# LOSING TOUCH: AN EMBODIMENT PERSPECTIVE ON ROBOTS AND COORDINATION IN SURGERY

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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 has emphasized its situated and emergent nature, but has seldom accounted 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, auditory perception, and manipulative dexterity. These bodily augmentations and reductions affected joint tasks performances and led to coordination adaptations (e.g., relocation, task redistribution, 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 why coordination and roles change following the introduction of a new technology.

Keywords: embodiment, coordination, 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 alter 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 et al. 2012). Thus, technologies that mediate bodily perception and action are likely to be associated with the profound transformation of work practices, coordination, and roles in the workplace.

In order to investigate such a transformation, we offer a study of the Da Vinci robot, 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 translate into precise movements of 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 coordination and role reconfiguration following a change in technological mediation? The context of surgery offers a

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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/
unique opportunity for answering this question. The work of surgery is highly reliant on the bodily skilled 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 & Townsend 2012). Hospital surgery is heavily protocolized, with a clear delineation of occupational roles. Specific rules guide the skilled handling of instruments (scalpels, monitors, 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, an endoscopic system for minimally invasive surgery, we find that the surgeons experienced both an augmentation as well as a reduction of what they can do with their bodies, including the changes to haptic, visual, 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 spatial rearrangements, redistributing tasks, and recognizing novel dependencies. In turn, these adaptations led to a reconfiguration of occupational roles. To explain how changes in technology mediation affect organizing, 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 solve such unexpected problems (Faraj and Xiao 2006; Kellogg et al. 2006; Bechky and Okhuysen 2011). In order to coordinate expertise across specialties, there is a need to: transform knowledge for it to cross occupational boundaries (Carlile 2004), use dialogic practices to integrate knowledge across specialties (Faraj and Xiao 2006), rely on mutual monitoring and co-participation (Heath and Luff 2000), 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 accomplishment 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.

A new technology can be enrolled to alter existing coordination arrangements for it often enables new mediations, representations, and information flows. New technological mediations can be associated with the displacement or substitution for human skill (Zuboff 1988), reduced reliance on hierarchy for coordination and control (Zammuto et al. 2007), delocalization of work (Bailey et al. 2012), and an increase in shared situational awareness (Majchrzak and Malhotra 2014). Relying on technology to coordinate work has not been unproblematic. When groups work 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 et al. 2018; Bailey and Leonardi 2015). The problem of how to sustain effective coordination without colocation becomes more acute when fast response is necessary. For example, when robotic telepresence is introduced in intensive care, residents, nurses, and attending physicians struggle to sustain dialogic sensemaking and to integrate their expertise in order to achieve agreement on the course of treatment (Beane and Orlikowski 2015). Similarly, Pine and Mazmanian (2017) found that a newly introduced electronic patient records system limited the effectiveness of social and dialogical coordination because it was inscribed with overly rigid coordination patterns that were at odds with the emergent needs of expertise integration around the patient. Thus, new technologies introduced
with the goal of improving expertise coordination among participants can unintentionally exacerbate collaboration problems or create new ones.

Coordination of work in organizations often rests on an occupational order that relies on occupational groups to allocate expertise, tasks, and responsibilities. Occupational groups often prefer to formalize their cross-disciplinary interactions via roles and well-defined professional boundaries (Kellogg 2014). 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 (Bechky 2003; Faraj and Xiao 2006; Barley 1990; Valentine and Edmondson 2015). Modern technologies can be destabilizing for occupational groups because it often combines automating existing tasks with informating previously opaque work activities. As opportunities emerge to perform, divide and organize work differently, changes in coordination and roles are bound to follow (Zuboff 1988; Zammuto et al. 2007; Barley 1986). Incorporating a new technology can as a result lead to work process exclusions and inclusions that weaken or empower certain occupational groups (Beane and Orlikowski 2015). Furthermore, new occupational roles may need to be introduced to solve coordination problems due to the need to integrate now 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, even when technology is supposed to bring about labor-saving effects (Barrett et al. 2012). Thus, when technology invites a role configuration among occupational groups, deeply-held professional identities and jurisdictions can contribute to struggles around role definition, boundaries, and the allocation of new tasks.

In sum, the extant literature on coordination would predict that technology introduction is likely to be accompanied by coordination struggles and contestation around roles in the workplace. In our setting, when the robot became embedded in the surgical practice, we saw less of a struggle and contestation than would have been expected. Instead, we saw a steady transformation in how individual bodily performances were achieved and joint action synchronized. Mostly, team members changed their spatial position around the patient, delegated tasks, reworked their role, and figured out workarounds to accommodate the augmentation offered by the technology or to overcome the
reduction associated with it. Changes in bodily action and perceptions seemed to drive the evolution of coordination and occupational roles. In order to trace this reconfiguration process and do justice to its bodily element, we adopt an embodiment perspective on coordination. In the next section, we review what is known about the role of the body in work and argue for an embodiment perspective of 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 sensory and bodily perception (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 appear to be a constitutive aspect of skilled 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 to 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 expert 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 in order 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 unfolds 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 (Hinds and Mortensen 2005; Hindmarsh and Pilnick 2007; Streeck et al. 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 et al. 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 the 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 the operation can even proceed (Moreira 2004; Zetka 2003; 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 training of the body 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 and this right cannot be claimed by a gastroenterologist or a radiologist without serious consequences (e.g., 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).

Embodiment is useful to trace 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; Riemer and Johnston 2017; Ihde 1979). 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 to 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. As a result, 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, but play an organizing role in allowing what 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 allows for different perceptions, actions, and interactions and thus bring about a change in coordination and a reconfiguration in roles. In the balance of the paper, we analyze how the introduction of a robot in surgery led to a set of transformations in coordination by offering 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 is 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 found that usage was sporadic, and concluded that the first-generation model was obsolete. The hospital foundation agreed to acquire a new-generation Da Vinci robot that went live 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 via small surgical incisions. The robotic system consists of the surgeon’s console, a patient side cart, articulated EndoWrist® instruments, and a vision cart. 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 stand at the operating table next to the patient’s body. Figures 1, 2 and 3 provide illustrations of the OR with the Da Vinci robot to demonstrate its key differences to conventional surgery.

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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 but where 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.
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

Medical studies evaluating the efficacy of robot-assisted surgery have measured patient outcomes but have not arrived at conclusive results. 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).

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\textsuperscript{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

\textsuperscript{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 during breaks in between surgeries (e.g., having lunch and coffee in the cafeteria, observing OR prepping, setting up the sterile field, team gowning, and accompanying nurses into storage rooms as they prepared for the procedures). After every robotic surgery, the researcher sketched physical movements of the surgical team, noted key interactions and events, and summarized team conversations. 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 of using the robot, difficulties faced in practice, the changes in the teamwork, what was gained by the robotic system, the challenges faced, 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 (open and laparoscopic surgery) 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 documentation were imported in 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 were thus conducted.

Table 1. Data sources

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<th>Number/Details</th>
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<tr>
<td>Observations of surgeries (from July 2014 to August 2015)</td>
<td>23 procedures (103 hours, 112 pages of field notes)</td>
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<tr>
<td>Formal interviews</td>
<td>39 (average duration: 50 minutes)</td>
</tr>
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<td>Surgeons</td>
<td>17 (including 2 residents)</td>
</tr>
<tr>
<td>Nurses</td>
<td>11</td>
</tr>
<tr>
<td>Anesthesiologists</td>
<td>10 (incl. 4 nurse anesthesiologists)</td>
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<tr>
<td>Manager</td>
<td>1</td>
</tr>
<tr>
<td>Informal interviews</td>
<td>43</td>
</tr>
<tr>
<td>Observation of conventional surgery (for a different study)</td>
<td>57 surgeries (197 hours)</td>
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<td>Documentation:</td>
<td></td>
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<td>- Publications on robotics by our respondents</td>
<td>7 articles</td>
</tr>
<tr>
<td>- PowerPoint hospital presentation on robotic surgery</td>
<td>2 (60 slides)</td>
</tr>
<tr>
<td>- FDA documentation</td>
<td>2 (22 pages)</td>
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<tr>
<td>- Hospital report on the decision to acquire the next generation robot</td>
<td>1 (11 pages)</td>
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<tr>
<td>- Surgical protocols</td>
<td>5 (15 pages)</td>
</tr>
<tr>
<td>- Database with robotic surgeries</td>
<td>1016 procedures</td>
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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 features and the 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 a tracing of evolving roles were more revelatory. For example, an important change observed was in how scrub nurses performed fewer activities related to serving the surgeons (such as dressing them in sterile scrubs and handing them the tools). 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 said change in order 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, anesthesiology, 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 the 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 respondents 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 changes in how coordination was performed. Analyzing these changes in coordination, 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 introduction. For example, for the surgeon, we abstracted from codes, such as “can no longer feel the texture of the tissue” to conceptualize them as a “reduction of haptic perception”. These codes formed the basis of our 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 team members “redistributing tasks”.

Finally, as we compared the new coordination patterns and the novel task performances 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 changes in team coordination and the subsequent reconfiguration of occupational roles in surgery.
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, as well as 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 a 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 bleedings in order to stop it. This requires the embodied skill to know how much pressure is safe to exert, recognizing whether it is an artery or a vein, and 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 and postponing the need to eat, drink, or go to the bathroom (Moreira 2004; Hirschauer 1991).

Surgery involves not only the work of individual surgeons, but also depends on the carefully coordinated performance of a team. Team members rely on a pre-assigned positioning around the patient’s body and a fairly stabilized division of bodily doings, centered around 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 highly trained 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” (#18, 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” (#16, 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 through 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, such as handing instruments, bringing food and drink, and ending with “cleaning up the mess” after they leave (#3, 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 1991).

As we explain below, the Da Vinci robot radically changed this surgery practice by both augmenting and reducing the capacities of surgeons, and, as a result, disrupting the work activities of the team and ultimately re-configuring highly established roles and the social order of surgery.

**FINDINGS**

In order to investigate how the incorporation of a new technology transforms work performance and affects coordination between occupations, we present results from our field study. We report on the changes associated with the introduction of robotic technology by first describing how the use of the surgical robot affected the surgeon’s use of his or her body during surgery and how this, in turn,
affected the embodied processes of other team members, changed coordination processes, and reconfigured roles.

**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” (#23, vascular surgeon). First, this enhanced visual perception revealed anatomical micro details – vessels, arteries, veins, tissue - in a clarity previously unavailable, not even through “dissecting a cadaver” (#9, 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” (#21, gynecological surgeon). Third, because minimally invasive surgery is associated with less bleeding and the view of the patient’s anatomy is less clouded by blood, surgeons can do more precise interventions: “because you can see all these different layers, you are able to stitch all the separate layers together” (#13, 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 are otherwise difficult to access. They could also perform more sophisticated, secure, and exact stitches or 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” (#23, 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!” (#12, gynecological surgeon). Because they could now control and switch between up to four robotic arms on their own, this reduced their reliance on the assistance of residents and provided them with an experience of independence, control, and flow.

*Reduced embodied performance.* Beyond augmenting the surgeons’ range of actions in the site of surgery, reliance on the robot 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 manipulative abilities to apply pressure intuitively on organs, to find the source of a bleed, and apply pressure to stop it - an unproblematic embodied act 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!” (#13, 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 screen).” (field notes, 09/12/2014, gynecological surgery).
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 meant that the visibility was narrowed, robbing 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” (#20, urological surgeon).

