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Sergeeva, Anastasia V.; Faraj, Samer; Huysman, Marleen

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LOSING TOUCH: AN EMBODIMENT PERSPECTIVE ON COORDINATION IN ROBOTIC SURGERY

Anastasia Sergeeva
Vrije Universiteit Amsterdam, KIN research group
a.sergeeva@vu.nl

Samer Faraj
McGill University, Desautels Faculty of Management
samer.faraj@mcgill.ca

Marleen Huysman
Vrije Universiteit Amsterdam, KIN research group
m.h.huysman@vu.nl

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ABSTRACT

Because new technologies allow new performances, mediations, representations, and information flows, they are often associated with changes in how coordination is achieved. Current coordination research emphasizes its situated and emergent nature, but seldom accounts for the role of embodied action. Building on a 25-month field study of the da Vinci robot, an endoscopic system for minimally invasive surgery, we bring to the fore the role of the body in how coordination was reconfigured in response to a change in technological mediation. Using the robot, surgeons experienced both an augmentation as well as a reduction of what they can do with their bodies in terms of haptic, visual and auditory perception, and manipulative dexterity. These bodily augmentations and reductions affected joint task performance and led to coordinative adaptations (e.g., spatial relocating, redistributing tasks, accommodating novel perceptual dependencies, and mounting novel responses) that, over time, resulted in reconfiguration of roles, including: expanded occupational knowledge, emergence of new specializations, and shifts in status and boundaries. By emphasizing the importance of the body in coordination, this paper suggests that an embodiment perspective is important for explaining how and why coordination evolves following the introduction of a new technology.

Keywords: embodiment, coordination, technological mediation, technology, robots, role reconfiguration, expertise, materiality, surgery.

INTRODUCTION

Human action in the world is increasingly mediated by technologies that augment perception and action at a distance. Using remote sensing and immersive digital environments, humans can now direct rovers on Mars, monitor and intervene in subsea oil exploration, and control drones flying on a different continent (Parmiggiani and Monteiro 2018; Vertesi 2012; Qaurooni and Ekbia 2017). These technologies overcome the physiological limitations of the human body and enable perceptions and manipulations that were not previously possible. While concerns have been raised about the impact of such technologies on knowledge job categories (Brynjolfsson and McAfee 2014; Frey and Osborne 2017), studies in actual work settings indicate that, rather than simply replacing human jobs with machines, such technologies reshape work and workplace relations in complex and unexpected ways. For example, robotic telepresence was found to transform hospital rounds by enabling new coordination modalities (Beane and Orlikowski 2015). Similarly, the introduction of a hospital pharmaceutical dispensing robot resulted in a redistribution of status and expertise across occupational groups (Barrett, Oborn, Orlikowski, and Yates 2012). Thus, technologies that mediate bodily perception and action are likely to be associated with the profound transformation of work practices and coordination in the workplace.

To investigate such a transformation, we offer a study of the da Vinci robot[1], an endoscopic surgical system for minimally invasive surgery, in a hospital operating theater. The da Vinci system allows a surgeon to operate on a patient remotely, relying on a three-dimensional image of the body, while seated at a console away from the operating table. By using the robot, the surgeons gain an immersive experience of operating, as they are able to "see," via the endoscopic camera inserted through laparoscopic incisions, with great detail and in three dimensions. The surgeon manipulates joysticks that control the robot's arms inside the patient's body. As a result, the surgeon is no longer confined to the vantage point along the operating table, but can see more within the body.

We focus on the following research question: how does the body matter in how coordination is reconfigured following a change in technological mediation? The context of surgery offers a unique

[1] As of July 2018, 4409 da Vinci surgical robots were in use worldwide and had been used for 5 million surgeries, see https://www.intuitivesurgical.com/

opportunity for answering this question. The work of surgery is highly reliant on the skilled bodily performance of multiple occupational groups (surgeons, residents, anesthesiologists, nurses) that work in a highly interdependent and co-located manner. Knowing how to perform incisions, how to repair arteries or organs, or how to quickly intubate a patient is a skilled performance that requires the operating team to collectively orchestrate their embodied actions without endangering patients' lives (Sabiston and Townsend 2012). Hospital surgery is heavily protocolized, with a clear delineation of occupational roles. Specific rules guide the skilled handling of instruments (e.g. scalpels, monitors and scissors), materials (e.g., organs), and regulate the use of physical space (e.g., standing at a specified position next to a patient's body). Thus, the introduction of a technology that allows a novel embodied performance, such as the remote manipulation of organs via an immersive experience for the surgeon, is likely to perturb the finely tuned coordinative arrangements in surgery.

Building on a 25-month field study of the introduction of the da Vinci robot, we find that the surgeons experienced both an augmentation as well as a reduction of what they can do with their bodies, including changes to haptic, visual and auditory perception, and manipulative dexterity. These augmentations and reductions had implications for the team's embodied interaction, requiring team members to engage in coordinative adaptations, such as relocating spatially, redistributing tasks, accommodating new perceptual dependencies, and mounting novel responses. In turn, these adaptations led to a reconfiguration of occupational roles. To explain how coordination evolves in response to novel technological mediation, we argue for an embodiment perspective that foregrounds the importance of bodily perception and embodied interaction in collaborative work. By going beyond the social and cognitive aspects of coordination, the embodiment perspective explains how specific technology-enabled augmentations and reductions in embodied work are consequential for coordination.

RESEARCH ON TECHNOLOGY AND COORDINATION

In recent years, coordination research has shifted away from a perspective that emphasizes structure and pre-specified arrangements, to one that emphasizes coordination as a situated practice or an ongoing accomplishment. When situations are fast-changing or equivocal, where boundaries are fluid, or when issues fall outside the domain of a single discipline, pre-specified coordination mechanisms become insufficient. Participants may turn to knowledge-sharing practices that are dialogic, cross-disciplinary, and emergent in order to adapt to such unexpected situations (Faraj and Xiao 2006; Kellogg, Orlikowski, and Yates 2006; Bechky and Okhuysen 2011). To coordinate expertise across specialties, there is a need to: transform knowledge for it to cross occupational boundaries (Carlile 2002), use dialogic practices to integrate knowledge across specialties (Faraj and Xiao 2006), rely on mutual monitoring and co-participation (Heath and Luff 1992), share relevant knowledge using common spaces (Kellogg et al. 2006), and rely on cross-profession brokerage roles (Kellogg 2014). This emergent emphasis on coordination as a situated process can be a valuable lens for studying moments of change, such as the introduction of a novel technology. Such a perspective allows the tracing of how coordination arrangements evolve following the introduction of a novel technology and puts the focus on the reconfigurations necessary to re-align actions, interactions, and roles.

While technologies are often introduced with the goal of improving productivity, they end up affecting work coordination in major and unexpected ways. New technological mediations can be associated with: decreased dependence on experience-based skills (Zuboff 1988), reduced reliance on hierarchy for coordination and control (Zammuto, Griffith, Majchrzak, Dougherty, and Faraj 2007), delocalization of work (Bailey, Leonardi, and Barley 2012), and an increase in shared situational awareness (Majchrzak and Malhotra 2014). When groups rely on technology to sustain coordination at a distance, conflicts can emerge due to a lack of familiarity and common ground between participants (Hinds and Bailey 2003; Hinds and Kiesler 2002) or because digital objects may not fully represent reality (Kallinikos, Aaltonen, and Marton 2013; Bailey and Leonardi 2015). Another challenge occurs when new systems inscribe rigid ways of working that may hinder efforts to coordinate the work. In such cases, when demands of complex work exceed what is possible via the system, workarounds become necessary to ensure effective coordination (Gasser 1986; Azad and King 2008; Pine and Mazmanian 2017).

When complex knowledge integration is necessary, technology mediation may impede the ability to sustain effective coordination. For example, when robotic telepresence was introduced in intensive care, residents, nurses, and attending physicians struggled to sustain dialogic sense-making and to integrate their expertise in order to achieve agreement on the course of treatment (Beane and Orlikowski 2015). In a robotic surgery setting, when the surgeon relocated to a console a few meters away, team members needed to invest significant effort to re-establish common ground and reduce cognitive and affective distance (Pelikan, Cheatle, Jung, and Jackson 2018). Thus, new technologies introduced with the goal of improving productivity or sustaining collaboration at a distance can unintentionally exacerbate coordination problems or create new ones.

Beyond affecting interaction, technological mediation can unsettle established organizational roles. Roles, as coordination mechanisms, help sustain cross-disciplinary interaction because they specify requisite expertise, allocate tasks and responsibilities, and draw the boundaries of professional jurisdictions (Barley 1990; Bechky 2006; Faraj and Xiao 2006; Kellogg 2014; Valentine and Edmondson 2015). Coordinating via roles can be effective because such arrangements establish mutual expertise expectations and facilitate task accomplishment without the need for recurrent allocation and negotiation of who-does-what. When new technologies are introduced, opportunities emerge to perform, divide, and organize work differently; thus, changes in previously negotiated role arrangements are bound to follow (Barley 1986; Zuboff 1988; Zammuto et al. 2007). Incorporating a new technology in the work process can lead to the weakening or empowering of certain occupational groups. For example, a study of the introduction of minimally invasive cardiac surgery found that successful surgery teams were the ones that proactively redefined roles in the team, which incorporated new ways for sharing knowledge and empowered nurses to speak up when patient safety was in question (Edmondson, Bohmer, and Pisano 2001). Furthermore, new occupational roles may need to be introduced to solve coordination problems in newly digitized distributed work (Bailey et al. 2012). Role boundaries between groups may be affected, because making room for new technologies may require certain groups to take on additional tasks or suffer from diminished opportunities to perform (Barrett et al. 2012; Beane 2018).

In sum, the extant literature on coordination would predict that technology introduction is likely to be accompanied by coordination upheaval, contestation around role definitions and occupational boundaries, and the re-allocation of new and old tasks. In our setting, when the robot became embedded in the surgical practice, we saw fewer struggles, contestations, and workarounds than would have been expected. Instead, we saw a steady transformation in how individual bodily performances were achieved and joint action was synchronized. Mostly, team members changed their spatial position around the patient, redistributed tasks, accommodated the augmentation and reduction associated with the technology, and mounted novel responses. To trace this reconfiguration process and do justice to its bodily element, we adopt an embodiment perspective on coordination.

TOWARD AN EMBODIMENT PERSPECTIVE ON COORDINATION

Adopting an embodiment perspective on coordination is useful because engaging with the world via technologies necessarily provides a different mode of perception and action, which can both enhance and limit work performance (Ihde 1979). Calling for "bringing the body in", the embodiment perspective on work contributes to management and organization research by offering an alternative to the traditional cognition or information-processing perspective on skills, decision-making, and problem solving. An embodiment perspective recognizes that we engage with the world not only through representations and cognitive models, but also through our senses and bodies (Merleau-Ponty 1962; Dreyfus and Dreyfus 1982; Shapiro 2010). By accounting for the presence of the body at work, researchers have emphasized how physical, sensory, and bodily skills are a constitutive aspect of expert work (Dreyfus and Dreyfus 2005), how the body's physiological limits clash with organizational expectations of long work hours (Michel 2011), and the direct relationship between work stress and individuals' overall health (Heaphy and Dutton 2008). Individual engagement in the workplace relies on the body to sense changing noise levels, orient to the presence of co-workers, and monitor the pace of work events (Gherardi 2001; Ancona and Chong 1996).

