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Silence is golden: the role of team coordination in health operations

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Abstract

Purpose – This study investigates the relationships between team dynamics and performance in healthcare operations. Specifically, it explores, through wearable sensors, how team coordination mechanisms can influence the likelihood of surgical glitches during routine surgery.

Design/methodology/approach – Breast surgeries of a large Italian university hospital were monitored using Sociometric Badges – wearable sensors developed at MIT Media Lab – for collecting objective and systematic measures of individual and group behaviors in real time. Data retrieved were used to analyze team coordination mechanisms, as it evolved in the real settings, and finally to test the research hypotheses.

Findings – Findings highlight that a relevant portion of glitches in routine surgery is caused by improper team coordination practices. In particular, results show that the likelihood of glitches decreases when practitioners adopt implicit coordination mechanisms rather than explicit ones. In addition, team cohesion appears to be positively related with the surgical performance.

Originality/value – For the first time, direct, objective and real time measurements of team behaviors have enabled an in-depth evaluation of the team coordination mechanisms in surgery and the impact on surgical glitches. From a methodological perspective, this research also represents an early attempt to investigate coordination behaviors in dynamic and complex operating environments using wearable sensor tools.

Keywords Behavioral operations, Team behaviors, Healthcare management, Wearable sensors, Teamwork, Surgery

Paper type Research paper

1. Introduction

Healthcare operations have become increasingly complex and interdisciplinary. The use and role of teams has thus grown significantly in healthcare organizations making teamwork an essential determinant of effective care delivery (Valentine *et al.*, 2015). Healthcare teams, especially in dynamic domains such as operating rooms, emergency medicine and intensive care, are typically multidisciplinary, work under quickly-changing conditions, and stay together for short periods with a dynamically fluctuating team membership (Bamford and Griffin, 2008; Denton, 2013; Vashdi *et al.*, 2013). These characteristics make healthcare teams very interesting but also hard to study (Shah and Breazeal, 2010; Wheelock *et al.*, 2015; Chang *et al.*, 2017).

The literature on operations management highlights the high impact that teamwork has on team performance and especially on the potential operational failures. Team dynamics are defined as behavioral relationships between members and the influential interpersonal processes that occur in teams over time (Levi, 2015; Forsyth, 2018), and seem to play a central role in healthcare (Manser, 2009; Broekhuis and van Donk, 2011; Berry *et al.*, 2016). This position is supported by many authors in various areas of healthcare: surgery (e.g. Mazzocco *et al.*, 2009; Siu *et al.*, 2016); intensive care (e.g. Dietz *et al.*, 2014); mental health (e.g. Deacon and Cleary, 2013);

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neonatal resuscitation (e.g. Williams *et al.*, 2010); and across entire hospital systems (e.g. Berry *et al.*, 2016). Consequently, researchers and health managers have investigated team dynamics in various healthcare settings to understand the determinants of performance and to define strategies for improving teamwork and team operational performance (Manser, 2009).

In this context, surgery has particularly attracted attention above all as a result of its impact on hospital budgets and patient care and safety (Jebali *et al.*, 2006; Gupta, 2007; Venkataraman *et al.*, 2018). The operating room is one of the most complex and challenging work environments in healthcare, where teamwork failures and human errors have been shown to cause the greatest amount of unintentional harm in a hospital (Wheelock *et al.*, 2015; Sun *et al.*, 2018; Rubbio *et al.*, 2019).

Team dynamics exert a great influence on surgical performance (Healey *et al.*, 2004; Siu *et al.*, 2016; Venkataraman *et al.*, 2018). Specifically, team coordination seems to play a key role in the management of dynamic work teams (Mathieu *et al.*, 2008; Rico *et al.*, 2008; Gorman, 2014), such as surgical teams. Team coordination, i.e. the behaviors that team members adopt to coordinate themselves during operational tasks, takes place through explicit and implicit coordination mechanisms and patterns (see Section 2.1. for a definition of these mechanisms). The balance between these two coordination mechanisms, which occur simultaneously in surgical teams, has a profound influence on team performance (Malone and Crowston, 1994; Crawford and LePine, 2013).

Although implicit coordination appears to increase team effectiveness, the best equilibrium between explicit and implicit coordination depends on the specific features of the operational tasks and the related operational context (Broekhuis and van Donk, 2011; Gorman, 2014; Butchibabu *et al.*, 2016). Accordingly, the best coordination strategy depends on how frequently a surgical procedure is carried out and the levels of uncertainty involved. Consequently, surgical teams should have different coordination behaviors with respect to *routine* and *non-routine* surgeries (Manser, 2009; Bogdanovic *et al.*, 2015).

Although routine surgeries are by far the most frequent in hospitals and overall have the greatest operational impact (e.g. Abbott *et al.*, 2017; Steiner *et al.*, 2017), past research has tended to focus on the less routine interventions since they are likely to be more interesting from a medical perspective (Seelandt *et al.*, 2014; Siu *et al.*, 2016; Gjeraa *et al.*, 2017).

We thus believe that an in-depth exploration of team coordination practices in routine surgery is crucial for helping healthcare organizations and researcher to improve health performance and patient safety. Evidence of direct relationships between team coordination practices and surgical outcomes are, in fact, scarce and not conclusive (Mazzocco *et al.*, 2009; Sun *et al.*, 2018).

To fill this gap, we therefore address the following Research Question:

RQ. How does team coordination tend to influence operational performance in routine surgeries?

Specifically, we explore the effects of different team coordination mechanisms, both explicit and implicit, on surgical outcomes through the evidence provided by a case study within the Breast Surgery Unit of an Italian university hospital. In addition to team coordination mechanisms, Team Cohesion was also taken in account in this investigation. Team cohesion, in fact, seems to play a key role in the dynamics and effectiveness of team coordination in surgery (Burtscher and Manser, 2012; Gorman, 2014; Sacks *et al.*, 2015).

This study exploits wearable sensors in terms of their ability to obtain automatic and objective measurements of individual and group behaviors. In fact, one of the main reasons for the lack of strong evidence in this context appears to be related to the difficulty in directly measuring coordination behaviors during real surgical procedures (Rosen *et al.*, 2014; Sun *et al.*, 2018).

The contribution of this work is in its assessment of the influence of team coordination on surgical performance in routine surgery, which are the most relevant from an operational viewpoint (Abbott *et al.*, 2017; Steiner *et al.*, 2017). The uniqueness of this study comes from our in-depth exploration of team coordination behaviors. We recorded in real-time many different aspects of practitioner behaviors during surgical procedures (e.g. body movement, speaking interactions, and proximity). To the best of our knowledge, this is the first time that such detailed individual and collective coordination behaviors have been evaluated while medical teams are carrying out surgery and then subsequently related to surgical outcomes.

We believe that our results will help (1) practitioners and health managers by highlighting sub-optimal coordination practices that seem to affect operational failures in routine surgery, and (2) health providers in training surgical staff and in planning surgical activities.

Our study also contributes to the operations management methodology. For the first time wearable sensors have been exploited for investigating relationships between team coordination behaviors and process performance in such a dynamic context (Rosen *et al.*, 2014; Chaffin *et al.*, 2017). Accordingly, this research also provides a first answer to the question of "how" to quantitatively investigate team dynamics and behavioral factors in healthcare operations and in other complex business environments (Croson *et al.*, 2013; Brocklesby, 2016).

The paper is structured as follows: Section 2 overviews related studies on team coordination and develops the research hypotheses. Section 3 presents the research method and describes the measurements. Section 4 reports the findings. Section 5 discusses the results and outlines the main contributions. Finally, Section 6 discusses the limitations of the method and suggests s directions for future research.

2. Theoretical background and hypotheses

2.1 The role of implicit - explicit coordination mechanisms and cohesion in teamwork

Coordination of work teams, defined as the actions of managing tasks performed by separate actors to achieve a common goal, is an important issue for operations management, particularly given the increasing number of business activities organized in teams (Malone and Crowston, 1994; Marks *et al.*, 2001; Mathieu *et al.*, 2008; Easton and Rosenzweig, 2015; Ben-Menahem *et al.*, 2016). Coordination enables team efforts to be organized and guided to predefined targets through various mechanisms, such as verbal communication, task assignment, and written feedbacks (Brannick and Prince, 1997). Past studies have shown that an appropriate level of coordination is very important for teams across all sectors and that poor team coordination has a negative impact on outcomes (Faraj and Sproull, 2000; Mathieu *et al.*, 2008).