Another reduction of surgeons’ embodied performance was owed to 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 were 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’” (#23, vascular surgeon).
<table>
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<tr>
<th>Bodily activity</th>
<th>Augmentation</th>
<th>Reduction</th>
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<tr>
<td>Visual perception</td>
<td><em>Can see more clearly via the magnified 3D interface</em></td>
<td><em>No longer able to view the rest of team or the patient’s body beyond the surgical cavity</em></td>
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<td>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. (#9, urological surgeon in training)</td>
<td>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! (#5, vascular surgeon)</td>
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<td>Haptic perception</td>
<td><em>Can more delicately handle tissues</em></td>
<td><em>Can no longer feel the texture of the tissue, or find source of bleeding by feeling the artery pulsation</em></td>
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<td>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 [...] (#13, urological surgeon)</td>
<td>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 (#6, gynecological surgeon)</td>
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<td>Manipulative dexterity</td>
<td><em>Can do better stitches, knots and control multiple robotic arms</em></td>
<td><em>Unable to stop bleeding by applying finger pressure</em></td>
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<td>[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 it [stitching] again and you can see it again (#13, urological surgeon)</td>
<td>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 (#16, urological surgeon)</td>
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<tr>
<td>Bodily positioning</td>
<td><em>Seated position outside sterile field relieves previous bodily constraints</em></td>
<td><em>Can no longer easily access and respond to emergencies</em></td>
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<td>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 (#2, urological surgeon)</td>
<td>There's 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 gaze 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. (#23, vascular surgeon)</td>
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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 2 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.

**Changes in embodied coordination**

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 flexible adjustments to each other’s actions. We found the shift to robotic surgery was associated with restrictions to how these activities could be performed, requiring team members to engage in spatial relocations, redistributing tasks, and recognizing novel dependencies. Table 3 summarizes these changes 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, tissue removal, suturing, or 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 bodies 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.” (#24, 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 screens 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” (#9, urological surgeon-in-training). Their surgical learning became impaired. 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 (#27, 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 20 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.” (#11, lead robotic nurse).

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.

*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” (#11, lead nurse in 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 hands-eye manipulation, and reliance on
the monitor for correct positioning. This required nurses to develop skills of recognizing anatomy
projected on the screen:

“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
screen. 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 July 31, 2014).

Immersed surgeons rely on detailed verbal communication to engage with the team. A
consequence of the almost total immersion of the surgeon 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
were replacing it, having dropped something. A surgeon emphasized the difficulty in 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: 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” (#24, 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 particularly challenging for the team to understand what the surgeon was trying to do, and vice versa for the surgeon to explicate the precise movements that were needed, triggering surgeons to articulate much of their embodied skill previously 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!” (#5, 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 is further restricted due to the movement of the multiple robotic arms. Further, the patient’s own arms are strapped alongside his body, to provide access for instrument changing at the robotic arm. Finally, the patient is tilted at a 45-degree angle, head down, a position that facilitates access to the pelvis as gravity pulls the intra-abdominal organs down. Thus, anesthesiologists have 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 puts 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” (#30, 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 to 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!” (#28, 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 an 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” (#32, anesthesiologist nurse).

As a result of reduced access, and to ensure patient safety, anesthesiologists developed innovations and changed their way of working. First, anesthesiologists fitted a special metal shield over the patient’s face in order 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 blocks access), they taped it 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 bricolaging new safety devices.
Table 3. Changes in embodied coordination of surgery

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<th>Changes in team member joint task performance</th>
<th>Coordinative adaptations by team members</th>
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<tr>
<td><strong>Resident:</strong> Unable to directly observe and participate in the embodied practice of surgeons</td>
<td>Residents move their body to the console</td>
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<td>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 (#27, vascular surgeon in training)</td>
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<tr>
<td><strong>Nurse:</strong> No longer able to hand instruments to surgeons and residents</td>
<td>Experienced nurses begin to assist with minor surgical activities</td>
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<td>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]” (#17, lead nurse in gynecology).</td>
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<td><strong>Anesthesiologist:</strong> Have difficulty accessing the patient’s body to monitor vitals and perform interventions</td>
<td>Anesthesiologists substitute for their body absence by developing new access points and artifacts</td>
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<td>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 &quot;be careful&quot; [to a surgeon], but also by making a hard shield, because he (surgeon) does not feel that he hits something, so when you say &quot;be careful&quot;, he does not feel if it is a nose, or it’s metal tube. These were the first problems. (#32, head anesthesia nurse)</td>
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<td><strong>Surgeon:</strong> Reduced ability to see, hear, and engage with the activities of the rest of the team</td>
<td>Immersed surgeons rely on detailed verbal communication to engage with the team</td>
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<td>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. (#13, urological surgeon)</td>
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Role reconfiguration in surgery

The coordinative adaptations of team members resulted in misalignments with the role arrangement typical 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 of these changes in Table 4.

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 screen, and gain a clear anatomical view. However, the residents’ interaction with the physical patient 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. Their learning activities were now typically performed by sitting on a chair next to a surgeon and passively following the surgeon’s movements on the screen, 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 screen. ‘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 screen and uses his hand next to the screen 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, 06/19/2015, urological surgery, 1st procedure of the day)

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” (#9, 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” (#12, 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 screen. 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 and substituted 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” (#4, 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” (#11, OR nurse). 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” (#1, 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 screen go everywhere, except for the spot you need!” (#29, 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” (#17, OR nurse).

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” (#1, 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” (#11, lead robotic nurse). 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” (#19, 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 nurse. 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” (#36, OR nurse). In a similar vein,
surgeon accepted that “It 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]
er 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” (#13, 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. Prior, in open surgery,
anesthesiologist 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 into the virtual world
of the robotic console, they effectively 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” (#25, 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” (#5, 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” (#18, 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” (#9, 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” (#5, vascular surgeon). Another surgeon similarly expressed:

“You were able to see, you know you have time when I do this - what happens, and when I do this - what happens. Also, some techniques to improve continence, some people 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 [...]” (#13, 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 4. Evolved roles

<table>
<thead>
<tr>
<th>New joint task performances create pressure on traditional roles</th>
<th>How roles are transformed</th>
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<tbody>
<tr>
<td><strong>Residents:</strong></td>
<td></td>
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<tr>
<td>Formed training program in robotic surgery for residents is introduced</td>
<td><strong>Demoted from participant to student</strong>&lt;br&gt;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 (#32, vascular surgeon in training).</td>
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<tr>
<td><strong>Nurses:</strong></td>
<td></td>
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<tr>
<td>Education of nurses now includes minor surgical acts</td>
<td><strong>Increase in autonomy and responsibility</strong>&lt;br&gt;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. [...] And with the robotics, you are all alone [at the table], you place clips, you can cut things and so, I like it (#29, OR nurse)!&lt;br&gt;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 (#19, general surgeon).</td>
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<tr>
<td><strong>Anesthesiologists:</strong></td>
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<tr>
<td>Formalize safety innovations into specialized protocols</td>
<td><strong>Increase the involvement in patient safety</strong>&lt;br&gt;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 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 (#34, anesthesiologist).</td>
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<tr>
<td><strong>Surgeons:</strong></td>
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<tr>
<td>Reduce their involvement in team supervision</td>
<td><strong>Specialization on the organ and decrease of team supervision</strong>&lt;br&gt;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 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 (#13, urological surgeon).</td>
</tr>
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DISCUSSION

This study examined how the organization and 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, surgeons gained the augmented embodied capacity to see and act inside the patient’s body but 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, recognizing new emergent dependencies, mounting novel responses, and enacting coordinative adaptations. 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 traditional organizing commonly found in 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 and roles. 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 leads to a need to re-establish embodied coordination. In turn, these efforts put pressure on existing roles and result in their eventual reconfiguration.

Figure 5. An embodiment perspective on how coordination is reconfigured in response to a change in technological mediation

What an embodiment perspective on work performance gives us

The embodiment perspective developed from our study offers a different way to trace the consequences of novel technologies for collaborative work. Our model foregrounds the embodied work performance, such as: how an actor engages differently their sensory capacities to perform skilled work, how the perception of work objects is now different, and how the position of the body in the workspace is changed. These embodied changes, while multifaceted, can be described principally as augmentations and reductions. For example, by associating with the robot, the surgeons augmented their bodily capacities to perform precise surgical intervention. Yet, they faced reduction in their perception of the broader 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 surgery. 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 roles and performance of surgery can be effectively explained through the specific augmentations and reductions in embodied work performances for all actors and their existing coordination practices.

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 is dependent on physiological limits and bodily capacities. More importantly, skilled work involves embodiment relations with tools and technologies where they 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 on embodied action (Merleau-Ponty 1962; Dreyfus and Dreyfus 1982; Ihde 1979; 1990), we highlight 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 their disruption and reweaving is consequential for joint performance.

Previous theoretical explanations of how and why coordination 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 co-constitution of the social and the material (Orlikowski 2010), or 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. By highlighting the importance of the body in sociomaterial performances, our perspective shifts the focus away from materiality of technology towards the materiality of the human form, including the importance of senses, body position in space and relative to others, to the awareness of others and objects and to 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 perceptions and
doings brought about by technological mediation.

Research on the work implications of new technologies has recognized how informating work
processes implicitly involves a break in our relationships with reality because it relies on digital
representations to mediate 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, validation, and sense of control over action. Even in the use of
cutting-edge crash simulation in car safety, representations are incapable to fully and accurately
replicate the physical car crashing process, requiring compensatory organizational effort and
reorganization to realign simulation results with reality (Bailey et al. 2012). Similar to Zuboff (1988)
and Bailey et al. (2012), our study highlights the challenges posed by moving from direct access and
manipulation to relying on digital representation and remote action. In our case, the digital
representation provided a high-resolution, three-dimensional view of the anatomic site and thus the
representation provided superior visual access to the site of surgery. Ironically, the gains of this
excellent representation came at a cost of the surgeons’ perceptual access to the outside the cavity
world. They suffered limits to peripheral vision and haptic manipulation, as well as auditory isolation.
Thus, our case highlights that even when technology provides an excellent representation of
underlying reality, it may limit the perception of other important non-focal aspects and break the
common ground that previously united the team in its performance.

The embodiment perspective developed from our study of robotic surgery 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. Such a 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 that “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 and 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, the whole practice of
surgery unwittingly changes. Thus, tools are not merely neutral devices for people to enroll or adapt to their needs, they are consequential in how they 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 changes in the equipment on the robot. 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.

**Work coordination**

Research on coordination has emphasized the importance of emergent and relational aspects of coordination practices with a focus on dialogue (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 the new technology, actors would prioritize sustaining the relational tissue that allows them to perform in a high-reliability manner. Instead, we find 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 involving a redistribution of critical tasks, changed monitoring responsibilities, and accepted new expertise dependencies. 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, but more about the establishment of a new configuration of the task and expertise dependencies.
Coordination research has highlighted that collaborative work is hindered by factors such as spatial separation (Hinds and Bailey 2003; Hinds and Mortensen 2005), inflexible technology setup (Pine and Mazmanian 2017), or the exclusion of certain actors from the knowledge flow (Beane and Orlikowski 2015; Bailey and Leonardi 2015). Our findings extend this line of work by emphasizing the elements of embodied interaction that get disrupted by the changed material conditions. In our setting, the robotic setup results in a number of disruptions to vision, hearing, actions, body placement, and intercorporeality that affect embodied work performance. In conventional co-located surgery, activities were choreographed and articulated by gesture, nods, pointing, grabbing, mutual monitoring, and anticipatory responses. With the robot introduction, the team is split between those clustering around the console and those around the body. Team members no longer share the same visibility and lose the benefit of embodied coordination. They no longer have access to the easy visibility of each other’s doings, or the same visibility of the patient’s body. Those around the console have access to a local and magnified view, while those around the body see with their eyes, but are hindered by the materiality of the robot’s body. As a result, they have a reduced ability to hear each other, to engage in anticipatory problem solving, and easily sustain shared understanding. Thus, in line with the work of communication scholars who emphasize that bodily actions by others can be an important source of communication (Streeck et al. 2011), our findings highlight the importance of embodied interactions for joint collaborative work.