An embodiment perspective on work emphasizes that expertise relies on the sensory faculties of touch, hearing, sight, smell, and taste, and thus resides in the human body. For example, Strati (2007) describes how roofers moving on a sloping roof at dangerous heights ensure their safety not by following safety protocols, but by feeling how their feet are bound to the roof and listening for suspicious sounds that imply imminent danger. Trainees in the perfume industry learn the art of smelling by a process of making progressively finer distinctions, and become known in situated parlance as "noses" (Latour 2004). In surgery, a field where the "medical gaze" is often prioritized, fieldwork of surgery indicates that sight is deeply intertwined with touch. Indeed, much of effective surgery depends on tracing and touching organs (especially when blood obstructs the view), applying the right force on a scalpel to cut a given tissue without damaging the organ beneath, and feeling the aortic pulse to know whether the surgery can proceed (Prentice 2007; 2014). Thus, a focus on embodiment allows a deeper discernment of how experts actually perform and how their expertise is entwined with the use of their bodies.

An embodiment perspective is useful to understand how coordination develops in expert teams. Team members whose bodies are in close proximity can rely on shared sensing, gesture, and visual data to coordinate effectively and reduce the need for explicit communication in at least three ways (Hinds and Mortensen 2005; Hindmarsh and Pilnick 2007; Streeck, Goodwin and LeBaron 2011). First, by noticing each other's facial expressions, following gestures towards common referents, and monitoring changes in activities, team members can quickly identify each other's moods and states, as well as struggles or urgencies, which speeds up coordination, bolsters shared context awareness, and reduces conflict (Hinds and Bailey 2003; Olson, Teasley, Covi and Olson 2002). Second, hearing is an essential part of coordination. For example, Heath and Luff (1992) describe how a team of underground controllers is able to coordinate the complex activity of running a city's subway service by overhearing each other's responses to emergencies and incidents. Because co-location affords common audibility of signals, announcements, and conversations, the controllers are constantly aware of unfolding events and can, therefore, modify their own actions more effectively in response to unexpected emergencies. Third, touching the same object can also provide team members with common knowledge that helps guide future coordinated action. Surgeons, for example, rely on the joint touching of organs, feeling their hardness, evaluating the pressure of an artery, to draw conclusions about patient condition and whether an operation can even proceed (Moreira 2004; Hirschauer 1991). Thus, shared sensing (joint seeing, hearing, and touching) can increase mutual understanding, facilitate concerted action, or elucidate the next action.

An embodiment perspective emphasizes that professional roles require not only cognitive mastery of specialized knowledge, but significant bodily training to be able to perform a collection of sanctioned doings, in a pre-assigned space, and the mastering of specialized tools and artifacts. For example, a surgeon is defined by the institutionally sanctioned right and training to cut into the patient's body; this right cannot be claimed by a gastroenterologist or a radiologist without serious consequences (Zetka 2001; Levin et al. 2005). To become a legitimate member of a profession, one has to train the body to expertly enact the role. For surgery, the role includes a bodily requirement: the surgeon must have unusual dexterity (often referred to as “golden hands”), the ability to concentrate and stand for long hours at the operating table, and the bodily control to suppress nausea, fainting, or revulsion when encountering blood and gore during the most gruesome procedures (Prentice 2007; Cassel 1987; Moreira 2004).

The embodiment perspective is useful for tracing how and why coordination evolves following the introduction of a novel technology. Specifically, embodiment scholars view tool usage as shaping of human perception and bodily actions. As specialists assimilate tools into their activity, they gradually lose awareness of the separateness of the tool (Heidegger 1962; Polanyi 1966; Ihde 1979; Riemer and Johnston 2017). When mediated by technology, bodily senses are both augmented (e.g., one can perceive more details and in sharper distinctions) and reduced (e.g., other aspects of perceptions fade into the background). For example, Ihde (1990) describes how the invention of the telescope allowed us to see the mountains and craters of the moon, but simultaneously removed other dimensions of spatial signification, such as its relative location in the sky or its movement with regard to other celestial bodies. Similarly, Goodwin (1995) explains how tools used by oceanographic scientists to collect sea samples shape their access to the hidden sea layers from which they are sampling. The tools and spatial organization of the ship directly shape how scientists can learn about the sea strata and how they coordinate their interdisciplinary interaction during the expedition. Thus, tools with which specialists perceive the world and through which they act on it, do not simply mirror the objective world out there. Instead, tools play an organizing role in allowing what, and in what manner, can be perceived, foregrounding some aspects of reality and backgrounding others.

In sum, theories of embodiment are crucial for understanding how incorporating technology in work settings prompts change in coordination arrangements by allowing for different perceptions, actions, and interactions. In the balance of the paper, we analyze how the introduction of a robot offered a fundamentally different sensory and bodily engagement for surgeons and how these changes prompted a reconfiguration in previously stable coordination arrangements.

RESEARCH SETTING

Our study was conducted in the surgical unit of a large academic hospital in the Netherlands that acquired a first-generation da Vinci robot in 2003. In the first decade, a total of 25 surgeons attempted to perform their surgeries with the robot, with only ten continuing to use the robot consistently. In 2013, the hospital performed a ten-year evaluation of the robotic experience and, finding that usage was sporadic, concluded that the first-generation model was obsolete. The hospital foundation agreed to acquire a new-generation da Vinci robot. Surgeries with this new robot commenced in March 2014, shortly after which we entered the field. The urology and gynecology groups were most active in using the new robot as a standard procedure (respectively 70% and 15% of total robot procedures).

The da Vinci robot is an endoscopic surgical system that facilitates the performance of complex surgical procedures in a minimally invasive manner. Using small robotic arms, miniature jointed instruments, and a high definition camera, the da Vinci allows surgeons to move instruments in a highly precise manner. The robotic system consists of the surgeon's console, a patient side cart, articulated EndoWrist® instruments, and a cart with monitors mounted on it. Robotic surgery is designed to be performed remotely, that is, by a surgeon sitting at a console away from the operating table, manipulating four "patient-side arms" through control joysticks. The assistant - typically a surgical resident in training - and the scrub nurse are envisioned as standing at the operating table next to the patient's body.

Figure 1. Schematic of the operating room during a robotic procedure (courtesy of Intuitive Surgical Inc., Sunnyvale, CA)

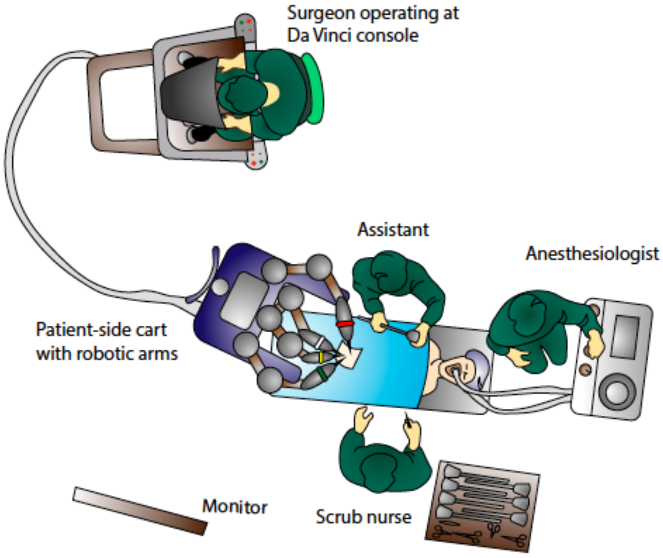
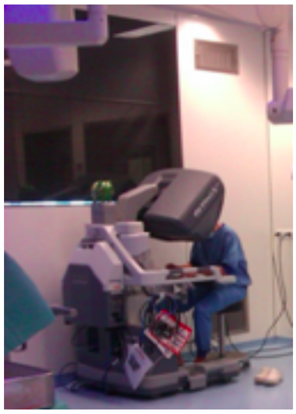


Figure 2 and 3. The robot (in sterile drapes) at the table and surgeon operating the console in the corner



Figures 1, 2 and 3 provide illustrations of the OR with the da Vinci robot to demonstrate its key differences from conventional surgery[2]. We use the term "conventional" surgery to refer to two types of surgery commonly practiced: open and laparoscopic. Open surgery relies on directly accessing the patient's organs through an open incision using a scalpel. Laparoscopic surgery is a minimally invasive procedure where organs are accessed through a small incision in the body using specialized instruments and a miniature camera. Robotic surgery allows doctors to perform minimally invasive surgery via a four-armed robot that is located at the operating table while the surgeon manipulates the arms and instruments at a distance. Technically, the surgeon could control the robot from any geographic location. However, according to legislative and safety requirements, the surgeon is still required to be in the same room as the patient.

Data collection

We conducted our fieldwork in the hospital over 25 months, from July 2014 to August 2016. During this period, the first author observed 23 surgeries (average length of surgery: 4.5 hours), spending in total 103 hours in the OR[3]. A total of 180 robotic surgeries were performed in the hospital throughout this period. The observed surgeries were selected to cover a diverse set of procedures and all of the specialties (urology, gynecology, general) working with the robot. In the OR, the first author focused on observing how the various actors engaged in their tasks and coordinated their activities. The

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[2] Systematic meta-analyses comparing robotic with other forms of surgery found that robots were associated with longer operating times but had a positive impact on post-surgery hospital length-of-stay and a reduced rate of post-surgery complications (Steffens et al. 2017; Tan et al. 2016).

[3] Videotaping, a preferred method to study micro-movements of participants, (e.g., Hindmarsh and Heath 2007) was not allowed in the OR.

researcher also shadowed the surgeons and nurses as they took breaks between surgeries, had lunch and coffee in the cafeteria, prepped the OR, set up the sterile field, gowned each other, and went into storage rooms to prepare for the procedures. During robotic surgery, the researcher sketched physical movements of the surgical team, noted key interactions and events, and summarized team conversations, which she expanded into more detailed accounts immediately following the surgery. The field notes also included photographs of the setting and a schematic representation of how actors were positioned in the room to convey how the "scene of action" was physically configured. To anchor our comparison between robotic surgeries and conventional procedures, we relied on the knowledge acquired from observing an additional 57 non-robotic surgeries (40 open and 17 laparoscopic) in the course of a different field study in the operating room of the same hospital. From the observations of robotic surgeries, we developed a thick description of how the surgeons immersed themselves in the robotic console, how people moved and positioned themselves around the robotic apparatus, how the team interacted with the robot or accessed the patient given the bulkiness of the robot, and how they dealt with the site of surgery and changed instruments in the robotic arms. We paid special attention to task coordination and noted interactions that seemed to differ from the ones pertinent to open surgeries (e.g., surgeons gloving and dressing themselves without nurses' assistance), as well as any glitches or interruptions (e.g., power going off in the hospital). We stopped observing surgeries when we reached theoretical saturation and had covered each surgeon at least twice.

We also conducted 39 formal semi-structured interviews that were transcribed verbatim (see Table 1 for details about informants). We identified interviewees using the hospital database of robotic surgeries and extracted the names of participating surgeons, nurses, and anesthesiologists. Every single active robotic surgeon in the hospital was interviewed (12 surgeons). In addition, three surgeons who stopped using the robot were interviewed, as were two surgeons who recently relocated to nearby hospitals. When interviewing surgeons, we followed a semi-structured interview protocol that focused on their experiences using the robot, difficulties faced in practice, changes in the teamwork, benefits of and challenges presented by the robotic system, and reflections on how robotic surgery differed from traditional surgery. We posed similar questions to anesthesiologists, focusing on the special constraints or challenges that they experienced within their disciplinary role. When interviewing nurses, we asked them to provide a detailed description of activities during robotic surgery, to compare the differences between robotic surgery and conventional surgeries, and to describe the skills that the new technology required. Often, early interviews offered generative hints and details about the change in roles and coordination that were probed further in later interviews. We used documentation provided to us by the hospital as a background for understanding general guidelines around robotic surgery and for identifying interviewees and their level of experience. All interview transcripts, field notes, and relevant documentation were imported into the Atlas.ti software to further track the analytical process.

