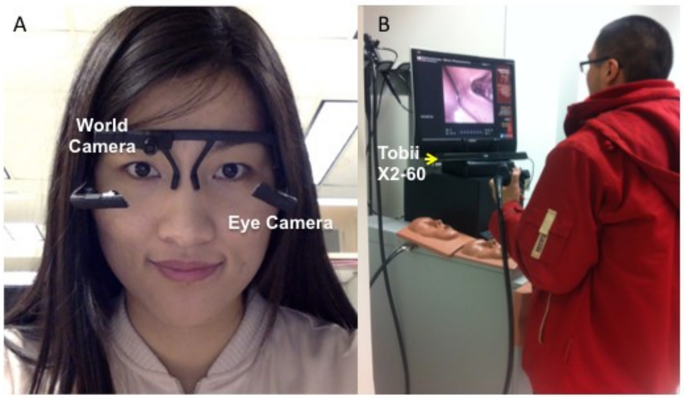


Figure 2.3 Examples of a head mounted eye tracker (A), composed of a world camera and eye cameras; and a remote eye tracker (B), capturing the subject's eye movement on the monitor

Gaze in revealing attention

The earliest eye tracking research dated back to 1967 by Yarbus, who recorded an observer's eye position when viewing a stationery picture. The result shows when looking at a human face the eyes jump, seem to fixate or rest momentarily, producing a small dot on the trace, then jump to a new region of interest. However, even during these fixations, or 'rest' times, the eyes are never still, but continuously producing fixation eye movements [108].

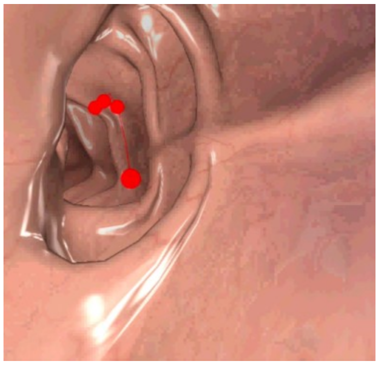


Figure 2.4 One individual's saccades and fixations while performing a colonoscopy procedure.

A number of eye movements has been identified to describe individual's cognition. For example, fixation and saccade are used to describe attention and ways for attention shift respectively [104-107]. Fixation is the maintaining of the visual gaze on a single location; saccades are quick, simultaneous movements of both eyes that suddenly change a fixation point; smooth pursuit movements are much slower constantly tracking movements to keep the moving stimulus on the fovea, for example, from word to word and line to line when reading; Vergence eye movement is closely connected to accommodation of the eye, for instance, the horizontal rotation of eyes in opposite directions (move toward or away from one another) to track targets in the third dimension to obtain or maintain single binocular vision [109].

Eye tracking may have value in skill teaching in various areas. For example, by tracking the eye gaze locations and fixations in experts, we can demonstrate to novices where an expert's attention is to facilitate the skill learning. There is much evidence showing the value of gaze training. Gaze training has been used as early as the 1970s by Vickers et al in sports players [110]. In addition to sports, in the last decades, eye-tracking technology has also been used to study surgeon's vigilance while he/she is performing a surgical procedure [104] and to distinguish the gaze patterns of experts and novices [105], with the purpose of education and training for new surgeons [106]. The other benefits of eye tracking include robustly providing reliable and quantitative data.

A scanpath encompasses at least one full fixation-saccade-fixation sequence [111]. Scanpath analysis is an example of temporal analysis. A scanpath is formed by point-by-point (x,y) by where a person looks on the screen. Figure 2.5 shows three examples of theoretical scanpaths. Through scanpaths analysis, one can identify experts and novices. For example, Plot B in Figure 2.5 is a notional characteristic scanpath of an expert which looks very systematic, whereas Plot C might be a hypothetical scanpath of a novice which looks helter-skelter.

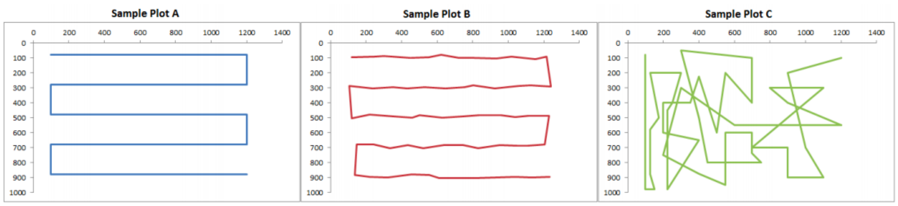


Figure 2.5 This figure presented three sample plots of scanpath data. The scanpath of Plot A is highly similar to Plot B, but is highly dissimilar from the scanpath of Plot C. All 3 plots are made with an identical number of raw gaze points [112]. Copyright 2018 by the Defense Technical Information Center.

Previous research done by Haulan et al. in 2008 used eye tracking as part of a validation effort for measuring both individual and team's situation awareness in an air traffic control simulated scenario [113]. The authors found that eye tracking could measure a team's situation awareness based on the co-occurrence of visual information seeking and acquisition (p. 301). In the OR, eye tracking can potentially be used as an assessment of focus and susceptibility to distractions, where it has already been used in demonstrating the risk of error [114].

In Dr.Mary E. Frame's report [112], she reviewed some common metrics in quantifying two eye movement trajectory similarities of the scanpaths and developed a software named ScanMatch to calculate the similarity. The development of this software is an important step in scanpath quantification research. However, scanpath research is used for comparing the scanpaths of observers, rather than a thesis time procedure, especially, the view of the working site keeps changing. In this thesis, we will explore the topic of quantifying the similarity of eye movement trajectories in a real time procedure which are recorded by videos.

Gaze Overlapping

According the previous study done by Nodine et al. and Khan et al. [115, 116], the authors suggested that the center of focal attention surrounded a 5° visual field for the area of interest. This implies that both team members are roughly looking at the same spot if the Euclidean distance is under 5° visual field.

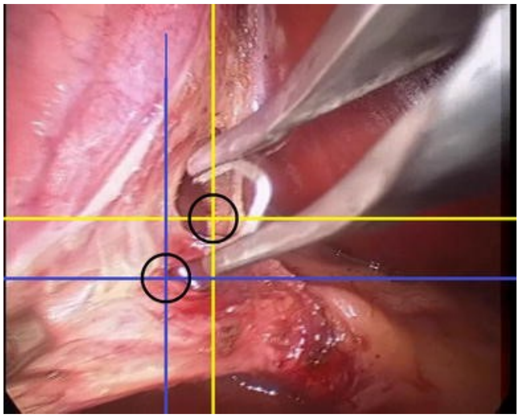


Figure 2.6 Example of a dual overlaid screenshot with operator's point of gaze (blue) and third-party watcher's gaze (yellow). The 3 degrees of visual angle is shown in black [116]. Copyright 2012 by the Springer Science + Business Media.

Khan and Zheng [116] was the first in using dual eye gaze similarity to examine the spatial similarity in eye-tracking between two surgeons (Figure 2.6). In the study, the experts' gaze was recorded while performing a task in the OR, and then the performance videos were watched by the experts and novices. The authors used 3° visual angle for calculation of gaze overlap. The result showed that experts had a significantly higher rate of gaze overlapping than novices.

CRA

Why CRA? Imagine a moment when one individual's eyes visited point A, B, C, and D, another individual visited these points too, but a few seconds earlier or later. Through gaze overlapping analysis, these two people might be not overlapped in eye gaze or have a low overlapping rate. In order to analyze the team's eye-tracking data in a spatial and temporal way, CRA seems like a promising tool in analyzing two dynamic data series. It has been used to study the similarity between the two different phase space trajectories. Richardson and Dale first used CRA to analyze gaze similarity recorded from two different persons in 2005 [117]. The authors studied the relationships between a speaker and a listener based on their eye movements and found that the coupling between a speaker's and a listener's eye movements indicate if the listener was engaged to the speaker or not. While the gaze movement of the speaker was recorded, he watched a television show and at the same time talked about it. Later, the listener watched the same show as he was listening to the previously recorded monologues and his gaze movements were recorded too. Finally, CRA was used to detect the matching behaviour between speaker and listener's gaze movement. The result shows that better listener’s eye movements were more closely coupled with speaker’s, and also with a shorter delay of eye signals [117].

The left side of Figure 2.7 shows two 7 sec-scarf plots of a speaker and listener, it shows a 20% recurrence rate is observed between the speaker and listener’s eye gaze. The right side of Figure 2.7 shows the gaze match rate between the speaker and the listener is 30% after CRA, and a 2 sec time lag is observed. A full CRP is formed by calculating the recurrence between subjects at all possible lag times, these points are shown in a CRP (Figure 2.8).

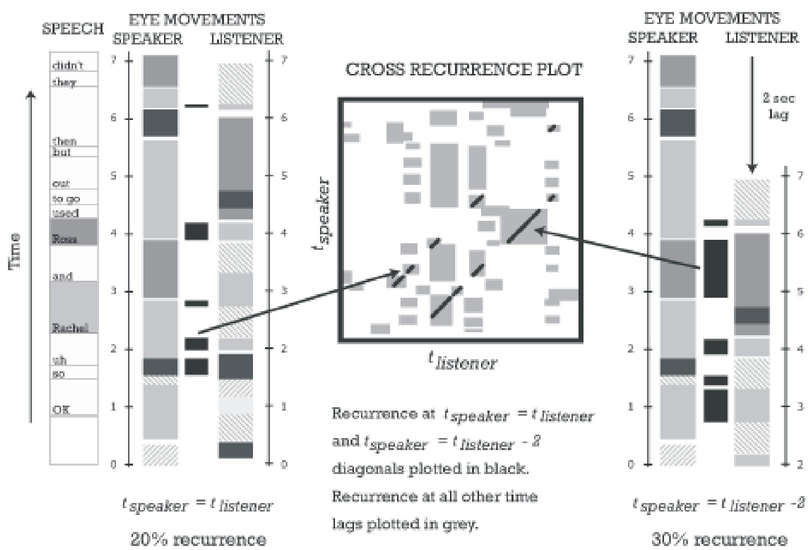


Figure 2.7 Example of a scarf plot from CRA [117]. Copyright 2005 by the Cognitive Science Society.

Figure 2.8 Example of CRPs of the eye movements of a speaker and a good listener/ bad listener/ randomized listener [117]. Copyright 2005 by the Cognitive Science Society.

Furthermore, CRA has been applied to team coordination research in aviation: A recent research used CRA to study the eye movements of two-person crews in a flight simulator environment [118] and also the communication of pilots' crews [119]. The CRA of eye movements of pilots shows crews exhibit coordinated eye gaze about 17% of the time. In spite of that, it is still unknown whether CRA can distinguish teamwork efficiency or not. The second part of this chapter further explores the application of CRA in team's eye tracking analysis. This chapter would be an innovative step in the study of shared cognition between two surgeons in a laparoscopic team using eye gaze analysis. Considering both Gaze overlapping and CRA enables us to reveal more reliable evidence for shared cognition of surgeons in laparoscopic surgery.

Pupil in revealing mental workload

Mental workload is a finite mental resource that a person uses to perform one or more tasks [120, 121]. The implication of quantifying the workload of surgeons is for safer surgery [121, 122], the size of the pupils in the eyes has been widely applied to reveal individual's cognitive load over the past decades [123-125]. The pupillary response has long been known to be associated with increased mental workload. For example, Jiang et al. [125] explored how pupil diameter responds to the task difficulty in surgical tasks under laparoscopic settings, the authors found that higher task requirement evoked larger pupil dilation; the harder the task, larger pupil dilation was evoked than an easier task.

It appears that eye tracking offers great benefits for team cognition researchers, since it can monitor exactly what an individual is attending to throughout a task; and allow a greater understanding of individual and potential team cognitive process. I, in a lab specialized in analyzing eye tracking signals, believe eye tracking can provide us with a window into team cognition research. In this thesis, I am interested in whether the joint pupil dilations could reflect shared team cognition.

To summarize, in this thesis, I will use the quantification of behaviour marker and eye-tracking technology for teamwork assessment. This will be presented in the following chapters.

Motion tracking

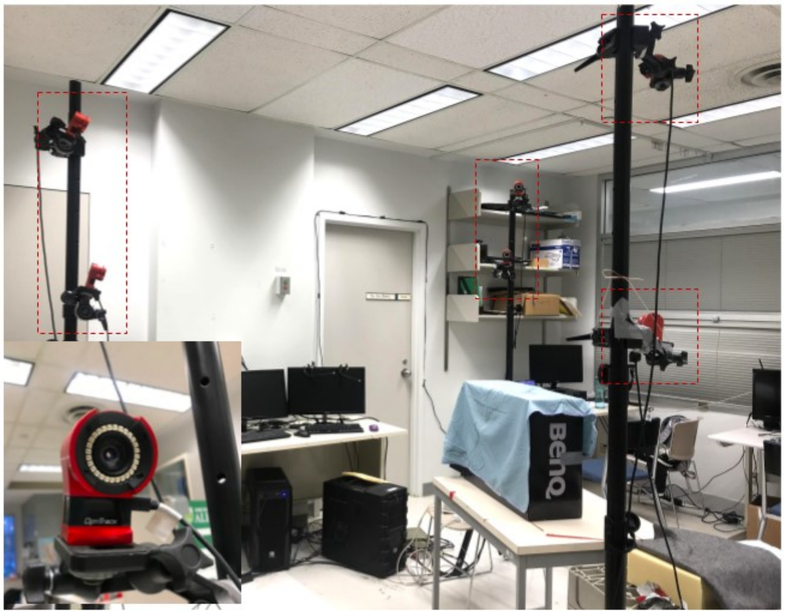


Figure 2.9 OptiTrack system Used in SSRL for Motion Tracking.