Previous literature on coordination has focused on how cross-occupational work can be facilitated by the use of protocols (Valentine and Edmondson 2014), boundary objects (Beckky 2006; Carlile 2002), common spaces (Kellogg et al. 2006) and boundary spanners (Lingo and O’Mahony 2010; Kellogg 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. As Bailey et al. (2012) found in their study, splitting joint perception of objects by relocating car crash simulation work to a distant site, prompted unexpected coordination demands to emerge. In surgery, a surgeon relocating to a few meters away from an operating table disrupts team possibilities for joint perception of the patient’s body and creates challenges for the team to problem solve. What is disrupted is also the process of embodied
interaction that is essential for effective coordination, such as: gesturing, nodding, pointing, grabbing, showing, mutual monitoring, and anticipating. Thus, we highlight that shared vision and joint manipulation of objects in highly proximate settings is an underappreciated but highly important facilitator of cross-disciplinary work, which reduces the need for formal coordinative mechanisms (e.g., specified roles, formal responsibilities, explicit dialogue) commonly emphasized in existing literature. As a result, when 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.

**Role reconfiguration following the introduction of new technology**

The literature on role reconfiguration following the introduction of new technology has often emphasized how certain material properties 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 matter for task engagement (Hinds et al. 2004). Our study indicates the need to go beyond the particular material characteristics of the technology and instead emphasizes how the particular material characteristics of the technology affect the embodied performance of work and, in turn, how these new embodied performances can upheave coordination and bring about a reconfiguration of roles. By offering the additional material properties of remote manipulation of objects, movements and actions that exceed human dexterity within a small space, and glorious three-dimensional visibility inside the surgical cavity, a process of change was put in place. For each role, the usual 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 or 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 do 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 staked process because members actively protect their role boundaries, as these are 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 did not find 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 previously within-surgery activities, 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 undermines their expertise or adds 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 and asserted their need 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 flux, and, as a result, gain unplanned status benefits.

CONCLUSION

Our field study has allowed us to trace how roles and coordination in surgery practice were reconfigured following the introduction of a surgical robot. Our embodiment perspective on working with technology offers a useful lens for engaging in initiatives aimed at incorporating novel tools in collaborative work, especially those promising to augment human action and overcome physical limitations of a human body in performing work. At a time when organizations are increasingly integrating robotic technology, augmented reality, and remote sensing technologies, our perspective suggests the need for organizations to be mindful of how changes in perception and bodily action afforded by such devices are likely to produce coordination breakdowns, especially in settings where multiple occupational practitioners need to collaborate closely. Advanced technologies such as sensors, visualization devices, as well as remote monitoring or manipulation devices (e.g., drones), extend not only our cognition but also various aspects of perception and action. 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 devices extend our actions. Future examinations of other emerging classes of technologies can benefit from such an emphasis on what happens to embodied work performances in the workplace, both for the focal actor and the collective.

REFERENCES


Dear Professor Hinds,

We were very pleased to receive such thorough, constructive and consistent reviews on our submission. We have deeply engaged with the clear feedback provided by you and the review team. As a result, the paper has been rewritten and now incorporates the generous suggestions provided by the review team. Our paper is now reframed to offer an embodiment perspective on coordination. Below, we summarize the changes that we made in the revision. We then follow up with the detailed responses to each member of the review team below.

Positioning of the paper
We have repositioned the paper away from the broad focus on “surgery practice” and now position it as a contribution to the coordination literature. This helped us to develop a much clearer framing and a more substantive literature review, which now centers around the relationship between technology and coordination. We feel that this focus helped us to much better capture the paper’s facets of interest, including skilled performance, embodied interaction and roles, all under a single umbrella of coordination. Focusing on coordination also made it much clearer how and where exactly the lens of embodiment constitutes an important contribution. We are now confident that the revised version provides a competent and clear assessment of prior research on role of the body for coordination.

Clarifying our embodiment perspective
We have worked on clarifying which aspects of embodiment are helpful in explaining the key puzzling aspects of our case. In our theory section, inspired by the feedback of all three reviewers, we give a more targeted and deeper tour of embodiment literature, incorporating more specific examples, and other important aspects of the embodied view, such as the use of tools and physical space. In response to Reviewer 3 comments, we have also carefully reworked our findings to make sure that the focus in our narrative remains on the matters of the body. Finally, we have reworked the discussion section to more clearly articulate how the embodiment perspective is effective in tracing how coordination and roles evolve following a technology’s introduction.

Improving the fit between data and theory
Guided by reviewers’ comments, we have worked carefully on abstracting from our data to a more general representation of relationships that emerged from our
data. Guided by the feedback received, we now offer a theoretical model (Figure 5) as well as an empirical model (Figure 4). Our presentation of data is improved by new tables that clarify the data-conceptual links, for example, illustrating how we distinguished between visual perception, haptic perception, and manipulative dexterity. Finally, the discussion now more clearly summarizes our theoretical contribution and how our findings link to existing literature.

For clarity of presentation, we reproduce all received comments in Times New Roman 12 font and interspersed our responses in Arial 13 font.

Again, we are most grateful for the deep and thorough engagement of yourself and the review team with our submission. We hope this revision is to your liking.

Sincerely,

Authors
Comments by Senior Editor

Three expert reviewers have completed their evaluations of your manuscript. Although their recommendations to me varied widely (minor revision, major revision, and reject), they are remarkably consistent in their assessment of the paper. On the whole, the reviewers were excited about your topic, your data, and your findings and believe that the issues in the current version can be addressed in the revision process. I agree and am pleased to offer you the opportunity to revise your manuscript and respond to the reviewers' comments. As you will see, the reviewers were generally excited about the "embodied view" and see great potential for further developing this framing.

We were very glad to see that the review team was as excited as we are about the contribution of embodiment. The insightful comments that we received from reviewers were extremely useful in developing our contribution. We are most grateful for their exceptional level of engagement.

First, you need a more targeted treatment of the literature in the front end of the paper. As R2 states, "you do not clearly highlight the scholarly conversation to which you intend to contribute." R3 similarly says "The paper's main problem is the front end framing, which gives the reader no real focal point for your investigation." More specifically, R1 asks for "an explanation of how particular aspects of the concept of embodiment help us better understand your key findings" and that you "state as clearly as possible what these literatures would lead us to expect to find in your setting." A significant reframing of the front end of the paper will be required in a revision. Each of the reviewers has made excellent suggestions for how this might be accomplished. A closely related concern is that the research question is never fully articulated (see comments from R2 & R3), which makes it difficult for the reader to understand how to interpret the literature you discuss and how your study contributes. I encourage you to make explicit your research question early in the paper.

After engaging with the review team comments on the paper’s framing and the suggestion that we focus on a focal literature, the theory section has been thoroughly rewritten. First, the theory section now centers on the relationship between technology and coordination. We build on the literature on coordination to show that such literature has primarily emphasized cognition or knowledge and has often not put emphasis on the body and on collective doings. This clarifies our contribution which is about the embodied nature of coordination. While the whole section was reformulated, we will point your attention to the following summary paragraph:
In sum, the extant literature on coordination would predict that technology introduction is likely to be accompanied by coordination struggles and contestation around roles in the workplace. In our setting, when the robot became embedded in the surgical practice, we saw less of a struggle and contestation than would have been expected. Instead, we saw a steady transformation in how individual bodily performances were achieved and joint action synchronized. Mostly, team members changed their spatial position around the patient, delegated tasks, reworked their role, and figured out workarounds to accommodate the augmentation offered by the technology or to overcome the reduction associated with it. Changes in bodily action and perceptions seemed to drive the evolution of coordination and occupational roles. In order to trace this reconfiguration process and do justice to its bodily element, we adopt an embodiment perspective of coordination. In the next section, we review what is known about the role of the body in work and argue for an embodiment perspective of coordination.

Second, following the lines of suggestions of Reviewer 1 and 2, we have clarified the specific aspects of embodiment that are most pertinent to theorizing the technology-coordination nexus. We now articulate with more precision how embodiment helps to understand our case and findings. This is now reflected in specific section titled “Toward an embodiment perspective on coordination” pp.6-8

Finally, given the feedback received about the need to reformulate our research question, we now offer a more specific question: “How does the body matter in coordination and role reconfiguration following a change in technological mediation?”

Second, all three reviewers expressed concern about the paper not abstracting to theory. R3 says "we cannot imagine much implication for broader theory at this point" and asks that you speak to something larger. R1 asks if it wouldn't be better to include "a more abstract process model that could be generalized to other settings rather than to include this process model which is specific to your setting." R2 similarly asks that your final figure be a "representation of the theoretical construct you have induced from your data." In a revision, it is essential that you more clearly articulate the theoretical contribution that emerges from this work.

We are deeply indebted to the reviewers for pushing us into this important direction of theorizing our findings beyond a specific setting. We have clarified
and expanded on how we abstract from our empirics towards a generalizable model. We have also clarified our findings’ implication for extant theory. The paper now includes an empirical summary model (Figure 4) as well as a separate theoretical model (Figure 5). Tables 2, 3 and 4 now clearly represent how we traced the changes in work, coordination and roles to form the basis of our theoretical model.

Specifically, our theorizing now proceeds as follow. We suggest that robotic surgery is best studied by focusing on the change in embodied work performance, that is, the augmentation and reduction of bodily capacities. These augmentations and reductions affect joint tasks performances in a team. To perform coordination under the changed conditions, the team members engage in spatial relocations, redistributing tasks, mounting novel responses and enacting coordinative adaptations. Performing joint tasks differently puts pressure on existing roles, triggering role evolution, including emergence of new specializations, changes in role-based knowledge, as well as shifts in status and boundaries.

In the rewritten discussion section we now emphasize how the embodiment perspective was necessary to arrive at such a tracing of changes in roles following the new technology’s introduction. Our discussion section now revolves around articulating what implications such a model has for studies of coordination and technology.

Third, we found it difficult to understand the unique contributions of your study. As stated by R1, "Your model clearly makes novel contributions, but there are aspects of it that overlap with the current literature, and it think it would be helpful for you to point out these overlaps." All of the reviewers have asked for more clarity about what has already been established and what you are establishing that is new. Relatedly, the current discussion seems rather disconnected from the front end of the paper. In a revision, the discussion will need to be more closely connected to the main ideas and questions you raise in the front end and more clearly articulate the novel contributions of your work vis a vis previous studies.

Indeed, we recognize that the previous version was at times a bit too ambiguous in terms of specific contributions vis-à-vis previous studies. We have now invested much effort in making the unique contributions to the scholarly conversation around technology and coordination as clear as possible. We have also made sure that the front-end is more tightly integrated with the discussion.
Our discussion section now starts with addressing the most important question of
"what embodiment perspective on work performance gives us" and is titled
accordingly. The other two sections of discussion are now dedicated to how
embodiment is informing two streams of literature that we review in the front-end
– work coordination and role reconfiguration following the introduction of novel
technology. We have refrained from centering on sociomateriality debate, but
instead focused on clarifying what is new in our theorizing in relation to existing
literature on coordination and roles.

Finally, reviewers pointed out an inconsistency in your view of technology. As mentioned by R2,
"your title and literature review tell the reader you have a deterministic view regarding
technology... yet in many other places... you espouse a more modern orientation that treats the
material enactment of practices as the prime causal mover..."  R3 comments that your headings
in the findings (and your title) are deterministic "when in fact you write a lot about what people
did, so outcomes were co-shaped." Resolving this inconsistency will be important to a revision.