Team coordination includes *explicit* and *implicit coordination*, which occur simultaneously during team operations. *Explicit coordination* refers to visible and external coordination mechanisms and patterns, such as mutual communication, direct monitoring, and team rules, which team members use intentionally to manage their multiple interdependencies (Malone and Crowston, 1994; Espinosa *et al.*, 2004; Ben-Menahem *et al.*, 2016). In work teams dedicated to a specific and pre-defined task, explicit coordination corresponds mostly to the transfer of information and resources in response to a direct request, which usually happens through verbal communication (Entin and Serfaty, 1999; Butchibabu *et al.*, 2016).

On the contrary, *implicit coordination* patterns operate imperceptibly and, thus, are more difficult to observe. Implicit coordination occurs when team members anticipate the actions and needs of their colleagues and dynamically adjust their own behavior accordingly, without the need for direct communication (Espinosa *et al.*, 2004; Rico *et al.*, 2008).

Given the requests for information amongst teammates, explicit coordination implies a higher communication overhead than implicit coordination, which implies anticipatory information sharing behaviors (Entin and Serfaty, 1999; Shah and Breazeal, 2010; Butchibabu *et al.*, 2016). Some studies have theorized (e.g. Rico *et al.*, 2008; Gorman, 2014) and have empirically shown (e.g. Butchibabu *et al.*, 2016) that implicit coordination, which frees up individuals' mental resources and contributes to harmonizing team activities, increases work team effectiveness and efficiency, while excessive explicit coordination behaviors may negatively affect team outcomes. Therefore, the right balance needs to be struck between explicit and implicit coordination, and this depends on the characteristics of the task involved.

In line with contingency theory, the appropriateness of team coordination mechanisms might depend on the specific operational context, and in particular on the level of task uncertainty and interdependence (Malone and Crowston, 1994; Donaldson, 2001; Okhuysen and Bechky, 2009; Broekhuis and van Donk, 2011; Crawford and LePine, 2013).

For instance, in highly interdependent tasks, in order to complete a task successfully team members should coordinate their actions and share their information continuously. In such cases, explicit coordination might lead team members to spend too much time and energy on coordination rather than on performing their jobs. Implicit coordination is thus likely to have a greater positive effect on team performance when teams perform highly interdependent tasks (Espinosa *et al.*, 2004; Rico *et al.*, 2008).

Regarding task uncertainty, when task routineness is high – and thus there is low task uncertainty – implicit coordination seems to improve team performance. In contrast, when task routineness is low (high uncertainty), the exclusive use of implicit coordination might have a negative effect on team performance (Espinosa *et al.*, 2004; Rico *et al.*, 2008; Broekhuis and van Donk, 2011; Riethmüller *et al.*, 2012). In fact, when tasks are ill defined, uncertain, and characterized by frequently-changing requirements, explicit coordination is needed to synchronize team members throughout unique and non-repetitive actions.

Past studies also show that in many situations where explicit coordination is avoidable, as occurs in routine tasks, a lower level of explicit communication leads to higher team performance (e.g. Manser, 2009; Gorman, 2014; Butchibabu *et al.*, 2016). This is justified by the decrease in the coordination overheads. Explicit coordination involves the mental efforts of team members which might increase the level of distraction during operational activities. This appears to be confirmed by empirical research across different business settings (Shah and Breazeal, 2010; Wheelock *et al.*, 2015; Chang *et al.*, 2017).

The effectiveness of coordination in work teams also seems to be influenced by *Team Cohesion*, i.e. the degree of shared ties and member integration that drive team members to work together, to commit to other members, and to accomplish the purposes of the team (Zaccaro *et al.*, 2001; Mathieu *et al.*, 2015; Salas *et al.*, 2015). Team cohesion mostly depends on the existence of sound shared mental models and on the development of a collaborative and constructive working environment, where everyone's contribution is appreciated and individual team members can freely share their ideas without being criticized (Kozlowski and Chao, 2012). Indeed, shared team mental models are defined as common knowledge structures held by members of a team that enable them to have shared expectations and explanations regarding the task and, thus to coordinate their actions and adapt their behaviors based on the objectives and behaviors of other members (Cannon-Bowers *et al.*, 1993; DeChurch and Mesmer-Magnus, 2010; Healey *et al.*, 2015). In this way, shared knowledge and a positive and collaborative environment enable team members to anticipate and predict each other's behaviors, and to back each other up during the team's activities (MacMillan *et al.*, 2004; Smith-Jentsch *et al.*, 2009; Kozlowski and Chao, 2012; Vashdi *et al.*, 2013; Gorman, 2014).

Past studies have shown that cohesive teams communicate more efficiently and use implicit coordination mechanisms more intensively, enhancing team coordination and team effectiveness (Stout *et al.*, 1999; Rico *et al.*, 2008; Fisher *et al.*, 2012; Gorman, 2014). Specifically, it appears that the impact of team cohesion on team performance is very important in many different team configurations and across sectors (Mathieu *et al.*, 2000, 2008; Burtscher and Manser, 2012; DeChurch and Mesmer-Magnus, 2010), though the influence on performance seems to be greater where a high level of implicit coordination is required (Rico *et al.*, 2008; Gorman, 2014).

2.2 Empirical research on team coordination in healthcare operations

Teamwork is increasingly assuming a crucial role in healthcare operations following the increase in care activities carried out by teams (Mitchell and Golden, 2012; Valentine *et al.*, 2015). Recognizing the relevance of team dynamics for patient care and safety, a growing number of studies have focused on the relationships between team coordination and related outcomes (Burtscher and Manser, 2012; Rosen *et al.*, 2018), so as to be able to provide indications for improving healthcare results in terms of operational effectiveness and efficiency (Sun *et al.*, 2018).

Due to the huge variety of healthcare activities, team coordination and team-building have been studied both in acute settings, such as emergency or surgery units, and in non-acute settings, such as primary care or rehabilitation clinics (Boyer and Pronovost, 2010; Miller *et al.*, 2018). However, it is on acute care settings that researchers have mostly focused so far. This is likely due to the high potential impact of coordination and teamwork on patient safety and care effectiveness for such short-term teams (Bamford and Griffin, 2008; Manser, 2009; Mazzocco *et al.*, 2009; Johnston *et al.*, 2019). In fact, without proper team coordination, wrong decisions can be made which affect team performance or even fatally compromise the patient safety (Siu *et al.*, 2016; Thomas *et al.*, 2018).

Although the issue of team coordination in healthcare has been explored, some methodological concerns still remain in investigating relationships between team dynamics and healthcare performance (Schmutz and Manser, 2013; Denton, 2013; Tiferes *et al.*, 2015; Berry *et al.*, 2016; Donohue *et al.*, 2018). The main challenge, not only in healthcare, is how to systematically and objectively measure team behaviors in such a dynamic environment (Kim *et al.*, 2012; Schmutz and Manser, 2013; Chaffin *et al.*, 2017).

Past research has essentially exploited two approaches for measuring team behavior: self-reporting and observational methods (Healey *et al.*, 2004; Manser, 2009; Rosen *et al.*, 2014; Carayon *et al.*, 2015; Senot *et al.*, 2016). With self-reporting methods, team members report and/or rate their perceptions about team behavior and coordination mechanisms through interviews, questionnaires, focus groups, and surveys. These methods are subjected to "self-reporting bias" and have other possible limitations: data collection is not in real time but performed in batches and discontinuously (e.g. at the end of health treatment), which involves the problem of "memory effects" by participants; the number of variables kept under control/analysis must be limited; the qualitative measurement and evaluation of human behaviors usually suffers from subjectivity, with different scales of perception for each participant (Lepine *et al.*, 2008; Kuula and Putkiranta, 2012; Schmutz and Manser, 2013; Rosen *et al.*, 2014; Chaffin *et al.*, 2017).