During or directly after surgery, a number of informal interviews took place where the researcher asked additional questions. These questions were focused on understanding specific events, as well as clarifying ongoing actions or interactions, why certain decisions were made, or whether a surgical complication was driving a change in surgical procedure. A total of 43 informal interviews (some with the same people on different dates) were thus conducted.

Table 1. Data sources

Observations of surgeries (from July 2014 to August 2015)	23 procedures (103 hours, 112 pages of field notes)
Formal interviews	39 (average duration: 50 minutes)
Surgeons	17 (including 2 residents)
Nurses	11
Anesthesiologists	10 (incl. 4 nurse anesthesiologists)
Manager	1
Informal interviews	43 (4 surgeons, 5 nurses, 13 residents / medical students, 1 anesthesiologist, 1 manager)
Observation of conventional surgery (for a different study)	57 surgeries (40 open and 17 laparoscopic) (197 hours)
Documentation: ● Publications on robotics by our informants ● PowerPoint hospital presentation on robotic surgery ● FDA documentation ● Hospital report on the decision to acquire the next generation robot ● Surgical protocols ● Database with robotic surgeries	 7 articles 2 (60 slides) 2 (22 pages) 1 (11 pages) 5 (15 pages) 1016 procedures

Data analysis

We adopted an interpretive approach with a focus on evolving practices as they occur in the field. We used qualitative data analysis methods, including memo writing, coding, and abstracting from the data

(Strauss and Corbin 1998; Miles and Huberman 1994). During the data collection, we met regularly as an author team to share insights, inform each other, and make sense of the observations. While collecting data, we also wrote multiple analytical memos to capture reflections, impressions and salient themes, and shared them amongst each other.

Our original analytical focus was to identify the features and material aspects of the robotic technology that affected team performance. However, based on early observations and preliminary analytical discussions, we found that a focus on the activities of team members and tracing evolving roles were more revelatory. For example, we observed that scrub nurses performed fewer activities related to serving the surgeons (such as dressing them in sterile scrubs and handing them tools) compared to traditional surgery. In our first round of analysis and further data collection, we focused on this theme of "role transformation" by asking more pointed interview questions about this change in the nurses' duties to glean a variety of perspectives from all groups on whether and how it was occurring.

In the next step of analysis, we turned to representing and comparing data across all occupational groups, that is: surgeons, anesthesiologists, nurses, and residents (Eisenhardt 1989, Langley 1999). We analyzed data from each occupational group in isolation and developed comparative tables by coding all instances in the field notes and interviews that reflected changes in the task performances of each of these groups compared to traditional surgery or how members of these groups perceived robotic surgery practice to be different from their own benchmark (typically, open surgery). This generated multiple lists of codes; for example, for nurses, the codes included: "doing a surgical movement", "need to know the anatomy"; for surgeons, the codes included: "no feeling in the hands, thus not knowing which tissue to cut", "putting a finger on a bleeder is impossible". Because informants often referred to differences not only in individual work, but also in working together, we created a separate comparative table for team changes. We then grouped these occupation-level codes into integrated tables that compared traditional and robotic procedures. Based on this comparison, we concluded that many of the changes described by team members related to adaptations in how joint work was performed. Analyzing these coordinative adaptations, we noticed that these were mostly the result of changes in how the surgeon engaged in his or her tasks when using the robot. For example, surgeons often referred to "losing the sense of touch" as one of the significant consequences for their skills, while anesthesiologists talked about how the lost touch of the surgeon increased their workload in terms of monitoring safety. From our initial list of codes for the surgeons' group, we selected those that represented changes in situated coordination, such as "inability to ask for help through gesture" and "inability to take instruments in and out", and then went through initial codes to identify those that represented responses of team members to cope with these coordination difficulties, such as "delegate cutting to nurses".

We then proceeded with abstracting from our data by developing an explanation of how the surgery team coordination evolved following the robot's introduction. For example, for the surgeon, we interpreted codes such as "can no longer feel the texture of the tissue" as belonging to the category "reduction of haptic perception". These categories formed the basis of our conceptual focus on how the surgeon's embodied performance underwent augmentation and reduction. This transformation of the surgeon's bodily performance affected how the joint tasks in the team were performed. The embodied coordination of the team seemed to suffer such that it required significant adaptations. For each team member, we identified augmentations and restrictions to their doings, which resulted in coordination modifications and a changed performance. For example, we conceptualized the code "surgeons rely on nurses' skill to respond to bleedings" as belonging to the category of team members "redistributing tasks". As we compared the new task performances in the team and traditional occupational roles, we found that team members had to realign what they were doing in practice with their formal roles. For example, we abstracted from the code "nurses insert trocars and do initial cut" to conceptualize this as a reconfiguration of "expanded occupational knowledge". Thus, we arrived at the conclusion that a focus on the embodied perceptions, actions, and interactions of members was essential to understand the reconfiguration of coordination in surgery.

To further validate the emerging story of how change unfolded, we performed a temporal analysis of our data. This was done to check if our narrative description of events indeed corresponded to how events unfolded in the field. Specifically, we re-coded our evidence, using yearly time markers (2014, 2015 and 2016) to categorize unfolding events for each occupational group. The analysis is presented in Table 2 and provides additional support for our description of the unfolding of coordination changes in surgery.

Table 2. Study timeline and summary of the evolving changes in the OR

Year	2009-2013	2014	2015	2016
	Based on retrospective accounts and documents	*Based on fieldwork*		
Events pertaining to robot	First generation da Vinci robot starts to be used in the OR in 2009, uptake is limited	-Second generation da Vinci robot is introduced -Urology finds the robot promising for prostatectomies and urinary diversion procedure	-Gynecology embraces the use of the robot and starts to use it consistently	-Gynecology publishes the results of their robotic trials for a novel procedure for transgender reconstructive surgery -ENT is considering using the robot
Surgeons /residents	Various specialties (vascular, urology, general, gynecology) experiment with the robot	Observational evidence: - Residents assist at the table for 55% of cases	Observational evidence: - Residents assist at the table 0% of the time - Some surgeons allow residents to take command of the console in 25% of cases - Rest of the time residents watch the procedure on monitor	New formal robotics training program for residents is launched (urology) (April, 1st)
Nurses	A handful of nurses realize the importance of specializing in robotic procedures	Interview evidence: -Lead nurse is trusted with assisting and is considered an exceptional nurse -Lead nurse tries to educate a few others -Management does not recognize robotic as a specialty for nurses; tensions around scheduling -Nurses do not feel safe when alone at the table -No formal education is provided Observational evidence: -In 45% of cases, the lead nurse is assisting at the table - Talk of the need to train more nurses because of uptake by different specialties - New nurses are brought in to be trained	Interview evidence: -Surgeons mention an increase in scrub nurses' responsibilities in robotics - Recognition of the need for special training and dedicated robotic nurses - Discussion of the establishment of a dedicated group specializing in robotic nursing specialty Observational evidence: - Nurses assist at the table in 100% of cases - Two instances of nurses educating interested residents at the table - Nurses are involved in surgical insertion of trocars in 83% of cases	Interview evidence: -Robotic nursing is formally recognized as a new nursing specialty -Some nurses are sent for training abroad -Nursing students who pick robotics as a specialty are trained in surgical skills
Anesthesiologists	Preliminary safety and prepping guidelines are developed for urology (2012)	Observational evidence: - Work continues on improving positioning and safety - Work starts on developing comprehensive anesthesia protocols with specification for different specialties	Observational evidence: - Surgeons comment to each other that anesthesia is again taking too long with their preoperative preparations Interview evidence: - Anesthesiologists mention their constant work on improving positioning and safety	Interview evidence: - Updated protocols are reviewed by various hospital instances - Gynecology anesthesia protocol is being finalized (formally approved in mid-2017); - Anesthesiologists continue to work to formalize the protocols for other specialties

The surgical context

To explain how the coordination arrangements evolved, we first present a description of conventional surgery with an emphasis on the expertise of surgeons, team coordination, and role arrangements. The skills of surgeons in open surgery include a complex combination of various perceptual and bodily skills – a combination of knowing and manipulating the anatomy through touch, vision, skillful use of hands, confidence to make quick judgments on the spot, and physical strength to endure strain on the neck and back from standing at the operating table for many hours (Cassell 1987). A type of occurrence that illustrates this skilled performance is the ability of surgeons to deal with unexpected bleedings, a typical occurrence with invasive procedures to access organs. When bleeding occurs, the surgical cavity fills with blood and visibility becomes impaired. Given that they cannot see the specific tissues and organs, surgeons must use their hands to search for sources of arterial pulsation via the sense of touch. Once the spot is found, they use their fingers to press directly on the source of bleeding in order to stop it. This requires the embodied skills of knowing how much pressure is safe to exert, recognizing whether it is an artery or a vein, and choosing whether to place a clamp or apply pressure gauze to stop the bleeding. The bodies of surgeons also face significant demands in terms of exertion and endurance, and require training to operate for long periods of time while postponing the need to eat, drink, or go to the bathroom (Moreira 2004; Hirschauer 1991).

Surgery depends not only on the work of individual surgeons, but also on the carefully coordinated performance of a team. Team members rely on a pre-assigned positioning around the patient's body and a fairly well-defined division of bodily doings centered on supporting the perception and action of the main operating surgeon (Hirschauer 1991). For example, for cutting and manipulating tissues, surgeons often require assisting hands (typically, residents) to hold tissue away, to suck out the bleedings, or to do the actual cutting or stitching. Moreover, to go through the layers of the skin, surgeons rely on the nurses' skills to hand them the right instruments and to do so at the right time and in the right manner, i.e., ideally without an explicit request and in a swift, confident anticipatory movement. Team members are also trained to understand requests for assistance without explicitly asking or updating each other on where they are. Such implicit coordination is achieved thanks to well-honed skills that enable effortless orientation to each other's movements, sounds, and expressions

(Hindmarsch and Pilnick 2007). For example, when the researcher mentioned to one of the surgeons how quiet it can be in open operations and that the members of the team almost never talk to each other, he explained that they "talk with their hands" (gynecological surgeon). As a surgeon mentioned, verbal interaction is minimal in surgery because the mutual understanding is embodied and intuitive:

> "If I do open operation with one of the other surgeons, you don't even need to give feedback to know what the next step will be. So, when I see that somebody is, for example, trying to remove the lymph nodes and he gets stuck somewhere, then I know, okay, I need to do this" (urological surgeon).

Surgery is typically characterized by a rigid occupational hierarchy. The surgeon is traditionally perceived as the central and leading actor who orchestrates all events, possesses the highest authority, is responsible for supervising the team, and is accountable for events in the OR. Residents' role requirements include supporting the main surgeon while simultaneously being responsible for learning more advanced procedures. Anesthesiologists, who also have a medical degree, are considered second in charge; they are responsible for maintaining the vitals of the patient throughout the surgery and facilitating surgical work. The tasks of scrub nurses are those of "serving" the main operating surgeons, starting from greeting them with the sterile scrubs upon entrance in the OR, anticipating their needs; by handing them instruments and bringing food and drink; and ending with "cleaning up the mess" after they leave (OR nurse). The interactions, expertise, and role relations in the surgical team are highly routinized and taught to novices from the very first training day (Prentice 2007; Cassell 1987).