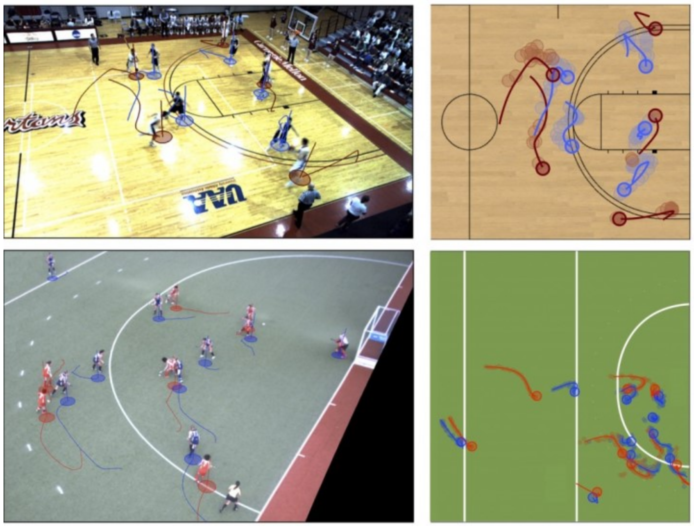


Figure 2.10 An Example of Motion Tracking with Sports Players [130]. Copyright 2013 by the Computer Vision Foundation.

Motion analysis is an objective tool that has been used effectively in fields such as gait analysis [126] and surgical skill assessment in MIS [127] (Figure 2.9). These methods usually make use of markers located on body articulations to garner movement information from a particular limb. In surgery, motion tracking has been mainly used for individuals' surgical skills assessment in measuring hand and instrument travel in laparoscopic surgery over the decade [128][129]. In regard to team's motion tracking, one study tracked multiple sports player's movement trajectories in basketball teams (Figure 2.10) [130]. It seems like motion tracking has mainly been applied to individual skill assessment, rather than team motion tracking.

Electroencephalography (EEG)

Figure 2.11 Cognionics Quick-20 Dry EEG Headset used by RH Steven's work. Copyright by the Cognionics.

RH Stevens's used EEG signals (Figure 2.11) to quantify neurophysiologic synchronies (NS) for studying the dynamics of teamwork [131, 132]. Much of the previous teamwork research had been focused on externalized events, who is the member of the team, *how* they work together and *what* they do to perform their work. There were few studies looking at *when* team interacts. Steven's work focuses on the modeling team neurodynamics: The authors collected each team member's EEG power levels and converted them into chains of symbols. Collectively these symbols of each second represented the neurodynamic organizational state of the team. For example, using 10 Hz frequency as attention and prioritizing stimuli [133, 134], 16 Hz frequency as action understandings [135], and 40 Hz frequency for maintaining working memory and long-term memory [136, 137].

It looks quite promising that EEG will be able to provide quantitative and real-time records to investigate team cognition, however, the analysis of brain signals is complicated and technically challenging for researchers and clinicians.

Functional Near-infrared Spectroscopy (fNIRS)

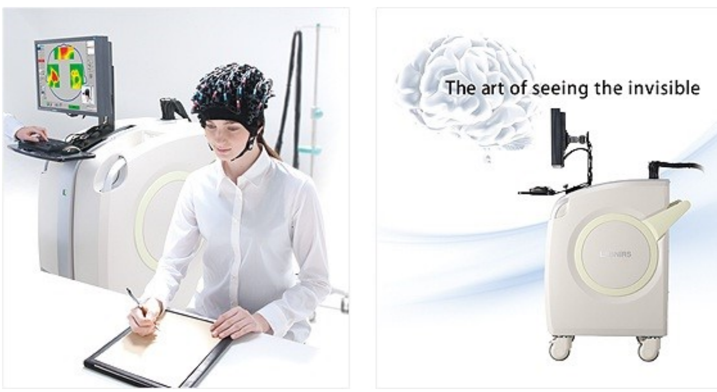


Figure 2.12 fNIRS System for Research. Copyright by the Shimadzu.

fNIRS (Figure 2.12) is an important brain imaging technology in cognitive neuroscience, mainly used in language, math and social cognition studies [138]. Researchers have employed the fNIRS-based hyperscanning approach to investigate the interpersonal neural synchronization (INS) between two or more people during communications [139]. People tend to synchronize their behaviour and minds when they communicate with one another through fNIRS evidence. Researchers from Beijing

Normal University have also established a multi-brain imaging system and multi-modality (fNIRS, EEG and fMRI) simultaneous imaging systems [140].

However, fNIRS has not been applied to medical teams, it is promising in team communications and teamwork research. In addition, the idea of using multi-brain imaging system and multi-modality (fNIRS, EEG and fMRI) would be an encouraging area to work on for team cognition research no matter the cost.

CHAPTER THREE: METHODOLOGY – EXPERIMENTAL SETTING

These series of studies are under exactly the same experimental setting. In this chapter I will describe the study environment, participants, apparatus, tasks and procedure. When we move to chapter four to six, we will only discuss different methodologies for data analysis in the method part, then followed by results and discussion.

3.1 PARTICIPANTS

A total of 14 subjects (surgical residents, surgeons, and university students) were recruited and a total of 22 dyad teams were formed (allowing some of the participants to change roles and re-join teams with another participant according to the time availability of the participants). 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 the study [5]. The self-reported case volume was adjusted by the year in surgical training to create a general score to describe individual surgical experience. Scores below 20 refers to novices, most general surgery residents can achieve a score ranging from 20-60 points depending on their year of training. Laparoscopic surgeons can easily earn 60–80 points in their experience [26, 141, 142]. When two members were assigned to a dyad team, the team score was calculated by averaging individuals' surgical experience scores in the team. As some of the participants might perform the task more than two times, one trial counts for one point towards experience score. This study was approved by Health Research Ethical Board of University of Alberta. Consent was obtained from each participant before entering the study.

3.2 APPARATUS

Figure 3.1 Two subjects working in a laparoscopic team in front of two separate surgical monitors, the camera holder (the person on the right side in picture A) manipulates the laparoscope to provide the view of the operating site for the primary operator (the person on the left side in picture A) to complete the object transportation task during the laparoscopic procedure. Two separate eye trackers are attached below each monitor, capturing eye motion of both team members. Picture B shows the laparoscopic tower used to provide the laparoscopic training environment.

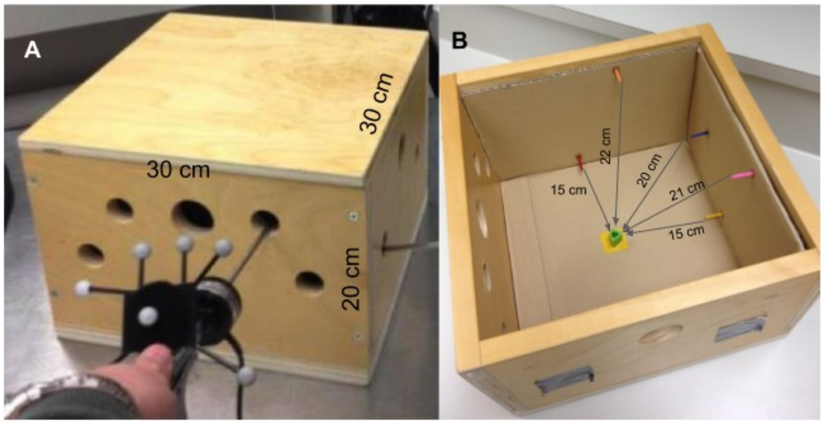


Figure 3.2 The outside (A) and inside (B) of the training box. Five pins in different colours are located within a wooden training box. The yellow plate in picture B is the home plate where the task starts.

The experimental apparatus (Figure 3.1) included four main components: 1) a standard laparoscopic tower (Stryker Endoscopy, San Jose, California, USA), including laparoscope, camera, light source and video monitor) was used to setup laparoscopic training environment; 2) In the center, a custom-made laparoscopic training box, measuring 30 x 30 x 20 cm was placed (Figure 3.2 A). On the bottom of this wooden box, a 2 x 2 cm^2 home position was labeled (the yellow plate in Figure 3.2 B). Five 2 cm pins, coded in different colours (blue, red, orange, pink, and yellow), were located on two sidewalls with different distances to the home position. The training box has ports on the other two sidewalls allowing for the insertion of a 0-degree laparoscope (Stryker Endoscopy, San Jose, California, USA) and a laparoscopic grasper (Ethicon Endo-Surgery, Cincinnati, OH, USA). 3) 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 images captured by a laparoscope. The scene inside the training box was captured by the laparoscope powered by the Stryker laparoscope tower. Then the video stream was split into two and fed into the two eye-trackers as external video sources and shown on the two monitors respectively, so both team members saw identical images from the work site. 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 an operator's eye motions unobtrusively within a comfortable viewing distance (75 cm).

3.3 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 required a team member (camera driver) to navigate the laparoscope to locate five different coloured pins for his/her teammate to grasp and transport a plastic triangular prism (2 cm long, 1.5 cm wide) among five pins. The sequence of the transportation was assigned by the experimenter by giving the colour 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 forward, backward, clockwise and counter clockwise to keep the target and the instrument at the center of view. The camera operator must also manually adjust the focus of camera to provide a clearer image of the operating site. The subjects were required to perform as fast and accurate as possible.

3.4 Data Recording and Exporting

Each team's procedure performance was screen recorded for further video analysis; Each individual's eye gaze data was saved by the eye tracking software, which can be exported at any time to CMD files for further eye gaze trajectories and pupil analysis.

CHAPTER FOUR: DISCOVERING COLLABORATIVE BEHAVIOUR IN LAPAROSCOPIC TEAMS USING VIDEO ANALYSIS

To find psychomotor evidence towards team collaboration, I took a conventional approach by observing team behaviour saved in the videos. Video analysis is not a novel technology: Zheng et al. had used this method in 2005 for laparoscopic cutting tasks analysis [4]. Field studies had been carried out in the operating room to study team collaboration of surgical team [102, 103]. In addition, Zheng et al. showed that video analysis is a powerful tool in capturing team collaboration pattern and revealing team performance [16]. However, when I adopted this technology into my study, I was facing a few challenges, 1) could we identify team behaviour in addition to individual behaviour? 2) could we define those moments directly pointing to team collaboration quality?

In this chapter, I will use video analysis technology to investigate the collaborative team behaviour between surgeon and assistant during a laparoscopic object transportation task, i.e., navigating the camera for the surgeon to transport an object to a defined location. Instead of exploring the collaborative moments in the videos, in this step of research, we will identify whether there is any moment when a team does not collaborate well. My goal is to find significant events through video analysis, pointing to team collaboration. The behaviour we defined was movement desynchronization between two people in a team. De-synchronized movement was from 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 desynchronization event would be recorded. Team members – a surgeon and an assistant – were asked to perform together in a simulated laparoscopic training setting to record their movement desynchronization, examine their behavioural changes, and to further correlate movement desynchronization with task performance.

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

4.1 Data Analysis

4.1.1 Video analysis

The task scene was captured through a laparoscope. Videos were analyzed frame by frame by me using VirtualDub 1.9.11 (Free Software Foundation, Inc. Cambridge, MA 02139, USA) to obtain the task performance variables. The video analysis was done by one individual under the same criterion. A quantitative approach was applied in quantifying the number of desynchronization events and errors. Inter-rater reliability did not have to be considered.

Defining team behaviour besides individual behaviour

For this specific task, individual behaviour referred to the primary surgeon's movement, for example, transporting the object from home plate to pin or pin to pin, etc. For the assistant, the individual behaviour was moving the camera to coordinate the primary surgeon's view demand of the task. Team behaviour referred to the primary surgeon and assistant in coordinating their movements, if the movements between primary surgeon and assistant were very synchronized, it is called the synchronization of movements. Oppositely, if the primary surgeon and assistant movements were not synchronized, we named it as movement desynchronization, which specifically referred to the moment that the surgical instrument or surgical site was out of view.

Defining moments directly pointing to team collaboration quality

For each trial, a number of events were identified with specific operational definitions (Figure 4.1). The subtasks include 1) object loading – the grasper with object touches the pin with the object, and subsequently releases the object onto the pin (Figure 4.1A) 2) homing – after release, the grasper and tool returns back to home position (Figure 4.1B) 3) reaching – the tool and grasper leaves home position and reaches back towards 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 towards 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.

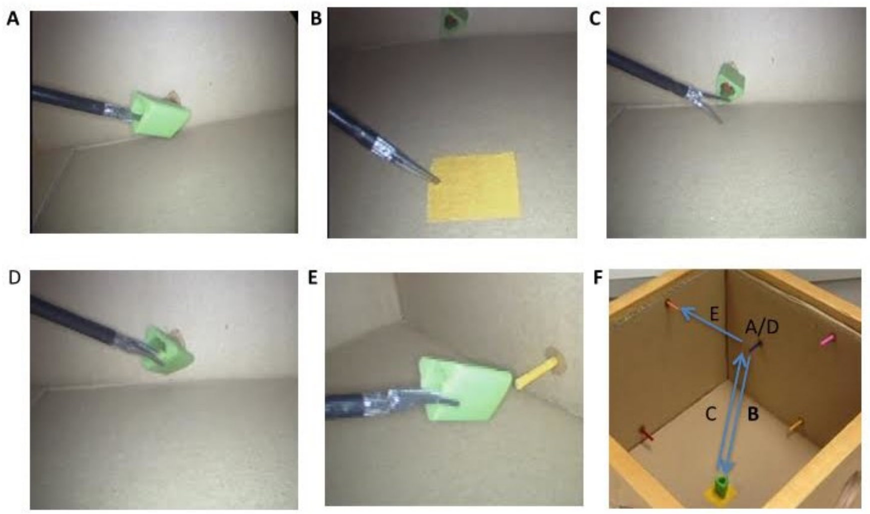


Figure 4.1 A series of snapshots from task video showing subtasks. Subtask 1, Loading object on a pin (A); Subtask 2, Bringing the grasper back to the home plate (B); Subtask 3, Reaching to the object (C); Subtask 4, Picking up the object from a pin (D); and Subtask 5, transporting the object to next pin (E); A still picture illustrating two types of movement: subtasks A & D are on-site manipulation; whereas Subtasks B, C, E are position-shifting movement.

