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Mechanisms for maintaining situation awareness in the micro-neurosurgical operating room

Hoorieh Afkari *, Roman Bednarik, Susanne Mäkelä, Shahram Eivazi

School of Computing, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland

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ABSTRACT

Interactions in micro-neurosurgical operating rooms form a complex orchestration of labor and information flows. In the center, there is the focus on patient safety and outcome quality in shortest possible time, while a neurosurgeon is fully focused on the task using a surgical microscope. To guarantee a successful outcome, maintaining a high level of situation awareness (SA) is essential. Suspension of action due to instrument exchange, interaction with a device, or communication affects information flows and collaboration. Situation awareness underlies these interactions. To further understand the mechanisms of SA, we used observations and interviews to gain insight into interactions in micro-neurosurgical theaters. We describe behaviors and strategies exhibited to maintain the interaction flow, in particular, between the scrub nurse and the surgeon. Results show how interactions based on action prediction and active observation within the well-organized environment are influenced, both positively and negatively, by the reliance of the work on the microscope. From this understanding, we discuss the opportunities in future technologies and interfaces for supporting situation awareness maintenance in operating rooms.

1. Introduction

From the moment a neurosurgeon performs an incision, through the critical steps during the surgery, and till the access point is closed, the complex interactions between medical personnel and their interactions with medical technologies have to be perfectly synchronized to achieve error-free operations (Hernesniemi et al., 2005; McLaughlin et al., 2013; Nardi et al., 1993). The success of the operation depends on careful planning and highly coordinated collaborative teamwork, which is led by the neurosurgeon but relies heavily on the skills and cooperation of each team member.

Recent studies on the use of surgical microscopes and interaction patterns in micro-neurosurgeries (Afkari et al., 2014; Eivazi et al., 2015) have revealed tensions among the procedure's different elements, including safety requirements, completion time and interruptibility of the procedure, and the steps required to complete the surgery. Hands-free interaction techniques, such as gaze-based interaction, have been suggested to help surgeons manage interruptions caused by manual adjustments of the microscope and to alleviate other problems related to the interaction with the microscope (Afkari et al., 2014; Eivazi et al., 2015). There are, however, concerns related to introduction of new technology to the intraoperative procedures (Mentis et al., 2012). The design of new interaction techniques and devices for micro-neurosurgery must therefore be based on a thorough understanding of how the team interacts and coordinates their actions throughout the operation.

Understanding the interactions of the supporting personnel in the operating room (OR) with other team members and with technologies has recently been the focus of medical human–computer interaction (HCI) and human-factors research (Afkari et al., 2014; Koch et al., 2012; Pence et al., 2014).

These studies have highlighted how crucial the coordination of activities between a surgeon and a scrub nurse, in particular, is for a successful outcome (Bezemer et al., 2011; Hazlehurst et al., 2007; Makary et al., 2006; Sanchez et al., 2007). In micro-neurosurgery, the surgeon's interaction with other team members is shaped by the considerable attention the surgeon must devote to the surgical microscope during use (Afkari et al., 2014; Eivazi et al., 2015). For this reason, any change to the way in which the surgeon interacts with the surgical microscope must take into account not only the surgeon, but also the intraoperative interactions among the members of the surgical team.

One of the primary reasons for human errors in tasks with a high workload is the lack of situation awareness (SA) (Endsley, 1999; Kaber and Endsley, 2004). A surgery is good example of a complex collaborative task in which efficiency and avoidance of

* Corresponding author.
E-mail address: hoorieh.afkari@uef.fi (H. Afkari).

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errors is crucial, placing high demands on a team's awareness during the operations. The errors that occur during development of SA have been found to harm the decision making process in anesthesia, for example (Schulz et al., 2013).

How awareness is built and maintained in micro-neurosurgery is affected by the use of the surgical microscope. The ways in which surgeons can coordinate their actions with the rest of the team are impacted by the considerable time surgeons spend looking through and interacting with the microscope during a micro-neurosurgery procedure. Furthermore, the microscope also blocks the other team members from direct view of the surgeon and the operative field. To our knowledge, there are no detailed accounts on how awareness is produced and sustained in such a setting; yet, understanding how a surgeon and a scrub nurse coordinate their actions and maintain awareness is crucial before introducing any new interaction techniques into micro-neurosurgery.

1.1. Awareness as a concept

Situation awareness (SA) as a construct has a long history. Dominguez (1994) defined situation awareness as *the continuous extraction of environmental information, and integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing future perception and anticipating future events*. In human-factors research, Endsley's model (Endsley, 1995) has been widely used to study situation awareness (Wickens, 2008). Endsley emphasises SA as a state of knowledge, making a clear distinction between SA and the processes to achieve it. Her model identifies three levels of SA: perception, comprehension and projection, and describes them in terms of cognitive functions and concepts such as mental models. An individual's SA and what information is searched and attended to affect each other in a circular process (Endsley et al., 2003).