We thank the reviewers for their sharp observations about our unintentional use
of the deterministic language. We collectively yearn for a different language and
that language is not easily available! The reviewers also sensitized us to be more
careful in implying causality in our usage of terms. In the current version,
deterministic language is carefully removed from the paper. We now emphasize
that outcomes are not predetermined or that they follow from the introduction of
the robot. As our ontological view emphasizes, outcomes are situationally based
and co-shaped. Thank you for challenging us to remove remnants of
deterministic thinking in our paper.
Comments by Reviewer 1

I really like this paper. The paper uses an in-depth field study of the introduction of the DaVinci surgical robot into a hospital to argue that change in response to new technology occurred in response to the disruption and reweaving of embodied performance of actors in the surgical team. The data are wonderful, the analysis is robust, and your findings provide important contributions to the literature on cross-occupational coordination, role reconfiguration in response to new technology, and sociomateriality. I have a few suggestions for how you could improve the paper.

We were thrilled to receive your feedback and want to thank you for your deep engagement in helping us articulate our contributions! Your commitment to help improve our submission has been essential in clarifying our thinking and has been transformative in how we reframed the paper. We are extremely grateful for this exemplary and actionable review.

MORE CLEARLY EXPLAIN THE CONCEPT OF EMBODIMENT UPFRONT

As someone who is not deeply familiar with the concept of embodiment, I found that I needed to read some of the articles you cited in your upfront embodiment section in order to more clearly understand what embodiment is and how the concept of embodiment helps you to contribute to the literature on coordination and role reconfiguration. The way your upfront section on embodiment is currently written, it provides more of a literature review on how the concept of embodiment has been used in prior studies than an explanation of how particular aspects of the concept of embodiment help us better understand your key findings. Since it seems that you are using the concept to explain how the surgical robot affected the surgeon’s use of his or her body during surgery and how this, in turn, affected the embodied processes of other team members, changed coordination processes, and reconfigured roles, I could have used some more specific examples in the upfront section of how embodiment is related to an individual’s technical work process. The medical student example was helpful for this.

In the embodiment readings you cited, I found helpful the Latour example of trainees in the perfume industry using kits to learn how to differentiate extremely dissimilar smells and then to make progressively finer distinctions (cited in the Prentice article). Skilled perfume experts become known as 'noses'. They use their bodies to enact their work process and sniffing skill and body part come into being together. I also found the Prentice article helpful for detailing how surgeons learn to do surgery by combining tactile sensation and visual knowledge. Surgeons learn that skin slightly resists a scalpel, while the same scalpel slides easily through fat. They learn that scissors, used in 'reverse', to spread tissues rather than cut them, puncture and widen incisions in fascia only with some difficulty. Thus, surgeons use their bodies to understand what part of the anatomy they are in contact with and this helps them operate more effectively.
Thank you for the deep and nuanced engagement with our literature review, the embodiment concept and the case. Upon re-read, we see clearly how our previous literature review was indeed a bit unfocused. We are very grateful that despite some of our discrepancies, you remained focused on helping us bring out the reasons why embodiment is an appropriate lens for this paper.

We agree fully that the examples by Latour and Prentice that you summarize -- so effectively! -- were essential to guide and sensitize us toward embodiment theories as the central lens for explaining what happened in our setting. These readings and examples offered the most fitting vocabulary for what our informants described as the most important skills constituting their work. Your comment here informed us that the previous version did not convey the importance of this turn and that there was a need for a deeper exposition to help the readers. In the current version, we sought to remedy this issue.

These two examples helped me to better understand that you are using the concept of embodiment to explain how the introduction of the robot required the surgeon to use his or her body in new ways. With the robot, the surgeon could no longer guide his or her operating by the feel of the body but, instead, used the robot to see inside the surgical cavity and make cuts in a different way. The surgeon’s new use of his or her body required the surgeon to withdraw from other activities in the OR which, in turn, led to the need for new coordination processes and to a reconfiguration of roles.

I don’t think that you need to use these two specific examples from Latour and Prentice if others would be better. But, for those of us not highly familiar with embodiment, it would be helpful for you to provide a more concrete understanding of only the aspects of the embodiment concept that we need to know in order to understand upfront how you will use this concept to help interpret your findings.

Many thanks also for your thoughtful summary of the points that we needed to develop further. We especially value your insightful comment about how we use the concept of embodiment “to explain how the robot affect surgeon’s use of the body and in turn changed coordination and roles”. This was in fact a sharper reformulation of our intended contribution.

In response to your helpful suggestion, we have reworked the second part of our theoretical background section to introduce only these aspects of embodiment that help to understand and interpret our findings in relation to the broader
literature. This is now reflected on p. 6-8 in the manuscript. We also strived to make this section less of a broad literature review of embodiment (which admittedly sometimes diverged toward the philosophical) and to focus it on how that perspective offers specific insight for organizational scholars. We structure this section into illustrating the concrete importance of embodiment for the literature on work, coordination and roles. To do this, we used multiple examples, including the ones that you mention from Latour and Prentice.

We have also dedicated a special section in the discussion to expand and elaborate how the concept of embodiment helps to explain the findings of our case. The section is titled “What an embodiment perspective on work performance gives us” and can be found on pp. 34-37.

TELL US WHAT THE CURRENT LITERATURE WOULD LEAD US TO EXPECT TO FIND IN YOUR SETTING IN ORDER TO CLARIFY YOUR OWN CONTRIBUTIONS

There are two outcomes of interest in your study: reconfiguration of role relations in response to a new technology and cross-occupational collaboration. I think that you could clarify your contributions by more clearly establishing what we would expect to find in your setting around each of these outcomes given the current literature. You review most of the literature that comes to mind for me in each of these domains, but I don’t think you state as clearly as possible what these literatures would lead us to expect to find in your setting.

The literature on role reconfiguration in response to the introduction of a new technology would lead us to expect that surgeons, anesthesiologists, nurses, and residents 1) would experience barriers to role reconfiguration stemming from resistance from the higher power occupational group (Barley, 1986; Zuboff, 1988) and deeply-held professional identities (Nelson and Irwin, 2014), 2) would be more likely to reconfigure their roles when the technology had particular material properties such as offering different exclusions and inclusions (Beane and Orlikowski, 2015), allowing for digital representations (Bailey et al, 2012) appearing more humanoid rather than machine-like (Hinds and Roberts, 2004), facilitating situational awareness (Majchrzak and Malholtra, 2014), and providing transparency of work activities (Zuboff, 1988; Zammuto et al, 2007); and 3) would reconfigure their roles using processes of imbrication (Leonardi, 2011), enactment (Orlikowski, 2000), affordance (Faraj and Azad, 2012), or tuning (Barrett et al, 2012).

Thank you so much for this succinct summary that compares the findings of our case with previous literature. We are very much indebted to you for this clarity of presentation and thinking. Your comment related to the two outcomes of interest was also especially useful as it helped us to structure our targeted literature both in the front end and discussion in a crisp manner. The insights you offer us here
Your main contributions to this literature on role reconfiguration as I see it are that this literature has examined the importance to role reconfiguration of particular material characteristics of the technology, but has not examined the importance of how these particular material characteristics of the technology can change the embodied performance of the work process and, in turn, how these new embodied performances can reconfigure the roles. In your particular case, the technology enabled the direct manipulation of objects at a distance, facilitated movement that exceeded human dexterity, and immersed the focal user in a high-resolution, three-dimensional visualization. This disrupted the surgeon’s embodied performance of surgery and led to a new embodied performance that, in turn, led to new embodied performances by the other actors as well. Thus, your contributions to the role reconfiguration literature are 1) the additional material properties of enabling the direct manipulation of objects at a distance, facilitating movement that exceeds human dexterity, and immersing the focal user in a high-resolution, three-dimensional visualization (but see my question 3 below); and 2) the additional role reconfiguration process of disruption and re-weaving of embodied dependencies.

Your comments have been instrumental for us to push our analysis and sharpen our theorizing further. In response to your specific comment, we have fully rewritten section 1 in the theoretical background and the two final sections in the discussion. We now specifically address the implications of our findings for the literature on “Work coordination” and the literature on “Role reconfiguration following the introduction new technology”. Following your suggestions as to how we contribute to the role reconfiguration stream of literature, we reframed the focus of the second part of the theory section (see pp. 5-6) and the discussion (see pp. 39-40).

The literature on cross-occupational collaboration would lead us to expect that surgeons, anesthesiologists, nurses, and residents would 1) experience barriers to collaboration stemming from factors such as different occupational information, meanings, and interests (Carlile 2002), spatial separation (Hinds and Bailey, 2003; Hinds and Mortensen, 2005; Bailey et al., 2012), and inflexible technology (Pine and Mazmanian, 2017); 2) would collaborate better when protocols (Valentine and Edmondson, 2015; Klein et al, 2006), boundary objects (Beckky, 2003, Carlile, Starr and Griesemer), boundary spanners (Lingo and O’Mahony, 2010; Kellogg, 2014), and common spaces (Kellogg, Orlikowski, and Yates, 2006); and 3) would collaborate using the processes such as transferring information, translating meanings, and transforming interests (Carlile, 2002).
Your key contributions to this coordination literature, as I see it, are 1) the additional facilitators of collaboration of shared visibility, collocated non-verbal interaction, and anticipatory responses; and 2) the additional collaboration process of embodied interaction (e.g. gesturing, nodding, pointing, grabbing, mutual monitoring, and anticipating).

Your comment about contributions to cross-occupational coordination was also very useful in developing our thinking about how our case can be positioned within this literature. We also faced a decision on how to align the literatures on role reconfiguration and cross-occupational collaboration. We have opted to unite them under one umbrella of coordination. Our theoretical section now deals more centrally with coordination as a key phenomenon of interest. Our literature review starts now with deeper engagement with the literature you summarize above (see pp. 3-4). Also, in our discussion we go in depth in explaining how the embodiment perspective can extend our thinking about coordination practices and their change over time. See pp. 37-39 for this explanation.

On a minor note, I think that your contributions to the literature on technology and the reconfiguration of roles most clearly communicates what you mean by embodiment. So, in your Discussion section, you might consider moving your contributions to this literature before your contributions to the coordination literature.

Thank you for this suggestion. We fully agree. We now start the discussion section with explaining the overall contribution of the embodiment perspective to understand how work and coordination change following the introduction of new technology. We then move towards the literature on coordination and reconfiguration of roles.

On another minor note, you suggest that your data show that change can occur in a cooperative manner. I was struck by the fact that the resident is left out of the new process. Since residents are the least powerful actors in the setting, I wondered if the role reconfiguration was truly cooperative or if the residents merely could not object to the new reconfiguration without risking their reputation by complaining.

Indeed, we fully agree that the statement about change occurring in a cooperative manner is somewhat inconsistent with negative consequences that residents experienced. Your comment made us go back to the data and reflect on this counterintuitive finding in more detail. We searched for evidence in our case that would indicate that residents may have been reluctant to complain about the new reconfiguration, which would be consistent with the existing literature on
residents lower status in surgery (e.g. Kellogg 2011). Interestingly, however, our data showed that residents were actually the ones who did speak up about how being left at the surgery table to assist with minor surgical tasks was unconducive for learning. By speaking up, the residents were allowed to migrate to the console, while nurses took over their role. Thus, this move by the residents was partly the trigger for the role evolution we observed. Even though indeed the resulting consequence for residents was less favorable (reduced active participation and constraints for skill acquisition), it did not seem to be connected to their relatively low power status. We included a section in the discussion (see p.40) to reflect on this observation as illustrating the potential for lower-status actors to be able to maneuver the process of change.

HIGHLIGHT EMBODIMENT MORE IN YOUR PROCESS MODEL

Since your main contributions lie in emphasizing the importance of change in embodied performances, I was struck by the fact that Figure 4 doesn’t include the word embodiment. I think that the three augmented performances and the three reduced performances are all embodied performances. So, are you saying that one of your contributions to the literature on role reconfiguration in response to the introduction of a new technology is that this literature does not consider how new technology can disrupt a particular set of embodied performances by magnifying focal vision, improving manipulation, increasing control over instruments and by leading to haptic loss, reduced peripheral vision, and reducing ability to intervene?