Conversely, observational methods, such as direct observation and video analysis, may be able to overcome the "self-reporting bias" due to memory effects and the subjectivity of participants (Schmutz and Manser, 2013; Morgan *et al.*, 2015; Ellway, 2016). Nevertheless, observational methods might still be exposed to the subjectivity of the observers; they are extremely time-consuming, due to the long period of observation, training, and monitoring over time; and the influence of the observers on the observed system might alter the results (Barley, 1990; Leonard-Barton, 1990; Kim *et al.*, 2012; Rosen *et al.*, 2014; Chaffin *et al.*, 2017). Furthermore, the observational methods can be affected by privacy concerns associated with the presence of observers or recording cameras in care settings.

Wearable sensors and similar technologies offer a novel means to measure and appraise teamwork through novel data-driven methodologies. Providing automatic and objective measurements of individual and group behaviors, these tools can efficiently collect a large amount of data in real time, thus increasing the number of observable behavioral variables (Kim *et al.*, 2012; Rosen *et al.*, 2014; Chaffin *et al.*, 2017). Wearable sensors, possibly integrated with self-reporting and observational methods, might mitigate the limitations of the traditional methods used to study teamwork in healthcare and in other dynamic environments (Kim *et al.*, 2012; Rosen *et al.*, 2014; Chaffin *et al.*, 2017).

2.3 Hypotheses development

Team coordination and effective communication play a key role in for providing high quality and safe patient care during surgery (Broekhuis and van Donk, 2011; Tiferes *et al.*, 2015; Singer *et al.*, 2016). Accordingly, a growing number of empirical studies have shown that errors and adverse events during surgery may be due to failures in team coordination and non-technical issues, rather than a lack of technical expertise (Healey *et al.*, 2004; Yule *et al.*, 2006; Schmutz and Manser, 2013; Siu *et al.*, 2016; Gjeraa *et al.*, 2017; Sun *et al.*, 2018; Rubbio *et al.*, 2019).

A communication and coordination strategy should thus be adapted to the specific type of surgery (Crawford and LePine, 2013; Vashdi *et al.*, 2013). In particular, in line with what was outlined in Section 2.1, the appropriate balance between explicit and implicit coordination strategies depends on the particular characteristics of the surgery performed (Vashdi *et al.*, 2013; Bogdanovic *et al.*, 2015).

Specifically, the degree of repetition and uncertainty of surgical procedures mean that they can be classified as *routine* and *non-routine surgery*, and thus coordination best practices can be identified (Manser, 2009; Bogdanovic *et al.*, 2015). Consequently, surgical teams should adapt their behaviors based on the task routineness of the specific surgery.

With regard to non-routine surgery, the exclusive use of implicit coordination seems to have a negative effect on surgical performance, because explicit coordination is more effective in synchronizing team members during moments of high uncertainty (Rico *et al.*, 2008; Manser, 2009; Riethmüller *et al.*, 2012).

Therefore, the amount of explicit coordination behavior, above all accomplished through verbal communication, should increase when the surgical procedures are non-standard and the level of task uncertainty is high (Tschan *et al.*, 2015; Sun *et al.*, 2018). In surgeries where the tasks are not well-defined at the beginning and change based on patient conditions/needs, operating teams should execute specific procedures defined during the surgery and, thus, they require explicit coordination to synchronize team members (Riethmüller *et al.*, 2012; Bogdanovic *et al.*, 2015). This does not mean that implicit coordination is irrelevant, but the importance of explicit coordination and unambiguous communication arises.

On the contrary, research seems to confirm that for routine surgeries, a lower level of explicit communication brings about higher team performance, while a high level of implicit coordination has a positive effect on performance (Broekhuis and van Donk, 2011; Wheelock *et al.*, 2015; Butchibabu *et al.*, 2016). When the standardization of a surgical procedure is high, a larger proportion of implicit coordination means that there can be a greater focus on the surgical task, since it frees up an individual's mental resources and there can thus be a more effective and efficient team communication (Manser, 2009; Gorman, 2014).

Intense discussions/talks in routine surgeries thus tend to be associated with a high probability of poorer surgical performance and increased risks to patient safety (Seelandt *et al.*, 2014; Tschan *et al.*, 2015; Wheelock *et al.*, 2015; Singer *et al.*, 2016). The importance of remaining vigilant throughout a case is also key, as is maintaining a highly efficient team operating in a silent environment, especially when the surgical procedure presents a high level of routineness (Wheelock *et al.*, 2015; Tschan *et al.*, 2015; Keller *et al.*, 2016).

However, empirical evidence regarding the most appropriate coordination strategies during routine surgery still remains scarce and not definitive (Mazzocco *et al.*, 2009; Sun *et al.*, 2018). For this reason and since routine interventions are by far the most frequent in hospitals (e.g. Abbott *et al.*, 2017; Steiner *et al.*, 2017), this work focuses on the study of team coordination dynamics in such a context.

We thus focus on routine surgery, and we hypothesize a negative effect of explicit coordination, which implies higher communication overheads and reduced focus on surgical task, and a positive effect of implicit coordination.

Thus, our first hypothesis is:

H1. The lower the explicit coordination of the surgical team through verbal interaction, the higher the team's performance

The dynamics and effectiveness of team coordination in surgeries also depend on *Team Cohesion*, recognizing, in particular, the important role of shared mental models (Cannon-Bowers *et al.*, 1993; Mathieu *et al.*, 2000; McComb and Simpson, 2014) and of a collaborative environment for providing high quality and safe patient care (Catchpole *et al.*, 2008; Mazzocco *et al.*, 2009; Ancarani *et al.*, 2011; Kurmann *et al.*, 2014; Siu *et al.*, 2016). Indeed, members of cohesive teams working in a collaborative and trusting environment experience fewer conflicts and discussions, tend to anticipate and support each other, and are able to increase their performance thanks to reduced stress levels (Arora *et al.*, 2010; Wheelock *et al.*, 2015; Singer *et al.*, 2016). In this way, team cohesion enhances implicit coordination and harmonizes team behaviors, thus improving their ability to cope with surgical problems, and to communicate more efficiently (Burtscher and Manser, 2012; Gorman, 2014; Sacks *et al.*, 2015; Gjeraa *et al.*, 2017). This in turn indirectly improves the quality and safety of surgical procedures.

The positive effects of team cohesion on team dynamics and on final surgical outcomes have been highlighted in several surgery contexts, irrespectively of the routine nature of the activities involved (Rico *et al.*, 2008; Manser, 2009; Sacks *et al.*, 2015). For instance, Gjeraa *et al.* (2017) found that team cohesion can increase patient safety during non-routine surgery, as shown by the case study in video-assisted thoracoscopic surgery. Catchpole *et al.* (2008) highlighted that also in routine surgeries, such as low-risk orthopedic operations, team building and understanding mutual needs decrease the occurrence of surgical problems. Nevertheless, the positive effect of team cohesion appears to be greater in contexts that need a high level of implicit coordination (Rico *et al.*, 2008; Manser, 2009; Gorman, 2014; Bogdanovic *et al.*, 2015).

In line with past evidence on team cohesion we hypothesize:

H2. The higher the level of team cohesion, the higher the performance of the surgical team

3. Method

Given the lack of in-depth empirical research on the coordination behaviors of surgery teams and the novelty of our measurement approach, we conducted an exploratory case study (Yin, 2017) in the Breast Surgery Unit of a large university hospital.

The research design exploited wearable sensors (i.e. Sociometric Badges) to retrieve data regarding team coordination dynamically and in real time in real settings, as well as to investigate our two hypotheses (Fernandes *et al.*, 2018).

Section 3.1 introduces the Sociometric Badges. *Section 3.2* outlines how we collected the data, and *Section 3.3* describes the measurements exploited in the research. Finally, the data analysis and the related results are reported in *Section 4*.

3.1 Sociometric Badges

A key challenge when studying team dynamics in the highly dynamic domains of healthcare, such as operating rooms, intensive care, and emergency medicine, is how to measure individual and group behaviors (i.e. the data collection phase) which are commonly assessed through interviews, direct observations, questionnaires, and reports (Manser, 2009; Carayon *et al.*, 2015). Previous studies have often been influenced by subjectivity and memory effects, or have been affected by the influence of the observers on the system (Barley, 1990; Leonard-Barton, 1990; Kim *et al.*, 2012; Chaffin *et al.*, 2017).