The task performance variables included time to complete a task, number of desynchronization (object/tool out of view in 1cm 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 (Table 4.1).

Table 4.1 Definitions for measures of task performance

Measures	**Definitions**
Task time	Time from instruction to begin the task until both grasper tips are returned to the home plate at the end of the task.
Number of error/drops	The total number of times the object dropped from the grasper.
Number of desynchronized movements	The total number of times the object/target/instrument out of view

4.1.2 Statistical Analysis

To test my hypothesis, the teams were divided into three performance groups based on their performance time. The rationale behind the grouping was there was no significant difference in the surgical experience score among the teams, so team performance time was used for grouping. For grouping, a histogram of total time was first created, then the percentiles (25, 25-75, 75) were used to divide the subjects into three performance groups (Elite, n = 5; Intermediate, n = 12; and Poor, n = 5).

Table 4.2 Demographic summary of participants by performance quartile.

Group	N	Age (year) (Mean ± SD)	Sex (M: F)	Handedness (R: L)	Surgical Experience Score (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

Statistical model

Dependent measures, including task time, errors, and desynchronization, were analyzed using a three (Performer groups: elite, intermediate, poor) × two (movement types: on-site vs. position-shifting) between subject ANOVA. Statistical analysis was performed using SPSS 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.

4.2 RESULTS

Table 4.3 Comparison of task performance over three different performance groups and two movement types.

Variables/ Mean ± SD	Performance group				Movement type		
	Elite	Intermediate	Poor	P	Onsite	Shifting	P
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
Desynchronization	2.9 ± 2.3	3.0 ± 2.8	4.9 ± 4.8	0.009	0.6 ± 0.9	5.3 ± 3.0	< 0.001

Table 4.3 shows the group effect of performers and movement types on task time, errors and desynchronization. Significant difference was found among performer groups for desynchronization (P = 0.009), but not for errors (P = 0.063). 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 (0.9 ± 1.5). Lastly, more numbers of desynchronization 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 desynchronization presented between elite and poor performers ($P = 0.005$), intermediate and poor ($P = 0.001$), but not between elite and intermediate performers.

The group effects of movement type were showed in task time ($P < 0.001$), errors (0.029) and desynchronization ($P < 0.001$). Specifically, on-site movement took longer time (113.5 ± 114.8s) than position-shifting movement (51.2 ± 38.7s). 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 desynchronization events in on-site manipulation (0.6 ± 0.9) than position-shifting movement (5.3 ± 3.0).

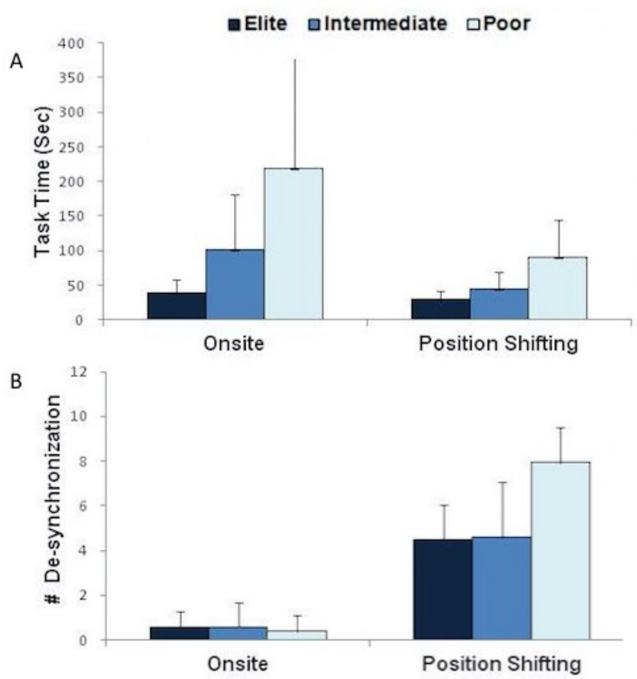


Figure 4.2 Interaction effect between different performer teams and type of movements in the measure of task time (A) and number of desynchronization

Interaction effects were revealed between performance group and movement type in task time (P = 0.010) and desynchronization (P = 0.003), not in errors (P = 0.722). As shown in Figure 4.2A, 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.

The three teams performed a similar amount of desynchronization during on-site manipulation, but differences became significant when they performed position-shifting movement. While the elite and intermediate teams increased the number of desynchronization events in a moderate manner, the poor team had increased much more dramatically (Figure 4.2B).

4.3 Discussion

My research hypotheses were supported by our results, where elite teams performed less amounts of movement desynchronization when performing tasks than intermediate and poor teams. Most of the desynchronization 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 team members towards a team goal [34]. It emerges from the interplay of the individual cognition while team members work in a team [143]. 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 behaviour to demands of the task and other team members"[144]. Few programs have assessed the shared cognition built among team members, which is the foundation for constructing an effective team [145]. It has been documented that when a team matures, the level of shared team cognition will grow stronger and movement coordination between team members will be more observable [146].

In this step of the analysis, I 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 enhancement of team performance was a result from the development of team cognition towards the team goal, based on their previous 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 [102]. Video analysis provides us with a useful tool to examine the coordination patterns of surgeons. For video analysis, defining the moments related with team collaborative behaviour is an important step of video analysis.

While trials had been recorded, I also tracked the eye motions of two team members. In the next chapter, I 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 evidence to describe the team cognition. I expect more distinguishable gaze patterns can be found from different teams based on temporal and spatial features in gaze.

4.4 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 behaviour in laparoscopic surgery. Elite teams displayed a smaller number of movement desynchronization than poor teams. This suggests movement desynchronization can serve as a behavioural marker when assessing team collaboration quality. The evidence where desynchronization occurred frequently during the position-shifting tasks rather than during the on-site manipulation suggests team collaborative behaviour can be affected by different task requirements.

CHAPTER FIVE: DUAL EYE-TRACKING FOR THE ASSESSMENT OF TEAM PERFORMANCE

In this chapter, I targeted eye movement trajectories analysis. The eye movement data was recorded simultaneously with last chapter’s video data. Previous studies on eye tracking were primarily focusing on individual’s eye movements, the authors reported fixation, saccades or smooth pursuit movement. What I was facing in this step of analysis was to define the moment that can describe similarity between two team members. Intuitively, I believed that when two people were gazing on the same spot, they are taking the same visual input, and showing guide/control movement in a similar way. Based on this assumption, I created a gaze overlapping concept to describe dual eye tracking similarity, I anticipated gaze overlapping will coordinate with a better team performance. Later, I took a more sophisticated dual signal analysis called CRA. CRA can describe the similarity of eye gaze spatiotemporally between two team members even though the two team members are not looking at the same spot at a defined time.

My hypotheses were that elite performance teams would demonstrate higher gaze overlapping rate through gaze overlapping analysis than low performance teams; CRA would show higher recurrence rate and a shorter delay of eye gaze between team members than low performance teams.

5.1 DATA ANALYSIS

Elite and poor teams' eye gaze were used for data analysis. Tool transportation period on the orange pin was chosen for analysis purposes, the reasons were as follows: 1) during tool transportation period, the camera moved constantly, at this period of time more team collaboration was more demanding than loading the object on the pin; 2) orange pin was selected because it had a relatively longer distance to home plate than other pins, which provides us a longer time period to analyze the eye gaze features of elite and poor teams.

Step 1. Trimming of eye gaze videos

Since both recorded videos of primary operator and assistant might start at a different time, this step was very important in ensuring the quality of accuracy. The eye tracking videos were reviewed concurrently to find the exact same starting time frames for both team members during the procedure.

Step 2. Cleaning eye tracking data

A MATLAB script was used to extract the useful data from the eye tracking data file. Timestamp, x-location, y-location were used for analysis. For each time stamp, one team member's gaze location has an x coordinate and a y coordinate. Typically, x- and y- coordinates collected by eye tracking systems were in pixels, with the origin set at the left corner of the screen. The resolution of the screen in this study was 1280×1024 pixels.

Step 3. Eye Movement Trajectory Similarity Measurements

The measurements of the eye movement trajectory similarity of elite and poor teams were based on the spatial and temporal features. Due to the volume of the data of eye gaze locations in two time series, it was not intuitive to compare them by visual inspection through time series analysis. Further, two sequences of data could not be compared by traditional statistical metrics such as Analysis of Variances or t-test. As data of time series are highly automatic correlated with one another. I used gaze overlapping analysis and CRA to evaluate the eye movement trajectory similarity.

Gaze Overlapping

According the previous study done by Nodine et al. and Khan et al. [115, 116], the authors suggested that the center of focal attention surrounded a 5° visual field for the area of interest. This implies that both team members are roughly looking at the same spot if the Euclidean distance between their eye-gaze locations is less than 50 pixels. In this step of analysis, we set the threshold of dyad team members eye gaze distance to 50 pixels at the same time frame, which indicates a gaze separation of almost 5° visual angle for our setup, which is about 1.3cm on the monitor.

Eye gaze distance calculation

The Euclidean distance was used for calculation of the distance between two eye gaze points at the same time frame (Figure 5.1).

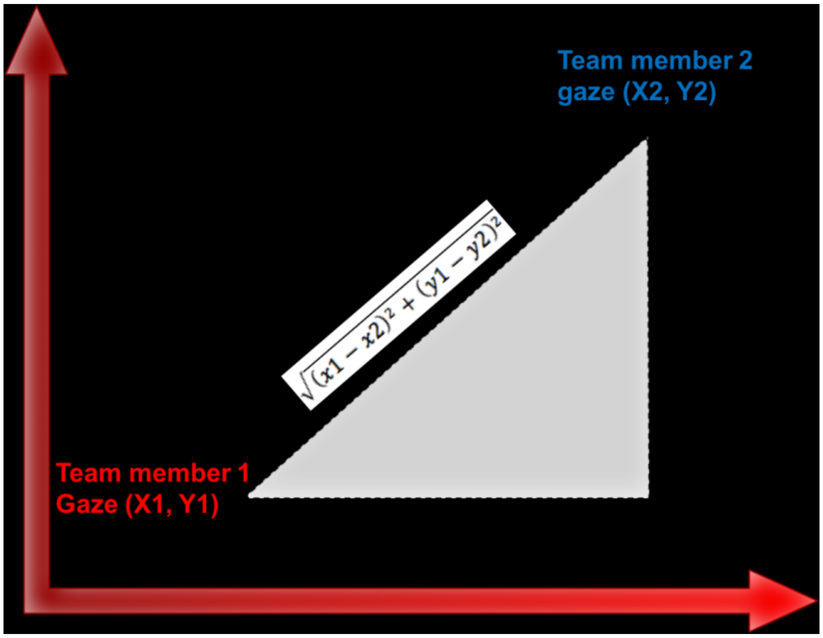


Figure 5.1 This graph stands for a combined interface having both participants' eye gaze. the calculation of the distance between gazes of two team members, team member 1 gaze (X1, Y1) and team member 2 gaze (X2, Y2) is by$\sqrt{(\boldsymbol{X1}-\boldsymbol{X2})^2+(\boldsymbol{Y1}-\boldsymbol{Y2})^2}$

In the Euclidean plane, the distance between team member 1 gaze (X1, Y2) and member 2 gaze (X2, Y2) is given by

$$Gaze\ distance = \sqrt{(X1-X2)^2+(Y1-Y2)^2}$$

CRA: Cross Correlation and Delay

In order to calculate the delay between two team members, I used cross-correlation. Cross-correlation measures the *maximum* similarity between x and shifted (lagged) copies of y as a function of the lag, and the lag is equal to the delay.

Cross correlation

Cross-correlation of two signals $X = (X_t)$ and $Y = (Y_t)$ is the function that gives the correlation of the two signals at different time points. In signal processing, cross-correlation is a measure of similarity of two series as a function of the displacement of one relative to the other. Cross-correlation is a measure of similarity between two signals. It can be used to detect if two signals are lagged relative to each other or for the time delay analysis.

Delay between two correlated signals

The maximum cross-correlation between the two signals is the point in time where two signals are best aligned. This represents a lag equal to the delay between the two signals.

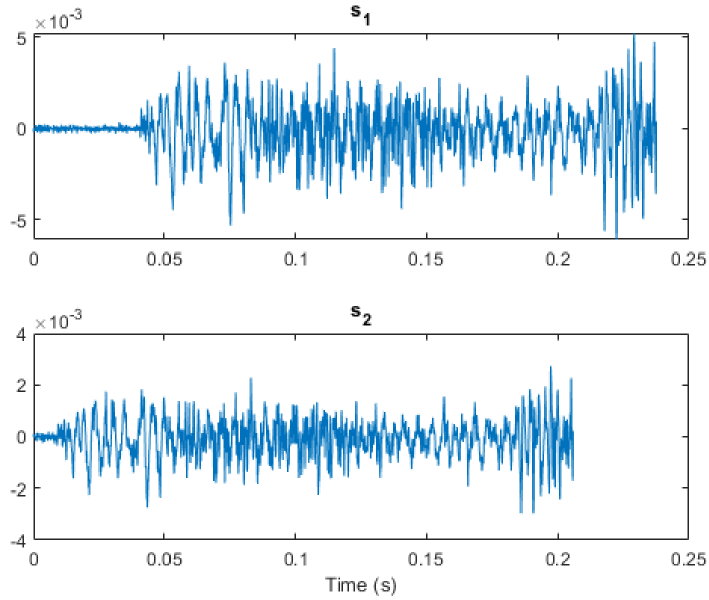


Figure 5.2 An example of a lag between S1 and S2. Adopted from https://www.mathworks.com/help/signal/ref/xcorr.html. Copyright by the Mathworks.

5.2 Results

5.2.1 Gaze Overlapping

Table 5.1 shows the gaze overlapping percentage for elite and poor performer teams during the whole procedure and orange-pin tool transportation periods. The average total gaze overlapping between two team members in the elite team was higher than the poor performer team (Elite: 35.87 ± 4.84%; Poor: 28.74 ± 6.34%; P = 0.018), while the average transportation overlapping for elite teams was significantly higher than the poor performer teams (50.97 ± 9.22% vs. 29.56 ±18.15; P = 0.023).

