Towards Supporting Intraoperative Coordination and Entrustment in Surgical Faculty-Resident Dyads: *Looking Together ≠ Seeing the Same Thing*

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ABSTRACT

Laparoscopic surgeries require a high degree of visuo-spatial coordination between attending and resident surgeons. The challenge is intensified when surgeons communicate verbally using visual cues. Most prior work in the space supports attending surgeons to give clearer instructions to residents. However, in order to achieve intraoperative success, shared understanding, coordination and trust between faculty-resident dyads is essential. Our work focuses on unpacking both attending and resident surgeons' experiences during intraoperative operations. We perform an interview study with 6 attending and 3 resident surgeons, in which we ask participants to share their thoughts on the utility and feasibility of capturing surgical dyads' joint visual attention (JVA) during live surgeries. We find that attending and resident surgeons have contrasting and complementary views about autonomy, communication and coordination during surgeries. We also see positive attitudes towards capturing surgeons' visual attention during live surgeries and using the data to support communication, coordination and instruction.

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CCS CONCEPTS

• Human-centered computing → Empirical studies in collaborative and social computing; **• Applied computing → Health informatics**.

KEYWORDS

Intraoperation Coordination; Joint Visual Attention; Surgical education; Surgical training

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1 INTRODUCTION

Learning how to do laparoscopic surgeries is a cognitively demanding task that requires a high degree of visuo-spatial coordination between attending (trainer) and resident (trainee) surgeons. Laparoscopic or video-guided surgery is when the surgeon's viewpoint of the operative field is facilitated through a laparoscope. Guided by two-dimensional video feed, both surgeons need to orchestrate the sequence and timing of what to see and how to see it, which informs subsequent actions during an operation. The highly symbiotic relationship between attending and trainee surgeons is crucial for laparoscopic training because it requires a delicate balance of maintaining patient safety while still offering the opportunities for training.

The importance for greater coordination and visual alignment among surgical team members was emphasized in a study of 252 cases of laparoscopic cholecystectomy which revealed that 97 percent of surgical errors resulted from visual misperceptions during the procedure [15]. Limited depth perception, loss of spatial orientation, need to interpret two-dimensional (2D) view of a three-dimensional (3D) operative field are characteristics that make laparoscopic surgery more difficult and can increase the learning curve of inexperienced trainees. Joint visual attention (when two or more individuals are looking at a common target at the same time) is vital for understanding intraoperative teaching, visual-spatial coordination, and teamwork. In a collaborative situation, both physical hand gestures and verbal explanations aimed at guiding visual attention to a target can easily be misinterpreted leading to miscommunication. Uncertainty over where the supervising surgeon wants the trainee to pay attention can cause confusion, stress and increased risk of errors when learning laparoscopic skills in the operating room.

To date, most research on surgery training with eye-tracking technology has either used offline video recordings to compare expert and novice surgeons gaze patterns or conducted in only simulated environments, thus lacking the psychological fidelity of real-world surgery and real-time shared gaze visualizations required for in-situ learning [6]. An important *gap* in the existing evidence base is that not much is currently known regarding visuo-spatial coordination challenges from the perspective of both attending and resident surgeons in laparoscopy training. Technologies to support intraoperative coordination mainly focus on the attending surgeon's perspective, e.g., expert-driven virtual pointers guiding trainee's gaze to a target or modeling a surgical technique [1, 4, 6]. However, the novice surgeons' views are equally important as their performance contributes to the success of the surgery and influences how attending surgeons provide instruction.

In this work, we take **a unique perspective of understanding both attending and resident surgeons'** challenges and desires during intraoperative operations. We hope this study is a starting point for developing technologies to support intraoperative coordination and instruction that meet both attending and resident surgeons' needs. Specifically, we explore two research questions:

(1) What are the current needs, challenges, preferences for intraoperative coordination and training support during laparoscopic cholecystectomy according to attending and resident surgeons?
(2) What is the desirability, utility and feasibility of using technologies to capture surgeons' visual attention and the attention alignment between surgical dyads during surgeries?