In this study, we used for the first time direct and quantitative measurements provided by Sociometric Badges in order to investigate behaviors of surgical team members. Sociometric Badges are wearable sensors developed by the MIT Media Lab. They catch the "honest signals" inherently related to human behaviors and group interactions (Pentland, 2008). They can automatically and directly measure individual and group dynamics in a quantitative way, exploiting four different sensors: accelerometers, microphones, Bluetooth, and IRDA (Olguín *et al.*, 2009a). In so doing, Sociometric Badges offer a systematic way to quantitatively investigate the individual and collective patterns of behavior and overcoming the traditional limitations.

Since privacy is one of the main concerns of any social science study, Sociometric Badges also guarantee compliance with privacy laws by not recording the content of the conversation and not permitting the identification of the speaker by analyzing the sociometric data - this is achieved through the sampling of audio signals which prevent the reconstruction of the raw speech (Olguín *et al.*, 2009a; Kim *et al.*, 2012).

Sociometric Badges are also less intrusive than a human observer, thus limiting social distortions of the data, and they can capture more nuances of behavior (Olguín *et al.*, 2009a; Rosen *et al.*, 2014). Sociometric Badges have proved suitable for monitoring individual and group behaviors during operational activities (Kim *et al.*, 2012), including healthcare (Olguín *et al.*, 2009b; Bucuvalas *et al.*, 2014; Yu *et al.*, 2016).

3.2 Data collection

Our case study concerns quadrantectomy and mastectomy related to cancer problems, in the Breast Unit of an Italian university hospital. These surgeries present a high level of task routineness and low uncertainty (e.g. McLaughlin, 2013), with the procedures being well defined beforehand.

The surgical team investigated in our study is made up of: two surgeons, one scrub nurse, and one assistant nurse. Frequently there are also one or two additional surgeons or nurses. In general, the analyzed team was made up of a minimum of 4 to a maximum of 7 team members.

A preliminary investigation of the surgical context, before the data collection phase, was conducted through interviews with all the practitioners involved and the direct observation of some surgeries. The aim was to identify all the features related to breast surgery, such as the task allocation, interactions between practitioners, and the practitioners' physical distribution in the operating room. This information was used to define the main research settings (e.g. the sociometric variables to be considered) and to allow Sociometric Badges to be fine-tuned (e.g. Kayhan *et al.*, 2018).

During the data collection phase, we collected the individual and group behaviors of team members for each investigated surgery exclusively using the Sociometric Badges (an improved version of the original one) to quantitatively assess the surgical team coordination behaviors. Each team member wore the Sociometric Badge for the entire duration of the surgery. Sensors allowed the collection of behavior data thought the accelerometer, microphones, and Bluetooth data.

In addition to the sociometric data, we collected the main features of the surgeries (e.g. the duration of surgery, the practitioners' experience) and patients (e.g. age). We also asked team members to fill out a "team cohesion" survey regarding their perception of the level of cohesion in each different team they participated in. By examining the surgical register, we also investigated operating room performance in terms of surgical glitches occurring in each surgical procedure.

Table 1 summarizes all the data collected with their respective sources and the roles assumed in the analysis.

All the measurements adopted in the study are described Section 3.3. They are subdivided into dependent variables, independent variables, and control variables, based on their role in the statistical models.

Data were gathered over a period of four months. Specifically, we collected the data of about 90 surgical operations (after data cleaning and preprocessing, 82 were considered as useable) with 362 individual recordings for a total of about 470 monitoring hours. All observed surgeries were chosen randomly.

To respect patient anonymity and privacy, no personal patient data or vital parameters were collected except for their general characteristics (e.g. age). In addition, Sociometric Badges do not record the content of the conversation and do not permit the identification of the speaker (see Section 3.1). This guaranteed patients and practitioners privacy. To fully comply with the privacy laws and principles of "research ethics," we followed the recommendations by Stopczynski *et al.* (2014) for sensor-driven human data collection. All participants read an information sheet on the tools exploited and signed an informed consent form for the research.

3.3 Measurements

3.3.1 Dependent variable. Each surgical performance was evaluated through the occurrence of surgical glitches. In fact, providing a safe and effective operation is the main goal of surgery and a surgical glitch may impact strongly on patient health and hospital expenditure.

We define the dependent variable *Glitches ON/OFF* as a binary variable to differentiate between the operations "with" and "without" surgical complications. *Glitches ON/OFF* takes the value of 1 if one or more surgical glitches affect the surgery, otherwise 0. In this study, we considered a surgical glitch as any medical/procedural problem that might affect the patient

Data	Data source	Role in the data analysis	Description
Coordination Behavior data	Sociometric Badges	Independent variables	Individual and group behaviors of team members were directly collected (in real-time) through Sociometric Badges sensors
Cohesion perceptions	Team Cohesion Survey	Independent variables	The perceptions of team cohesion of each working team were assessed through a "Team Cohesion" survey filled in by each participant of the team
Surgery & Patient Characteristics	Surgical Register & Hospital information systems	Control Variables	The main characteristics of the patient and surgery event were retrieved from the Surgical Register and from the Hospital Information Systems. To be noted that this class also includes the characteristics of surgical team (e.g. Practitioners' experience)
Surgical Performance	Surgical Register	Dependent Variable	All the data related to the surgical glitches occurring during the surgeries were gathered from Surgical Register

Table 1.
Data collection

care or their length of stay in the OR, for example small bleedings, incorrect counting of gauzes, imperfect stitching, and defects in sampling for cancer tests. The binary classification of surgeries into two classes (with/without glitches) was decided following the suggestions of surgeons and unit managers. Indeed, a numerical count of surgical complications is very often questionable when multiple complications happen (possible "domino effect").

3.3.2 Independent variables. We defined a series of independent variables for this study by exploiting the sensors embedded in the Sociometric Badges and the manufacturer's software. The software was used for data processing and for the analysis of the sensor data series, as well as for extracting the features and the characterization of collaboration behaviors for each work team by appropriately combining the series of individual data.

To assess the level of cohesion in a team, our independent variables were "team cohesion" and "team cohesion variance," which were evaluated through a dedicated survey.

We divided the independent variables into five groups (Table 2), based on the sensors used and the type of measurements: *Movement*, *Speech*, *Interaction*, *Group Flow*, and *Perception* (measured by survey). Table 3 reports the complete list of measures, grouped by class.

3.3.3 Control variables. To exclude potential confounding effects derived from the specifics of the surgery, eight control variables were employed:

Operating team – The size of the surgical team (see Section 3.2), i.e. the number of people with the Sociometric Badges.

Type of breast surgery – This variable assumes two values: 0 for quadrantectomy and 1 for mastectomy.

Patient age – The age of the patient involved in the surgery, as this can affect the risk of surgical complications.

Groups of independent variables	Data source	Descriptions
Movement variables	Sociometric Badges	These variables are based on the accelerometer data and try to measure the movements of team members during the surgery from various viewpoints (e.g. level of physical activities, movement consistency, walking activity)
Speech variables	Sociometric Badges	These variables are based on the Front and Back microphone audio data and assess the speaking behaviors demonstrated by team members during the surgery
Interaction variables	Sociometric Badges	These variables are Social Network Analysis measurements (e.g. betweenness centrality, closeness, etc. – See Wasserman and Faust, 1994) based on the proximity of team members. The team member proximity is obtained through the proximity-Bluetooth data series
Group Flow variables	Sociometric Badges	These variables are built to understand the similarity in the behavior of the team members during the surgery and are theoretically founded on the mirroring ("mirror neurons") theory (e.g. Rizzolatti and Craighero, 2004; Kohler *et al.*, 2002; Chartrand and Bargh, 1999). Indeed, these mirroring variables try to grasp the subconscious replication of nonverbal and/or paralanguage (voice) signals between team members (Iacoboni, 2009; Hall *et al.*, 2019). Thus, the group flow variables are created for assessing the implicit coordination of teams. These variables are based on accelerometer, microphone audio, and proximity data
Perception	Survey	These variables evaluate the opinions of team members about the "team cohesion" through a survey, trying to assess how much team members share the same values/ideas and how much members feel to be involved in the specific surgery team