Table 5.1 Gaze overlapping for elite and poor performer teams

Teams	Total Overlap (%)	Transportation Overlap (%)
Elite	35.87 ± 4.84	50.97 ± 9.22
Poor	28.74 ± 6.34	29.56 ± 18.15
P value	0.018	0.023

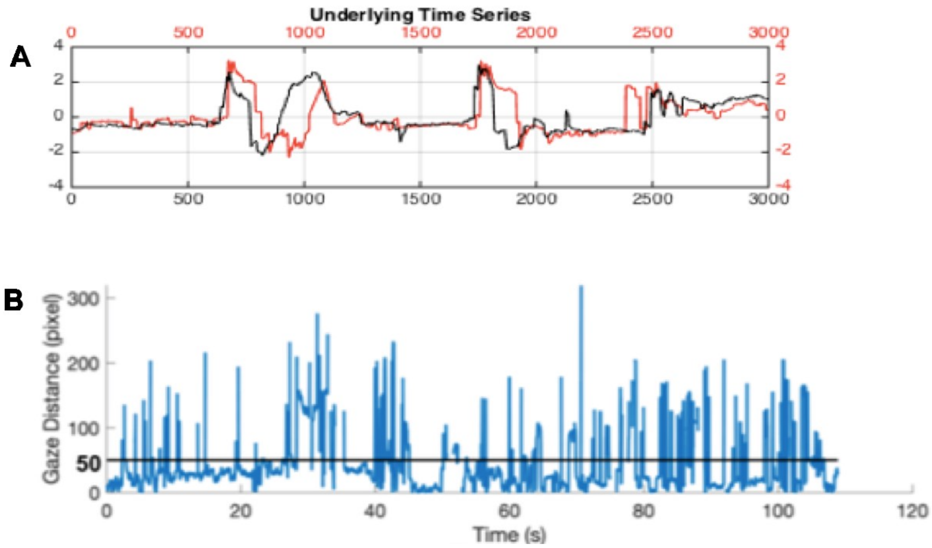


Figure 5.3 A. Two members' eye gaze locations change overtime; B. All values below the x-axis (50 pixels, 5° visual angle) indicate an overlapping of eye gaze. Values above the x-axis (50 pixels, 5° visual angle) indicate gaze desynchronization.

Figure 5.4 (a) shows team task completion time distribution of elite and poor teams. The red horizontal line in Figure 5.4 (b) shows 50 pixels separation threshold on the gaze overlapping of two gaze signals (blue curve), if the gaze overlap is under 50 pixels, we consider the eye gazes were overlapped, and vice versa. The white and green circles in Figure 5.4 (c) demonstrate an example of two eye gazes at a same-time frame.

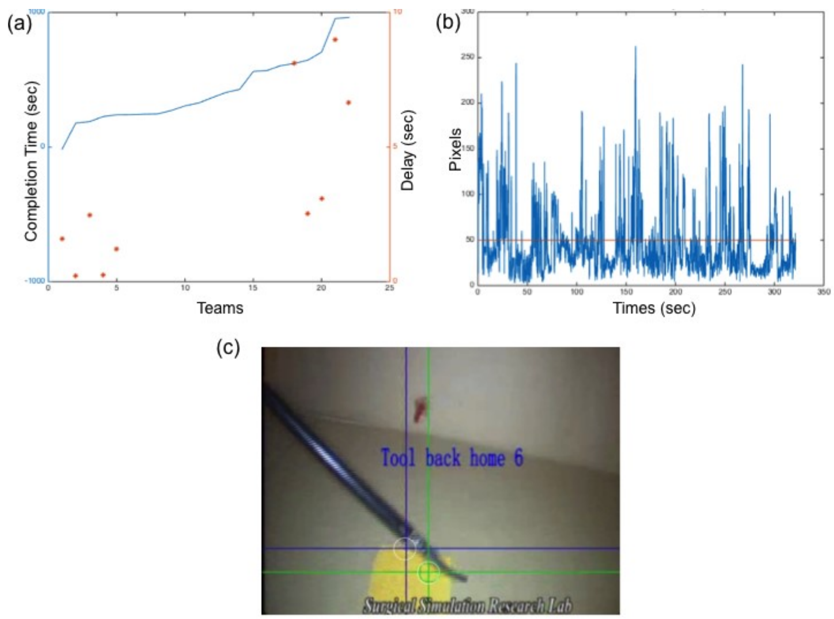


Figure 5.4 (a) Team's overall completion time and corresponding delay between members' eye gaze; (b) eye gaze signal distribution and overlap area; (c) an example of a frame of the dual overlay

5.2.2 CRA: Correlation and delay analysis

The average delay for elite and poor performer teams is presented in Table 5.2. CRA reveals a higher recurrence rate between two team members for elite teams (78.06 ± 25.93 %) than the poor team (34.41 ± 34.42 %; P = 0.0412). Further analysis showed that two team members in poor teams displayed a 2.25 ± 2.54 sec gaze delay; whereas the delay dropped to 0.26 ± 0.11 sec for elite teams; P = 0.032. Also, the camera holder leads the performer in the elite teams while in the poor performer teams the performer leads the camera holder. The red dots in Figure 4.6a shows the corresponding delay for elite and poor performer teams. Table 1 shows a higher recurrence rate corresponds to a shorter delay between two eye gaze signals.

Table 5.2 Recurrence rate and delay for elite and poor performance teams

Teams	Recurrence Rate (%)	Delay (sec)
Elite	78.06 ± 25.93	1.78 ± 1.06
Poor	34.41 ± 34.42	6.06 ± 3.00
P value	0.0412	0.032

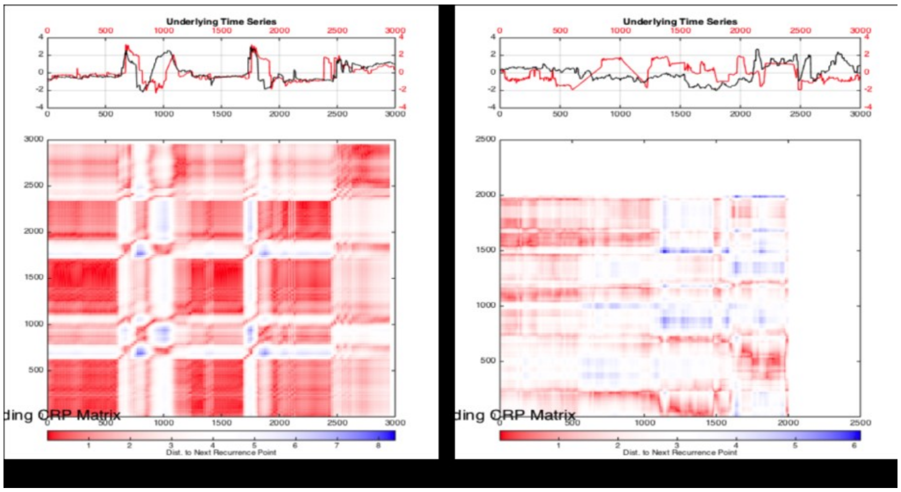


Figure 5.5 Examples of Cross Recurrence Plot (CRP) of an Elite and Poor Team, on the left the elite team's plot appears to be denser and more clustered, while the plot for the poor performer team on the right side looks more random and does not show the overlapping patches very well.

5.3 DISCUSSION

The results presented in this chapter support the hypotheses that the top performance teams displayed higher gaze overlapping rate, higher recurrence rate and shorter delay than poor performance teams. Specifically, team members in elite teams had a higher chance of scanning over the same operating site, whereas members in the poor performance teams had less chance of scanning over the same operating site, and the camera holder's eye gaze constantly falls behind the operator. Generally, the delay was longer and recurrence rate and overlapping would be lower for teams with longer completion time.

This is the first time that Gaze Overlapping and CRA are used to describe team cognition between two surgeons in laparoscopic surgery based on dual eye-tracking evidence. Although team cognition is believed to be the foundation for team performance, there is no direct and objective/quantitative way to measure it, especially in the healthcare setting. In fact, the deficiency in tools for objective team assessment has been a major barrier in promoting surgical team training. Previous studies showed that spatial features such as overlap analysis can be a measure of team cognition [19-21]. However, due to the dynamic nature of the eye-gaze signals, gaze overlapping calculated from spatial feature is not sufficient. The temporal features of gaze signals should be analyzed too, as team members might scan over the same surgical spot at different time slots. CRA allow us to capture this temporal feature. Therefore, I believe they provide a more powerful tool for spatial-temporal analysis and refer better to shared team cognition than the gaze overlapping.

Based on the results of our study, dual eye tracking and CRA is demonstrated to be a powerful tool for revealing team cognition, which potentially can help assess team cognition and improve the training quality of a surgical team.

CHAPTER SIX: SYNCHRONIZATION OF PUPIL DILATIONS REVEALS TEAM PERFORMANCE

Eye movement trajectories in many ways present a subject's visual search strategy, it can tell us where a subject is looking and how long he/she is looking. As it has been shown in the previous chapter, when two people are taking the same visual input, they are able to generate motion more synchronized and could result in better team performance. The pupil dilations of the subjects were recorded simultaneously with eye movement data by the eye trackers. In this chapter, I take the analysis one step further to examine whether two team members are able to perceive workload synchronously. It has been known that when an individual is working in an elevated stressful environment, it will induce the pupil to dilate. In this chapter, I would like to know whether two team members are able to perceive the change of workloads and react simultaneously in pupil dilation. To our knowledge, this is an innovative approach by analyzing dual pupil response in the effort of revealing team collaboration.

This chapter's data analysis is broken into two parts, with the aim to investigate team's pupil response similarity within different performance teams and different collaborative levels of the teams. I hypothesized that the members of an elite performance team will perceive task workloads more synchronously and produce a more synchronized pupil response pattern than a poor performance team, and a more collaborative team will have higher pupil similarity than a less collaborative team.

6.1 DATA ANALYSIS

6.1.1 Define subtasks and events

In this chapter, the procedure is divided into three separate phases: task initialization, main task, and task finishing phases. The task procedure was initialized by the primary operator picked up the object from the home plate, transported to load it onto the first pin, and then brought the grasper back to the home plate. The main task phase consisted of 6 consecutive cycles of picking up and transporting the object from one pin to another one, each cycle had 6 subtasks (for example picking up the object from the blue pin and taking it to the orange one as an example: subtask 1, the grasper resting on the home plate; subtask 2, the grasper was moved from the home plate to the blue pin; subtask 3, picking up the object from the blue pin; subtask 4, transporting the object to the orange pin; subtask 5, the object was loaded onto the orange pin; subtask 6, the grasper was retrieved back to the home plate, waiting for another command. The task finishing phase was to bring the object back to the home plate and rest the grasper on the home plate. The participants were given a practice trial to get used to the simulation environment and the task procedure before the real trial. The order of the target pins was assigned by the experimenter. The subtasks and the corresponding task events were summarized in Table 6.1 and Figure 6.1. Only the main task phase was included in the data analysis.

Table 6.1 An example of events marked from one cycle of the procedure.

Events	Descriptions
Event 1	The grasper tip touches the home plate
Event 2	The grasper leaves the home plate
Event 3	The grasper touches the object
Event 4	The object leaves the pin
Event 5	The object touches another pin
Event 6	The grasper released from the pin

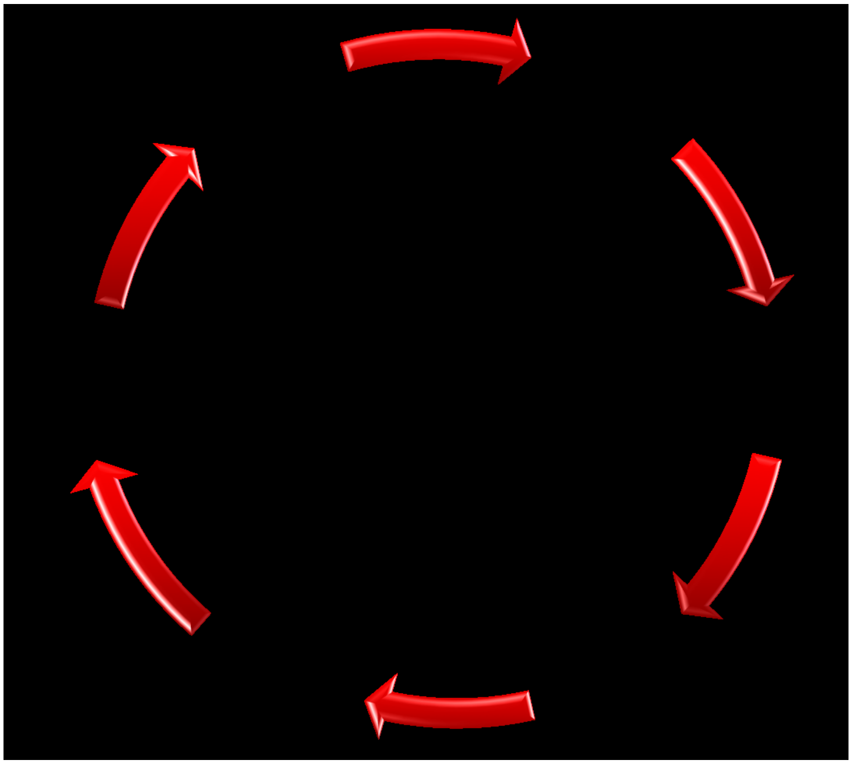


Figure 6.1 Each cycle of the procedure is separated into six subtasks.