As we explain below, the da Vinci robot radically changed this surgery practice by both augmenting and reducing the capacities of surgeons, which disrupted the work activities of the team and ultimately spurred them to re-configure highly established coordination arrangements.

FINDINGS

Embodied changes in the surgeon's skilled performance

Augmented embodied performance. There were several changes in how surgeons could perform an operation once the da Vinci robot was in place. The first change related to how surgeons could see the site of surgery. The robot's console provided extreme magnification and a three-dimensional view, generating a feeling among surgeons of "floating in the patient's belly" and being "right where you want to be" (vascular surgeon). This augmented visual perception manifested in at least three ways. First, it revealed anatomical micro details—vessels, arteries, veins, tissue—in a clarity previously unavailable, not even through "dissecting a cadaver" (urological surgeon in training). It was now possible to easily zoom in and out on specific areas, an advantage that was just not possible with unmediated human sight during open surgery. Second, it was now possible to position the robotic camera in a fixed position, resulting in a steadier image compared to the unsteady human-held camera used in laparoscopy. As a gynecological surgeon remarked, assistants who hold the camera get tired and their hands start trembling after some time, producing a shaky image, which impairs surgeons: "so you get physically nauseous because of the assistants". Third, because minimally invasive surgery is associated with less bleeding and the view of the patient's anatomy is less clouded by blood, surgeons could do more precise interventions: "because you can see all these different layers, you are able to stitch all the separate layers together" (urological surgeon).

Beyond enhancing visual perception, the robot allowed surgeons to use their hands differently, increasing their dexterity in manipulating organs and tissues. With the robotic instruments, surgeons could dissect tissues more carefully and with less trauma, as well as reach organs that were otherwise difficult to access. They could also perform more sophisticated, secure, and exact stitches and more easily tie difficult knots. This benefit of precision and care of manipulation was afforded not only by the increased dexterity of instruments, but also by the remote setup of the system. Because surgeons could now sit comfortably on the chair behind the console without wearing sterile scrubs they were relieved of the bodily exertion of standing for hours while operating, which increased the possibilities of what they were able to perform on the patient, such as the number and quality of stitches made:

> "With the robot, you are ergonomically very relaxed and with a body position, no strain on your back, no strain on your neck and when you are comfortable as a surgeon, and the stitches are easy - you make better stitches, and you do more stitches, closer together, because you see it so well. I even had to put, after a while, you make this anastomosis and this is the aorta [draws this on a piece of paper], at a certain point I made stitches like this [draws dense stitching], while this [draws loose stitching] could be plenty" (vascular surgeon).

Finally, with the robot, surgeons could achieve increased control over the tools that were at their disposal. While in the open or laparoscopic procedures, surgeons had to rely on the assistants to handle tissues, the camera, or instruments; now surgeons could call on the additional robotic arms to perform activities that previously required assistants: "surgeons often say 'Ah, I wish I had a third hand', and with the robot you have it!" (gynecological surgeon). Because surgeons could now control and switch between up to four robotic arms on their own, they could rely less on the assistance of residents and experienced independence, control, and flow.

Reduced embodied performance. While reliance on the robot augmented the surgeons' range of actions in the site of surgery, it simultaneously reduced their abilities to perceive and act in different ways. One reduction was the loss of haptic feedback: that is, the surgeons were now unable to directly feel the tissues with their fingers. With robotic mediation, they could no longer explore whether a tissue's structure was vascular (through pulsation), push to assess the hardness of the tissue, or intuitively feel the pressure applied by their instruments. Surgeons experienced a loss in the manipulative abilities to apply pressure intuitively on organs, find the source of a bleed, and apply pressure to stop it - unproblematic embodied acts in open surgery. Losing the sense of touch was one of the most significant reductions in active perception for the surgeons. As a response, they compensated with an increased reliance on visual perception:

> "The problem of course with the robotic surgery is that you don't have any feeling in the patient, so you develop a sort of, we call it a visual feedback, so if you pull one of the needles, you have to see how strong you can pull! Because you don't feel. And if you pull too hard, it breaks!" (urological surgeon).
>
> *(Gynecological surgeon, operating, head in the console):* "This is so weird, actually there is no sensual, tactile feedback in the robot, but in fact I am quite certain that this tissue here *(points to one spot with his instrument)* is really soft and this thing here *(points to a different spot)* is really hard. *(The rest of the room can follow his pointing on the monitor)*" (field notes).

Another reduction of the surgeons' range of actions related to the scope of vision of the operative site. The robotic console required surgeons to press their head deeply into the console (see Figure 3), and thus be essentially "cut off" from the rest of the OR environment. This narrowed visibility robbed surgeons of the holistic view of the patient's body. It also meant that the surgeons could no longer maintain an overview of the area where the equipment and other team members were located, which deprived them of the ability to monitor or direct the team. Interestingly, most surgeons appreciated being visually blocked and physically separated from what was unfolding at the periphery, as it afforded more opportunities to concentrate without the distraction of the sounds and hassles of the operating room.

"Well, I like that! [being blocked from the rest of the room] It's beneficial I think not to see

> everything. I think you have to concentrate on doing the operation well. And you should not be bothered with all kinds of things happening in the periphery or all kinds of noises that come from behind the curtain from the anesthesiologists [...] You can concentrate on what you are hired for" (urological surgeon).

Another reduction of surgeons' embodied performance stemmed from the new bodily positioning, which separated the surgeon from the operating table. Sitting at the console in the corner of the room meant that surgeons could no longer perform any unmediated physical activity on the patient. They were now located outside the sterile field and un-gowned. The activities performed directly at the patient's body – such as exchanging instruments, taking tissues out of the cavity, inserting gauzes, or verifying instrument malfunctions – were now outside of the surgeon's direct physical reach. Practically, for surgeons, it meant a significant reduction in the ability to intervene quickly when needed, for which they had to learn to rely on the staff remaining at the table. As a vascular surgeon put it: "If I do an open operation, I can grab the assistant's' hand and say 'Hey, don't do that!' [And in robotics] you cannot just go walk, go over there and say 'Let me quickly show you how to do it'" (vascular surgeon).

In summary, these augmentations and reductions of embodied performance were highly consequential for the work of the surgeon; the robotic mediation of their work transformed how they perceived situations, immersed themselves in the surgery, manipulated their tools, and acted on the patient's body. Table 3 summarizes these augmentations and reductions. Beyond the direct impact on the surgeon and his or her work, the robot was also consequential for how other team members could perform their work and coordinate with each other. In the next section, we offer an analysis of these collective activities and how they had to be adjusted.

Table 3. Changes in embodied work performance of surgeons

Bodily activity	Augmentation	Reduction
Visual perception	*Can see more clearly via the magnified 3D interface* "In robotic procedures, actually, we get for the first time the same picture as we have in our anatomy books. It is almost the same, now we can see much more structures, we can see some blood vessels, we could see all the structures inside the abdomen, all the vessels, nerves" (urological surgeon in training).	*No longer able to view the rest of team or the patient's body beyond the surgical cavity* "It's like you are looking into a 3D box and you are working there in this 3D box and the rest of the world is a bit away, and it gets you - it's like another world you are in! It's like playing a video game a bit!" (vascular surgeon).
Haptic perception	*Can more delicately handle tissues* "All the movements you can make with the wrists, you can do it with the robotic instrument. You have the 3D view on the operative field and you have a stable view on the operation field because the camera is also held by the robot system. So, especially these instruments - make it very easy to do…" (urological surgeon).	*Can no longer feel the texture of the tissue, or find source of bleeding by feeling the artery pulsation* "But if you have a problem that is really attached and you need to feel the tissue, that's what you miss and the most important thing I missed with the robot is missing the feeling. If you touch the tissue, you see how it moves in reaction what you are doing, but you don't have any idea how hard it's going or how much damage you do sometimes" (gynecological surgeon).
Manipulative dexterity	*Can do better stitches, knots and control multiple robotic arms* "[In robotics] you are really able to put the stitches exactly where you want to. And with the open, it's difficult, [to stitch] and if it's not really 100% okay, but it's 76%, then we accept this. With robotic surgery, if we are not satisfied, you can do [the stitching] again, and you can see it again" (urological surgeon).	*Unable to stop bleeding by applying finger pressure* "It is challenging to [handle bleedings] with the robot. If this is open [surgery], then I know – okay, the bleeder is here, I can put my hand or gauze there and then stop the bleeding. Sometimes, you can feel if it is from the aorta or artery you can feel 'where are my pulsations', where is the kidney artery. But the fact that you can put your hand, have your bleeder under control, clean the space, remove your hand slowly, that's a big advantage compared to only two arms of the robot, with scissors and small forceps" (urological surgeon).
Bodily positioning	*Seated position outside sterile field relieves previous bodily constraints* "When you do very long surgery, three hours for radical prostatectomy, you stand beside the patient for three hours and look [points at the back of his neck], so there is more neck pain, and so surgeons use more pain killers, and have more hernias. In robotics you can sit, in a good manner with your back straight up and your arms resting on the pad of the console" (urological surgeon).	*Can no longer easily access and respond to emergencies* "There are all kinds of things that can go wrong, and you have a bleeding and in the open operation you just put your finger on it. In the robotic procedure] you can put a little trocar or a gauze on it, and that can sometimes fix it. But if you have a severe bleeding, you are too late. Then you want to open the patient, - and then you need to first put the whole machine on the side" (vascular surgeon).

Embodied coordinative adaptations

In traditional surgery, thanks to shoulder-to-shoulder clustering of the surgical team around the patient, the team primarily coordinates via non-verbal communication, joint sensemaking, visible gestures, anticipatory responses, and making adjustments to each other's actions. We found the shift to robotic surgery was associated with restrictions on how these activities could be performed, requiring team members to adapt by engaging in spatial relocations, redistributing tasks, accommodating new perceptual dependencies and mounting novel responses. Table 4 summarizes these adaptations and we elaborate on them below.

Residents move their bodies to the console. Of the various dependencies in open surgery, none is more important than the surgeon's reliance on the residents' assistance to help with the cutting of non-core tissue, suturing, and holding the surgical cavity open. Such activities are part of the residents' training and, over time, can grow into more important surgical responsibilities. Because the robot allowed the surgeons to control up to four fully functional robotic arms, surgeons took over some of the activities that were previously the domain of the residents. Thus, the residents experienced less need for their skills and interventions. Where previous surgical action was distributed across several members of the surgical team and required considerable effort to achieve a competent coordinated surgical maneuver, in the new form of surgery, all the required expertise became concentrated in just one person. A surgeon described the benefit of gaining greater control:

> "So, you put tension with one static arm and then operate with the other two, and that is much better than if you have an assistant. Because they will never know exactly what sort of tension you want and in what direction you want to move the tissue and then it's always like: 'Go a little bit to the left, a little bit to the right - yes, a bit more tension, a little bit less tension, yes, that's it!' And now you can just do it with your [robotic] arm - you put it there and that's where you want it [fixed] and you can continue" (gynecological surgeon).