Table 2. Groups of independent variables

Variable group	Variable	Description
Movement	Body Movement	The energy magnitude over the 3 movement axes measured by the accelerometer during the surgery. The team value was estimated as the average of the team members' value
	Activity-Walking	It measured the percentage of time that the badge wearer was moving/walking (based on the accelerometer's energy magnitude over the 3 axes of measurement). The team value was estimated as the average of the team members' value
	Body Movement Consistency	The consistency of each badge's Body Movement (BM). Consistency ranges from 0 to 1, where 1 indicates no changes in activity levels, and 0 indicates the maximum amount of variation in activity levels. The team value was estimated as the average of the team members' value
	Posture Activity	The absolute angular velocity measured by the accelerometer during the surgery. The team value was estimated as the average of the team members' value
	Posture Consistency	The consistency of each badge's Posture. Consistency ranges from 0 to 1, where 1 indicates no changes in posture activity levels, and 0 indicates the maximum amount of variation in posture activity levels. The team value was estimated as the average of the team members' value
Speech	Speaking	The percentage of time in which the member was speaking. The independent variable, for each surgery, was determine as the average of the team members' values
	Speaking overlap	The percentage of time in which the member was speaking while somebody else is speaking. The independent variable, for each surgery, was determine as the average of the team members' values
	Silence	The percentage of time in which the member and all others in his/her proximity were silent. This shows the proportion of time wherein a member did not participate to the conversation at all. The independent variable, for each surgery, was determined as the average of the team members' values
	Turn-Taking	The number of changes of the members that are speaking during the surgery, normalized by time and by number of team members participating in the surgery. More "turns" in the conversation mean more involvement in the discussion by members. Hence, this index shows how much members are involved in the conversation
	Audio Consistency	The consistency of each badge's speech amplitude. Consistency ranges from 0 to 1, where 1 indicates no changes in speech amplitude, and 0 indicates the maximum amount of variation in speech amplitude. The team value was estimated as the average of the team members' value
Interaction	Proximity	Bluetooth detections to determine the number of minutes that each badge was within strict interaction-distance of every other badge. The team value was estimated as the average of the team members' value
	Betweenness Centrality	Betweenness centrality (Wasserman and Faust, 1994) measured on the proximity network of team members. The team value was estimated as the average of the team members' value
	Closeness Centrality	Closeness centrality (Wasserman and Faust, 1994) measured on the proximity network of team members. The team value was estimated as the average of the team members' value
	Degree Centrality	Degree centrality (Wasserman and Faust, 1994) measured on the proximity network of team members. The team value was estimated as the average of the team members' value
	Cohesion	Cohesion (Wasserman and Faust, 1994) measured on the proximity network of team members

(*continued*)

Table 3.
Independent variables

Variable group	Variable	Description
Group Flow	Mirroring	It assesses the similarity in the behaviors of team members during the surgery. It is estimated analyzing the speaking (recorded by the microphone), the body movement (recorded by the accelerometer) and the proximity (through the Bluetooth) data series. For every pair of team members it is possible to evaluate how similar their speaking data series and body movement data series are over time when they are within interaction-distance. These values range from 0 to 1, where 1 indicates that the data series of speaking and body movement follow identical patterns and 0 indicates no similarity. For every surgery, Mirroring was calculated as the average of the values for every pair of team members. This measure evaluates how similar the members' behavior in term of speech and movement patterns are, i.e. how much subconscious replication of non-verbal and paralanguage (voice) signals is happening. Therefore, this index can be used for estimating how much team members were anticipating actions/needs of their colleagues and dynamically adjusted their own behavior accordingly. Consequently, given the definition of implicit coordination, we considered this measurement as a proxy for assessing the level of implicit coordination of the surgery (see Table 1 and the related references for further details on the theory behind)
	Group Flow - Speech	The similarity in the speaking behaviors of team members during the surgery. It is estimated analyzing the speaking (recorded by the microphone), and the proximity data (through the Bluetooth) through the Sociometric Data Lab Software. For every pair of team members it is possible to evaluate how similar their speaking data series patterns are over time when they are within interaction-distance. These values range from 0 to 1, where 1 indicates that the data series of speaking follow identical patterns and 0 indicates no similarity. For every surgery, Group Flow-Speech was calculated as the average of the values for every pair of team members. This measure evaluates how similar the members' behavior in term of speech patterns are (see Table 1 for further details)
	Group Flow - Body Movement	The similarity in the body behaviors of team members during the surgery. It is estimated analyzing the body movement (recorded by the accelerometer) and the proximity data (through the Bluetooth) through the Sociometric Data Lab Software. For every pair of team members it is possible to evaluate how similar their body movement data series are over time when they are within interaction-distance. These values range from 0 to 1, where 1 indicates that the data series of body movement follow identical patterns and 0 indicates no similarity. For every surgery, Group Flow-Speech was calculated as the average of the values for every pair of team members. This measure evaluates how similar the members' behavior in term of movement patterns are (see Table 1 for further details)

Table 3.

(*continued*)

Variable group	Variable	Description
Perception	Team Cohesion	How much the team members felt to be part of a cohesive team was assessed on a Likert scale from 1 to 5 using a specific six-item survey (Salas *et al.*, 2015; Mathieu *et al.*, 2015). It assesses both prospective social/interpersonal- and task-oriented aspects of the team as expected by team members before the beginning of the surgery. The six aspects evaluated are: feeling of belongingness among team members; feeling of unity and cohesion of team members; shared expectations about the task; shared views of the way of working; shared ideas about correct patterns of communication; feeling of positive "trusting climate". The survey was filled in by practitioners for each different team they took part in. This independent variable, for every surgery, was determined as the average of the single team members' evaluations. This measure tries to assess how much team members share the same values/ideas and how much members feel to be involved in the specific surgery team
	Team Cohesion variance	It is based on the results obtained in the survey described for *Team Cohesion*. This independent variable, for every surgery, was determined as the variance of the team members' evaluations about team cohesion (rather than the average). This measure tries to assess the presence of strong differences between team members in the perception of team cohesion

Table 3.

Surgery duration – The duration of the surgery in minutes. We did not include the preparation and post-operation activities, just the length of the actual operation.

People inside OR – The number of people inside the operating room (OR). In addition to the operating team, there were other people present who did not really intervene in the surgical activities, such as trainee nurses, anesthetists, external doctors, and other observers.

Practitioners' experience – The average surgery experience of operating team members expressed in years. In fact, the level of experience of practitioners can affect their behavior during the surgery.

Practitioners' experience variance – The variance of surgery experience of operating team members. Not only the average level of experience can characterize the surgery, but also highly different experience levels can influence individual and team behaviors (e.g. teaching behaviors of senior surgeons).

Team familiarity – The average seniority (years of service) in the unit of operating team members, as inter-personal experiences can influence individual and team behaviors.

4. Results

After excluding any surgical operations with incorrect registrations or missing values, "Pearson's correlation" (*Section 4.1*) and logistic regression (*Section 4.2*) were performed using the data collected during the breast surgeries to assess the proposed hypotheses. Practitioners' interviews, focus groups, and a few direct observations of breast surgeries were then exploited to interpret the results, to verify the absence of potential bias in the research, and to draw additional implications from a managerial viewpoint.

4.1 Correlation analysis

To gain some preliminary insights from the data, we performed Pearson's correlation between the independent variables, the dependent variable, and the control variables using

SPSS®. Correlation analysis enabled us to explore the relationships between the behavioral variables and the dependent variable (i.e. Glitches ON/OFF); between different behavioral variables; and between the control variables and the dependent variable. Table A1 shows the results obtained. The findings achieved from this analysis allowed to better guide the subsequent phase of regression analysis, highlighting the strongest relationships and the presence of potential statistical criticalities (e.g. relationships between control variables and dependent variables).

Three statistically significant correlations between the dependent variable (*Glitches ON/OFF*) and the independent variables were discovered. The strongest ($R = -0.421$) and most significant ($p = 0.000$) correlation of *Glitches ON/OFF* was with *Silence*. The second significant correlation of the dependent variable was with *Turn-Taking* ($R = 0.289$), while the third was with *Team Cohesion* ($R = -0.245$).

Similarly, we considered the correlations between the control variables and the dependent variable to exclude any potential effects of the control variables. *Operating team*, *Type of surgery*, *Patient age*, *Surgery duration*, *People inside OR*, *Practitioners' experience*, *Practitioners' experience variance*, and *Team familiarity* were not significantly correlated with *Glitches ON/OFF*. This seems to confirm the absence of relationships between dependent and control variables. However, the influence of the control variables and of the collinearity between independent variables was investigated and is reported in the next section.