We conduct semi-structured interviews with 6 attending and 3 resident surgeons in the United States from June to November 2021. This study makes two contributions. First, our interviews provide a rare description of both attending and resident surgeons' experiences during intraoperative operations. Our findings reveal that both residents and attendings face difficulties in managing the high cognitive load during surgeries and making visuo-spatial coordination. Furthermore, we observe contrasting and complementary interpretations of the challenges between attending and resident surgeons. This highlights the need of understanding and prompting resident surgeons' needs when developing intraoperative operation support. Second, we present surgeons' attitudes towards the utility and feasibility of capturing attention data throughout live surgeries. We discuss surgeons' needs and wants with regard to the use of novel technologies in the space and propose several future directions to support intraoperative coordination, instruction and entrustment, including visualizing in-the-moment attending's and resident's gaze alignment when requested, and extracting teachable moments and identifying missed feedback during postoperative debriefings.

2 RELATED WORK

Previous research has established the importance of visual attention and coordination in surgical training. A number of studies have examined the effects of expert surgeon visual guidance on trainee visual search strategy, visual attention and skill acquisition by using various techniques, such as gestures, virtual pointers, augmented reality virtual pointer, telestration, offline videos with gaze overlay – all in conjunction with verbal instructions(s) [4, 5, 8–10, 12].

There is a well-documented body of literature that shows the ability of eye-tracking to produce robust quantitative data and serve as an objective measurement method, with possible applications in surgical training and skill assessment. Ashrafa et al. [2] reviewed the current evidence for use of eye-tracking methodology to improve training, assessment, and feedback practices in the clinical setting. Studying differentiated gaze patterns between expert and novice surgeons, this study found a significant performance advantage of individuals who had been gaze-trained to focus on target locking fixations rather than tool movement. Adapting to the gaze strategies of experts, these gaze-training individuals performed better in the eye-metric assessment. The ability to quickly adapt gaze behaviors, without significantly improving skill, to perform better in the eye-metrics assessment has major implications on the use of using gaze behavior assessment alone with no other assessment tools.

It has conclusively been shown that attending and residents have distinctive gaze patterns [1, 2, 4]. For example, Khan et al. [9] captured the eye gaze of two expert surgeons performing a laparoscopic cholecystectomy. He then replayed the video to 16 experts and 20 junior residents and recorded their gaze while they were watching the video. They found that experts who watched the original video had significantly higher (55% of the time) overlap with the two experts in comparison with the residents who had overlap 43.8% of the time. Wilson and colleagues [16] found similar results from two studies where expert surgeons demonstrated substantially greater fixation of relevant anatomic targets in laparoscopic procedures. Similarly, Richstone and colleagues [13] were able to reliably differentiate inexperienced and expert surgeons with the use of linear discriminate and nonlinear neural network analyses on pupillometric data available from eye tracking in both simulated and live laparoscopic procedures.

Another research strand focuses on using eye-trakcing technology for surgical skill assessment. For example, Evans-Harvey et al. [5] analyzed the relationship of gaze behavior and technical skill during laparoscopic cholecystectomy. Dwell time (%) and fixation frequency (count/s) were tracked with wearable eye tracking

Figure 1: A sketch of a typical operating room setup and surgical team in a laparoscopic cholecystectomy surgery. In this figure, the resident surgeon (in red hat) is the primary surgeon, and the attending surgeon (in blue hat) is playing the supporting role. The other two clinicians in white hats are nurses. Both the attending and residents surgeons look at the monitor while performing the surgery. Surgeons often communicate using visual cues such as "That's arteries right there.", "I think this is bottom right here."

glasses. Their results showed that during critical portions of the operation, more technical proficiency is associated with greater focus on significant surgical objects and a lack of visual attention to non-essential stimuli.

Along with the potential of surgical skill assessment, other studies have focused more on gaze training. For example, Feng et al [6] examined the effects of a real-time virtual pointer for simulated laparoscopic training. During laparoscopic training, the expert-guided virtual pointer effectively increased surgical trainees' in-the-moment gaze concentration by minimizing gaze dispersion and focusing their attention on the anatomical target. Chetwood and colleagues [4] tracked the gaze patterns of attending surgeons and overlapped them on the simulated laparoscopic screen of trainees to aid instruction. They found that both completion time of the task and number of errors were reduced when they were using this method of gaze instruction. Using gaze behavior information allows faculty and students to better understand the location of one another's visual attention in order to better communicate with each other.