Residents struggled to cope with this reduced need for their hands-on assistance. Initially, they remained at the patient's body, ready to assist occasionally with the suctioning of fluids and other simple activities. However, because of the obduracy of the robotic apparatus and the moving arms, they could no longer follow the surgery progress except through a monitor hanging above the operating table. Residents were eager to do more surgical manipulations. As one resident explained, "we always want to do more [...], after three - four procedures, you say, okay, now I want to use the robot" (urological surgeon-in-training). Another resident lamented: "In the open surgery, you are assisting, so you are helping, you hold some tissue, hold some needle, hold some stitches, so you are in the active role [...]. But in robotic surgery, it is only helping with the beginning, the positioning of the instruments, then it's operation of the robot and the surgeon alone [...] so I am not needed" (vascular surgeon in training). The lead nurse explained the struggles for the team coordination:

> "The residents did not learn anything besides suction and well, after ten or twenty times you have had enough of that! The residents come here to learn surgery, to learn to become a surgeon, and not to learn assisting, and that's one of the biggest problems, I think, of the robotics, that you have to create a situation where everybody should learn the things that they should learn. And in robotics the only way to make sure that residents learn their surgery is behind the console" (lead nurse in urology and robotics).

Thus, the new remote setup made it difficult for residents to participate meaningfully in the procedure and to acquire surgical skills via joint engagement with the surgeon. This culminated, at one point, when one resident explicitly refused to perform assisting tasks and asked one of the most experienced nurses to take over. Thus, the residents responded to the decreased learning opportunities by spatially migrating away from the operating table to sit with the surgeon to discuss essential points, while also following the progression of the operating procedure on the large monitor. The migration of residents to the console, ostensibly to support their learning, was detrimental for team coordination, as the residents stopped performing ancillary but important surgery acts. These tasks still needed to be undertaken and other team members had to step in, which in turn had repercussions for team coordination.

Experienced nurses begin to assist with minor surgical activities. While residents migrated to the console from the table, the need to assist at the patient's body remained. Surgeons had to rely on others to insert and remove instruments from the robotic arms, and these tasks started to be delegated to scrub nurses who remained available at the table. A nurse recalled: "One day there was a resident who said to me 'I am not going to do this [assisting], you are going to do this!' So, I did it and it went very-very well! So, after that it happened more often. More often and more often, and in the end, I was the best assistant that they had! So, if we had a schedule of operations and there was no resident available, there was no problem, because I could do it. And from there, I started educating other nurses" (lead nurse in urology and robotics).

As a result, nurses started performing a growing number of acts that were previously the responsibility of the surgeons. A critical change for nurses was in the positioning of instruments inside the body. This became an extension of the nurses' responsibility, where now they were trusted with the critical surgical task of exchanging instruments using the trocar (instrument holding mechanism) within the robotic arm. Given the robotic arm's extension into the surgical cavity, the instrument actually needed to be positioned within the body and thus required surgical skills traditionally learnt in laparoscopic surgery, such as expert hand-eye coordination and reliance on the monitor for correct positioning. This required nurses to also develop the skill of recognizing anatomy projected on the monitor:

> "The gynecological surgeon is finishing the procedure: performing suturing inside the body. He is assisted by the lead scrub nurse in gynecology, who is alone at the table. She is helping the surgeon by cutting off the sutures after he is done with tying a knot. For that she uses scissors that she needs to manipulate inside the cavity using hand-eye coordination with the monitor. Surgeon directs her by saying: 'Now go to the left, now upwards, over there, yes, that's it!'. It takes the nurse some effort and time to catch the suture; from the speed of her movements it is apparent that this is one of the first times she does it. The anesthesia team is watching intently how she is slowly trying to move instruments inside. When she finally catches the suture – she turns to them, gasps with relief and exclaims 'This is much more difficult than you think!'" (field notes).

Immersed surgeons rely on detailed verbal communication to engage with the team. A consequence of the almost total immersion of the surgeons into the robotic console was that they lost visibility over the activities of the rest of the team, along with the ability to communicate via gestures or other signals, such as pointing, directional gazing, touching, or relying on joint perception. Thus, the team faced greater difficulty in coordinating, following, and adapting to each other's activities, which was previously easily achieved through co-presence and shared visibility. Routine requests for assistance, such as asking to help with suction or to exchange an instrument in the robotic arm, needed to be asked more explicitly, which required more verbal articulation from the team members. Unable to follow the actions of others intuitively, the surgeons often felt it took the nurses too long to fulfill their requests, not realizing that the nurses were busy fixing an instrument, looking for it, or replacing it if it had been dropped. A surgeon emphasized the difficulty of not being able to perform such embodied interaction:

> "I am not a very good communicator when my ears are blocked and my field of vision is blocked, so I try to do it more like that you would do when in the airplane *[referring to the handoff between pilot and co-pilot]*: when I give the lymph node to the assistant, and say 'Well, I give you the lymph node', just report back to me, when you have got it, when you have taken it out and it's complete. So, there is more verbal feedback, because you can't see anything and you don't hear much" (gynecological surgeon).

The surgeons also had difficulty solving problems with the team members at the table when unusual events occurred, such as in situations of malfunctioning equipment, tangled cables, or clashing robotic arms. The lack of co-presence made it challenging both for the team to understand what the surgeon was trying to do and for the surgeon to explicate the precise movements that were needed, which triggered surgeons to articulate much of their embodied skill that had previously been entangled with their own individual bodies. A surgeon expressed frustration with his inability to use his body to guide the team: “Sometimes, that's a bit frustrating, because they are just doing it not how you wanted it and then you have to correct them and you could say ‘Pff, give it to me I'll show you’, but you can't! So, you have to do it verbally. You have to give good orders!” (vascular surgeon).

Anesthesiologists develop new access points and artifacts. The robotic apparatus at the patient’s bedside occupied approximately half the space around the surgery table. Space was further restricted due to the movement of the multiple robotic arms. Further, the patient’s own arms were strapped alongside his or her body to provide access for instrument changing at the robotic arm. Finally, the patient was tilted at a 45-degree angle, head down, a position that facilitated access to the pelvis as gravity pulled the intra-abdominal organs down. Thus, anesthesiologists had reduced access to the patient's airways, i.e., the breathing and circulatory life functions that are the focus of the anesthesiologist’s professional work. As an anesthesiologist put it, “In normal surgery, it's a lot easier just to ask the surgeon ‘Can you step out of the way for a second, I just need to check?’, but with the robotic surgery there's less access to the patient, because the robot is standing over your patient” (anesthesiologist).

The reduced access to the body made it more challenging for anesthesiologists to monitor the patient’s condition based on pulse, skin color, circulation, breathing, oxygenation, or temperature, as well as to check the functioning of their own equipment and adjust their devices in case of complications. As another anesthesiologist explained, “If there is a problem, there is nowhere where we can reach the patient! Because there is nowhere you can draw blood because the patient is wrapped with his arms next to his body, the legs are up and then the whole patient is upside down and the robot is on top of the patient. If we lose the airway, if we lose the venous access, if we lose whatsoever, we just can't get to the patient!” (anesthesiologist).

Not only did the material setup of the da Vinci robot occupy a whole side of the OR table, but the robotic arms also hovered closely over the body and moved in three dimensions. Often, rotary manipulation of the surgical instruments by the immersed surgeon yielded unpredictable larger movements of the robotic arms. These movements could sometimes endanger the body of the patient, including the head. As an anesthesiologist nurse explained: “When the surgeon sweeps a [robotic] arm, he does not feel that he hits something, so when you say, ‘Be careful’, he does not feel if it is a [patient's’] nose” (anesthesiologist nurse).

As a result of reduced access, and to ensure patient safety, anesthesiologists developed innovations and changed their ways of working in several ways. First, anesthesiologists fitted a special metal shield over the patient’s face to safeguard it from unexpected movements of the robotic arm. Second, they developed a hard shoulder cushion to hold the inverted patient in place as an alternative to thoracic straps, which were found to interfere with ventilation. Third, to reduce the potentially catastrophic possibility of the breathing tube falling out of the patient’s mouth (now that the robot blocked access), they taped it to the patient at the beginning of surgery. Finally, they inserted a second intravenous (IV) line to ensure redundant access in case of problems. In other words, the anesthesiologists coped with the materiality of the robotic set-up by improvising new safety devices.

Table 4. Embodied coordinative adaptations

Restrictions to joint task performance	Coordinative adaptations by team members
<u>*Resident:*</u> *Unable to directly observe and participate in the embodied practice of surgeons*	*Residents move their body to the console* "I think you always learn from looking, but in the open surgery, you are assisting, so you are helping, you hold some tissue, hold some needle, hold some stitches, so you are in the active role, because when the assistant is not very good or not doing anything at all, then it's a very difficult operation for the surgeon, so he needs me. But in robotic surgery, it is only helping with the beginning, the positioning of instruments, then it's operation of the robot and the surgeon alone and afterwards the instruments have to come out, put the stitch on the wound and it's finished, so I am not needed" (vascular surgeon in training).
<u>*Nurse:*</u> *No longer able to hand instruments to surgeons and residents*	*Experienced nurses begin to assist with minor surgical activities* "We do not assist by other specialties so much, because there is always an assistant. And now, in robotic surgeries – we do. And that's the main change. […] And, you know, sometimes it looks easy when you observe the surgeon and you think 'Oh, that's easy'. But when you have to do it yourself, I think 'Oh, my God! Now I know how hard this is!' So, you have to practice too, to see, okay, now here is the uterus, now I can make that comparison - the uterus is there [that direction], so I have to move my instrument there [in the other direction]" (lead nurse in gynecology).
<u>*Anesthesiologist:*</u> *Have difficulty accessing the patient's body to monitor vitals and perform interventions*	*Anesthesiologists substitute for lack of access by developing new access points and artifacts* "There is no feeling in the arms of the robot, so when [surgeon] sweeps an arm, he doesn't know if he hit something. We had to learn to protect [the patient] and not only by saying "be careful" [to a surgeon], but also by making a hard shield, because he (surgeon) does not feel that he hits something, so when you say "be careful", he does not feel if it is a nose, or it's metal tube. These were the first problems" (head anesthesia nurse).
<u>*Surgeon:*</u> *Reduced ability to see, hear, and engage with the activities of the rest of the team*	*Immersed surgeons rely on detailed verbal communication to engage with the team* "With open surgery, you are standing opposite to each other and you talk directly, mumble and now you have to be really clear, because you are far away from each other, I cannot see what she is doing, when I am in the console working! So, you have to communicate quite clearly" (urological surgeon).

Role reconfiguration in surgery

The coordinative adaptations of team members resulted in misalignments with the roles typical for coordination arrangements in conventional surgery. Over time, necessary adjustments in interdependent teamwork crystallized into shifting expectations and shared understandings of how roles in robotic surgery should be organized, thereby forming an evolved role. We elaborate on the reconfiguration of roles below and provide a summary in Table 5.

Residents are demoted from participants to students. Residents faced major role changes to their surgical assisting and learning. In open surgeries, residents were closely involved in the procedure, standing shoulder-to-shoulder with the surgeon. Thus, their work and learning were interwoven and tightly coupled with the work of the surgeon. In the robotic setup, residents tried to regain closeness to the surgeon by joining them at the console. They could follow the procedure, magnified on a large overhead monitor, and gain a clear anatomical view. However, the residents' interaction with the patient's physical body was then restricted to the commencement of the operation, when they positioned the trocars and set up the robotic arms together with the scrub nurse. The rest of their learning activities was now typically performed by sitting on a chair next to a surgeon and passively following the surgeon's movements on the monitor, occasionally answering the surgeon's didactic questions, as illustrated in this field note:

> "Dr. Janow is operating at the console and Dr. Fisherman (another surgeon) is also present, together with a couple of students. Dr. Janow starts asking students (via microphone) to name the organ and anatomy details that they see on the monitor. 'What is the structure here?' They start guessing: 'Urethra?' 'No' 'Aorta?' 'No'. 'Hmm, isn't it the stomach fat?' Two of the students take turn guessing. Dr. Fisherman rolls his chair closer to the monitor and uses his hand next to the monitor to help illustrate. He draws the contours of the body next to the monitor, to visualize how it corresponds to the real body of the patient. 'Here are the legs and they are pointing like this', he explains. Finally, the students get it right: 'Aha, so it is the area around the navel'" (field notes).