Endsley's model has been criticized for being too linear, information-processing type of model and for not addressing the dynamic nature of SA (Salmon et al., 2008). Several other approaches have been suggested that emphasize the fact that SA is a process that is grounded in interaction over time with external artifacts and people (Fioratou et al., 2010; Salmon et al., 2008; Stanton et al., 2006; Smith and Hancock, 1995). In Artman and Garbis (1998), for example, SA in teams is seen as *distributed situation awareness*, where a team's SA is seen as a cognitive property of the system (Salmon et al., 2008).

In CSCW research, the concept of *awareness* has its roots in workplace studies that highlighted the importance of being sensitive to what others are doing in collaborative activities (Heath et al., 2002). During the past two decades, the concept has been used according to a wide variety of different meanings, but Schmidt (2002) has suggested limiting its use to the situations that involve joint cooperative effort; according to him, awareness *denotes those practices through which actors tacitly and seamlessly align and integrate their distributed, yet interdependent, activities*. Awareness in contemporary CSCW is not seen as a state of mind or cognitive ability, but rather as becoming aware of something, which is embedded in the activities people do and is continuously built through collaboration (Heath et al., 2002). As such, it challenges the idea of awareness as a common frame of reference, or that individuals' awareness could ever be overlapping.

Awareness as an activity involves skilled practices that actors use to collaborate in settings where tools, technologies, and environment may reduce the accessibility of activities in many ways (Heath et al., 2002). Schmidt (2002) describes two basic practices of monitoring and displaying that highlight the interactional, complementary nature of awareness. When *monitoring*, actors observe their colleagues to understand what is happening and how their own activities need to be adjusted. *Displaying*, on the other hand, refers to how actors make visible some aspects of their activities to make it easier for others to monitor their activities. According to Schmidt, no clear difference exists between monitoring or displaying and directing attention for other purposes. Rather, it is a question of degrees and modes of obstrusiveness: the actors use their skills to choose an interactional modality and a manner that is appropriate for each situation.

1.2. Awareness in the operating room

One of the research interests related to SA in a medical context is the producing and sustaining of SA during collaborative work in the operating room (Koch et al., 2012; Gaba et al., 1995; Schulz et al., 2013). To date, many SA studies in the medical domain have focused on the visual aspect of SA, such as the design and use of displays. Kusunoki et al. (2013), for example, categorized the patterns of vital sign monitor use of the team during resuscitation. They showed the relevance of the type of monitor use (short glances, short looks, long looks) for the activities of the team members and their decision making process. Jalote-Parmar and Badke-Schaub (2010) found that decision making and performance during surgery could be improved by using an intraoperative visualization system which provides imaging guidance to the surgeon. This approach resulted in enhancement of SA in surgical workflow.

Other studies have focused on interaction between surgeons and other team members, highlighting how their communication and actions contribute to awareness in the OR. In surgical operations, a major part of the collaboration involves the surgeon making requests to other members of the team, either verbally or by using gestures or manipulating the instruments.

The study performed by Mondada (2014b) showed how these requests are produced within an ongoing activity, with an expectation of immediate response. Her study found that surgeons use very economic and brief communication and often accept responses tacitly by merely continuing the work. Camera assistants, on the other hand, were found to orient to the ongoing operation so that they were not merely responding to surgeon's directives but to the repositioning of the instruments.

Sanchez et al. (2007) revealed how scrub nurses organize and change the arrangement of the instruments during the operation to make it possible for a surgeon to work as efficiently as possible. In their analysis, the authors emphasize that awareness in the operating room does not rely simply on shared information but rather on collaborators' actions such as using instruments in various ways to orientate to the needs of others and to what will happen next. Koschmann (1994), on the other hand, discusses the practice of displaying in tool exchange. Timeliness and accuracy are particularly important in tool exchanges during operations; one example of violating these expectations could be the surgeon's hand being in the air waiting for an instrument that has not arrived while the scrub nurse withholds a tool until it is clear it is the correct one. In this example, the expectations of both the surgeon and the scrub nurse are being violated.

In this paper, we explore the collaborative team work in micro-neurosurgery ORs, focusing on mechanisms that surgeons and scrub nurses use to build awareness and coordinate their activities. Our motivation stems from a desire to understand better how highly skilled collaborative work takes place during a neuro-surgical procedure, and how it is shaped by technology, particularly the surgical microscope. The previous studies detailed earlier in this paper have shown that awareness is a crucial part of successful cooperation in surgeries, and that it is affected by and can be improved through the way in which technology is designed. Furthermore, the studies have revealed how the interaction between a surgeon and a scrub nurse can be both verbal and non-verbal, and how the building of awareness