Drawing on previous research, understanding and tracking the joint visual attention of attending and residents has the potential to improve the learning experience within the medical field. Although joint visual attention has been assessed previously with the use of recorded offline videos mostly in the simulated environments, this study lays the foundation for understanding the attending and resident surgeons' distinct needs and potential use of the Joint Visual Attention system to facilitate intraoperative teaching and coordination in live laparoscopic cholecystectomy surgeries.

3 CONTEXT

This study focuses on a frequent case that all general surgery residents encounter and partake in, the laparoscopic cholecystectomy, which is commonly known as the gallbladder removal surgery. We will refer to the surgery as Lap Chole in the rest of the paper. There are three reasons that we chose to explore surgeons' needs and challenges in this context. First, it is the most basic surgery that every surgical resident needs to learn, practice and master. It is common that resident surgeons will be the primary surgeons while the attending surgeon will act as the assistant directing the resident as they operate (see Figure 1). Second, these surgeries also entail the identification of key structures and planes and frequent reorientation between attending and trainee surgeons. In other words, visual cues and visual alignment between surgeon dyads is critical. The critical portions of laparoscopic cholecystectomy often require high levels of precision and visual alignment between attending and resident surgeons including e.g., identification and dissection of the key structures (cystic duct and artery). Third, these surgeries have clear distinction between steps [7], which provides the convenience for us to segment a surgery into episodes and analyze the critical portions.

4 METHOD

4.1 Positionality

Given that the focus of this paper is on surgical training, the authors believe it is important to share their own professional identities that contribute to their perceptions of a training culture in surgery, role of technology in medical education, and long-term goals in supporting surgeon preparation. Two of our co-authors are resident surgeons, 1 co-author has extensive experience on surgical training as a faculty member, and 3 authors have backgrounds in educational technology and HCI research. We consider it crticial and immensively beneficial to have our target users (resident surgeons and surgical educators) on the team, especially in reflecting on the practical implications of our research ideas on real stakeholders.

4.2 Participant Recruitment

We carried out this IRB-approved research at at a university teaching hospital of large surgical volume in the U.S. Since surgeons are often on shifts and have busy schedules especially during COVID, it was very challenging to recruit surgeon participants. We sent recruitment advertisements to resident surgeons' mailing lists and recruited through our cycles. Nine surgeons participated in our study, with 6 attending surgeons (two female and four male), and 3 resident surgeons (all male; post graduate years 2, 4 and 6). The attendings have a minimum of 5 years of experience with mentoring surgical trainees and extensive experience performing Lap Chole procedures. The surgical residents performed over 30 Lap Chole surgeries in the operating room. It is worth noting that we realized in our recruiting process that our participant population (at least in the context we investigated) skewed towards White Male. We recognize this lack of diversity in our study sample, which was reported as an issue with the surgeon community [11]. We hope our research, among others, help support intraoperative coordination, surgical training, surgeon preparation, which could in turn increase the inclusivity and diversity of the field.

4.3 Interview Procedure and Analysis

Each semi-structured interview session took about one hour via Zoom and included two main portions focusing on: 1) understanding instruction, coordination and operation needs and challenges pertinent to Lap Chole surgeries and 2) probing into participants' attitudes on capturing joint visual attention (JVA) during live surgeries. For the first portion, participants were asked to recall their most recent experience of a Lap Chole surgery, we asked participants to share what they thought worked well and what were some challenges they experienced relative to intraoperative coordination and entrustment. The interview questions were the same for attending and resident surgeons with the particular questions tailored to the role of the participant. For example, for an attending, when giving instructions, "are there moments when you feel the resident is not looking at the same location as you or understanding your instructions? If yes, please tell me about one of these times." For a resident, when receiving instructions from the attending surgeon, "are there ever moments when you think the attending and you are looking at two different places? Tell me about one of the moments? What made it challenging?" In addition, the interview included questions regarding problem-solving (e.g., What challenges (if any) did you have conveying visual cues in the process?), communication (e.g., Recall a recent moment when you were not sure whether you and a resident surgeon were on the same page during a surgery. How did you recognize this lack of coordination? What did you do when this happened?), trust and leadership (e.g., For critical portions of the case, how does your intraoperative teaching or level of autonomy change, if at all?). In the second part, participants were shown a demo video where both surgeons wear eye-tracking glasses and their visual attention was captured throughout a surgery. We used this as a design probe to investigate participants' thoughts around capturing visual attention during surgeries, in particular how they may envision using this information to support intraoperative coordination, instruction and learning, and what are some perceived risks with this approach. We will refer to the design probe as JVA (Joint Visual Attention) in the rest of the paper.