With their bodies away from the operating table and little access to the console, residents could no longer acquire the embodied skills of cutting and performing core interventions. As one resident explained: "But in robotic surgery, it's only helping in the beginning, the positioning, the instruments, but then it's the surgeon alone who operates the robot [...] You learn from looking at the anatomy, that's for sure, but not in an active role" (urological surgeon in training). The teaching surgeons also realized the limitations imposed by the new work arrangements for residents' learning. As a surgeon recognized, "sometimes it's quite boring [for the one at the table], because the one at the console is doing the trick" (gynecological surgeon). Students thus ended up in a paradoxical situation: they had abandoned the patient's body and crossed the sterile field in order to regain co-presence with the surgeon. Yet, given the single point of control (the immersive headset) for the robot, they remained unable to reconnect with the surgeon's work and still remained at the periphery of the action with reduced bodily engagement. This led to a change in learning role: less co-mingled active support at the site of surgery and more attention to observing and noting the action on the larger monitor. In short, they had become primarily passive learners. Because the situation reduced learning opportunities, the surgeons were forced to institute a new training program to reestablish the learning component of the role of residents in surgery. Now to learn robotic surgery, residents were required to register for a seven-hour online simulation to learn how to control the robot, which was followed by an exam. Only then were they allowed to occasionally sit at the console to perform simple parts of the procedure, such as easy sutures or cutting fat layers. Thus, the hands-on apprenticeship model of residency was replaced by a more structured and formal training format. As a result, the role of residents as core to the surgical procedure was reduced to a role with a more formal and isolated form of skill acquisition.

Nurses have increased autonomy and responsibility. The decreased involvement of residents was accompanied by increased responsibilities of scrub nurses who took over the remaining patient-side tasks. Because increasing numbers of nurses received training to assist at the table, surgeons started to expect that such duties should naturally constitute the scrub nurses' task domain. As one nurse mentioned, surgeons stopped bringing their assistants with them because they "almost expect it from all the scrub nurses that they can be alone at the robot" (OR nurse). The scrub nurses' reaction to this significant role expansion was ambivalent. On the one hand, they felt that taking on new tasks and acquiring the skills of cutting into the body enhanced their jobs. As a nurse reflected, "We do things that we normally don't do! And in normal laparoscopies we don't have any role in a surgical sense. And in robotics, we do. So, we do things that normally surgeons do. It's exciting and it's fun and we can develop our own skills" (lead nurse in urology and robotics). Another nurse proudly mentioned that in Germany, "You never were allowed to go with the instrument in the body, it was just the surgeon's part. Here, you have to do it – they [surgeons] expect it from you" (OR nurse).

On the other hand, the nurses expressed concerns that such an extension of their responsibilities in practice did not align with their traditional expertise and training. A scrub nurse described the moment of insertion of the robotic camera and trocars in the body: "We [nurses] are asked to hold the camera and we are like: 'Huh?' You see the monitor go everywhere, except for the spot you need!" (OR nurse). Another nurse reflected on the inadequacies of their training, "Because you know, we only have training of three years. You get anatomy, but not as much as surgeons. It's a different education, training. We get superficial training. But now, you are doing this operation. You have to know more" (lead nurse in gynecology).

This shift in the role of nurses was also perceived as a status increase relative to their previous, more subordinate position. Because the traditional role of scrub nurses is associated with the tasks related to the preparation of instruments, cleaning up, and serving the surgeon, being autonomous in standing at the table without the surgeon was a sign of increased responsibility and expertise for them. One nurse reflected on the role enhancement, “It's quite interesting and this is really good, that makes it more interesting to work here” (OR nurse). Another reflected on the role change: “We did not really have a role! Now we are starting to have a role in things, and we can do things that surgeons do. And it makes it a lot more exciting” (lead nurse in urology and robotics). Surgeons also recognized the need to delegate control and responsibility:

> “It's a lot of responsibility for the team, so the whole team needs to work differently. Everybody has a different job, for example, the scrub nurses change the instruments because the surgeon is behind the console. That's completely new because normally the surgeon is in control. The scrub team will have a more active role. I think there is more responsibility to the scrub team, especially since the surgeon is behind his console. As a surgeon, you are more dependent on the (scrub) team, doing robotic surgery” (general surgeon).

The change in the role of nurses extended beyond the actual surgical procedure. For example, we observed on several occasions that nurses, while occupied with calibrating the robotic camera, did not have time to gown and glove the surgeons upon their entrance in the operating room - a traditional role for surgical nurses[4]. Initially, the surgeon would routinely stand waiting with his or her arms raised as a sign of being ready to be gloved, but the nurse was too engaged with camera calibration to help. In two such observed occasions, the surgeons started to dress themselves, clumsily trying to open a sterile package of gloves and then going to the nurses’ preparation room to roll out their instrument table themselves (a responsibility of a nurse) to expedite the procedure. Thus, some surgeon-focused tasks that were previously the domain of nurses have been replaced by other higher-value activities specific to the robot. Some nurses experienced it as a status increase. As one nurse reflected, the surgeons had started to lose their “arrogant attitude” and accepted a new configuration: “Now [in robotics] he needs, really needs you. Normally, in the open procedure, they need you too, but they don't feel it that way, but now they really feel that they need you” (OR nurse). In a similar vein, a surgeon accepted that “It

[4] During the initial trocars’ insertion, surgeons are required to be dressed in sterile gloves and gown. After the insertion is completed (which takes approximately 5-10 minutes), surgeons take off the sterile attire and settle down at the console.

is like giving away some responsibility, because normally in the open surgery, you have a bleeding and you can put your finger on it, now you have to rely on [the nurse] her skills and what she can do to solve the problem within a minute, because it takes some time for me to get to the table to help her" (urological surgeon).

Anesthesiologists increase their responsibility for patient safety. The responses of anesthesiologists to the challenge of accessing patients resulted in expanding preparation time ahead of the first incision and in formalizing these arrangements into protocols. In open surgery, the anesthesiologist's role was to adjust, monitor, and tweak medication and devices to ensure a safe procedure. They could easily and continuously intervene to ensure an effective sedation. Now, in robotic surgery, they had reduced access to the patient body and were hindered by the hulking presence of the robotic apparatus. Anesthesiologists perceived that their role needed to expand to ensure patient safety. They evaluated different scenarios of where things could go wrong and developed responses for each. While before they could easily ask the surgeon to step aside in order to restore circulation or breathing, the limited mobility of the robotic apparatus precluded it. Surgeons, who historically had shared the responsibility of ensuring patient safety, now relinquished that part of their role. Their own bodies consigned to beyond the sterile zone and immersed in the virtual world of the robotic console, they could no longer see nor touch the body outside the surgical cavity. As a result, the anesthesiologist's preparation time ahead of surgery increased and they focused on building redundant safety measures, such as inserting a second IV line.

This role expansion did not go unnoticed by surgeons, as they often complained about long preparation times and unnecessary precautions. Anesthesiologists, however, stood their ground as guardians of the patient's safety: "Surgeons were like 'Is this really necessary?' Yes, this is necessary! They were not too happy about [the long preparation times] [...] That's a good thing when you have a protocol - it's in a protocol, so yes, I need to do this" (anesthesiologist nurse). Thus, not only did anesthesiology expand its tasks and expertise to include the area of patient safety, but they were able to use this goal of ensuring a safe surgery to increase their occupational standing vis-à-vis surgeons.

Surgeons specialize on mastering their surgical craft. Surgeons were fully aware of their reduced involvement in team supervision. A surgeon expressed relief at having less coordinative and supervisory responsibility: “When you are operating together with someone, you always have to watch - what is he doing, where are they, are they doing weird stuff, are they pulling hard enough, heh? And I say - put the clamp on, help me with this [tissue]. And in robotics, you have to do it all yourself” (vascular surgeon). Thus, the surgeon’s role evolved from orchestrator of the team to being a craftsman entwined with the robot, located apart from the team. A surgeon described himself as engaged in “not very social surgery” (gynecological surgeon). Another saw an advantage to focusing on the surgical site:

> “I think it's an advantage of the robot, because actually we don't want to know things around the patient. You only have to do the procedure inside the patient and when there are some problems during the procedure, for example, with the blood pressure or with breathing, anesthesiologists will tell you” (urological surgeon in training).

The related consequence of this increased distance for surgeons was the growing focus on technical mastery and prowess with the robot. Surgeons now spent more time on finessing the details of their techniques, such as exploring anatomy, trying out various stitches, perfecting knots, and demonstrating mastery by decreasing the operative time. A vascular surgeon recounted how he came up with an alternative procedure for first rib resection: “The 3D vision, it's enhanced visibility, so I was looking at that first rib and thought: "Ah, it's such a nice vision. I see it so well" and then I said: "Oh, here I see the artery, there I see the vein", so I thought that I should take this approach". Another surgeon talked excitedly about new opportunities for developing surgical techniques:

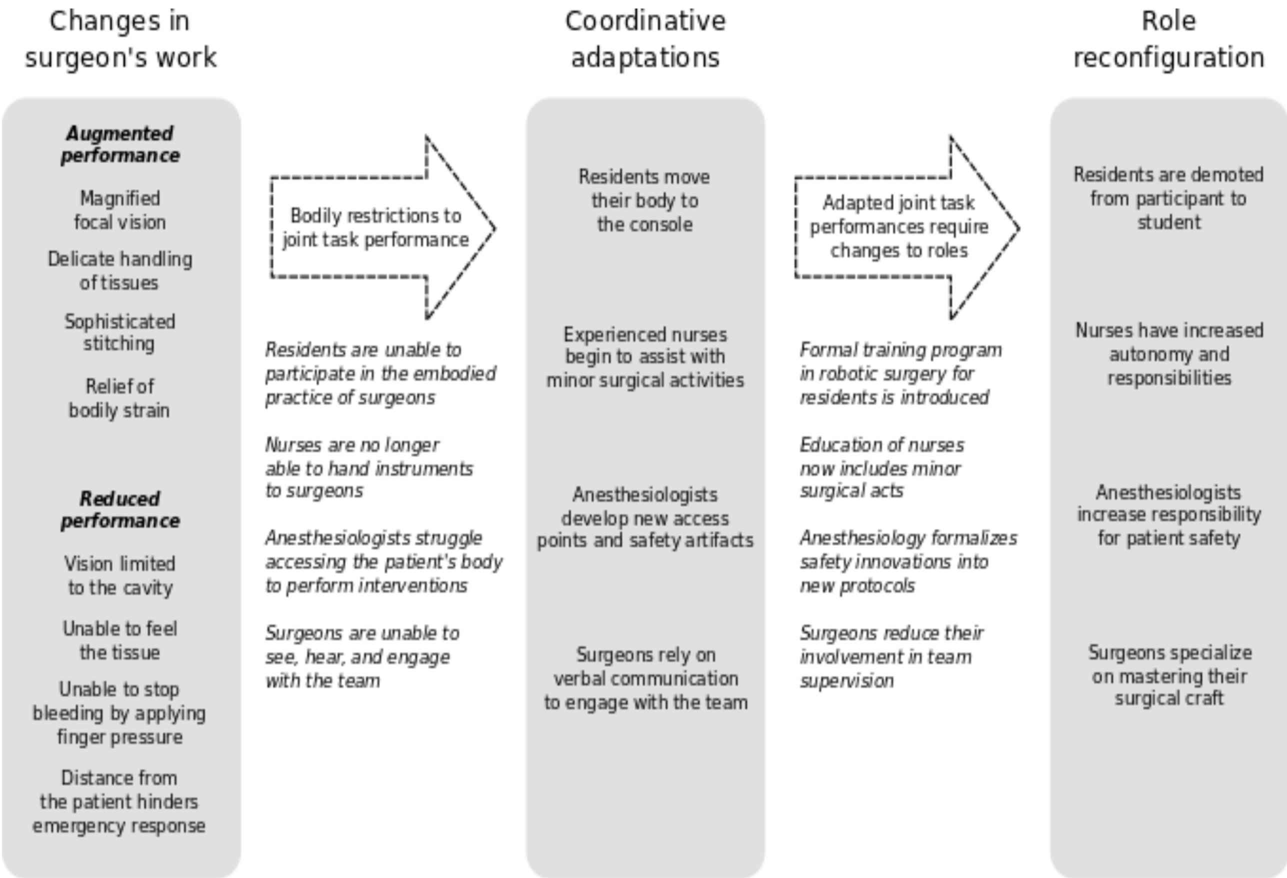
> “[To improve continence in prostate surgery] some surgeons put an extra layer of tissue under the anastomosis, because you can see all these different layers, you are able to stitch all the separate layers together. With robotic surgery, if we are not satisfied, we can do it again” (urological surgeon).