6.1.2 Pupil Data processing

The pupil diameter data were exported from Tobii client software (Tobii Clearview) to CMD files (Combined Data file), then synchronized with the event segmentations that were annotated from task videos by the experimenter. The analysis of the raw pupil data was carried out in the following way. Firstly, the raw pupil data was median filtered using a window of 140 ms; the window size was empirically chosen. A baseline for each trial was derived from the periods when the tool was resting at the home plate (subtask 1) and averaging from all the 6 cycles. The normalized pupil diameter (Npd) was derived by subtracting the baseline pupil diameter and then divided by the baseline, as seen in Equation (1). The schematic illustration of the data process is shown in Figure 6.2.

$$Npd = \frac{\text{pupil}_{\text{diameter}} - \text{baseline}}{\text{baseline}} \quad (1)$$

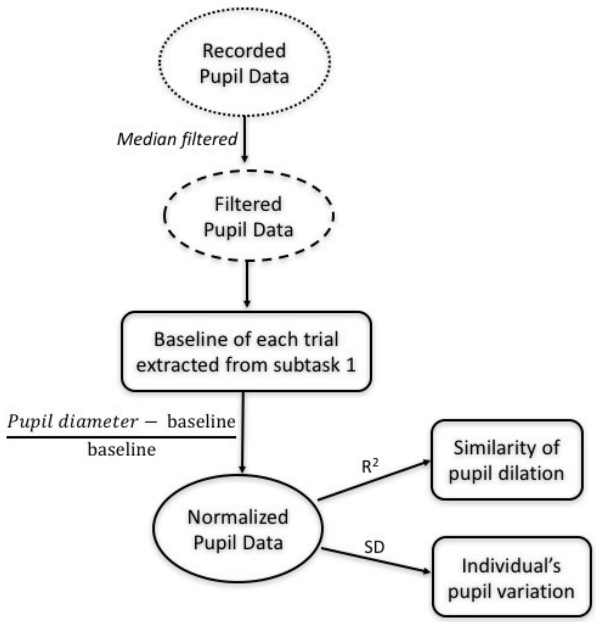


Figure 6.2 Process of pupil data processing, including filtering, baseline selection, normalization and measurement. R^2 and SD in the figure stand for the coefficient of determination and standard deviation, respectively.

6.1.3 Measures

Two measurements were used for analysis, 1) the similarity of pupil dilation was represented by Coefficient of determination (R^2, *Equation 2*), which is square of the correlation coefficient of normalized pupil size during each subtask between team members; the higher degree of similarity between two people's pupil dilation, a larger coefficient was reported; 2) Individual's pupil variation was represented by the standard deviation of individual's pupil size data within each of the subtasks.

R^2 was calculated as:

$$R^2 = \frac{(N\sum_1^N x_i y_i - \sum_1^N x_i \sum_1^N y_i)^2}{(N\sum_1^N x_i{}^2 - (\sum_1^N x_i)^2)(N\sum_1^N y_i{}^2 - (\sum_1^N y_i)^2)} \ (Equation\ 2)$$

where x_i and y_i are the normalized individual pupil diameter values of two team members, respectively, and N is the number of samples in each subtask. R^2 reflects the proportion of one variable similar to the other variables, with its output value of 0 to 1 representing the similarity between the primary operator and assistant's normalized pupil diameter values ranging from no correlation ($R^2 = 0$) to exact match ($R^2 = 1$).

Statistical model

A two-way between-subject ANOVA was conducted; the independent variables were the team levels (Performer groups: elite, intermediate, poor) and subtasks (2-6). Subtask 1 (tool resting at home) was served as the baseline and excluded from analysis. The dependent variables were the pupil dilation similarity, operator's pupil size variation, and camera holder's pupil size variation, respectively. Statistical analysis was performed using MATLAB R2018a (The MathWorks, Inc., Natick, Massachusetts, United States), $P < 0.05$ was considered to be statistically significant. Mean and standard deviation were reported in this chapter.

6.2 RESULTS

Figure 6.3 showed an example of normalized pupil diameter over time of a team (from Team No.3). A whole trial of the example data of a surgeon (curve black) and an assistant (curve blue), the different coloured vertical lines represent different cycles (Figure 6.3 A); One of the cycles joint pupil changes are shown in Figure 6.3 B.

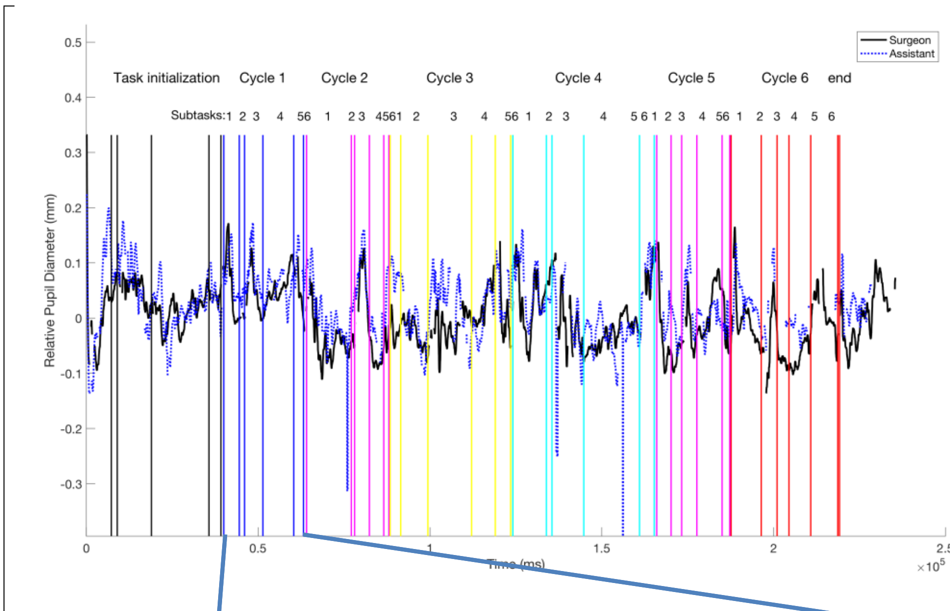


Figure 6.3 A

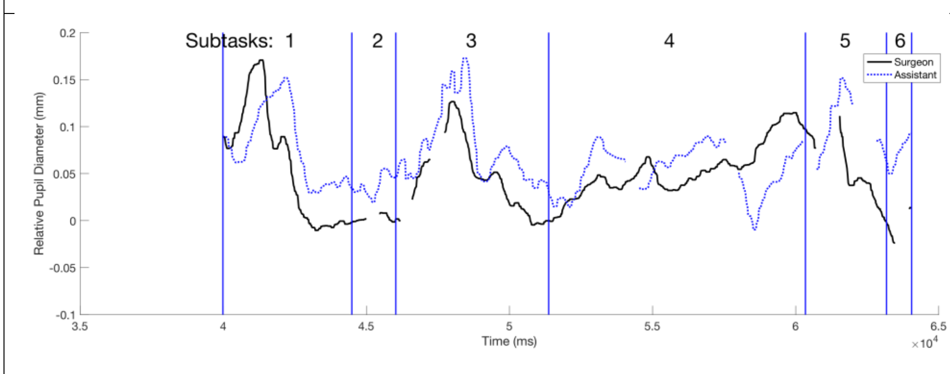


Figure 6.3 B

Figure 6.3 An example of joint pupil changes. A) The whole trial of the example data, with different colour groups vertical lines for different cycles. B) One of the cycle's joint pupil changes data.

The Similarity of Pupil Dilation (coefficient of determination) between Team members

There were significant effects of both team level ($F = 16.46$, $P < 0.001$) and subtasks ($F = 17.49$, $P < 0.001$) on coefficient of determination; there was no significant effect of the interaction between these two factors. Post hoc test (Tukey's HSD) showed that elite teams had significantly higher pupil similarity than poor teams (0.364 ± 0.220 vs. 0.209 ± 0.143; $P < 0.001$), and no significant difference of coefficient of determination was found between poor and intermediate teams. Post hoc test (Tukey's HSD) on subtask showed that only subtask 6 (Bringing grasper to home) has significant higher coefficient of determination than those of subtasks 2-5.

Operator's pupil size variation

For the operator, there were significant effects of both team level ($F = 14.09$, $P < 0.0001$) and subtasks ($F = 16.98$, $P < 0.0001$) on pupil diameter variation; there was no significant effect of the interaction between these two factors. Post hoc test (Tukey's HSD) showed that elite teams had significantly lower pupil variation than poor teams (0.027 ± 0.012 vs. 0.043 ± 0.017; $P < 0.001$) and no significance between poor and intermediate teams. Post hoc test (Tukey's HSD) on subtask showed that there was significant difference between subtask 2 and 3 ($P = 0.003$) and subtask 5 has significantly lower variation than other subtasks.

Camera holder's pupil size variation

Post hoc test (Tukey's HSD) showed that camera holders in elite teams had significantly lower pupil variation than poor teams (0.028 ± 0.012 vs. 0.047 ± 0.017; $P < 0.001$) and no significance between elite and intermediate teams. Post hoc test (Tukey's HSD) on subtasks showed that there was significant difference between subtask 2 and 3 ($P = 0.002$), subtask 6 had significantly lower variation than other subtasks.

6.3 Discussion

The hypothesis is supported by the results. The operator and assistant of the elite teams displayed a higher degree of synchronization on their pupil dilation than those of the poor teams. As pupil response is affected directly by operator's perception on the task requirement, more synchronized pupil dilations of a team indicate a more shared visual search strategy and further cognitive process during the course of a task. I thus can infer that better performance of elite teams was achieved due to a more shared cognition between the team members.

This is the first study using the similarity of joint pupil dilations between team members to study shared cognition. Although reported from the surgical simulation scenario, this innovative method can be applied to other team settings and serve as an indicator for shared cognition among team members. From the results, higher pupil similarity was reported from better task performance team. This suggested that elite team members might visually perceive the task requirement and translate to movement control by the similar strategies. This argument can be further supported by our results acquired from subtask 6 (bringing grasper to home). In all teams, two team members displayed significantly higher pupil similarity on subtask 6. I believe this was caused by the nature of low task difficulty of subtask 6 compared to other subtasks. As bringing the grasper to home plate is an easy locating task compared with loading the object on the pin, so there was less variation of team members' pupil change. Higher pupil variation of team members was noticed at subtask 5, while loading the object onto the pin, I believe this was caused by the loading task being the most difficult task for the primary operator, while the easiest task was the camera assistant's, which results in higher variation of pupil dilations of team members.

The other finding from this study was that individuals' (operator and camera holder) pupil variation also indicates team performance. Members in the elite teams displayed relatively small pupil variation as opposed to those in the poor teams. This indicates that the mental workloads of the elite teams' members were smaller than those of the poor teams during the task, since the higher mental workload usually elicits higher pupil variations [124, 125]. To further prove this argument, I will inspect individuals' pupil variations over different subtasks, especially comparing subtask 6 to other subtasks. Bringing the instrument back to the home plate (subtask 6) is the easiest task to perform compared to other subtasks where the object needed to be grasped, transported and loaded to a pin. In subtask 6, individuals displayed the least mental workload, which was represented by the smallest pupil variations. In the future analysis, we could do investigations while teams face challenges, for example, when the object is dropping out of view, what would team's pupil response be like? Would the team members have same pupillary response under a difficult moment?

Dual pupil analysis can reveal rich evidence for team cognition, there are two key aspects in regard to dual pupil analysis, 1) baseline selection, in general, a baseline should be a period where pupils show the least variation, for example, in this thesis, we selected the easiest subtask during the procedure. Practically, the best way to define baseline is to select a period at the beginning of the experiment and calculate the average pupil dilation during this period as the baseline. For example, staring at the computer screen for 10 seconds before starting the procedure, the 10 sec-baseline while freely observing without actually performing the task would be an accurate baseline; 2) defining subtasks and events, pupil dilation is affected by many factors, different tasks might affect pupil dilation differently. So, we need to analyze event-related pupil response. An important step in analyzing pupil dilations in a procedure is to divide the procedure into different subtasks, and then break the subtasks into events. The events are the trigger that clearly define and divide the subtasks.

6.4 Conclusion

The present work is the first study explored the joint pupil dilations between team members during a surgical procedure to reflect team performance. It is found that elite teams have higher similarity of pupil dilations than poor teams. The results suggest the analysis of joint pupil dilations can be used to reveal shared team reaction between team members.

CHAPTER SEVEN: CONCLUSIONS, DISCUSSIONS AND FUTURE DIRECTIONS

7. 1 CONCLUSIONS

In summary, our overall goal of this thesis was to find more objective, continuous and quantitative assessment tools for team work. This objective was met by the findings of psychomotor evidence through video analysis, eye gaze trajectory analysis and pupil analysis presented in this thesis.

Firstly, using video analysis even without eye tracking, one could identify observable team collaborative behaviour, i.e., whether movement desynchronization between team members are synchronized or not. For example, in Chapter 4, we found a behaviour marker for team performance level in laparoscopic surgery. The result showed that elite performance teams had less movement of desynchronization than poor performance teams. Secondly, the findings based on eye tracking evidence revealed that elite performance teams had higher amount of overlapping of eye gaze between two team members than those in the poor performance teams; besides that, Cross Recurrence Analysis showed that the eye gaze of elite performance teams had higher chance of visiting the same spots than poor performance teams, and a shorter phase delay of eye gaze was observed for one team member to be maximally aligned to the other team member in elite performance teams than in the poor performance teams. Lastly, exciting new evidence was found from dual pupil analysis, it showed that the elite performance teams had higher pupil dilation similarity than the poor performance teams, which indicated the members of elite performance teams were more cognitively synchronized during the tasks than the members of poor performance teams.

7.2 IMPLICATIONS FOR FUTURE TEAMWORK ASSESSMENT

The findings from this thesis work provide us with new insights into teamwork assessment besides paper assessment. I am fully aware the fact that eye tracking might not be available for all surgical training centres. Here, I would like to suggest to our readers who would like to adopt these methods to team assessment; even without eye tracking, and other advanced devices and using technical challenging analysis method, video analysis is a handy, easy to master and practical way in finding out behavioural evidence related with teamwork.