4.2 Regression analysis

To measure the potential effect of independent variables on the dependent variable, we adopted logistic regression, since *Glitches (ON/OFF)* is binary (Hosmer and Lemeshow, 2004).

Table 4 shows the logistic regression model obtained. The model revealed that *Silence*, *Team Cohesion*, and *Mirroring* explain a significant part of the variance in the occurrence of glitches. The model (Table 4) is strongly significant ($p = 0.000$) and explains 50.2% of the variance as reported by the *Nagelkerke* R^2 (Nagelkerke, 1991). All the variables included are statistically significant (column "Sig."). In addition, the Hosmer and Lemeshow test also confirms the significance of the model (Hosmer and Lemeshow, 2004). To counteract the potential problem of multicollinearity between the independent variables, we quantified the Variance Inflation Factor (VIF). The very low values obtained, which were way below the threshold value of 3 (O'brien, 2007), seem to rule out any multicollinearity among the independent variables.

Turn-Taking, which was correlated with the dependent variable, was excluded from the model due to multicollinearity. When included, it was not significant and presented a high VIF value.

Variables	*B*	S.E.	Sig	Exp(*B*)	VIF
Logistic regression model					
Silence	−2.21	0.70	0.009	0.11	1.19
Team Cohesion	−1.71	0.66	0.001	0.18	1.03
Mirroring	−1.59	0.75	0.034	0.21	1.17
Constant	−2.76	0.73	0.000	0.06	–
Model Summary					
−2 Log likelihood		*Cox & Snell R^2*		*Nagelkerke R^2*	
38.32		0.31		0.50	

Table 4. Logistic Regression Model with Glitches ON/OFF as dependent variable

The logistic model (Table 4) highlights the positive effect of *Silence* on performance, i.e. a higher value of *Silence* implies a lower likelihood of experiencing a surgical glitch. *Mirroring*, included with the negative sign, also has a positive effect on performance because it seems to reduce the chance of glitches during surgery. Considering *Mirroring* as a proxy for assessing the level of implicit coordination (see Section 3.3.2, Table 3) during surgery, the regression model suggests that implicit coordination behaviors positively affect team performance. Finally, *Team Cohesion* appears to positively affect surgical performance, as shown by the negative sign in the model.

To rule out the potentially key influence of glitches on the dynamics of the surgery ("reverse causality") and confirm the results obtained, the trends during surgery of *Silence* and *Mirroring* were analyzed. This evaluation proved that both *Silence* and *Mirroring* are quite steady during surgeries and, above all, they do not vary substantially during (or after) a glitch, thus ruling out reverse causality problems.

The model supports *hypothesis H1*, by confirming that a high level of explicit coordination (high level of verbal interaction) negatively affects the outcome of routine surgeries, while implicit coordination (high level of mirroring) appears to favor it. Team members coordinating continuously through explicit verbal interactions seem to lose focus on the ongoing tasks and the probability of glitches typically increases. On the contrary, when they coordinate implicitly, they remain more focused on the job and the chance of glitches tends to decrease. This result is aligned with the insights gained from informal interviews that we had with practitioners and direct observations carried out to explain the findings obtained.

The model also supports *hypothesis H2*, showing the positive influence of the team cohesion on the surgical outcome through the decreased likelihood of glitches. Team cohesion seems to increase the supportive behaviors by team members, team communication efficacy, and practitioners' engagement. Thus, it positively affects surgical performance.

To further confirm the validity of our findings, we tested the models by evaluating the effect of the control variables. In the first test, we added the control variables, individually and together, to the regression model obtained with *Silence*, *Team Cohesion*, and *Mirroring*. For each model, the resulting *Nagelkerke* R^2 did not change considerably and the control variables inserted were non-significant, while *Silence*, *Team Cohesion*, and *Mirroring* still remained significant. Table A2 reports the model obtained including the eight control variables.

In a second test, we built regression models exclusively with the control variables. Again, no model including the control variables was statistically significant ($p > 0.05$) and the best "control" model had a very low *Nagelkerke* R^2 (0.098). These tests would seem to confirm the validity of our model, ruling out any potential effect of the control variables on the dependent variable.

5. Discussion and managerial implications

5.1 Theoretical contribution

Our findings suggest that many operational failures (glitches) in routine surgery are caused by sub-optimal coordination practices, supporting the idea that the occurrence of adverse events during surgery can be affected by team dynamics and other non-technical aspects as argued in previous studies (e.g. Healey *et al.*, 2004; Yule *et al.*, 2006; Siu *et al.*, 2016; Gjeraa *et al.*, 2017; Rubbio *et al.*, 2019).

Specifically, *Mirroring* supports the theory that anticipatory behaviors of team members might improve the surgical performance by decreasing the likelihood of glitches. Such implicit coordination mechanisms permit practitioners to anticipate actions/needs of their colleagues and dynamically adjust their own behavior accordingly (Rico *et al.*, 2008; Butchibabu *et al.*, 2016). In so doing, they contribute to increasing the ability of the surgical team to manage the most critical surgical phases and to deal quickly with any issues that arise.

In addition, we found that a non-parsimonious use of explicit coordination, such as excessive verbal interactions (as shown by *Silence*), during surgery lead to a rise in surgical glitches. Redundant or unnecessary explicit coordination increases the noise and might cause misunderstandings in the operating room leading to distractions and thus less focus on the specific tasks (Wheelock *et al.*, 2015; Singer *et al.*, 2016; Keller *et al.*, 2016). This may also have a negative impact on coordination during the most crucial moments of the surgical procedure or when the team has to make important decisions.

Our research also contributes to the literature investigating the role of team cohesion and research suggesting that "soft skills," reflected in factors such as emotional intelligence, team personality, and shared mental models, can affect team performance (e.g. Lvina *et al.*, 2018). From this perspective, our results confirm that team cohesion (as shown by variable *Team Cohesion*) lowers the probability that a team will experience a glitch during routine surgery. Cohesion among the team members creates a positive and collaborative working environment so that practitioners can act under a lower level of stress and cooperate more effectively (Arora *et al.*, 2010). Consequently, team members tend to harmonize their behaviors during surgical operations and communicate more effectively (Burtscher and Manser, 2012; Sacks *et al.*, 2015; Gjeraa *et al.*, 2017). Such a favorable working environment enables practitioners to exploit their professional skills and react more promptly to problems, thus reducing the chances of glitches and obtaining a better care result.

Looking at the wider literature (Marks *et al.*, 2001; Ilgen *et al.*, 2005; Mathieu *et al.*, 2008) and the factors that influence a team's operational performance, our empirical findings attribute a key role to team coordination dynamics in terms of "team process," and team cohesion in terms of "team input" (Ilgen *et al.*, 2005). In particular, the positive influence of implicit coordination and the negative impact of excessive explicit coordination on team performance would seem to be theoretically supported by the literature (e.g. Rico *et al.*, 2008; Gorman, 2014). These results highlight the importance for managers and researchers to investigate the role of the coordination dynamics emerging during teamwork.

In line with previous work regarding team cohesion (e.g. Burtscher and Manser, 2012; Kovács *et al.*, 2012; Gorman, 2014), our findings confirm the importance of soft skills, such as "team input," for team outcomes. Although already examined in the literature, the importance of soft skills is still largely neglected during the composition of teams and job assignments in real business contexts (Mura *et al.*, 2016; Donohue *et al.*, 2018).

From a methodological perspective, this research also represents an early attempt to investigate coordination behaviors with sensor-based measurements of human behaviors. The paper thus provides a first empirical contribution to the call for investigations on the implications of Big Data and innovative data science methods for management research (George *et al.*, 2014, 2016; Dubey *et al.*, 2019). Indeed, novel approaches in organizational studies, based on new tools (e.g. wearable sensors, smartphones, social network platforms) and methods of analysis (e.g. machine learning, data mining), provide an opportunity to better answer past research questions and, most interestingly, to respond to new ones (George *et al.*, 2016; Kache and Seuring, 2017).

However, exploiting such innovative approaches in real business settings is challenging and still quite limited (George *et al.*, 2016; Chaffin *et al.*, 2017). From this perspective, this research provides a first evidence on the use of wearable sensors for investigating issues in operations management. Specifically, our findings appear to endorse the usefulness of sociometric sensors for studying coordination behaviors and their relationship with operational performance in healthcare.