Thus, surgeons reduced their dependencies on the other occupations by lessening their involvement in patient safety, resident training, and team coordination. They used their immersion in the virtual patient body to focus and enhance their own surgical craft. Ironically, the increased involvement inside the patient body deepened as they moved away from the patient and their team. Thus, by embracing the robot and welcoming the new division of roles, surgeons freed themselves from now inessential supervisory responsibilities and threw themselves into the brave new anatomical world.

Table 5. Role reconfigurations

Role adaptation needed to match task performance	How roles are transformed
<u>*Residents:*</u> *Formal training program in robotic surgery for residents is introduced*	*Decrease in direct involvement in surgical performance* "For residents, it's not an operation we like to do because we stand by. We want to do it by ourselves and it's very difficult [in robotic surgery] because there's only one console so it's very difficult to switch, so we don't learn much. In the beginning we learn because it's new when we see how it works, but we are not able to practice ourselves, so that's a pity" (vascular surgeon in training).
<u>*Nurses:*</u> *Include minor surgical acts in nurses training*	*Increase in autonomy and responsibility* "In the robotics - you are very independent, you are the only one at the table, the surgeon is at his workstation and the assistant most of the time sits next to the surgeon and watches with them, and then they discuss the operation with each other. So, you are, as a scrub nurse all alone, next to the patient and you do a lot [..], you place clips, you can cut things and so, I like it!" (OR nurse) "That's completely new because normally the surgeon is in control. So, the scrub team will have a more active role. I think there is more responsibility to the scrub team, especially since the surgeon is behind his console. As a surgeon you are more dependent on the (scrub) team, doing robotic surgery" (general surgeon).
<u>*Anesthesiologists:*</u> *Formalize safety innovations into specialized protocols*	*Increase in involvement in patient safety* "I remember in the beginning, because it took so long, it was also very challenging for us, because if you hang a patient upside down, pressure in the airway and in the eyes starts rising on the lungs and then they start tolerating it less and less [...] And now we improved. We know now how to keep the patient warm, we improved. It's like we tricked the system. Which pillows do we need to use? We tricked the system. How to put the IVs? Where to put the IVs? Put in the arterial line, yes or no? It's like all these tricks we developed" (anesthesiologist).
<u>*Surgeons:*</u> *Reduce their involvement in team supervision*	*Increase in focus on surgical skill and decrease in team supervision* "You see it also, everything that is published about prostatectomies, since introduction, of the robot, you see lot more operating techniques, about how to remove the prostate, inter-facial, because we were able to see all this fascia around the prostate. We were able to see the neurovascular bundles, we were able to see the anastomosis, because we were able to vary in this anastomosis technique, we could do it with the continuous stitch, we would do it with the separate stitches, so that's something we were able to experience with it - and it's because we were able to see it so very good! I think the robot really developed this operating technique" (urological surgeon).

Figure 4. How coordination changed in surgery after the robot introduction

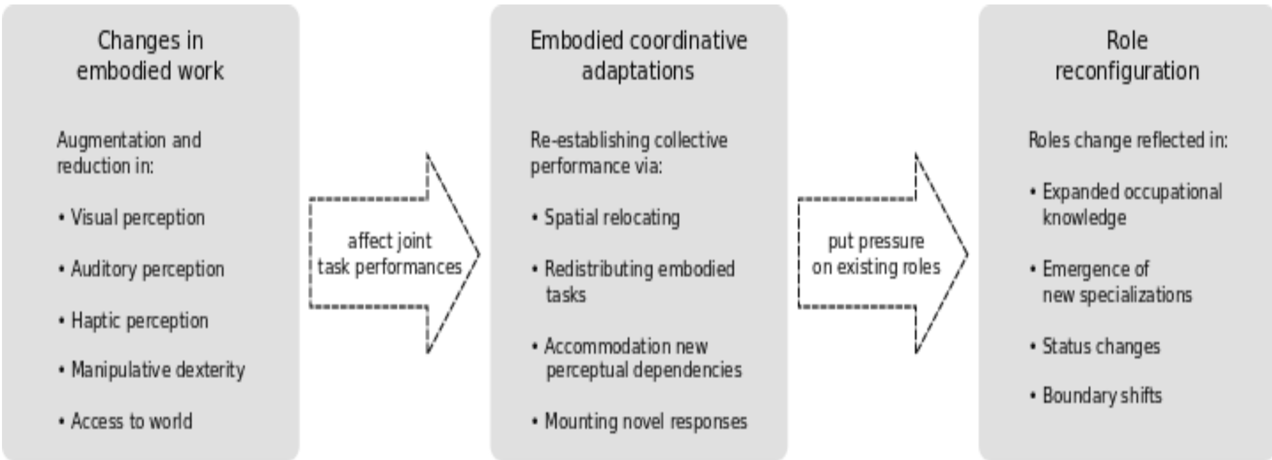


DISCUSSION

This study examined how the coordination of surgery changed following the introduction of a surgical robot. By entering in an embodiment relation with the robot, surgeons found themselves performing surgery differently, which, in turn, disrupted established embodied interaction within the surgery team and prompted coordinative adaptations and ultimately evolved into role reconfiguration. In robotic surgery, a surgeons' embodied capacity to see and act inside the patient's body were augmented, but they were no longer able to guide surgical action through traditional haptic manipulation and proximate involvement in the team's activities. In response, the team enacted major changes in how they coordinated their activities: engaging in spatial relocation, redistributing tasks, accommodating new perceptual dependencies and mounting novel responses. These coordinative adaptations evolved over time into new role arrangements, whereby the actors formalized new responsibilities and shared expectations of each other in novel protocols and training formats, accompanied by shifts in status and boundaries. As a result of the series of changes in how bodies participate in collaborative work, the coordination of surgery with the robot no longer reflected the organizing commonly found in traditional surgery.

Building on the findings of the case, we offer a general explanation of how incorporating a technology that mediates bodily perception and action is consequential for coordination. Figure 5 shows an abstracted depiction of how coordination, including action, interaction, and roles, evolves after a change in technological mediation. The model emphasizes how augmentations and reductions in embodied work performance lead to a need to re-establish collective performance via coordinative adaptations. In turn, these efforts put pressure on existing roles and result in their eventual reconfiguration.

Figure 5. A model of change in embodied coordination following technological mediation



What an embodiment perspective on technology introduction gives us

The embodiment perspective developed from our study offers a different way to trace the consequences of using novel technologies for collaborative work. Our model foregrounds the changes in embodied work performance when a new technology is introduced, such as changes in: the ways actors engage their sensory capacities to perform skilled action, the perception of work objects, and the position of the body in the workspace. These changes in embodied work, while multifaceted, can be described principally as augmentations and reductions. For example, by associating with the robot, the surgeons augmented their bodily capacity to perform precise surgical intervention. Yet, they faced a reduction in their broader perception of the patient. Residents faced a reduction in their direct engagement with the co-located surgeon and from active involvement in doing surgery. Thus, they moved away from the patient's body and positioned their own bodies closer to the console. Nurses, left alone at the patient's body, took on the responsibility of the robot-patient interface and thus gained the capability to perform minor surgical maneuvers. Finally, the anesthesiologists, facing reduced access to the patient's body, gained an expanded capability by taking on the holistic responsibility for patient safety. Thus, our model suggests that ultimate changes in work arrangements following the introduction of a new technology can be effectively explained through the specific augmentations and reductions of embodied work performances for all actors and the resulting need to re-establish joint task performances.

Our model foregrounds the embodied nature of our engagement in the world. It emphasizes that work is actually performed via the body and how skilled work performance depends on physiological limits and bodily capacities. More importantly, skilled work involves embodied relations with tools and technologies that consequentially shape our perception and bodily experience of the world. As described by Ihde (1979), such transformation "contains the possibilities, again co-implied, of both a certain extension and amplification of experience and a reduction and transformation of experience" (p.10). In contrast to a largely individual view of embodied action (Merleau-Ponty 1962; Dreyfus and Dreyfus 1982; Ihde 1979; 1990), we emphasize that augmentations and reductions of sensory perceptions are consequential for existing task and expertise dependencies in collaborative work. Extending embodiment to emphasize social and joint action puts in focus the multiplicity of embodied relations that exist between various actors and tools in the workplace and helps to trace how the disruption and reweaving of these relations affects joint performance.

Previous theoretical explanations of how and why work practices and roles change following the introduction of technology have emphasized interaction scripts (Barley 1986), the agency of human actors in selecting and enacting technology features (Orlikowski 2000), the inclusions and exclusions that accompany the material enactment of work practices (Beane and Orlikowski 2015) and the imbrication or tuning of material and human agencies (Leonardi 2013; Barrett et al. 2012). Much of that research casts the material aspects of work in terms of technology and artifacts, but seldom accounts for the body. Our perspective shifts the focus away from the materiality of technology towards the materiality of the human form, including: the importance of senses, body position in space and relative to others, awareness of people and objects, and the perceptual access to the world made possible by the tools and space. Our model suggests that changes in work coordination and roles can be effectively explained through the tracing of changes in embodied perceptions and doings brought about by technological mediation.

Previous research on how digital representation transforms work has emphasized the impoverished engagement with reality that occurs when technology mediation disrupts what was previously a direct perceptual experience that united workers with the object of work. As described by Zuboff (1988), this loss of direct sensory access to the world leads to problems of interpretation and validation as well as a sense of a loss of control over action. Similarly, Bailey et al. (2012) found that even in the use of cutting-edge crash simulation in car safety, representations cannot fully and accurately replicate the physical car crashing process; compensatory organizational effort and reorganization are required to realign simulation results with reality. Our study contributes to this line of research in two specific ways. First, technological mediation may not only impoverish, but also significantly and positively augment engagement with reality. For example, the high-resolution, three-dimensional representation of the anatomy of the surgical site allowed unprecedented perceptual and manipulative access for the surgeon. Second, that these gains may come at a cost of other aspects of perception or action possibilities. For example, the gains in visual perception and manipulation came at the cost of the surgeons' perceptual access to the external world (loss of peripheral perception), as well as limits to what they could easily do before (e.g. stop a bleeder using a finger). Thus, our case highlights the multi-faceted nature of technology mediation and emphasizes how it may simultaneously augment action possibilities and yet interfere with the perception of important non-focal aspects, and as a result, break the common ground that previously united the team in its performance.