The interview were first transcribed. We conduced a thematic analysis [3] using NVIVO. First, two authors familiarized themselves with the data by reading the interview transcripts and memos. Two authors then did open coding with two participants' transcripts (one attending and one resident) independently and then met to discuss and compare their codes. After that, one author coded the remaining data through an iterative process, in which she met with other authors regularly to discuss the codes and iterate on the findings.

5 RESULTS

5.1 Challenges of intraoperative coordination between surgical faculty-resident pairs during Lap Chole: Attending's perspective

5.1.1 It is cognitively demanding to balance planning, operating, and instructing at the same time. From the perspective of the attending, one is required to simultaneously make multiple complex decisions while managing an operation. These decisions primarily center around observation, instruction, and patient care. The ability to anticipate or foresee is critical for managing cognitive load and effective teamwork, coaching and performance. A2 said: *"when you become an attending, you just want to do it safely. You're worrying three steps down the line, everything they're going to do and what's going to go wrong, what you're going to do if it goes wrong, and how are you going to prevent it from going wrong. It's sort of a cognitive load during the case. So when I see a resident dissecting unsafely.. how do I get them out of there? If they get into the bile duct? What am I going to do? You're making all these micro judgments and micro assessments in your head..."*

5.1.2 I'm constantly assessing how much autonomy I should give to a resident to make sure the surgery proceeds safely. Trainees are paired with any number of attendings and other personnel, all of which may have different mental models of training. Supervising faculty typically gauge the resident's skill set to assess how much autonomy should be given to them based on the continuous observation of specific verbal and nonverbal behaviors as markers of readiness and trustworthiness for patient care (e.g., instrument handling, discussion of the operative plan, problem solving, leadership by the surgical resident). Residents who are more prepared and further along in their training are expected to demonstrate higher levels of independence, confidence, and clinical competency. As A1 noted: *"I don't know what their past experiences have been. "*

Further, the cumulative experience of an attending-resident dyad working together helps supervising faculty decide the degree of operative autonomy that can be granted to residents and how closely they need to monitor and guide residents' actions. In addition, a surgical resident can explicitly state their needs and goals prior to or during an operation, which allows both attending and resident to develop clear expectations and improve coordinating behavior. Attending-resident dyads lacking in shared understanding have reduced coordination, which can potentially increase the strain for both surgeons and the risk of errors.

5.1.3 It's hard to communicate verbally where they should be looking at. Most interviewed attending surgeons felt that guiding trainees' visual attention to a specific target is a major focus in laparoscopic training. During the interviews, nearly every participant described a scenario in which there was a disagreement or discrepancy stemming from differences in mental models and visual misalignment between resident and attending surgeons.

Issues related to mismatch of visual attention due to different perspectives were prominent in the interviews. For example, A3 said *"sometimes...instead of focusing on my screen, I turn around and focus on their screen to see if what they're seeing or what I'm seeing is the same...Let's say there's bleeder one, two and three bleeder. Number one for them is more prominent on their screen than it is on my screen. It does happen just because of the way the intensity angles are... there could be disagreement, visual disagreement on the information that's being conveyed."*