Our novel approach, which could also be combined and complemented with self-report and observational approaches, enables team dynamics to be detected and examined in more depth and could mitigate the limitations of previous approaches such as memory effect, subjectivity, and observers' influence. Therefore, through the use of Sociometric Badges, this work provides a first answer to the question of "how to" quantitatively investigate behavioral aspects in dynamic and complex operating environments (Croson *et al.*, 2013; Brocklesby, 2016).

5.2 Managerial contribution

This study also provides hospital organizations with managerial insights for improving surgical team coordination. Specifically, as shown by our findings, practitioners can benefit from using implicit coordination behaviors during surgery, for example fostering deliberative and concise communication rather than reactive communication, and also fostering anticipatory behaviors (e.g. Butchibabu *et al.*, 2016). Such behaviors could be enhanced through appropriate training and encouraged by the professional communities and top management commitment (Bendoly *et al.*, 2015).

In addition, healthcare managers and practitioners should encourage a well-defined planning and distribution of surgical tasks, thus, reducing unnecessary verbal interactions during the surgical procedure. Similarly, concise communication by the surgical team leader can be useful to update the other members regarding the ongoing tasks and to focus on the surgical procedure. Periodic ward meetings could also be promoted allowing providers to discuss the issues affecting the operating teams during the surgical procedures. This would help limit unnecessary speaking or discussions during the operations both in terms of number and intensity, by solving the open issues deriving from different opinions among practitioners (Wheelock *et al.*, 2015).

Finally, our evidence suggests that when selecting team members, healthcare managers should pay attention to the soft skills that facilitate team cohesion, and not just purely medical skills (Sacks *et al.*, 2015; Donohue *et al.*, 2018). Specifically, it could be valuable to find ways to identify and assess practitioners with similar values and "compatible" working behaviors that might enhance the internal cohesion. In line with this perspective, healthcare managers could plan team-building sessions to improve cohesion among all the staff (Amos *et al.*, 2005). They could also promote a collaborative mindset for practitioners within the surgery unit and discourage a "culture of blame" (Khatri *et al.*, 2009).

Although it is challenging to control for all the determinants of team coordination, these simple recommendations may help health managers in planning surgical activities and in training surgical staff in leadership, coordination, and collaboration skills.

6. Conclusions

This paper has investigated the relationships between team coordination and the related performance in routine surgery, using an innovative approach based on wearable sensors. We applied direct and quantitative measures for evaluating coordination behaviors in order to obtain more exhaustive measurements of individual and group behaviors, and to find more in-depth linkages between team coordination mechanisms and process performance. To the best of our knowledge, this is the first time that such relationships have been empirically explored using automated tools.

Specifically, our findings support our two hypotheses highlighting that: (1) the likelihood of adverse events and errors during routine surgeries is lower if the members of surgical teams coordinate implicitly rather than through explicit coordination; (2) the likelihood of adverse events and errors during routine surgeries is lower if the surgical team displays a higher level of team cohesion.

This research is not exempt from limitations that point out directions for future research. Drawing on a single case study, our results might be affected by the specific application and cultural context. This is a common issue for many behavioral studies and clearly limits the results from being generalized (Tröster *et al.*, 2014).

Moreover, even though the number of monitored variables and related indicators was high, the study is clearly not conclusive. Other significant metrics describing coordination dynamics of surgery teams, which were not caught by sociometric measures, might exist. In addition, the control variables considered might be not exhaustive, and thus it might be desirable to consider a larger number of control variables for future research. Finally, although we checked for a reverse causality bias, due to privacy issues, the sociometric data do not permit the topic of the conversation to be identified, and, thus do prevent the dynamics and the effects of the "content" of verbal behaviors from being analyzed.

As a future development, it might be interesting to repeat this study in different cultural contexts to confirm our findings and to strengthen the practical recommendations. Culture tends to strongly shape individuals' values, language, demeanor, cognitive schemas, and preferences for how best to organize the work (Earley and Gibson, 2002). Therefore, coordination behavior patterns during surgery and their relationships with surgical performances might be different according to the cultural contexts, particularly if very dissimilar cultural contexts are compared (e.g. Western culture vs Eastern culture).

In addition, since different surgery settings may require different coordination mechanisms and interaction patterns (e.g. Manser, 2009), we suggest extending the research by reapplying this methodology to non-routine surgeries to enable a comparison of results between different operating contexts. It would also be interesting to empirically extend the effect of implicit and explicit coordination mechanisms on performance to other business settings, such as consulting, product development, as well as different healthcare settings, to verify whether the relationships revealed in our study can be generalized to other areas.

Lastly, more teamwork research enabled by wearable sensors would help to confirm the effectiveness and suitability of our approach.

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Appendix

Table A1. Correlations between dependent variable (Glitches ON/OFF), independent variables, and control variables

	Body Movement	Activity-Walking	Body Movement Consistency	Posture Activity	Posture Consistency	Speaking	Speaking overlap	Silence	Turn-Taking	Audio Consistency	Proximity	Betweenness Centrality	Closeness Centrality	Degree Centrality	Cohesion	Group -Flow Body Movement	Group -Flow Speech	Mirroring	Team Cohesion	Team Cohesion Variance	Operating team	Type of breast surgery	Patient age	Surgery duration	People inside OR	Practitioners' experience	Practitioners' experience variance	Team familiarity	*Glitches ON/OFF*
Body Movement	1	0.288*	−0.237*	0.301*	−0.257*	0.026	−0.185	0.168	−0.015	−0.235	−0.076	0.215	−0.115	−0.186	−0.164	−0.241*	0.112	0.071	−0.222	−0.033	−0.030	−0.214	−0.189	−0.208	−0.074	0.096	0.060	−0.007	0.092
Activity-Walking	0.288*	1	−0.329**	0.434**	−0.075	0.117	−0.118	0.113	−0.088	−0.163	−0.326**	0.188	0.144	0.077	−0.247*	−0.069	−0.065	−0.220	0.051	0.022	−0.164	0.033	0.106	−0.214	−0.165	0.096	0.064	−0.070	−0.150
Body Movement Consistency	−0.237*	−0.329**	1	−0.279*	0.056	−0.176	0.069	−0.168	0.128	0.160	0.240	−0.203	−0.198	−0.111	0.169	0.112	0.098	0.162	−0.065	−0.055	0.141	−0.031	−0.059	0.097	0.131	0.023	−0.084	0.161	0.093
Posture Activity	0.301*	0.434**	−0.279*	1	0.045	0.077	−0.172	0.134	−0.089	−0.219	−0.064	0.322**	0.091	0.000	−0.257*	−0.143	−0.145	0.024	0.200	0.029	−0.172	−0.044	0.052	−0.194	−0.151	−0.057	0.041	−0.166	−0.092
Posture Consistency	−0.257*	−0.075	0.056	0.045	1	−0.138	0.116	−0.125	0.058	0.201	0.139	−0.118	0.129	0.185	0.128	−0.228	−0.203	0.198	0.060	0.148	0.064	0.233	0.029	0.005	0.132	−0.130	−0.053	−0.262*	0.075
Speaking	0.026	0.117	−0.176	0.077	−0.138	1	0.663**	−0.576**	0.393**	−0.332**	0.351**	0.261*	−0.130	−0.184	−0.231	−0.207	−0.168	−0.072	−0.058	0.200	−0.143	−0.097	0.170	−0.106	−0.212	0.128	0.002	0.050	0.211
Speaking overlap	−0.185	−0.118	0.069	−0.172	0.116	−0.663**	1	−0.668**	0.614**	−0.039	0.399**	−0.093	0.116	0.109	0.152	0.111	0.114	0.143	0.075	−0.162	0.273*	0.024	−0.147	0.229	0.302*	−0.175	−0.152	−0.030	0.241
Silence	0.168	0.113	−0.168	0.134	−0.125	−0.576**	−0.668**	1	−0.431**	0.082	−0.218	0.093	−0.104	−0.102	−0.128	−0.125	−0.213	−0.167	0.133	0.185	−0.107	−0.070	0.209	−0.162	−0.115	0.247*	0.182	0.128	*−0.421***
Turn-Taking	−0.015	−0.088	0.128	−0.089	0.058	0.393**	0.614**	−0.431**	1	−0.392**	0.259*	0.027	−0.080	−0.098	−0.094	0.244	0.311*	0.174	0.121	−0.164	0.241	−0.019	0.055	0.122	0.224	0.067	−0.100	0.219	*0.289**
Audio Consistency	−0.235	−0.163	0.160	−0.219	0.201	−0.332**	−0.039	0.082	−0.392**	1	0.301*	−0.332**	0.278*	0.346**	0.218	−0.125	−0.122	0.048	−0.018	−0.252*	0.141	0.193	−0.215	0.121	0.157	−0.110	0.139	−0.192	0.048
Proximity	−0.076	−0.326**	0.240	−0.064	0.139	0.351**	0.399**	−0.218	0.259*	0.301*	1	−0.133	0.126	0.141	0.153	0.248*	0.178	0.179	0.122	−0.232	0.073	0.104	−0.196	0.170	0.111	−0.195	−0.093	−0.039	0.170
Betweenness Centrality	0.215	0.188	−0.203	0.322**	−0.118	0.261*	−0.093	0.093	0.027	−0.332**	−0.133	1	−0.303*	−0.497**	−0.494**	0.185	0.231	0.001	0.170	0.221	−0.177	−0.207	−0.017	−0.184	−0.208	−0.030	0.148	0.015	−0.171
Closeness Centrality	−0.115	0.144	−0.198	0.091	0.129	−0.130	0.116	−0.104	−0.080	0.278*	0.126	−0.303*	1	0.910**	0.596**	−0.095	−0.074	−0.004	−0.095	−0.228	0.230	0.151	−0.211	0.209	0.226	−0.021	−0.099	0.023	0.091
Degree Centrality	−0.186	0.077	−0.111	0.000	0.185	−0.184	0.109	−0.102	−0.098	0.346**	0.141	−0.497**	0.910**	1	0.675**	−0.151	−0.145	−0.003	−0.132	−0.017	0.153	0.201	−0.173	0.185	0.229	−0.006	−0.129	0.008	0.104
Cohesion	−0.164	−0.247*	0.169	−0.257*	0.128	−0.231	0.152	−0.128	−0.094	0.218	0.153	−0.494**	0.596**	0.675**	1	−0.032	−0.035	0.110	−0.117	−0.183	0.168	0.071	−0.093	0.169	0.127	−0.138	−0.150	0.023	−0.018