My confusion with this figure made me wonder if it wouldn’t be better to include a more abstract process model that could be generalized to other settings rather than to include this process model which is specific to your setting.

We really appreciate your careful assessment of our theorizing! We have modified the empirical model (current Figure 3 and previous Figure 4) to emphasize specifically how performances were disrupted in the context of surgery. But in accordance with your recommendation, we now offer a theoretical model that is not specific to our setting and that goes to a higher level of abstraction, thereby making reference to existing literature stronger. Our newly developed theoretical model is now presented on p. 34.

MORE CLEARLY DETAIL HOW THE CURRENT LITERATURE DOES EXPLAIN SOME OF WHAT YOU FOUND

Your model clearly makes novel contributions, but there are aspects of it that overlap with the current literature, and I think it would be helpful for you to point out these overlaps. For example, you show that particular material aspects of the technology such as inflexible robot
setup and spatial separation between team members change coordination. Since the current literature shows that inflexible technology set-up (Pine and Mazmanian, 2017) and spatial separation (Hinds and Bailey, 2003; Hinds and Mortensen, 2005) make coordination more difficult, I think it would be helpful to say that and then to say what it hasn’t taken into account.

We have carefully reworked our discussion section to point the reader to the specific overlaps with existing studies and articulating what has not been taken into account. The debate alluded to above is now fully addressed in the discussion on p. 38. Thank you for the very helpful suggestion and framing.

WHAT ARE THE REAL WORLD/MANAGERIAL IMPLICATIONS OF YOUR MODEL?
I think that your study is fascinating and provides great contributions to our understanding of the introduction of new technologies into organizational settings. I think it would be helpful for you to include a short section somewhere in the Discussion where you say what the implications of your findings are for managers in organizations.

Thank you for this comment, indeed implications for organizational settings are important to be articulated explicitly. We added a short reflection on the managerial implications in the conclusion section, see p. 41.

Again, we are most grateful for the deep and thorough engagement with our submission. We hope this revision is to your liking.
Comments by Reviewer 2

I was glad for the opportunity to review your ethnographic research focused on robotic surgery, given the relative lack of empirical study of the implications of advancing machine intelligence for the world of work. In particular I think your focus on robotics - in contrast to technologies centered on information and algorithms - is timely and promising. Gathering data on work involving bulky technologies that move matter in spaces typically reserved for human-and-small-tool work allows you to ask different questions at in the midst of the recent scholarly conversation at the intersection of materiality and organizing.

We agree fully about the need to investigate technologies that go beyond information and the algorithm. We are grateful for your positive assessment of our focus.

As it stands, however, I see four significant problems with your manuscript that precluded a contribution: insufficient connection to a literature, an underdeveloped interpretive lens, insufficiently abstract findings and insufficient data. Your title, abstract and final figure reveal these problems, and they reverberate throughout the rest of the paper. I think the first three of these must be addressed in order for you to make a substantive contribution via Organization Science.

We would like to thank you for such a clear and constructive engagement with our manuscript! We benefited immensely from your feedback and are grateful for the four clear points that you raised. We have worked hard on engaging with each of your very helpful points. As a result, we believe we have produced a much stronger manuscript, which has been shaped and guided by your deep and thoughtful comments.

Connection to the Literature. With respect to the literature, I saw three issues. First, prior studies have covered much of the ground you claim, second you do not highlight a primary literature for your contribution, and third you theorize technology in ways that are inconsistent with what appear to be your general theoretical leanings. On the first issue, you hold up the transformation of surgery as your primary contribution to the literature. You specifically indicate that you are adding to theory by showing that change may arise without being attributable "to a specific technological feature or to a deliberate organizational restructuring" (your abstract). Barley (1986) and Orlikowski (1996) highlighted these points some time ago, however. Indeed in his CT scanner study and in subsequent work (1990, 2015) Barley focused squarely on how roles and role relations were reconfigured through the ongoing use of novel technology, with significant implications for workers, customers and managers. You highlight these kinds of findings as novel, so if you are focused on the way that change occurred here and the
implications for the work (and therefore role relations), you must go beyond these (and subsequent related) papers.

Regarding your first point. Thank you for your deep engagement with our theory section. After reviewing the literature again and looking at how our paper channels it, we agree that we have not positioned the paper appropriately. Upon reread, we do recognize that our previous formulation could be understood as a paper about being surprised that transformation of surgery was “not attributable to deliberate organizational restructuring”. This is not a fair representation of our empirics and clearly not the key insight from our study. We agree that the work of Barley and others has explored in depth how roles and role relations get reconfigured with the ongoing use of novel technology. Indeed, our paper contributes more specifically than merely agreeing with the now classical Barley studies. We thank you for pointing out how parts of our formulation were theoretically unsurprising.

The new version of the paper is now focused on how the ongoing use of novel technology is related to changes in work coordination. Following your suggestions, we have recycled between theory and data to more clearly identify the primary contribution to the most fitting literature. The most important aspect of our study, in our minds, is how the new robot somehow is consequential for existing coordination arrangements and how this process puts in focus how those arrangements are crucially constituted by the bodily forms of action and interaction. In turn, this focus made us confident that the embodiment perspective that we offer as our key contribution, is indeed a novel addition to existing literature.

On the second issue, you do not clearly highlight the scholarly conversation to which you intend to contribute. In many (perhaps most) places you seem focused on explaining change, given the introduction of novel technology. In others, you lean more towards explaining successful coordination in robotic surgery (your abstract, your literature review, your discussion (p27, Ins 15-19)) and in yet others you focus on how learning and training proceeds, given emerging, novel role relations in robotic surgery (as an aside, this angle has very recently been addressed by Beane (2018)). Even if your paper offers contributions in all three directions, you likely (in my experience) only have the data to make a genuinely substantive and novel contribution to one core literature. I suggest specifying this clearly in your title, abstract and final figure, leaving the others for the implications section.
Indeed, you are right in pointing to overly ambitious reach we made in terms of contributions to literatures on organizational change, learning and role relations, as well as successful coordination. This was too wide of a contribution target. We now focus our contribution on the scholarly conversation around technology and coordination. This narrowed focus is now reflected throughout the paper. The literature review now focuses on reviewing studies that address the relation between technology and coordination arrangements. We have applied the same consistency to our titles, tables and figures, as you suggest.

On the third issue, your title and literature review tell a reader you have a determinist view regarding technology (i.e. it is the robots that do the transforming), yet in many other places (e.g., "the introduction of the robot was consequential for the practice of surgery") you espouse a more modern orientation that treats the material enactment of practices as the prime causal mover in organizational affairs. I presume you have more modern ontological and epistemological leanings, so you will need to scrub determinist language (e.g., in your literature review: "technology often changes not only formal coordination mechanism, but also situated coordination arrangements..." p4, ln17, "New technology can force a difficult transformation away from tasks..." p5, ln31, "robotic technologies create a fundamentally different sensory and bodily engagement..." p6, ln 5) from your paper, or (perhaps more interestingly) make a much clearer and stronger case as to why robotic technology is somehow different in kind with respect to causality than other technologies that have been studied up to this point. I think there may be a "third way" forward with respect to this ontological divide, but as of now you are speaking out of both sides of your proverbial mouths.

You are making some wonderful points! We are embarrassed by the semi-deterministic language that we have fallen back on. It is amazing how hard it is for thinkers who fully embrace “modern ontological and epistemological leanings” to write about technology in a different way. One reason is that the language is not fully available yet, or at least, we have not fully internalized it.

In the revised version, and pursuant to your advice, we have done our best to scrub determinist language from our paper and reorient the literature review to the tone that is more consistent with our ontological position. With your encouragements, we have put more emphasis on the embodiment aspect of work and coordination. This focus on embodiment is precisely the most fruitful “third way forward” that you have alluded to. Besides the more focused framing, our discussion section now includes a major section on what the embodiment perspective can offer to research that traces technology related change (see e.g. pp. 34-37).
Interpretive Lens. Different scholars rely on different language to refer to the theory brought to bear to explain behavior in a particular context, thereby making a contribution in a literature. I rely on the term "interpretive lens" for this task, and in your case, I do not think you have sufficiently justified or made sufficient connections between your embodiment lens and your target literature. The first sentence of your "body in practice" section of your literature review should - but does not - make the case that theories of embodiment are crucial for understanding or making predictions about a particularly puzzling aspect of your empirical data. The central claim ("engaging the world via a robot necessarily provides a different mode of perception and action…", p6, ln 15) is extremely broad, unsupported by evidence and easy to contradict. There are many robots that do not fulfill these criteria, and there are many non-robotic technologies that do. I strongly recommend you invest your conceptual energies in the ideas you are reaching for in this sentence, however. What, very specifically, is special about a robot that makes your case particularly useful for building new theory? I encourage you to stay away from the categorical (i.e. claims of exclusivity, necessity) yet to retain your conviction that robotics show us something new.

To frame this another way: your second paragraph in this section focuses on matters of perception, making links to the human body. I get the sense that you believe that robotics at least highlights (and at most involves something truly unique related to) the role of the body in matters of organizational change involving technology, coordination involving technology and/or role relations involving technology. What is this, very specifically? As it stands, your literature review does not give us a directed tour of the embodiment literature with respect to one of these broader scholarly conversations - it reads more like a general tour, indicating ways that embodiment has and may make a difference for a variety of phenomena.

Thank you for raising this important theoretical issue. Indeed, your comment above urging us to “make the case for theories of embodiment as crucial for understanding puzzling aspect of our data” was crucial for us in revising the manuscript. We followed your suggestion to engage in providing a more direct tour of embodiment with respect to one specific scholarly conversation, namely coordination.

Our second part of the literature review is now titled “Towards an embodiment view on coordination” and argues that situated coordination practices are sustained by the use of the body, which then necessitates examining the evolution of coordination as an embodied achievement. We now structure our directed literature review on embodiment around four aspects. First, we highlight how bodily senses are constitutive of work. Second, we explain how coordination
is sustained via embodied interaction. Third, we explain that roles are sustained in bodily conduct. Fourth, we explain how tools are consequential in shaping the bodily perception and action.

Relatedly, I believe your embodiment lens does not yet account for your phenomena, but that it could, if you enrich it. You make reference to a sociomaterial lens at the end of your literature review. As it stands, this amounts to what Siobhan O'Mahony and others have called "patchwork theorizing" - yet one more moving part, brought together without strong integration. By the time I get to your conclusion (e.g., p30, lns 11-35), I can strip out the word "bodily" without doing violence to your findings. The opposite should be true - it should be obvious to me by that point that embodiment (or an alternate lens) is the best/highest way to account for the phenomena you observed, and that without that concept we would struggle to understand that phenomena.

If I step back from the logic of your argument and look at your empirics, however, I can well understand why you were compelled to include this paragraph. It seems to me that theories of embodiment may not go far enough for you, however. The shape of the Da Vinci console, tower and robot, the wraparound headrest, the interchangeable instruments, the cabling, the anesthesiologist's cart, and so on - all of these things, plus the configuration of the visual and auditory organs and "end effectors" (e.g., hands) on the human body - put together it seems these things have a great deal to do with what is possible in this work. If you want to turn to work on embodiment to explain change (or some other phenomenon) by showing how novel practices restructure perception, diagnosis and action, I think you must therefore make explicit theoretical reference to physical space, the role of physical objects in that space, the range of activity and perception that such space affords, and so on. This is obviously very hard work, but I think there are clear links to be made here between sociomateriality and embodiment. Related work (largely in the STS tradition) may help your theorizing (Dale 2005, Doyle J and Roen K 2008, Goodwin 1995, Hirschauer 1991, Koschmann et al. 2011, Moreira 2004).