Compared with other kinds of instruction, attendings are limited in their hand movements and other visual references to help their verbal explanations, which may cause misunderstanding. A common need amongst interviewees was to have more visual aids and pointer tools to supplement verbal information and guide visual attention during a surgical task. There were three popular strategies according to the participants to communicate visual information: (a) using surgical instruments at hand, e.g., a grasper or Q-tip to point at a screen, (b) controlling the camera angle, zoom and focus to denote an area of interest, and (c) modeling by taking over the instruments and showing exactly what and where to focus. A4 noted *"it's not like I have another hand free to go into the body and* *point to things. The best way to just point at the screen. I like the Kittner (Q-tip like instrument), it helps, you are both looking at the same screen. They [resident] still have control of the instruments, and then you're just pointing to the screen. It's real time feedback, I guide them to, you know...dissect that."*

5.2 Challenges of intraoperative coordination between surgical faculty-resident pairs during Lap Chole: Resident's perspective

5.2.1 I want to do as much of the surgery as possible. As attendings described that it consumes cognitive load to constantly evaluate residents' capabilities and decide how much autonomy to give them, residents also shared their views on autonomy. All residents shared that they want more autonomy during surgeries, and they need to demonstrate their capabilities to the attending to be able to perform during surgeries. E.g., R2 said *"To try and get more autonomy from the attending typically requires you to really know the step that you're on and multiple steps moving forward. Otherwise they're going to take over from you. And you have to assist them perfectly. And there's a worry that they'll just keep going and you won't get to practice your part of the surgery."*

Residents also shared the emotional consequences when they were not given enough autonomy and trust during intraoperative operations. R1 said *"It's part of your identity as a resident is to do as much of the surgery as you can every day. Because those are learning opportunities and you don't want to feel like a bad student. If it gets take away from you, you know, no one wants to feel that way."* R2 added to that sentiment *"When you get a surgery taken away from you, as a resident, it feels like you've messed up or you felt like something went wrong, you're not good enough, there's a lot of emotion, there's actually like there's an interesting emotional switch."*

5.2.2 When disagreement or visual misalignment happens, I do not have a way to effectively communicate with the attending. The attendings shared their challenges in providing instructions based on visual cues and some frustration around visual misalignment between them and the residents. From the residents' perspectives, they viewed some of the challenges as a lack of communication.

As R3 recalled his disagreement with an attending surgeon in a recent case: *"The reason that I wasn't succeeding is because I disagreed with his approach, I didn't think it was the way to go. And then at certain times, when I was like, Okay, I'll try that, it either wouldn't work, or I was interpreting his words differently. It was so sort of like a telephone game eventually what happened is that we sort of swapped places a couple of times, just so that one of us could do the operating and the other can do the talking and then rotated. It was an exquisitely painful experience."*

R2 also shared *"And so the challenge in that scenario becomes the attending says something one way and I say something another way, sometimes that's good, or we kind of interpret each other's words. What happens really, in most instances, is that the resident is getting two different directions. Right there. I say, I'll work your way down here with this instrument, and the attending says no, and work your way up there with that instrument. And so what I usually do is I just because clearly know I'm not gonna win. So I just sit quietly and let the attending do the takeover."*

5.3 Utility of Joint Visual Attention to Foster Intraoperative Coordination and Instruction

The study participants on the whole acknowledged the benefits of capturing visual attention during surgeries and suggested two promising modes of using visual attention data: 1) intraoperatively (during the surgery) to visualize both surgeons' visual attention during live surgeries; 2) postoperatively (after the surgery) to extract confusing portions during the surgery where the visual attention of both surgeons do not align.

5.3.1 Motivation to use JVA intraoperatively. ***Provide real-time gaze data on request.*** Two divergent opinions emerged with respect to the JVA utility intraoperatively. Most attending surgeons felt the real-time gaze visualization could be distracting during the surgery if it is on all the time and not as meaningful because looking together is not the same as seeing the same thing. For instance, A3 illustrated his point by saying *"that would be very distracting. I think it would be very, very difficult to have it on all the time, in real time. You could have it selectively on, but interacting with technology while you're in a sterile field is difficult. A foot pedal would be nice. Like if I had a little foot pedal that I could like, tap it whenever I want to see where they're looking, might be useful."*