Previous studies of the introduction of novel surgical technologies have emphasized the importance of social factors such as team adjustments and leadership for a successful adoption (e.g. Edmondson et al. 2001), and found a subsequent loss in learning opportunities and an increase in cognitive distance (Beane 2018; Pelikan et al. 2018). Our model allows the reinterpretation of these findings through the lens of embodiment. In the Edmondson et al. (2001) minimally invasive surgery case, the surgeon remained at the table, but with reduced visual and haptic perception of the cavity, since they were now threading a catheter through the artery navigating via a black and white X-ray imaging system. To compensate for the loss in joint team perception during minimally invasive procedures, effective surgeons elected to wear a head camera so that the rest of the team could see what they saw in the cavity or started verbalizing their specific actions. In the Beane (2018) case, residents' limited chances to practice direct haptic and manipulative intervention on patients led to their resorting to deviant, "shadow learning" practices in order to acquire these missing embodied surgical skills. Our model would thus emphasize viewing technological change from the perspective of sensorial and action breaches that if not remedied, can lead to serious negative consequences for some, if not all, team members. As a result, we suggest studies of technology have too often zeroed-in on social explanations and that such explanations can be enriched by first accounting for differential breaches and remediations in sensing and acting in the world.

The perspective developed here has the potential to guide research that aims to trace technology-related change without resorting to a clear distinction between the body and the machine, or their separate agencies. The embodiment perspective recognizes that our relation to tools or technological objects is one of hybridity, rather than one of ontological separation. Foregrounding embodied activities shows the limit of the commonly accepted aphorism, "people use tools to do tasks". Our tracing of the transformation of embodied skilled work shows that tools may order the world in novel ways, often without humans realizing the extent of the change. When a surgeon does robotic surgery, he or she is incorporating the technology into his or her bodily action and, due to augmentations and reductions of his or her performance, unwittingly changing the whole practice of surgery. Thus, tools are not merely neutral devices for people to employ or adapt to their needs; they can actually shape perception and bodily action. Specifically, through subtle changes in embodied activities, the tools bring into the world new categories of subjects and new orderings in work organizing. For example, in our setting, the boundaries between what constituted a "surgeon" and a "nurse" have blurred and a "robotic surgery nurse" has emerged as a different kind of nurse that deviates from the traditional "surgery nurse" in the ability to perform surgical interventions and maintain robotic equipment. Thus, an embodiment lens may help researchers to explain the re-orderings of roles and work arrangements that follow the introduction of a new technology without necessarily resorting to actor-centric explanations.

What an embodiment perspective contributes to work coordination research

Our study also offers new insight to research on work coordination. Increasingly, the material aspect of coordination practices is being recognized as important for understanding how coordination is entwined with the workings of technologies and how changes affecting the latter can result in coordination difficulty (e.g., Bailey et al. 2012; Schakel et al. 2016; Orlikowski and Scott 2008). As Beane and Orlikowski (2015) have shown, how interconnected medical rounding practices in an ICU are materially enacted - through an entanglement of technologies, participants, objects, devices and documents - directly affects coordination effectiveness. Our theoretical model recognizes the importance of a materiality-focused view on practices, but raises the ontological prominence of the body and embodied relations for understanding how technological mediations are constitutive of coordination performance. Such a framework offers that a collective performance affected by technological mediation can be analyzed in terms of transformed sensorial and action capabilities, and that these transformations are emergent over time. Further, our model invites a rethink of the coordination research emphasis on expertise, relations and organizational arrangements toward more specific accounting for embodied performances in the material world.

Previous literature on coordination has focused on how cross-occupational work can be facilitated by the use of protocols, boundary spanners, and common spaces (e.g., Kellogg et al. 2006; Kellogg 2014; Valentine and Edmondson 2014). Our study highlights that, beyond reliance on these organizing mechanisms, coordination is facilitated by shared visibility, joint perception, co-located embodied interaction, and the joint manipulation of work objects. Understanding the elements of embodied interaction that sustain coordination is particularly important when new technological mediations are put in place. Technology scholars have highlighted how coordination suffers from factors such as spatial separation (Hinds and Bailey 2003; Hinds and Mortensen 2005), inflexible technology setup (Pine and Mazmanian 2017), the exclusion of certain actors from the knowledge flow (Beane and Orlikowski 2015; Bailey and Leonardi 2015), and from an uneven access to objects (Bailey et al. 2012). Our theoretical model helps explain why these breaks occur by reminding us of the need to account for changes in the coordinative tissue and the importance of embodied interactions. For example, shared vision and joint manipulation of objects in highly proximate settings is an under-appreciated but highly important facilitator of cross-disciplinary work that reduces the need for formal coordinative mechanisms (e.g., specified roles, formal responsibilities, explicit dialogue) commonly emphasized in existing literature. As a result, the embodied perspective on coordination explains why whenever technology is used to separate worker bodies from the object of work, there is a danger of forgetting the coordination cost associated with the loss of intersubjective and intercorporeal alignment.

Research on coordination has emphasized the importance of emergent and relational aspects of coordination practices with a focus on dialogic responses (Faraj and Xiao 2006), quality of relationships (Gittel 2001), shared understanding and mutual adjustment (Heath and Luff 1992), and cross-boundary spanning work (Kellogg et al. 2006). Building on this relational coordination perspective, we would expect that, faced with a new technology, actors would prioritize sustaining the relational tissue that allows them to perform in a highly reliable manner, a typical response to technology, also identified in the studies of workarounds (Gasser 1986). Instead, we found that the introduction of the robot was the occasion for a disruption of the established coordination arrangement. Contrary to expectations, the surgery team gave up on the relational and dialogic practices so important for surgical outcomes and instead experimented with new arrangements. For example, traditional expertise dependencies (e.g., expectation that the nurses will always gown the surgeons) became an impediment and were abandoned once the robot was taken up in surgery. Given that the nurses were occupied with setting up the robot (calibrating it and draping the arms with a sterile covering), the surgeons began to gown themselves. Thus, achieving effective coordination under changed material conditions may be less about preserving traditional relational aspects of coordination and finding workarounds, and more about coming up with alternative configurations of task and expertise dependencies that reflect changes in the embodied collective performance.

What an embodiment perspective contributes to role reconfiguration research

The literature on role reconfiguration following the introduction of new technology has often emphasized how the material enactments of technologies in practice can lead to the emergence of different social inclusions and exclusions (Beane and Orlikowski 2015), allow for novel digital representations that are consequential for work structuring (Bailey et al. 2012), and how giving robots humanoid features can affect task engagement (Hinds et al. 2004). Our study indicates the need to go beyond a recognition of the technology's materiality and instead offers an analytical approach to trace how engagement with a specific technology transforms the embodied performance of work, and in turn, how the new embodied performances bring about a reconfiguration of roles. The surgical robot instigated such a process of change by allowing remote manipulation of objects, the ability to perform movements and actions that exceed human dexterity within a small space, and three-dimensional visibility inside the surgical cavity. For each role, habitual actions were affected (some positively and some negatively), which in turn led to the need to re-establish collective performance and realign actions, which ultimately resulted in a new configuration of roles. Thus, our findings extend the literature on role reconfiguration by highlighting how reconfiguring bodily skilled activities - who does what, what sensory and bodily skills we draw on, and how we support each other - is central to understanding role change in the workplace.

Prior research on how role relations change in response to a new technology has emphasized that changes in roles may be a conflictual and politically fraught process because members actively protect their role boundaries, which have been stabilized over long periods of time and are entwined with deeply held professional identities (Nelson and Irwin 2014; Barrett et al. 2012; Truelove and Kellogg 2016). Our study found little evidence of inter-occupational conflict and seems to indicate that change can occur in a cooperative manner. We found that occupational members willingly relinquished role-associated responsibilities and allowed boundaries to shift when those did not correspond to their embodied activities. Specifically, the robot allowed surgeons to augment operating skills, but at the cost of hindered engagement with others. As a result, they found it convenient to abandon previously guarded role boundaries and to involve nurses in surgical activities that had been solely the surgeon's responsibility, such as cutting and manipulating laparoscopic instruments in the body cavity. Thus, our case shows that role boundaries are entwined with embodied doings and may become malleable when new technology offers attractive novel augmentation and reduction of embodied work performance. Under those circumstances, occupational boundaries may shift in a cooperative and emergent manner.

Previous research on role reconfiguration has also emphasized that status differences may affect how role reconfiguration is negotiated or stabilized. Role change is often led and controlled by high-power groups that seek to reap the benefits of a change, such as the introduction of a new technology. Lower-status actors often have to accept the imposition of new roles that undermine their expertise or add to their workload. As a result, technology introduction creates winners and losers with the low-status group suffering from a loss of identity and craft (Zuboff 1988), deskilling (Vallas and Beck 1996; Noble 1984), and constrained possibilities for skill acquisition and mastery (Beane 2018). Our findings indicate that lower status occupational groups can maneuver to take advantage of the opportunities that emerge from the fluctuating situation. Facing the loss of surgical training opportunities, residents refused to stay at the operating table where they were reduced to a support function. They insisted on migrating to the console in an attempt to learn the advanced techniques from the surgeon at the console. Similarly, nurses took ownership of the residents' vacated space at the site of surgery and effectively pushed to acquire basic surgical skills. Protocols, schedules, and training had to be altered in response. Surgery training protocols for residents were redeveloped and a new surgical nursing training program resulted in the development of a higher status robotic nursing specialization. Thus, we suggest that when team embodied activities change in unexpected ways, lower-status actors can take advantage of opportunities by engaging in novel bodily activities, taking over tasks whose ownership may be in flux, and, as a result, gain unplanned status benefits.

CONCLUSION

Our study offers practical implications for practitioners involved in managing the introduction of new technologies in organizational contexts. Too often technologies are brought into the organization with promises of higher performance, faster response, or just the lure of the new. Some groups may champion these technologies for their own professional reasons. Our model suggests that decision makers need to be aware of the potential for disruption at the level of work, coordination, and professional roles and try to evaluate its extent. We recognize that such planning processes around new technologies are highly contingent, uncertain, and unpredictable. However, not paying attention to how practices will necessarily need to evolve can lead to unexpected difficulties and thus limit organizational performance. Practitioners need to move from a focus on how to accelerate the diffusion of innovation to a focus on how to align it with practice needs. Our study offers a framework that may be helpful for practitioners to plan ahead for the necessary organizing changes needed to ensure that artifacts perform in practice and are accepted by organizational actors.

As work is becoming increasingly mediated via technologies such as immersive controls, telepresence robots, augmented reality, and digital instrumentation, our embodiment perspective offers a promising way to make progress in evaluating how changes in perception and human action afforded by such devices are likely to produce deep or unexpected changes in coordination. Much of the existing scholarship on change surrounding new technology has emphasized the disruption to human presence and common ground, but has done so by evaluating it against a "gold standard" of a nostalgic richness of the unmediated experience of the world, and the collocated coworkers. We have argued that with new technologies increasingly offering a cyborgian human-machine entanglement, there is a need for renewed attention to the relation binding corporeal humans and technology. For that reason, the embodiment perspective put forward in this study is important because it allows us to examine not only hermeneutic engagement with the world, but also the embodied ways in which technological tools extend engagement with others and with the world.

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