Your point here is well taken and sensitizing. We focused our efforts on how we could enrich an embodiment lens to be able to account for our phenomenon. Our reworked manuscript is now much clearer in arguing why the embodiment perspective is the best way to trace the reconfiguration of coordination we observed in our setting.

Your pointers to relevant papers in STS tradition were extremely valuable. We have found the studies on ethnographies of surgical work by Moreira (2004), Hirschauer (1991), and Koschman et al. (2011) beautifully illustrating the bodily nature of work and coordination in surgery. We also learned from the work of Dale (2005) about social and material production of space and its relation to...
organizational control, and from Doyle and Roen (2008) about embodied subjectivity and the link between body and psyche. Many of the insights made in these papers gave us additional support for embodiment as a contribution. We also built on the work of Goodwin (1995) in order to enrich our embodied lens, to theorize the range of activity and perception that is afforded by physical space and tools that actors use. Goodwin’s view on embodiment is the broadest, as it does make explicit theoretical reference to physical space, tools and the range of activity this space and tools afford. His and related work on situated interaction makes it especially clear how collaborative work is consequentially shaped by the tools and spatial arrangements that organize perception of practitioners.

These insights now form a core part of our theory section and discussion. In our section “Toward an embodiment perspective on coordination” we now offer a more directed review on the role of the body in sustaining effective coordination, and extend this review with the role of tools in augmenting and reducing bodily perception and action. This enriched embodiment perspective thus allows to explain how bodily senses are sustaining coordination, and also, that tools consequentially shape bodily perception, thereby playing an organizing role. Emphasizing how tools augment and reduce bodily perception and action, was the needed link to justify why embodiment is the most useful lens for our case. We thank you for your guidance and patience in encouraging us to more fully deploy this viewpoint.

Findings
Your title, abstract and final figure reflect your overall focus on transformations in the practice of surgery, given robotic technology. This is too close to your data for a journal like Organization Science; your primary contribution must be theoretical. Your final figure, for example, must make limited if any specific reference to the particulars of your context (e.g., surgeons, surgery, Da Vinci), instead providing a representation of the theoretical construct you have induced from your data (Becker 1998). You do not explicitly name your research question in your paper, and I think working on this more carefully may be a good initial gambit as you seek to remedy this issue. One implied version of your question that leans farthest away from the purely empirical resides in the first sentence of the second paragraph of your introduction (“...how robots are consequential for work practices," but the tail end does not point to the conceptual phenomenon of interest (e.g., change, coordination), and is therefore too broad.

Thank you for these valuable comments. Of course, we agree. We have taken the following steps: First, the title has been reworked to be more in line with our theoretical framing. Thank you for taking the time to notice our discrepancy.
Second, we have now developed a theoretical model (see Figure 5) that explicitly represents our theoretical contribution that rises above the empirical setting. We did retain an empirical model (Figure 4) to summarize and clarify the sequence of changes. We believe both figures are of use. Third, we have included an explicit research question in the introduction of the paper (see p.2) that now reads as: “How does the body matter in coordination and role reconfiguration following a change in technological mediation?”

Data
I find that any data set seems somewhat insufficient when the frame for a paper is not in good shape. I am therefore somewhat agnostic about yours. That said, I am often quite willing to entertain weaker frames for a paper given very strong datasets. I do not think yours fits in that category. You observed robotic surgery for slightly over a year, and during that time gathered data on only 23 procedures. Without a referent, this total seems low: how many total procedures were performed during this time period? Further, ethnographies typically revolve around "living with and living like" (Katz 1997) your research informants so that you can make convincing leaps from the emic to the etic, but you do not make it clear how much raw time did you spent on site at this hospital during your overall time in the field. I suggest making this clear, especially if you hang your hats on change-related findings; these would be much more credible if you had clearly spent time in (and cited data from) the interstices between procedures and interviews.

Additionally, I was surprised that you did not include any data gathered during actual procedures. In any subsequent manuscript I suggest you do so, given the known problems with retrospective accounts of situated activity (Jerolmack and Khan 2014). Your interview totals pose similar problems. Given the elapsed if it were clear to the reader that you had interviewed 86% (for example) of the surgical staff for this institution, your data would be more compelling. I did find it interesting and useful that you interviewed surgeons who elected to discontinue use of the Da Vinci, by the way - we do not often study technological relinquishment, which seems very tied up with technological change to work methods. Also, I found (but you did not report in table 1) that you observed a significant number of open and laparoscopic procedures during the study period. Your change (or at least your "augmented" and "reduced") related findings would not have been credible without this comparative data, so I strongly encourage you to highlight it in table 1 and more extensively your writing.

I presume collecting additional data is not feasible for you. If so, I think it will be particularly important to address my feedback in the first three sections of this review, as you will have to offer particularly compelling theoretical contribution to overcome these data-related limitations.

Thank you for pushing us to provide more detail with regards to our data. We do agree that more justification is warranted. First, our data presentation table...
(Table 1) now describes in greater detail the various times spent in the hospital. In the table, beyond the specific robotic surgeries observed, we clarify that we observed 57 conventional surgeries. These observations covered 197 hours. They were crucial in giving a deep understanding of the work of the team, their roles, and the surgery practice in general. We do not emphasize this data here because we view it as focused on open surgery and not robotic surgery. But since it is the same hospital and the same OR, it is indeed highly relevant to ensure that our immersion in the site is adequate and credible. Second, the setting was just not conducive to “living with and living like” that would be reasonable in other field settings. At bottom, the multidisciplinary team seemed to only assemble in order to perform surgery. Since this was our focus, we chose to emphasize the OR joint work rather than their broader lived experiences.

Third, we did observe 23 out of the 180 procedures that took place during the period of our fieldwork. Attending more surgeries during the research period was not always possible because access to unscheduled surgeries was sometimes difficult to obtain and also because of frequent changes in the OR scheduling (other non-robotic surgeries shared the operating theatre). Also often, for example, there were 4 surgeries scheduled for the day, but the team ended up performing only one because of complications. Given that each surgery took an average of 4.5 hours in the OR, that they involved extensive prep time, and we often asked clarification questions following the surgery, it was thus difficult to effectively observe more than one per day.

Fourth, we did spend time with team members in-between procedures and when the prepping for surgery was taking place. It is during this time that we had the majority of our informal interactions (referred to in table 1 as informal interviews). We view these 43 informal conversations as crucial to fully understand events and utterances and to increase our comfort in the leap from the emic to the etic.

Finally, regarding the reporting of observational data. We agree that in the previous version, we seemed to put the observational data in the tables and seemed to prefer to emphasize quotes in the actual text. That was not intended but emerged from an attempt to keep the text short and easily flowing. In the current version, we now present more accounts of observed situated activities in the text. That way, the presentation of data is effectively stronger. We thank you for this judicious reminder.
Summary
I know my feedback is largely critical, and this may be difficult to bear. If so, take heart: I meant every word in my opening paragraph with equal sincerity. You have overcome a wide range of significant barriers to acquire valuable data and insight, and I trust you will find a way to redeem this work in a scholarly publication. I offer my feedback in that spirit, and I wish you the very best as you consider the most useful way forward with this work.

We are deeply grateful for your constructive guidance, which we took to heart while advancing our analysis and theorizing. We hope that our thoroughly revised manuscript will meet your expectations.
Comments by Reviewer 3

Your paper on the introduction of a Da Vinci robot into surgeries and the subsequent changes in skilled performance, coordination, and roles is quite fascinating, and I very much enjoyed reading it. You have superb data and a lovely set of findings. Your analysis is strong overall, with just a few places where I will push you to reconsider. The paper’s main problem is the front end framing, which gives the reader no real focal point for your investigation. As a result, the connections that a reader might expect that tie the front end to the methods to the findings to the discussion are a bit ambiguous or implied. My comments below are primarily concerned, then, with helping you determine an appropriate framing and showing you how you need to connect that framing to later parts of the paper, for example in your discussion of what you paid attention to when observing surgeries, how you organize your findings, and even how you label your headings in the findings and the discussion. You have a lot of work ahead of you, and I would caution you against making only slight revisions: you need some fundamental and significant changes to draw out clearly your contributions to new knowledge in the field. That said, your paper has tremendous potential, and I want to commend you on such a good first submission.

Thank you for taking the time to so deeply engage with our paper and for your appreciative comments and constructive feedback. In so many ways, you seem to know our research as well as we do. Your help in framing and improving the paper is beyond the call of duty! Your straightforward questions and rich feedback have been instrumental in sharpening our theorizing, enrich our data presentation, and to clarify our contributions. Overall, the paper has been rewritten almost entirely but retains its key elements. We hope that you will find the new version to be more aligned with your generous feedback and engagement.

Front End. You need to do more work on framing your work theoretically in the front end. Right now, the lit review talks for the first two pages about general findings of new technology implementation in the workplace. It then pivots to the introduction of robots with the claim that robots change sensory and embodied engagement with the physical world, thus prompting an embodied view of the technology-human relation. The remainder of the lit review discusses prior work that either theorizes what those changes might be or provides some empirical evidence of them across the various categories of expertise and sensing, tool mastery, team coordination, and occupational orders. The review ends by claiming that the embodied view can “extend our understanding of change by foregrounding how various actors get redistributed and how their bodily doings are affected.”

This framing is incomplete in a number of ways. To begin, I have no clear sense what the research question is that this inquiry will address. You need to establish what new knowledge
your study is after. If indeed your concern is how actors get redistributed and how their bodily doings are affected, I would argue that Zuboff (1988), whom you cite only in relation to occupational order and with no detail, did a rather thorough job of explaining these issues when describing the introduction of computers to paper pulp mills. Mill workers had to use their bodies in completely different ways, their redistribution into a central computerized office prompted a wholly new and thoroughly social approach to problem solving, and the analytical content of their jobs increased as the distance to physical phenomena decreased (now represented virtually via flow diagrams that did not match the physical layout of the plant). Her work makes clear that robots are not the first technology to have this impact. David Noble’s (1977) history of CNC machines and David Hounshell’s (1984) accounts of assembly lines speak to the impact on worker redistribution, role changes, and bodily doings from even earlier technologies. In the direct context of surgical teams, Amy Edmondson’s (1992) work on a new procedure, MICS, altered team interactions and prompted the need for different communication by altering who could see what. Thus, if you intend a technological stance in the front end (i.e., robots cause something new that other technologies do not), you need to better theorize robots.

As it stands, you note on p. 5 that robots enable the direct manipulation of objects at a distance (I agree), allow movement that exceeds human dexterity (I agree), and immerse the focal user in a high-resolution, three-dimensional visualization (I disagree). That last trait is true of the Da Vinci robot, but clearly not true of all robots. And if it is that last trait that is most important, why do you limit your perspective here in the front end to robots when augmented reality and virtual reality technologies share this trait? I would think you should be attempting for something universal here, and then introduce the robot as an appropriate target of inquiry in the methods. But in your methods, you remark that you began from a technological stance by looking at what features of the robot prompted change, and gave that up, which I think was the right call.

Thank you for providing us with this sharp summary of the underlying logic of the previous framing. Upon re-reading, we see clearly how such presentation and assessment of the literature did not fully convey what we felt was the strongest insight emerging from our study. You are right that the previous motivation for our research question could have been read as misleading at times and does not appropriately refer to the classical studies on automation. Your comments below were a huge help in reconstructing the framing so that it became stronger.