(continued)

Table A1.

Group Flow-Body Movement	−0.241*	−0.069	0.112	−0.143	−0.228	−0.207	0.111	−0.125	0.244	−0.125	0.248*	0.185	−0.095	−0.151	−0.032	1	0.348**	0.148	0.040	−0.110	0.018	−0.087	−0.166	−0.151	0.128	0.048	0.008	−0.065	0.070
Group Flow-Speech	0.112	−0.065	0.098	−0.145	−0.203	−0.168	0.114	−0.213	0.311*	−0.122	0.178	0.231	−0.074	−0.145	−0.035	0.348**	1	0.145	0.077	0.166	0.069	−0.069	−0.181	−0.138	0.164	0.009	−0.024	−0.016	0.089
Mirroring	0.071	−0.220	0.162	0.024	0.198	−0.072	0.143	−0.167	0.174	0.048	0.179	0.001	−0.004	−0.003	0.110	0.148	0.145	1	−0.037	−0.029	−0.092	0.069	0.003	0.081	0.004	−0.047	−0.171	0.048	0.010
Team Cohesion	−0.222	0.051	−0.065	0.200	0.060	−0.058	0.075	0.133	0.121	−0.018	0.122	0.170	−0.095	−0.132	−0.117	0.040	0.077	−0.037	1	0.022	−0.021	0.199	0.014	0.155	−0.010	−0.187	−0.075	−0.129	−0.245*
Team Cohesion Variance	−0.033	0.022	−0.055	0.029	0.148	0.200	−0.162	0.185	−0.164	−0.252*	−0.232	0.221	−0.228	−0.017	−0.183	−0.110	0.166	−0.029	0.022	1	−0.065	−0.206	0.040	−0.146	−0.187	−0.017	−0.126	0.110	−0.132
Operating team	−0.030	−0.164	0.141	−0.172	0.064	−0.143	0.273*	−0.107	0.241	0.141	0.073	−0.177	0.230	0.153	0.168	0.018	0.069	−0.092	−0.021	−0.065	1	−0.111	−0.166	0.186	0.471**	−0.216	−0.057	−0.052	0.227
Type of breast surgery	−0.214	0.033	−0.031	−0.044	0.233	−0.097	0.024	−0.070	−0.019	0.193	0.104	−0.207	0.151	0.201	0.071	−0.087	−0.069	0.069	0.199	−0.206	−0.111	1	0.087	0.573**	0.076	0.039	−0.241	−0.231	−0.083
Patient age	−0.189	0.106	−0.059	0.052	0.029	0.170	−0.147	0.209	0.055	−0.215	−0.196	−0.017	−0.211	−0.173	−0.093	−0.166	−0.181	0.003	0.014	0.040	−0.166	0.087	1	−0.019	−0.051	0.209	0.137	0.143	−0.120
Surgery duration	−0.208	−0.214	0.097	−0.194	0.005	−0.106	0.229	−0.162	0.122	0.121	0.170	−0.184	0.209	0.185	0.169	−0.151	−0.138	0.081	0.155	−0.146	0.186	0.573**	−0.019	1	0.349**	0.052	−0.154	−0.030	0.230
People inside OR	−0.074	−0.165	0.131	−0.151	0.132	−0.212	0.302*	−0.115	0.224	0.157	0.111	−0.208	0.226	0.229	0.127	0.128	0.164	0.004	−0.010	−0.187	0.471**	0.076	−0.051	0.349**	1	−0.002	−0.054	−0.007	0.159
Practitioners' experience	0.096	0.096	0.023	−0.057	−0.130	0.128	−0.175	0.247*	0.067	−0.110	−0.195	−0.030	−0.021	−0.006	−0.138	0.048	0.009	−0.047	−0.187	−0.017	−0.216	0.039	0.209	0.052	−0.002	1	0.054	0.398**	−0.232
Practitioners' experience variance	0.060	0.064	−0.084	0.041	−0.053	0.002	−0.152	0.182	−0.100	0.139	−0.093	0.148	−0.099	−0.129	−0.150	0.008	−0.024	−0.171	−0.075	−0.126	−0.057	−0.241	0.137	−0.154	−0.054	0.054	1	0.110	0.106
Team familiarity	−0.007	−0.070	0.161	−0.166	−0.262*	0.050	−0.030	0.128	0.219	−0.192	−0.039	0.015	0.023	0.008	0.023	−0.065	−0.016	0.048	−0.129	0.110	−0.052	−0.231	0.143	−0.030	−0.007	0.398**	0.110	1	−0.121
Glitches ON/OFF	0.092	−0.150	0.093	−0.092	0.075	0.211	0.241	*−0.421***	*0.289**	0.084	0.170	−0.171	0.091	0.104	−0.018	0.070	0.089	0.010	*−0.245**	−0.132	0.227	−0.083	−0.120	0.230	0.159	−0.232	0.106	−0.121	1

Note(s): **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed)

Variables	Logistic regression model (with control variables) *B*	S.E.	Sig	Exp(*B*)	VIF
Silence	−2.61	0.92	0.005	0.07	1.61
Team Cohesion	−2.11	0.85	0.007	0.12	1.07
Mirroring	−1.86	0.94	0.039	0.16	1.28
Surgery duration	1.59	1.06	0.134	4.92	1.20
People inside OR	−0.58	0.66	0.380	0.56	1.43
Operating Team	0.04	0.97	0.965	1.04	1.64
Type of breast surgery	−0.87	0.81	0.283	0.42	1.87
Patient age	0.08	0.59	0.887	1.09	1.16
Practitioners' experience	−0.65	0.65	0.316	0.52	1.39
Practitioners' experience variance	1.26	0.81	0.118	3.53	1.15
Team familiarity	−0.67	0.70	0.340	0.51	1.33
Constant	0.66	4.69	0.888	1.94	–

Table A2. Logistic Regression Model for Glitches ON/OFF with the control variables

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