On the other hand, surgical resident participants reported that watching attending surgeons' in-the-moment gaze behavior could help them better understand why, when, how and where to focus their attention. R1 said *"I think live could be helpful rather than after the fact. I think sort of intermittently, like there's a button where you can say, hold on, we're not figuring this out, you're in your one page and I am on another page. A circulating nurse, can you come hit the button and turn on my eye tracking, and I'll tell you where I'm looking."*

Affordances of combining AI and eye-tracking technologies. Some of the attending surgeons suggested combining AI and eye-tracking technologies to help identify potential safety issues, autocorrect an anatomic variant and co-regulate human perception by prompting alternative steps and offering new visual cues. A2 noted *"Even as an expert, you can be looking at the wrong thing, because most errors and most safety issues come from misidentification, or structured thinking that you're seeing something that you're not really seeing. I think it is exciting that based on training the system or training a camera, we can overcome human bias and what we're seeing through autocorrecting during the case. We're seeing this but the AI is seeing this and entering the interface to prevent danger."*

5.3.2 Motivation to use JVA postoperatively. Most attending surgeons applauded the use of JVA to analyze postoperative case videos. Three main affordances of JVA emerged from the interview data: (a) enrichment of coaching opportunities (b) making decision-making visible to foster post-surgery self-assessment and reflection, (c) understanding effects of faculty-resident intraoperative teaching interactions.

Enriching coaching opportunities. There was a clear sense among the attending surgeons that the shared gaze visualizations could help identify a teachable moment through the automated analysis of most concordant and discordant segments during the critical portion of the surgery and inform precision-feedback. A5 noted *"there's a way to provide that data back and say hey, at minute 10 it was off, at minute 14 and it was off at minute 22 it was off and then focus in on those moments where it was different and then start the conversation with coaching and provide feedback with those moment... "*

Making decision-making visible to foster post-surgery self-assessment and reflection. A common view amongst attending surgeons was that the postoperative case video analyses with overlaid gaze data may enable trainees to better learn from performance errors, identify missed feedback, reverse engineer intraoperative micro judgments and to inform deliberate practice. A3 said *"I think retrospective is a great idea...often I think in order to make progress in the case, eventually you have to get on the same page and look at the same tissue. It might be an interesting question: when you're struggling in a case, for how long? Are you not looking at the same spot? And is that the reason for it? So I think those are some interesting things."*

Understanding effects of faculty-resident intraoperative teaching interactions. JVA technique may additionally enable the attending surgeons to evaluate the effectiveness of their instructions during surgeries. As A6 noted *"what kind of cues make the resident's eyes go from right field to where I [attending] want them to look...There are clear implications in relation to communication and cognitive load, specifically in the operating room. This is in effect using technology to evaluate how we communicate in the operating room. "*

5.4 Barriers of JVA approach

When asked about potential barriers of capturing visual attention in the operating rooms, there were three main concerns brought up by the participants. First, whether it would interfere with the flow and the conduct of the operation. Second whether eye-tracking technology would elicit a dyadic Hawthorne effect, when individuals change their behavior in response to their awareness of being observed. Third, the limitations of using the alignment of visual attention to assess residents' surgical skills.

6 LIMITATION AND FUTURE WORK

This study is a first step towards supporting intraoperative coordination, instruction and entrustment, in which we take a unique perspective of understanding both stakeholders' views during intraoperative operation. One main limitation of the study is that our participant sample is small. This is an ongoing project where we are continuously recruiting participants and elicit new participant feedback. We have also performed a field study in the operating room observing how surgeons respond to eye-tracking glasses in authentic scenarios. We are in the process of analyzing data and consolidating findings. Based on the suggestions from our participants, we are excited about several future directions to support intraoperative operation, including 1) Develop AR-based applications to project both surgeons' visual attention on the monitor when requested during the surgery and investigate the effects. 2) Investigate the reliability of using JVA metrics as a formative assessment of resident entrustability, e.g., through correlating JVA metrics with expert ratings [14] 3) Develop systems that enable attending surgeons to capture teachable moments based on JVA data and provide additional deliberate practice opportunities to surgical residents.

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