Upon reflection, we are in full agreement that our study is less about the robot. Like many of the scholars you point us to, we view the introduction of the robot in surgery as an occasion to study how coordination is reconfigured as the team attempts to perform surgery using the possibilities offered by new apparatus. To reflect this more streamlined theorizing, we have rewritten and streamlined our
theory section. This first part of the theory section is titled “Research on technology and coordination”. We now go directly to studies of work coordination and review what role the technologies have been playing in reshaping coordination. We specifically foreground many of the key studies you have pointed us toward. We then conclude the section on coordination with comparing the previous studies with a puzzling observation from our case that required us to adopt a different lens - i.e. embodiment - to be able to trace the changes in coordination, accounting for the changes in embodied work performance and embodied interaction. Thus, the second part of the theory section offers a review of the embodiment perspective and how it is relevant for understanding how coordination evolves in conjunction with new technology. The section offers arguments specific to: “individual work performance” (action level), “embodied interaction” (interaction level) and “roles” (occupation level). As a result, we think our theory section is now more focused, which we would not have been able to achieve without your help. The revisions are reflected on pp. 3-8 of the manuscript.

If a technological stance is not your direction, then perhaps “the embodied view” is; currently, the front end reads primarily as a justification for and motivation to employ this view. Focusing on an embodied view may prove a better theoretical tact than adopting a technological stance for motivating your study, but still you need to demonstrate what prior (presumably unembodied) accounts of new technology implementation leave unanswered.

It may be that poking a bit harder at sociomateriality, which you address in your final paragraph, will help you here. I suspect that most folks who are thinking about sociomateriality cast the material aspects of work in terms of technology and artifacts, not the body. The body is perhaps merely the vessel that gets a person to other people, allowing for the social aspects of work. (I appreciate that the point of sociomateriality is the blending and inseparability of the social and the material, but please permit this simplification to make the point.) An embodied view pays attention to the materiality of the human form, to our five senses and to proprioception and to our awareness of others and objects. The virtual team literature tells us what happens when we use technologies to hold meetings that separate bodies from each other. Are we less aware of what happens when we use technologies to separate bodies from material work artifacts? Again, I would encourage you to explore existing work about other technologies because past studies do speak to these effects, but no doubt incompletely. Here, I think Bailey et al.’s (2012) discussion of digitization, representation, and virtuality with respect to work and technology may be useful.

Thank you for your suggestions. Your appreciation of the embodiment perspective as the “better theoretical tact” for the study was very encouraging!
This specific comment was especially inspiring, as it followed very much our original thinking. Indeed, we started off with the theoretical hunch that embodiment seemed to be very much in line with the ongoing debate and writings on sociomateriality, but there seemed to be gaps in sociomateriality when it comes to thinking about the human body. We too thought it was surprising that sociomateriality thinking, a theoretical lens that is supposed to foreground the material aspects of work, had not paid much attention to the human body. Because of these reasons, we have further reduced our engagement with that literature for it is not a great base for our theorizing. But we do suggest in the discussion that there is a need to pay attention to the material aspect of the body and not just to the material aspect of artifacts. We address it in the discussion in the following paragraph:

[p. 35-36]: Previous theoretical explanations of how and why coordination 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 co-constitution of the social and the material (Orlikowski 2010), or 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. By highlighting the importance of the body in sociomaterial performances, our perspective shifts the focus away from materiality of technology towards the materiality of the human form, including the importance of senses, body position in space and relative to others, to the awareness of others and objects and to 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 perceptions and doings brought about by technological mediation.

[I’ve now finished your paper and return to my comments here. Your findings suggest that the body is interesting for several reasons: (1) body activities in terms of what it can or cannot do, and (2) body placement in terms of where it is positioned with respect to other workers and to relevant material work artifacts (here, the patient and the robot most significantly). In addition, you are focusing on the body in a situation in which work is highly coordinated, directed by a proximate leader, and performed synchronously in close quarters, all of which bring to the fore issues of body activities and position. For these reasons, I think you should drop the rather generic “how new technologies reshape work” front end and go straight for studies of coordination, what role technologies have shown to have in prompting alteration of it, and the
under-emphasis, surprising in this age of sociomateriality, on the materiality of the body as opposed to the technology when thinking about coordination. I think one of the first things I read that paid attention to where people stood was Walker and Guest’s (1952) study of the assembly line; I have some dim memory that Mark Mortensen may have drawn on that piece in writing about team coordination. At any rate, I think you are right to later to talk about individual skills, coordination, and roles in your findings and discussion, but I think you might couch them all in terms of coordination and what it requires: people performing individual acts while interacting with others and in alignment with roles. Then you want to understand how the introduction of a new technology, by occasioning and allowing alteration of sociomaterial relations (who can touch what, see what, feel what, and who is near what or near whom), changes coordination. This isn’t just a “let’s explore how robots change work” paper; it is, I think, a paper that is about coordination.

Thank you for your further engagement with the paper’s framing. Indeed, we struggled in the initial submission to choose the focal angle for we were torn between practices, technology, expertise, and cross-occupational roles. All these were present in the empirical setting and were all affected by the use of the robot.

We see two very important points in this significant comment of yours. We dwelled on them for a while, as they were very instructive for how to reconstruct the storyline to make it flow smoothly, while retaining all important insights. First, your suggestion to emphasize coordination as the main contribution of the paper helped us to align our own empirically-informed thinking with the theoretical lens. Second, you pointed us to the underlying theoretical problem - “underemphasis on the materiality of the body, as opposed to technology, when thinking about coordination” - that gave us the confidence in how to justify the need to focus on embodiment and position it as a contribution to the previous studies on coordination.

We have embraced these two points to write a more focused theory section. We made a choice, using your suggestion, to couch work, interactions and roles under a single umbrella of coordination, because literature on coordination covers tasks, interactions, and roles. Given that our empirical story involves how individual tasks, joint tasks and roles are reconfigured, it seemed to be the most appropriate framing. As a result, we think our theory section is more focused, which we would not have been able to achieve without your help. The revisions are reflected on pp. 3-8 of the manuscript.
Methods. Given your focus on movement (“how people moved and positioned themselves,” interactions, and the redistribution of bodies, I am a bit surprised that you chose observation rather than video methods. Please explain why in the text. For example, explain that you were not interested in how small movements may have prompted actions by others, as in the case of ethnomethodological accounts, but in how changes in where one stood or what one did, which were readily observable without attention to micro-level affairs, altered coordination. You say that you noted non-routine interactions, which implies that you did not note routine ones. Explain. Further, how did you identify non-routine interactions? I think you need to note earlier that you previously studied traditional surgeries so that others do not have this question. To that point, you use three words to modify existing types of surgery: open, traditional, and conventional. Chose one term only. It seems open and laparoscopic are two types of existing surgeries. Define both of them briefly so that readers understand the difference between open and laparoscopic and between those two and robotic surgery. I think a key thing to mention is that laparoscopic surgeries altered coordination by limiting who could see what (similar to Edmondson’s study, true here as well?), but surgeons still stood beside patients and interacted physically with the rest of the team. The robot altered that physical relationship in addition to altering the visual one. Those details are important for your story.

Thank you for pushing us to provide more detail and precision with regards to our method choices and analytical procedures. We do agree that more clarity was warranted to explain our choices, specificity of types of surgeries, and steps in data analysis.

A number of changes were introduced in the methods section to more clearly establish the various sources of data and justify our method choices. First, we explain why we chose observations as one of the methods of data collection. We note in the text that videotaping, which would have been a preferred method for studying micro-movements of participants, was not allowed in the OR. Second, we expanded our data presentation table (Table 1) to describe in greater detail the various times spent in the hospital. In the table, beyond the specific robotic surgeries observed, we clarify that we observed 57 conventional surgeries (40 open and 17 laparoscopic). These observations covered 197 hours. They were crucial in giving us a benchmark to what differences to pay attention to when noting down actions and interactions in the OR. Third, we explain the terms we describe to refer to various types of surgeries. Specifically, we write:

[p. 9]: 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 but where 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.

In addition, we have responded in great detail to Reviewer 2 about why we chose certain methods and how we went about our field work. Please see our response to them. We do not reproduce them here for length reasons.

You say that your first analytical focus was to identify features and the material aspects of the robotic technology. That speaks implicitly to a research question. Then you changed your focus to activities and roles, which speaks implicitly to a different research question. If your paper is about coordination, then you need to motivate activities, interactions, and roles clearly in the front end of the paper; currently, you do not emphasize them and they get little more than a paragraph or two. You can discern activities and interactions from your observations, but roles are an analytic construct. How do you gain understanding of them: from your interviews, from analysis of the activities and interactions in your observation as building blocks to roles, or from both? Explain how. On page 12 at the top you say that you coded all instances that reflected how groups acted; I don’t know what that means. I think you mean you coded all actions that differed from typical actions in existing surgeries. If you stick with dependencies and disruptions (and I am not convinced that you should because you have a lot of ground to cover, but that is your choice), you need to motivate them in the front end also.

We have also followed your suggestions here to strengthen the consistency between the front-end framing and the description of data analysis process. We have excised language that points to a framing that wants to “identify features and the material aspect of the robotic technology”. As stated earlier, we have essentially decided to focus on the relationship between technology and work coordination. Our introduction now explicitly puts forward the research question, which reads as “How does the body matter in coordination and role reconfiguration following a change in technological mediation? “

The roles we refer to in the paper are primarily roles that are predefined because of the occupational jurisdictions. In our setting (surgery) roles are specialty based and leave little room for individual latitude. To trace role change, we relied on
both observation and interview data. For example, we could see that nurses now routinely engaged in “cutting” in the patient’s body. We could see that they no longer gowned and gloved the surgeons (whom we saw struggling to do so by themselves). All the participants talked about the role change and the need to adapt to the new role configuration. We did observe that these changes were formalized in training, protocols, and consistent doings. In contrast, in conventional surgery, these changes did not happen. Nowhere else in the hospital were nurses allowed to “cut” the patient. “Cutting” is universally recognized as the domain of surgeon, and in our interviews both surgeons and nurses spoke about the increased role of nurses in performing the initial cuts and pushing trocar inside the patient body.

To summarize, we gained our understanding of cross-occupational role change from: 1) comparing robotic surgery doings to that of conventional surgery and analyzing those differences; and 2) from the interview responses to questions about stable arrangements and division of responsibilities. Our confidence was further increased when respondents volunteered information about these issues without our explicit probing.

I find absolutely brilliant your description of how you associated changes purely in what the surgeon did with disruptions to team dependencies and how you abstracted that to reduction or augmentation of skilled performance for the surgeon or others. Well done! You might just cast these steps in a different light as I have been describing but that will be your choice (of whether to stick with dependencies and disruptions).

Thank you for such an enthusiastic assessment of our analysis. We find your attention to detail and the care with which you are helping reshape the manuscript amazingly helpful. As you can see from the reworked manuscript, we have taken all your feedback to heart and have made the suggested changes.

Findings. The first sentence here is a huge disappointment, but easily remedied. “To explain how the Da Vinci robot occasioned change in the practice of surgery” suggests that this missing explanation is in essence your research question. Yet, because this question is dependent on a single phenomenon in a single setting, we cannot imagine much implication for broader theory at this point. I love a descriptive tale, but you need to open strongly here, not weakly, by speaking to something larger (and directly related to an RQ). The information on open surgery (introduced by the second half of the first sentence) you should provide as background in the methods section.
Thanks a lot for this clear and instructive guidance. As we clarified earlier, we have embraced our new research question and rewrote the findings section to directly answer this question. Our findings section now opens with a more general introductory statement, referring to the implications of novel technology for work performance and coordination. This way, we retain the focus that is broader than a specific setting and put forward propositions that can be informative for scholars interested in coordination, roles and technology. We open the findings section now with the following:

[p. 16] In order to investigate how the incorporation of a new technology matters for work performance and affects coordination between occupations, we present results from our field study. We report on the changes associated with the introduction of robotic technology by first describing how the use of the surgical robot affected the surgeon’s use of his or her body during surgery and how this, in turn, affected the embodied processes of other team members, changed coordination processes, and reconfigured roles.