Simply by capturing team performance with video, we can find rich evidence towards team collaborative behaviours. Here we reported movement synchronization between two surgeons in a team. Other studies identified anticipatory movements as a good behavioural marker between the surgeon and the scrub nurse [99]. There were several researchers using video to analyse communication patterns among team members [6, 80-82]. I would like to emphasize that the behavioural marker itself can be different from case to case; yet the method of extracting those data can be similar. It only requires a researcher to observe those videos repeatedly before setting up criteria to define those behaviours that can be sensitively associated with team collaboration. Then a sound analysis can be done towards teams in the different training stages.

And also, video analysis is the necessary step before we apply eye tracking data analysis. Defining events and decomposing the entire surgical procedure into subtasks allow us to carry out a meaningful analysis of our eye-tracking data. After dividing the procedure into different subtasks through frame by frame video analysis, we can carefully examine operators' eye response according to different tasks' requirement; the eye gaze and pupil response can be analyzed based on surgeons' perception on and manipulation strategy on each of subtask. Therefore, we address the importance of using video as an essential technology to the objective assessment on team performance.

In most operating room, video recording system is available. We recommend scientists and educators to learn steps of video analysis when comes to behavioural study. If you have the chance to employ eye tracking for your study, you would collect abundant and more reliable psychomotor data relevant to teamwork comparing with videos. Eye tracking not just records data of task performance, it also describes visual attention, visual search strategies of the surgeons. Eye-tracking is the more effective method for us to examine the cognitive workload.

As early as in the 1960s, pupil size has been validated as a reliable indicator for mental workload [147, 148], and also reflects the difficulty of the task, the harder the task could evoke larger pupil dilation [148, 149]. Comparing with eye gaze, pupil size is the closest neurophysiological signal in eye tracking to reveal an individual's cognition. I believe it is promising in revealing team cognition through team pupil size analysis. Here

I would like to address applying team pupil dilation in the future study. I believe it is promising in revealing team cognition through team pupil size analysis. Using programming language to extract eye tracking data might be challenging for medical practitioners, it is necessary for us to have interdisciplinary collaboration with computing scientists to process the eye tracking data. One important thing you should keep in mind is that, once you have the video segmentation in hand, the eye tracking data could be easily processed by a computing scientist. For the detail of pupil data processing, one can refer to chapter 6.3 in baseline selection and the steps of pupil data analysis. I believe with the advancement of technologies; a smart framework might be introduced to easy process video and eye tracking data.

The results from gaze overlapping and pupil analysis were in concordance with Cannon-Bowers's view that for effective team coordination, a certain degree of overlap among team mental models is needed for effective team coordination [30]. As tasks that require teams to perform are likely to be so complex that they must be divided among several individuals to perform distinct subtasks and each individual has specific role to perform, too much overlap will probably result in "group think" [74]. Klimoski and Mohammed also hold a similar idea that "completely overlapping team mental models are viewed as dysfunctional with regard to team performance" (p. 420)" [75]. Throughout the CRA study, I found that elite performance team had a higher chance of co-visitation of the same gaze spots than poor performance teams (78% vs. 34%). From this result, I can infer that the team members of an elite performance team have higher shared visual attention, which could mean they have higher mutual understanding of the tasks. I believe the ideal overlap would be a suitable degree of overlapping of eye gaze among team members, which would result in the best team performance.

7.3 Future directions

In the future, more work will need to be done to extend these methodologies into a real surgical case in the OR and apply to surgical team training. It is also practical to find out the correlation between psychomotor evidence presented in this paper and other paper assessment tools(e.g. OTAS). Could we validate OTAS based on objective evidence presented by this thesis research? How could we correct and improve the current paper-based assessment teamwork tools? To be able to answer these questions, we would need to design a study that compares these assessment tools with paper assessments and provide detailed recommendations for the assessment tools. If we are about to validate OTAS with objective evidence, then we can confidently use paper-based instrument for team assessment, save our time and energy in setting up sophisticated system to do the objective assessment.

In addition, the correlation between behavioural evidence and neurophysiology evidence will be an interesting area to study. Along with eye tracking, there are other technologies on the market that could provide us richer and more detailed psychomotor evidence. For example, one could add motion tracking for the surgical tools to reveal more behavioural evidence of team motion pattern. There are other physiological/biometrics measurements could be used to reveal team cognition, which could be brain activity (e.g. EEG, fNIRS), heart rate, etc. For instance, Pei-pei Sun et al.

have applied fNIRS to detect the functional roles of certain parts of the brain in social interaction in 2018 [150]. I believe it is a quite promising area of research in combining physiological measurements with behavioural evidence to study teamwork.

Currently, laparoscopic training is mainly focused on basic individual skills training. It has been proven to help with the acquisition of technical skills and progress in the learning curve using simulation [151, 152]. The value of laparoscopic team training has been addressed in reducing operating time, improvement of patient care and decrease costs [16, 153]. However, the overall impact of surgical team training in laparoscopic surgery has been poorly described, and laparoscopic team training has not been incorporated in the standard laparoscopic skills training curriculum. Ideally, laparoscopic team training can be done in a skills laboratory with simulation rather in the OR. In the future, more studies are needed to be done in the efficacy of team training in advancing patient safety.

When comes to the design of simulation task for laparoscopic team training, we believe that object transportation task is a good choice. This task forces two team member to build collaboration between visual searching and task manipulation. In real surgery, the camera holder needs to move the scope to different surgical site under the instruction of primary surgeon. In simulation, we dramatically increase opportunities for camera movements as the primary surgeon need to move the object to different target sites. During object transportation, higher level of movement synchronization is needed. Our results show elite teams showed less desynchronized movements than the poor teams, and most of the uncollaborative (desynchronized) movements were in the shifting tasks. In the future team training, we will continue to incorporate task that specifically aimed for training team collaboration between team members, such as asking the primary surgeon to reach various spots on the different sites, enforcing the camera holder to read mind of the primary surgeon and perform constantly collaborating movements to provide the appropriate views.

7.4 LIMITATIONS AND SOLUTIONS

There are some limitations to this thesis. Firstly, the major limitation of this study was the grouping of the teams, which was based on task performance time during data analysis. There is a theory that we have to consider is speed/accuracy trade-off, which has been studied by psychologists as early as in 1899 [154]. The studies of Forster found both speed and accuracy were affected by subjects' concerns of accomplishments, and concerns with responsibilities and safety. The first three studies did by Forster et al. showed that when participants were asked to draw faster, their accuracy was decreased; the fourth study found participants could be both fast and accurate to the extent that the task at hand included easy problem that had a maximize efficiency requirement [155]. For this thesis study, the subjects were required to perform as fast and accurate as possible, so the grouping was based on the hypothesis that the best team was the fastest and most accurate team. The results from video analysis demonstrated that the elite teams (fastest team) had the highest accuracy (the least errors/drops), and the poor teams (slowest teams) had the least accuracy (the most errors/drops), although the significance was not found among the groups.

How can we group better?

Grouping for teams in future team study should be based on how long the team has been working together. Some people might argue, why individual surgical experience is not a standard for grouping teams? Do you mean two experienced surgeons cannot form an expert team?

If you recall about the interview I mentioned in Chapter one, an expert team should be team members not only have extensive individual experience toward to task performance but also with adequate team knowledge is developed among team members. We should keep in mind that two experts who have never operated together can form a novice team, an expert and a student who have been operating together over a period of time can form a collaborative team. We argue to use team co-working experience for grouping the team instead of purely using individual surgical experiences such as reported in previous team study [156]. In the upcoming study design, I believe the perfect grouping for team cognition study should be using real expert teams and novice teams. For example, the expert teams are composed of team members who have been working together over 1000 hours, the novice teams are team members who have been working together under 10 hours.

Secondly, the tasks used for this thesis might be too overly simplified to represent a true surgical task for laparoscopic procedures. The reason why we designed this object transportation task was it specifically required the team members to work closely to each other, the camera holder should move the camera continuously to provide the view of the target (e.g. pin and home plate). If we applied a real surgical procedure for this thesis research, the task requirement for the consistent collaboration of the camera holder and primary surgeon would be less demanding than the current study design, as it is possibly that the camera holder need to hold the camera steady for a view for over 10min in a real surgery. The goal of this thesis was to validate these methods for the objective assessment of teamwork and this goal could be better met under simulation-based team training environment. However, it could be interesting to apply the current methodologies to study team collaboration in the real OR.

Thirdly, the coordination between surgeon and camera holder, although important, contributes only a part of teamwork in the entire operating team. In reality, it would be beneficial to study collaborative patterns among a complete surgical team including additional surgeons, nurses, and anesthesiologists. Lastly, our current study was limited by the application of screen-based eye trackers. The surgical task had to be completed by both surgeons working together in a laparoscopic surgery/image guided surgery environment, with the eyes of both surgeons being tracked with two separated screen-based eye trackers.

In order to assess teamwork in a real surgical case including the whole surgical team in the future, we may need to develop new technology of tracking entire team's hand and eye motions beyond those of using screen-based eye trackers for only two people in a dyad team. It is commonly to see that the nurse and the surgeon might have some moments they are working closely, some moments they are not. A nurse might spend most of his/her time around an instruments table, where most of her eye gaze falls on the instrument table, a lesser percent of her eye gaze would fall on the surgical site/monitors during laparoscopic surgery. Most importantly, the nurse would not be able to understand the surgeon's approach and probably would not need to understand all the surgeon's approach. This is called the heterogenous feature of a team.

Challenges of applying mobile eye tracking in open surgery

My thesis research on the assessment of teamwork was not based on the heterogenous, but the homogenous feature- gaze overlap, recurrence rate of eye gaze and similarity of pupil dilation between team members. We are aware that calculating gaze overlap is extremely challenging in a real surgical case. We are considering using wearable eye tracking devices in an open surgery environment. In order to calculate the gaze overlapping among the team members; Taking pupil lab mobile eye tracking headsets as an example, a surface is needed to be defined within work environment using fiducial markers to make sure the team's eye gaze falls on a same surface [157]. However, this is not an easy task to complete, but we are collaborating with computing scientists working on this area.

Once we solved the technology problems, we will be able to record accurate gaze trajectory data as well as pupil dilation data. A team's pupil synchronization among team members, in assessing team cognition, would not be limited by the location of eye gaze to reveal team's cognitive processing. In the future, team's pupil analysis could be considered to reveal team cognition among multiple team members even under an open surgery environment.

To conclude, this thesis builds on and contributes to the work in the field of the assessment of teamwork through psychomotor evidence by video and eye tracking analyses. The significant contribution of this study was we could measure two people's eye gaze simultaneously in a surgical setting and we could successfully process dual eye gaze and pupil data. The future of assessing teamwork should be more objective and quantitative based on this thesis research.

REFERENCES

1. Mazzocco, K., et al., *Surgical team behaviours and patient outcomes.* Am J Surg, 2009. **197**(5): p. 678-85.

2. Holden, J.G., J.M. Flach, and Y. Donchin, *Perceptual-motor coordination in an endoscopic surgery simulation*. Surgical Endoscopy, 1999. **13**(2): p. 127-32.

3. Zheng, B. and L. Swanstrom, *Video analysis of anticipatory movements performed by surgeons during laparoscopic procedures*. Vol. 23. 2009. 1494-8.

4. Zheng, B., et al., *Video analysis of endoscopic cutting task performed by one vs two operators*. Vol. 19. 2005. 1388-95.

5. Zheng, B., L.L. Swanstrom, and C.L. MacKenzie, *A laboratory study on anticipatory movement in laparoscopic surgery: a behavioural indicator for team collaboration.* Surg Endosc, 2007. **21**(6): p. 935-40.

6. Halverson, A.L., et al., *Communication failure in the operating room.* Surgery, 2011. **149**(3): p. 305-10.

7. Kripalani, S., et al., *Deficits in Communication and Information Transfer Between Hospital-Based and Primary Care PhysiciansImplications for Patient Safety and Continuity of Care.* JAMA, 2007. **297**(8): p. 831-841.

8. Rosenstein, A.H. and M. O'Daniel, *A Survey of the Impact of Disruptive Behaviours and Communication Defects on Patient Safety.* The Joint Commission Journal on Quality and Patient Safety, 2008. **34**(8): p. 464-471.

9. Brock, D., et al., *Interprofessional education in team communication: working together to improve patient safety.* BMJ Quality & Safety, 2013. **22**(5): p. 414.

10. Lingard, L., et al., *Team communications in the operating room: talk patterns, sites of tension, and*

implications for novices. Acad Med, 2002. **77**(3): p. 232-7.

11. Taylor, J.C., *The effects of crew resource management (CRM) training in airline maintenance [microform] : results following three years experience / J.C. Taylor and M.M. Robertson*. NASA contractor report ; NASA CR-196696., ed. M.M. Robertson and C. Ames Research. 1995, Moffett Field, Calif. : [Springfield, Va: National Aeronautics and Space Administration, Ames Research Center ; National Technical Information Service, distributor.

12. Burke, C.S., et al., *What type of leadership behaviours are functional in teams? A meta-analysis.* The Leadership Quarterly, 2006. **17**(3): p. 288-307.

13. Barnes, C.M., et al., *Harmful help: the costs of backing-up behaviour in teams.* J Appl Psychol, 2008. **93**(3): p. 529-39.

14. Salas, E., et al., *Does Team Training Work? Principles for Health Care.* Academic Emergency Medicine, 2008. **15**(11): p. 1002-1009.

15. He, W., et al., *The composition of surgical teams in the operating room and its impact on surgical team performance in China.* Surg Endosc, 2014. **28**(5): p. 1473-8.

16. Kenyon, T.A., et al., *Cost and benefit of the trained laparoscopic team. A comparative study of a designated nursing team vs a nontrained team.* Surg Endosc, 1997. **11**(8): p. 812-4.

17. Gregorich, S.E., R.L. Helmreich, and J.A. Wilhelm, *The structure of cockpit management attitudes.* J Appl Psychol, 1990. **75**(6): p. 682-90.

18. P. R. Smith, H., *A Simulator Study of the Interaction of Pilot Workload with Errors, Vigilance, and Decisions*. 1979.