Per your advice, we also relocated the information on open surgery to the method section. The section titled “Surgery context” on pp. 14-16 is now providing these details.

LOTS of great findings here, hats off for a truly lovely set of findings! I have some ideas for how you might reorganize them, however. The basic idea is this: whatever headings you employ here should speak to the main concepts that you motivate in the front end. Right now, the headings (and for that matter, the title of your paper) are far more deterministic than most OS readers will like (the robot caused this, the robot caused that, when in fact you write a lot about what people did, so outcomes were co-shaped; for example, the resident could have stayed at the table but chose to go to the console—the robot did not force that change). Moreover, your headings focus on surgeon skilled performance, team coordination, and team roles, none of which you tell us much about in the front end. This focus on the robot’s role may be appropriate if your front end takes a technological stance. If instead you focus on the embodied view, note how that view is not the central aspect of your headings.

These ideas were extremely inspiring, thanks for much for thinking along and engaging into our narrative. It is so hard to talk about technology directly without lapsing into possibly deterministic language! Indeed, we recognize that the framework we chose for the case presentation diverged at times from the central
contribution of embodiment. We have embraced your suggestions here and worked on developing tables that put a greater emphasis on bodily action.

As a result, we rewrote the findings to reflect the focus on embodied performance, both individual and collective. We have changed the headings of each section, subsections and also have revised the majority of the labels in the tables. To remove the deterministic language, we dropped any references to robot “transforming the work”, but rather refer now to changes in “embodied work performance” and “embodied coordination”. This, in our view, helps to better illustrate our focus on tracing changes in situated bodily activities - the main point of embodiment perspective. For example, you will find our Table 2 introducing several dimensions of perceptions, including haptic, auditory, visual perception and manipulative dexterity. Similarly, Tables 3 and 4 specify concrete bodily tasks performances.

To facilitate a greater emphasis on the body in the findings, as I read through the impact on the surgeon, I wondered if some kind of table might not work well here, with rows arranged according to what the surgeon can newly do and what the surgeon can newly not do, and columns arranged with respect to the body: with their hands, with their eyes, with their senses, with their bodies, with the robot’s arms. That scheme places emphasis on the body, and you could use a new heading to support it, something about embodied changes in skilled performance (or activities). Another framework that is body-oriented might present results in this section by what a person attends (or not) to: the patient’s physical body, the patient’s virtual body, others’ bodies. Or perhaps you might focus on where the body is (by the table, by the console), or some combination thereof. But I think your findings need to resonate first with the matters of the body (what it can do, where it is placed) and then later, rightly as you have done, with the implications for coordination (changes in individual activities, interactions with others, and roles).

Per your advice here, we worked carefully on our tables to illustrate the main emphasis on the body. Our revised table now traces how specific augmentations and reductions in the work of the surgeon affected what they could do with their hands, eyes, and bodies. We specifically refer to these changes as visual, auditory, haptic perception, manipulative dexterity and bodily positioning. Your suggestions here helped us to dig deeper to have more precision in our theorizing of what embodied changes are and how we could think about them.

Similarly the next two sections become not what the robot did, but the impact of these changes in what bodies do and where they are (that is what you wrote in the methods, so this would be consistent with that). Specifically, the section on coordination (you might reframe as interactions
if this all builds to coordination) could also have a body focus: the residents move their body to
the console, the nurses use their body to act on the patient, the surgeons use their voice to give
clear directions because they cannot use their body anymore, and the anesthesiologists don’t do
much new with their body, but because they cannot do with their bodies what they used to do
(push aside the doctor’s body and insert their own beside the patient) are more attentive to the
patient’s body. In section on roles, you cast aspersions on what happens to the residents,
describing their change as a demotion. A body focus would suggest instead that you call out a
change in how residents learn: less with their bodies in action at the surgery table, more with
their eyes and minds and hands in virtual training and then in legitimate peripheral participation
at the console as they first watch and then take on small tasks. Their learning has become more
virtual and you need to speak to that before diminishing it as more student-like than before. It has
also become less engaged with others: the resident is less an acting member in team coordination
than an apprentice of the surgeon. The nurses use their bodies to prepare their own prep and no
longer attend to the doctors’ flailing arms (that was rather funny and a good addition in your
findings). The surgeons now have to mind their own bodies. And most impressively and
ironically, but you don’t point this out well enough I think, although the physical distance
between the doctor’s body and the patient’s body has increased, the psychic distance (perhaps
you will call it something better) has decreased: alone with the virtual viewing of the robot’s
interface, the doctor is immersed in the patient’s virtual body. The link between doctor and
patient is thus closer while at the same time the link between doctor and rest of team is more
distant. Lots to play with there, and here your findings add something that Zuboff did not give
us. In paper pulp mills, operators were both physically and psychically distant from the machines
with which they once worked (their patients) because of the computer interface; in your case,
physical distance increased but psychic distant decreased. I keep calling it psychic and that is
probably not the right word; you’ll figure it out. Why is that? Again, I would urge you to
consider that the representations of the paper pulp mill equipment on the computer did not match
their physical reality (in terms of shape and position relative to one another), whereas the robot’s
representation does match the body and the console itself acts as a blinder to the rest of the work
setting.

Inspired by these comments about sections of coordination and roles, we have
also reworked our analysis of these sections to bring out the precision and most
important emphases on the bodily aspect of coordination and roles. Tables 3 and
4 now provide more direct references to what each member of the team could or
could not do with their body to perform joint tasks, and then trace what
adaptations each member engaged in to re-establish team performance in
surgery. In the section on roles, like you rightly suggested, we needed to provide
more details to which specific novel activities precluded team members to
perform their existing role (e.g. residents could not perform traditional learning
when sitting on a chair and passively watching the screen). Such focus helps to
bring to the forefront how the embodiment perspective is an effective way to trace the reconfiguration of actions, interactions and roles.

We were grateful for your pointers towards the literature on relationship between representations and reality (Zuboff 1988; Bailey et al. 2012). We value this point greatly and have developed it as a cornerstone of our discussion. Please see the following paragraph from the discussion:

[p. 36]: Research on the work implications of new technologies have recognized how informing work processes implicitly involves a break in our relationships with reality because it relies on digital representations to mediate 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, validation, and sense of control over action. Even in the use of cutting-edge crash simulation in car safety, representations are incapable to fully and accurately replicate the physical car crashing process, requiring compensatory organizational effort and reorganization to realign simulation results with reality (Bailey et al. 2012). Similar to Zuboff (1988) and Bailey et al. (2012), our study highlights the challenges posed by moving from direct access and manipulation to relying on digital representation and remote action. In our case, the digital representation provided a high-resolution three-dimensional view of the anatomic site and thus the representation provided superior visual access to the site of surgery. Ironically, the gains of this excellent representation came at a cost of the surgeons’ perceptual access to the outside the cavity world. They suffered limits to peripheral vision, limits on the haptic manipulation and auditory isolation. Thus, our case highlights that even when technology provides an excellent representation of underlying reality, it may limit the perception of other important non-focal aspects and break the common ground that previously united the team in its performance.

Overall, I very much like the body focus and I think that your attention to it is appropriate. But you are not the first to attend to the body, so you need to set up for us what is unknown. If we get no further than “the robot caused this” then the case remains largely descriptive, and we’ll need new studies every time a new technology enters the workplace, and we could probably have a hundred papers right now just on the different variations of robots in the workplace. You need to take it up a step analytically to show us the role of hands in collaborative work, the role of vision in collaborative work, the role of feeling in collaborative work, the role of the body’s position in collaborative work, and so on, and how the introduction of a new technology changed those matters. Beyond the references I have already made, I think you will find examples in Heath and
Luff’s description of vision in the underground subway control room, and Barley’s description of how being able to read CT scans altered technicians’ roles with respect to radiologists’ roles.

We were very encouraged by your appreciation of the body focus and for your expert suggestions of relevant literatures to ground this analysis in. We worked hard to enact your encouragement to go further than “robot caused this” and identifying the places and ways in which our findings were merely descriptive. We fully agree with your comment, and indeed felt that our study was revelatory for bringing the body into studies of technology and coordination, by emphasizing how vision, hearing, haptic, and other senses matter for collaborative work. The challenge for us, however, was in effectively bridging the theories of embodiment, the studies on technology consequences for work and the studies on coordination, all the while not slipping into deterministic language. The way out was to adopt a focus on coordination, like you suggested, and bring the interest in action, interaction and roles under the umbrella of coordination. We have revisited the details of the studies Barley (1986; 1990) and Heath and Luff (1992; 2000) with this focus in mind and found them very helpful for our building the theory section.

Discussion. The discussion is on the right track, but will need some adjustments as you reframe the front end. I would advise that you remove generic mentions of past technology and work implementation studies and that you only minimally mention sociomateriality, but that instead you tell us in bold and clear terms (including changes to your headings) what an embodied view of coordination gives us. Now might be a reasonable time to return to the features of the technology that provided the opportunity for these changes: for example, it featured two pieces, arms at the table and a console distant from the table, it allowed for movement at one and vision at the other, and so on. I mention these features because they help us to abstract so we know not just that a robot helped occasion changes, but what features we might look for in other future technologies to anticipate such changes. Your focus, though, should be on the body, what we learn about the importance of vision, feeling, acting, body placement, and so on in coordination. Such matters have long been the domain of industrial engineers and human factors experts; what does their consideration by organizational scholars yield new for organizational theory? Similarly, does the literature on embodied communication have relevance for your study in terms of your methods, concepts, or findings? I am most familiar with Jurgen Streeck’s work and suggest you begin there if you are unfamiliar with that literature; I provide a book reference below.

After repositioning our paper toward coordination, we have accordingly rewritten the discussion section to reflect this reframing. Following your suggestions, we
now start the discussion with a clearer statement of what we think is our contribution. We have also added a newly developed section in the discussion, titled “What embodiment perspective on work performance gives us”. This section offers an overview of what we learned about the importance of human form and senses for collaborative work and organizational matters. Our fully revised discussion section now engages with the literature on embodiment (e.g. Ihde 1990, Streeck et al. 2011), literature on technology-enabled change (Barley 1986, 1990) and the literature on representations, automation and work (Zuboff 1988; Bailey et al. 2012).

All these changes may take more space. I think you can drop Tables 2, 3, and 4 (which you never explain in the text); I am no fan of quotes in tables and your text has sufficient evidence of the changes you claim. That yields three pages, and I believe you also have a page limit of 45 pages. You will need this space for a deeper and expanded front end. If you keep Figure 4, then you will need to spend more time describing disrupted dependencies, which I am not opposed to, nor do I see it as problematic if you retain a performance-coordination-roles framing rather than an actions-interactions-roles one under a single umbrella of coordination. But I do think you need to find a way to put the body front and center in your findings and remove the deterministic perspective that again presents itself in Figure 4’s title.

We thank you for this focused guidance on increasing consistency of our framing and presentation. We did experiment with various ways to represent the data, including dropping tables and relocating evidence into text, as well as trying out to include tables for introducing analytical categories. In the end, we chose to use tables as summaries of the analytical narrative, and also as a way to offer further empirical evidence, something asked for by another reviewer. The quotes in our revised tables also serves a comparative purpose: quotes help to illustrate how novel tasks and activities that team members had to perform compare with each other.

Finally, to better establish our contribution, and to ensure that our findings do not remain at the level of the specific case we studied, we now include a theoretical model (Figure 5) that provides an embodiment perspective of how coordination and roles are reconfigured in response to a change in technological mediation. We believe such presentations helped best to put the body front and center, and also reduce the deterministic perspective as you suggested.
In sum, we would like to again thank you for your precise and encouraging expert guidance throughout this revision.

References