19. L Schmidt, L., et al., *Risk of Performance Errors Due to Poor Team Cohesion and Performance, Inadequate*

Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation Risk of Performance Errors due to Poor Team Cohesion and Performance, Inadequate Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation. 2009.

20. Birch, D.W., et al., *Canadian consensus conference on the development of training and practice standards in advanced minimally invasive surgery: Edmonton, Alta., Jun. 1, 2007.* Canadian Journal of Surgery, 2009. **52**(4): p. 321-327.

21. McCulloch, P., et al., *The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre.* Qual Saf Health Care, 2009. **18**(2): p. 109-15.

22. Neily, J., et al., *Association between implementation of a medical team training program and surgical mortality.* Jama, 2010. **304**(15): p. 1693-700.

23. Dunkin, B., et al., *Surgical simulation: a current review.* Surg Endosc, 2007. **21**(3): p. 357-66.

24. Feldman, L.S., V. Sherman, and G.M. Fried, *Using simulators to assess laparoscopic competence: ready for widespread use?* Surgery, 2004. **135**(1): p. 28-42.

25. Moorthy, K., et al., *A human factors analysis of technical and team skills among surgical trainees during procedural simulations in a simulated operating theatre.* Ann Surg, 2005. **242**(5): p. 631-9.

26. Zheng, B., et al., *Building an efficient surgical team using a bench model simulation: construct validity of the Legacy Inanimate System for Endoscopic Team Training (LISETT).* Surg Endosc, 2008. **22**(4): p. 930-7.

27. Healey, A.N., S. Undre, and C.A. Vincent, *Developing observational measures of performance in surgical teams.* Qual Saf Health Care, 2004. **13 Suppl 1**: p. i33-40.

28. Undre, S., et al., *Teamwork in the operating theatre: cohesion or confusion?* J Eval Clin Pract, 2006. **12**(2):

p. 182-9.

29. Salas, E., et al., *Using simulation-based training to improve patient safety: what does it take?* Jt Comm J Qual Patient Saf, 2005. **31**(7): p. 363-71.

30. Cooke, N.J., et al., *Measuring team knowledge.* Hum Factors, 2000. **42**(1): p. 151-73.

31. Whittaker, G., et al., *Teamwork Assessment Tools in Modern Surgical Practice: A Systematic Review.* Surg Res Pract, 2015. **2015**: p. 494827.

32. Healey, A.N., S. Undre, and C.A. Vincent, *Developing observational measures of performance in surgical teams.* Quality and Safety in Health Care, 2004. **13**(suppl 1): p. i33.

33. Salas, E., et al., *The Effect of Team Building on Performance: An Integration.* Small Group Research, 1999. **30**(3): p. 309-329.

34. Cooke, N.J.S., Eduardo; Kiekel, Preston A.; Bell, Brian and E.E.F. Salas, Stephen M. (Ed), *Team cognition: Understanding the factors that drive process and performance*. 2004, Washington, DC, US: American Psychological Association. 268.

35. Salas, E., N.J. Cooke, and M.A. Rosen, *On teams, teamwork, and team performance: discoveries and developments.* Hum Factors, 2008. **50**(3): p. 540-7.

36. Salas, E., et al., *Toward an understanding of team performance and training. Teams: Their training and performance.* In Swezey R. W.& Salas E. (Eds.), Teams: Their Training and Performance, NJ: Ablex, pp.3-29.Sandstorm E, De Meuse KP, Futrell D.,(1990)“Work Terms: Applications and Effectiveness” American Psychologist.;45(2):120–33., 1992.

37. Morley, L. and A. Cashell, *Collaboration in Health Care.* Journal of Medical Imaging and Radiation Sciences, 2017. **48**(2): p. 207-216.

38. Baker, D.P., R. Day, and E. Salas, *Teamwork as an essential component of high-reliability organizations.* Health Serv Res, 2006. **41**(4 Pt 2): p. 1576-98.

39. Weiser, T.G., et al., *Estimate of the global volume of surgery in 2012: an assessment supporting improved health outcomes.* The Lancet, 2015. **385**: p. S11.

40. Thimbleby, H., *Technology and the future of healthcare.* Journal of public health research, 2013. **2**(3): p. e28-e28.

41. Weaver, S.J., et al., *Does teamwork improve performance in the operating room? A multilevel evaluation.* Jt Comm J Qual Patient Saf, 2010. **36**(3): p. 133-42.

42. Sexton, J.B., E.J. Thomas, and R.L. Helmreich, *Error, stress, and teamwork in medicine and aviation: cross sectional surveys.* Bmj, 2000. **320**(7237): p. 745-749.

43. Reader, T.W., R. Flin, and B.H. Cuthbertson, *Communication skills and error in the intensive care unit.* Curr Opin Crit Care, 2007. **13**(6): p. 732-6.

44. Roberts, K.H., *Managing High Reliability Organizations.* California Management Review, 1990. **32**(4): p. 101-113.

45. Weick, K.E. and K.H. Roberts, *Collective Mind in Organizations: Heedful Interrelating on Flight Decks.* Administrative Science Quarterly, 1993. **38**(3): p. 357-381.

46. Helmreich, R.L. and J.A. Wilhelm, *Outcomes of crew resource management training.* Int J Aviat Psychol, 1991. **1**(4): p. 287-300.

47. Wiener, E.L., Kanki, B. G., & Helmreich, R. L. , *Cockpit resource management*. Cockpit resource management., ed. E.L. Wiener, B.G. Kanki, and R.L. Helmreich. 1993, San Diego, CA, US: Academic Press. xxi, 519-xxi, 519.

48. Cannon-Bowers, J.A. and E. Salas, *Team Performance and Training in Complex Environments: Recent Findings From Applied Research*. Current Directions in Psychological Science, 1998. **7**(3): p. 83-87.

49. Helmreich R L, M.A.C., *Culture at Work in Aviation and Medicine: National, Organizational, and Professional Influences.* Brookfield, VT: Ashgate, 1998.

50. Salas, E., et al., *Does Team Training Improve Team Performance? A Meta-Analysis.* Human Factors, 2008. **50**(6): p. 903-933.

51. Jamali, F.R., et al., *Evaluating the Degree of Difficulty of Laparoscopic Colorectal Surgery.* Archives of Surgery, 2008. **143**(8): p. 762-767.

52. Roslyn, J.J., et al., *Open cholecystectomy. A contemporary analysis of 42,474 patients.* Annals of surgery, 1993. **218**(2): p. 129-137.

53. Flum, D.R., et al., *Intraoperative cholangiography and risk of common bile duct injury during cholecystectomy.* Jama, 2003. **289**(13): p. 1639-44.

54. Flum, D.R., et al., *Bile duct injury during cholecystectomy and survival in medicare beneficiaries.* Jama, 2003. **290**(16): p. 2168-73.

55. Nuzzo, G., et al., *Bile duct injury during laparoscopic cholecystectomy: results of an Italian national survey on 56 591 cholecystectomies.* Arch Surg, 2005. **140**(10): p. 986-92.

56. Waage, A. and M. Nilsson, *Iatrogenic bile duct injury: a population-based study of 152 776 cholecystectomies in the Swedish Inpatient Registry.* Arch Surg, 2006. **141**(12): p. 1207-13.

57. Hamad, M.A., et al., *Major biliary complications in 2,714 cases of laparoscopic cholecystectomy without intraoperative cholangiography: a multicenter retrospective study.* Surg Endosc, 2011. **25**(12): p. 3747-51.

58. Halbert, C., et al., *Beyond the learning curve: incidence of bile duct injuries following laparoscopic cholecystectomy normalize to open in the modern era.* Surg Endosc, 2016. **30**(6): p. 2239-43.

59. Berguer, R., W.D. Smith, and Y.H. Chung, *Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery.* Surg Endosc, 2001. **15**(10): p. 1204-7.

60. Mohsen Zahiri, C.A.N., R Gonzalo Garay-Romero, Dmitry Oleynikov, *Robotics and Mechatronics.* 2016: Springer, Cham.

61. Zheng, B., O.N.M. Panton, and T.A. Al-Tayeb, *Operative length independently affected by surgical team size: data from 2 Canadian hospitals.* Canadian journal of surgery. Journal canadien de chirurgie, 2012. **55**(6): p. 371-376.

62. See, W.A., et al., *Laparoscopic surgical training: effectiveness and impact on urological surgical practice patterns.* J Urol, 1993. **149**(5): p. 1054-7.

63. Dexter, M.D.P.D.F., et al., *Making Management Decisions on the Day of Surgery Based on Operating Room Efficiency and Patient Waiting Times.* Anesthesiology, 2004. **101**(6): p. 1444-1453.

64. Xiao, Y., et al., *What Whiteboards in a Trauma Center Operating Suite Can Teach Us About Emergency Department Communication.* Annals of Emergency Medicine, 2007. **50**(4): p. 387-395.

65. Azzi, A.J., et al., *Surgical team turnover and operative time: An evaluation of operating room efficiency during pulmonary resection.* J Thorac Cardiovasc Surg, 2016. **151**(5): p. 1391-5.

66. Razzouk, R. and T. Johnson, *Shared Cognition*, in *Encyclopedia of the Sciences of Learning*, N.M. Seel, Editor. 2012, Springer US: Boston, MA. p. 3056-3058.

67. Kozlowski, S.W.J. and D.R. Ilgen, *Enhancing the Effectiveness of Work Groups and Teams.* Psychological Science in the Public Interest, 2006. **7**(3): p. 77-124.

68. De Dreu, C.K.W. and L.R. Weingart, *TASK VERSUS RELATIONSHIP CONFLICT: A META-ANALYSIS.* Academy of Management Proceedings, 2002. **2002**(1): p. B1-B6.

69. DeChurch, L.A. and J.R. Mesmer-Magnus, *The cognitive underpinnings of effective teamwork: a meta-analysis.* J Appl Psychol, 2010. **95**(1): p. 32-53.

70. Mathieu, J.E., et al., *The influence of shared mental models on team process and performance.* J Appl Psychol, 2000. **85**(2): p. 273-83.

71. Cooke, N.J., J.C. Gorman, and J.L. Winner, *Team Cognition*, in *Handbook of Applied Cognition*. 2008, John Wiley & Sons Ltd. p. 239-268.

72. Flin, R. and N. Maran, *Identifying and training non-technical skills for teams in acute medicine.* Quality & safety in health care, 2004. **13**(Suppl 1): p. i80-i84.

73. Langan-Fox, J., J. Anglim, and J.R. Wilson, *Mental models, team mental models, and performance: Process, development, and future directions.* Human Factors and Ergonomics in Manufacturing & Service Industries, 2004. **14**(4): p. 331-352.

74. Cannon-Bowers, J.A., E. Salas, and S. Converse, *Shared mental models in expert team decision making*, in *Individual and group decision making: Current issues.* 1993, Lawrence Erlbaum Associates, Inc: Hillsdale, NJ, US. p. 221-246.

75. Klimoski, R. and S. Mohammed, *Team Mental Model: Construct or Metaphor?* Journal of Management, 1994. **20**(2): p. 403-437.

76. Morgan, B.B., E. Salas, and A.S. Glickman, *An Analysis of Team Evolution and Maturation.* The Journal of General Psychology, 1993. **120**(3): p. 277-291.

77. Klingberg, T., *Limitations in information processing in the human brain: Neuroimaging of dual task*

performance and working memory tasks. Vol. 126. 2000. 95-102.

78. Driskell, J.E., E. Salas, and J. Johnston, *Does stress lead to a loss of team perspective?* Group Dynamics: Theory, Research, and Practice, 1999. **3**(4): p. 291-302.

79. Aveling, E.-L., et al., *Factors Influencing Team Behaviours in Surgery: A Qualitative Study to Inform Teamwork Interventions.* The Annals of thoracic surgery, 2018. **106**(1): p. 115-120.

80. Manser, T., *Teamwork and patient safety in dynamic domains of healthcare: a review of the literature.* Acta Anaesthesiologica Scandinavica, 2009. **53**(2): p. 143-151.

81. Gluyas, H., *Effective communication and teamwork promotes patient safety.* Nurs Stand, 2015. **29**(49): p. 50-7.

82. Lingard, L., et al., *Communication failures in the operating room: an observational classification of recurrent types and effects.* Qual Saf Health Care, 2004. **13**(5): p. 330-4.

83. Cannon-Bowers, J.A. and E. Salas, *Reflections on shared cognition.* Journal of Organizational Behaviour, 2001. **22**(2): p. 195-202.

84. Cooke, N.J., et al., *Team cognition in experienced command-and-control teams.* J Exp Psychol Appl, 2007. **13**(3): p. 146-57.

85. Sevdalis, N., et al., *Observational teamwork assessment for surgery: construct validation with expert versus novice raters.* Annals of surgery, 2009. **249**(6): p. 1047-1051.

86. Hull, L., et al., *Observational teamwork assessment for surgery: content validation and tool refinement.* J Am Coll Surg, 2011. **212**(2): p. 234-243.e1-5.

87. Yule, S., et al., *Development of a rating system for surgeons' non-technical skills.* Med Educ, 2006. **40**(11): p. 1098-104.

88. Beard, J.D., et al., *Assessing the surgical skills of trainees in the operating theatre: a prospective observational study of the methodology.* Health Technol Assess, 2011. **15**(1): p. i-xxi, 1-162.

89. Crossley, J., et al., *Prospective observational study to evaluate NOTSS (Non-Technical Skills for Surgeons) for assessing trainees' non-technical performance in the operating theatre.* Br J Surg, 2011. **98**(7): p. 1010-20.

90. Mishra, A., K. Catchpole, and P. McCulloch, *The Oxford NOTECHS System: reliability and validity of a tool for measuring teamwork behaviour in the operating theatre.* Quality and safety in health care, 2009. **18**(2): p. 104-108.

91. Fletcher, G., et al., *Anaesthetists' Non-Technical Skills (ANTS): evaluation of a behavioural marker system.* Br J Anaesth, 2003. **90**(5): p. 580-8.

92. Violato, C., J. Lockyer, and H. Fidler, *Multisource feedback: a method of assessing surgical practice.* BMJ, 2003. **326**: p. 546-548.

93. Yang, Y.Y., et al., *Assessment of first-year post-graduate residents: usefulness of multiple tools.* J Chin Med Assoc, 2011. **74**(12): p. 531-8.

94. Paisley, A.M., P. Baldwin, and S. Paterson-Brown, *Feasibility, reliability and validity of a new assessment form for use with basic surgical trainees.* Am J Surg, 2001. **182**(1): p. 24-9.

95. P. J. Driscoll, N.M., and S. Paterson-Brown, *The high fidelity patient simulator and surgical critical care*, in *Proceedings of the Annual Scientific Meeting of the Association for the Study of Medical Education*. 2003: Edinburgh, UK.

96. Mitchell, L., et al., *Evaluation of the Scrub Practitioners' List of Intraoperative Non-Technical Skills (SPLINTS) system.* International Journal of Nursing Studies, 2012. **49**(2): p. 201-211.

97. Russ, S., et al., *Observational teamwork assessment for surgery: feasibility of clinical and nonclinical assessor calibration with short-term training.* Ann Surg, 2012. **255**(4): p. 804-9.

98. Costa, A.d.S., Jr., *Assessment of operative times of multiple surgical specialties in a public university hospital.* Einstein (Sao Paulo, Brazil), 2017. **15**(2): p. 200-205.

99. Zheng, B., et al., *A quantitative study of disruption in the operating room during laparoscopic antireflux surgery.* Surgical Endoscopy, 2008. **22**(10): p. 2171-2177.

100. Zheng, B. and L.L. Swanström, *Video analysis of anticipatory movements performed by surgeons during laparoscopic procedures.* Surgical Endoscopy, 2009. **23**(7): p. 1494-1498.

101. Bao, B., W. He, and B. Zheng, *Performance of single versus two operators in laparoscopic surgery.* Laparoscopic, Endoscopic and Robotic Surgery, 2018. **1**(1): p. 15-18.

102. Zheng, B., et al., *Video analysis of endoscopic cutting task performed by one versus two operators.* Surg Endosc, 2005. **19**(10): p. 1388-95.

103. Zheng, B., L.L. Swanström, and C.L. MacKenzie, *A laboratory study on anticipatory movement in laparoscopic surgery: a behavioural indicator for team collaboration.* Surgical Endoscopy, 2007. **21**(6): p. 935-940.

104. Tien, G., B. Zheng, and M.S. Atkins, *Quantifying surgeons' vigilance during laparoscopic operations using eyegaze tracking.* Stud Health Technol Inform, 2011. **163**: p. 658-62.

105. Khan, R.S., et al., *Analysis of eye gaze: do novice surgeons look at the same location as expert surgeons during a laparoscopic operation?* Surg Endosc, 2012. **26**(12): p. 3536-40.

106. Vine, S.J. and M.R. Wilson, *The influence of quiet eye training and pressure on attention and visuo-motor control.* Acta Psychol (Amst), 2011. **136**(3): p. 340-6.

107. König, P., et al., *Eye movements as a window to cognitive processes.* 2016, 2016. **9**(5).

108. Yarbus, A., *Eye Movements During Perception of Complex Objects*, in *Eye Movements and Vision*. 1967, Springer US. p. 171-211.

109. Cassin, B.D.o.E.T.S.S.G., Fl: Triad Publishing Company. ISBN 0-937404-68-3.

110. Vickers, J.N., *Advances in coupling perception and action: the quiet eye as a bidirectional link between gaze, attention, and action.* Prog Brain Res, 2009. **174**: p. 279-88.

111. A. Poole, L.J.B., *Encyclopaedia of human-computer interaction.*, ed. C. Ghaoui. 2006, Pennsylvania: Idea Group Inc. 211-219.

112. Frame, M.E., *Quantifying Eye Movement Trajectory Similarity for Use in Human Performance Experiments in Intelligence, Surveillance, and Reconnaissance (ISR) Research*. 2018, Wright State Research Institute Beavercreek United States.

113. Hauland, G., *Measuring Individual and Team Situation Awareness During Planning Tasks in Training of En Route Air Traffic Control*. Vol. 18. 2008. 290-304.

114. Marquard, J.L., et al., *Nurses' behaviours and visual scanning patterns may reduce patient identification errors.* Journal of Experimental Psychology: Applied, 2011. **17**(3): p. 247-256.

115. Nodine, C.F., et al., *Recording and analyzing eye-position data using a microcomputer workstation.* Behaviour Research Methods, Instruments, & Computers, 1992. **24**(3): p. 475-485.

116. Khan, R.S.A., et al., *Analysis of eye gaze: Do novice surgeons look at the same location as expert surgeons during a laparoscopic operation?* Surgical Endoscopy, 2012. **26**(12): p. 3536-3540.

117. Richardson, D.C. and R. Dale, *Looking to understand: the coupling between speakers' and listeners' eye movements and its relationship to discourse comprehension.* Cogn Sci, 2005. **29**(6): p. 1045-60.

118. Gontar, P. and J. Mulligan, *Cross Recurrence Analysis as a Measure of Pilots' Coordination Strategy*. 2016.

119. Gontar, P., U. Fischer, and K. Bengler, *Methods to Evaluate Pilots' Cockpit Communication: Cross-Recurrence Analyses vs. Speech Act–Based Analyses.* Journal of Cognitive Engineering and Decision Making, 2017. **11**(4): p. 337-352.

120. Cassenti, D.N. and T.D. Kelley, *Towards the Shape of Mental Workload.* Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2006. **50**(11): p. 1147-1151.

121. Arora, S., et al., *The impact of stress on surgical performance: a systematic review of the literature.* Surgery, 2010. **147**(3): p. 318-30, 330.e1-6.

122. Hull, L., et al., *Assessment of stress and teamwork in the operating room: an exploratory study.* Am J Surg, 2011. **201**(1): p. 24-30.

123. Hyona, J., J. Tommola, and A.M. Alaja, *Pupil dilation as a measure of processing load in simultaneous interpretation and other language tasks.* Q J Exp Psychol A, 1995. **48**(3): p. 598-612.

124. Jiang, X., et al., *Pupil responses during discrete goal-directed movements*, in *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. 2014, ACM: Toronto, Ontario, Canada. p. 2075-2084.

125. Jiang, X., et al., *Pupil responses to continuous aiming movements.* International Journal of Human-Computer Studies, 2015. **83**: p. 1-11.

126. Khan, T., J. Westin, and M. Dougherty, *Motion Cue Analysis for Parkinsonian Gait Recognition.* The Open Biomedical Engineering Journal, 2013. **7**: p. 1-8.

127. Moorthy, et al., *Motion analysis in the training and assessment of minimally invasive surgery.* Minim Invasive Ther Allied Technol, 2003. **12**(3): p. 137-42.

128. Gödri, V., et al., *3D Motion Tracking for Laparoscopic Surgical Skill Assessment*. 2012.

129. Yu, D., et al., *Impact of novel shift handle laparoscopic tool on wrist ergonomics and task performance.* Surgical endoscopy, 2016. **30**(8): p. 3480-3490.

130. Liu, J., et al. *Tracking Sports Players with Context-Conditioned Motion Models*. in *2013 IEEE Conference on Computer Vision and Pattern Recognition*. 2013.

131. Stevens, R.H., T.L. Galloway, and A. Willemsen-Dunlap, *Neuroergonomics: Quantitative Modeling of Individual, Shared, and Team Neurodynamic Information.* Hum Factors, 2018: p. 18720818781623.

132. Stevens, R.H. and T.L. Galloway, *Toward a quantitative description of the neurodynamic organizations of teams.* Soc Neurosci, 2014. **9**(2): p. 160-73.

133. Klimesch, W., P. Sauseng, and S. Hanslmayr, *Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res Rev 53: 63-88*. Vol. 53. 2007. 63-88.

134. Klimesch, W., *alpha-band oscillations, attention, and controlled access to stored information.* Trends Cogn Sci, 2012. **16**(12): p. 606-17.

135. Hari, R., *Action-perception connection and the cortical mu rhythm.* Prog Brain Res, 2006. **159**: p. 253-60.

136. Roux, F. and P.J. Uhlhaas, *Working memory and neural oscillations: alpha-gamma versus theta-gamma codes for distinct WM information?* Trends Cogn Sci, 2014. **18**(1): p. 16-25.

137. Bonnefond, M. and O. Jensen, *Gamma Activity Coupled to Alpha Phase as a Mechanism for Top-Down Controlled Gating.* PLOS ONE, 2015. **10**(6): p. e0128667.

138. Jiang, J., et al., *Leader emergence through interpersonal neural synchronization.* Proceedings of the National Academy of Sciences, 2015.

139. Nozawa, T., et al., *Interpersonal frontopolar neural synchronization in group communication: An exploration toward fNIRS hyperscanning of natural interactions.* Neuroimage, 2016. **133**: p. 484-497.

140. Duan, L., et al., *Cluster imaging of multi-brain networks (CIMBN): a general framework for hyperscanning and modeling a group of interacting brains.* Frontiers in Neuroscience, 2015. **9**(267).

141. Zheng, B., et al., *Validity of using Fundamentals of Laparoscopic Surgery (FLS) program to assess laparoscopic competence for gynecologists.* Surg Endosc, 2010. **24**(1): p. 152-60.

142. Zheng, B., et al., *Quantifying surgeon's contribution to team effectiveness on a mixed team with a junior surgeon.* Surgery, 2011(6): p. 761.

143. Flin, R. and N. Maran, *Identifying and training non-technical skills for teams in acute medicine.* Qual Saf Health Care, 2004. **13 Suppl 1**: p. i80-4.

144. Cannon-Bowers, J.A., Salas, E., & Converse, S. A, *Shared mental models in expert team decision making*. Team performance assessment and measurement: Theory, methods, and applications, ed. E.S. Brannick, & C. Prince. 1993: Mahwah, NJ: LEA.

145. Xiaomin, L., B. Xinwen, and L. Lin, *Effects of Similarity and Accuracy Indices of Shared Mental Models on Team Creativity.* Acta Psychologica Sinica, 2014. **46**(11): p. 1734-1747.

146. Sailer, U., J.R. Flanagan, and R.S. Johansson, *Eye-Hand Coordination during Learning of a Novel Visuomotor Task.* J Neurosci, 2005. **25**(39): p. 8833-8842.

147. Hess, E.H. and J.M. Polt, *Pupil Size as Related to Interest Value of Visual Stimuli.* Science, 1960. **132**(3423): p. 349.

148. Hess, E.H. and J.M. Polt, *Pupil Size in Relation to Mental Activity during Simple Problem-Solving.* Science, 1964. **143**(3611): p. 1190.

149. Zheng, B., X. Jiang, and M.S. Atkins, *Detection of Changes in Surgical Difficulty: Evidence From Pupil Responses.* Surgical Innovation, 2015. **22**(6): p. 629-635.

150. Sun, P.-P., et al., *Feasibility of Functional Near-Infrared Spectroscopy (fNIRS) to Investigate the Mirror Neuron System: An Experimental Study in a Real-Life Situation*. Vol. 12. 2018. 86.

151. Roberts, K.-E., R.-L. Bell, and A.-J. Duffy, *Evolution of surgical skills training.* World journal of gastroenterology, 2006. **12**(20): p. 3219-3224.

152. Bashankaev, B., S. Baido, and S.D. Wexner, *Review of available methods of simulation training to facilitate surgical education.* Surg Endosc, 2011. **25**(1): p. 28-35.

153. Birch, D.W., et al., *Canadian consensus conference on the development of training and practice standards in advanced minimally invasive surgery: Edmonton, Alta., Jun. 1, 2007.* Canadian journal of surgery. Journal canadien de chirurgie, 2009. **52**(4): p. 321-327.

154. Woodworth, R.S., *Accuracy of voluntary movements.* Psychological Review,, 1899. **3**: p. 1-101.

155. Fitts, P.M., *The information capacity of the human motor system in controlling the amplitude of movement.* Journal of Experimental Psychology, 1954. **47**(6): p. 381-391.

156. Zheng, B., et al., *Quantifying surgeon's contribution to team effectiveness on a mixed team with a junior surgeon.* Surgery, 2011. **149**(6): p. 761-5.

157. Pupil Labs. *Pupil v0.3.6 - Marker Tracking*. 2019 [cited 2019 22 Feb.]; Available from: https://pupil-labs.com/blog/2013-12/pupil-v0-3-6-marker-tracking/.

APPENDIX

APPENDIX A: LAPAROSCOPIC EXPERIENCE SURVEY

ID No.: ____________ **Date:** ____________

Gender: Male Female **Age:** ______ **Handedness:** R L

Level of Training: Student R1 R2 R3 R4 R5 Fellow Staff

Number of Years doing Laparoscopic Surgery: 0 1-3 4-6 7-9 10+

Please circle the number of times you have performed each of the following procedures as a

Surgeon *(in column 1)* **and as an assistant** *(in column 2).*

	Performed as Surgeon	Performed as Assistant
Procedure	**Frequency**	**Frequency**

1) Laparoscopic Cholecystectomy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
2) Diagnostic Laparoscopy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
3) Laparoscopic Appendectomy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
4) Laparoscopic Nissen Fundoplication:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
5) Laparoscopic Splenectomy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15

6) Laparoscopic Bowl Resection:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
7) Laparoscopic Adrenalectomy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15

Procedure	**Performed as Surgeon Frequency**					**Performed as Assistant Frequency**				
8) Laparoscopic Nephrectomy:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
9) Laparoscopic Bariatric surgery:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
10) Laparoscopic Inguinal Hernia Repair:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15

11) Laparoscopic Incisional Hernia Repair:	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15
12) Other Advanced Procedure(s): Please Name Procedure(s):	0	1-5	6-10	11-15	>15	0	1-5	6-10	11-15	>15

Total Score: ___________________________