Noise, distractors and communication during surgeries

Impact on patient outcome and intra-operative team processes

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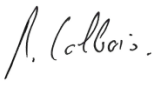

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Abstract

Performing long abdominal surgeries requires concentration for the surgeons at the individual level, and adequate teamwork behaviors at the team level. However, the work environment in the operating room (OR) is complex, with potential sources of noise and distraction; at the same time, taskwork and teamwork require attention. The papers included in my dissertation focus on determinants and consequences of teamwork, noise, and distractions in the OR.

The first paper presents a survey study that investigated teamwork as perceived by OR teams. We compared assessment of teamwork in general and after specific surgeries. We showed that the assessment of teamwork is different when teams assess teamwork on a general basis than when after specific surgeries. In particular, whereas senior surgeons assessed teamwork better than nurses in general, nurses were more satisfied with teamwork than senior surgeons after specific surgeries.

In the second paper we investigated the effects of observed distractions and communication on surgical site infections, one of the most frequent complications after abdominal surgery. More case-relevant communication was associated with a decreased likelihood of surgical site infections (specifically organ/space infections), whereas increased case-irrelevant communication during the closing phase was associated with an increased risk of surgical site infection (specifically incisional infections). We found no direct effect of observed distractions on surgical site infections.

The third paper focused on the impact of team familiarity on surgical complications. The results indicated that complications where more frequent when a senior and a junior surgeon where less familiar with one another (first month of their collaboration) that when they were familiar (sixth month of their collaboration). More noise and a decreased concentration of senior surgeons where also found when less familiar teams operated.

In the fourth paper, we related measured noise levels during different phases of surgeries to reported concentration of OR teams. Junior surgeons were distracted by higher noise levels during the main and also most critical surgical phase. Anaesthetists were most distracted by noise during the closing phase, which is a high load phase for the anaesthetists because of patient emergence. We found no effect of noise levels on concentration of senior surgeons and scrub nurses.

The fifth paper aimed to investigate the effects of noise peaks on communication within the surgical team, focusing on five-minute intervals. Whereas case-relevant communication decreased in intervals with more frequent noise peaks, case-irrelevant communication tended to decrease under high noise peaks conditions. Interestingly, there was no effect of noise peaks on case-relevant communication during the phase of the surgery led by senior surgeons. Thus, the results indicated that communication of junior surgeons, during the less critical phase of the surgery, was most impaired by noise.

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I also thank the head of the research project that allowed the studies we conducted in the OR. The research project and the present dissertation benefited from the broad expertise in the domain of work and organizational Psychology that Norbert K. Semmer brought with him in collaborating on the project. I thank Guido Beldi, for the development of the research project with Franziska Tschan and Norbert K. Semmer. Guido Beldi managed the medical part of the project and with Daniel Candinas, made the research project in the operating room possible. Among the medical experts who supported the project, my thoughts go especially to Anita Kurmann, who tragically deceased August 7th 2015. I profited from her experience in noise levels measurements, and I'm thankful I could collaborate on the studies she began. I particularly will remember our discussions about the effects of noise on communication in Boston, July 2014. She gave me precious advices, and the way she did research and made the link with her concrete experiences in the OR was admirable.

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Introduction

My dissertation is a paper based dissertation and include five manuscripts or papers. One of the papers is published, a second is accepted for publication and available as an online preview, and the three remaining papers are currently submitted for publication. All the papers report studies that were conducted as part as a large interdisciplinary project between Psychology and Medicine. The research project was supported by the Swiss National Foundation (Grant CR13I1_138273 and CR13I3_156882). This means that the papers are co-authored with other members of the research team.

The topic of this dissertation relates to teamwork in the operating room in the context of long abdominal surgeries. The first main goal of the dissertation was to investigate the impact of distraction and communication during surgeries on patient outcome. The second main goal was to investigate to what extent distractions, and in particular noise, can impact on concentration and disturb important teamwork processes, in particular communication. Thus, these two aspects are the milestones of this dissertation. Going beyond the theoretical backgrounds presented in each paper specifically, I use this umbrella as an opportunity to give a more detailed theoretical background, discussing first the impacts of noise in the OR (operating room), and second the functions of communication in the OR. Third, I present an overview of the methods that we used to conduct the studies reported here. Fourth, I shortly explain the role of each paper in the dissertation and give an abstract of their content. Fifth, all the papers are presented. Finally (sixth), I discuss some key results reported as part of this dissertation, and draw a potential future research line that would go beyond the work presented here.

Theoretical background 1: Noise and its effects on (surgical) performance

Disclaimer: This umbrella chapter was written in parallel with the paper "noise peaks influence communication in the operating room: an observational study" that it introduces. Thus, some sentences and formulations may be similar in both documents.

Noise in the OR is not a new concern and has been discussed for a few decades (e.g. Bovenzi & Collareta, 1984; Shapiro & Berland, 1972). Since the first studies on this topic, researchers showed increasing interest for patient safety on the one hand (Cima & Deschamps, 2013; Dindo & Clavien, 2014; Lawton et al., 2012). The goal of this research was - and still is, to improve patient safety in getting a better knowledge of the parameters that threaten medical staff performance. On the other hand, studies, mostly conducted in laboratories (see Banbury and Berry (2005) for an exception), demonstrated the detrimental effects of loud and distracting environment on human performance (e.g. Dobbs, Furnham, & McClelland, 2011; Hygge & Knez, 2001; Kjellberg, Landström, Tesarz, Söderberg, & Akerlund, 1996; Murphy, Craik, Li, & Schneider, 2000). However, the two research traditions did not elicit any radical change in noise levels in ORs.

Thus, noise in the OR stays an issue. In this dissertation, three papers focused on research questions related to higher noise levels in the OR: "Impact of team familiarity in the operating room on surgical complications" (paper 3), "Noise in the operating room distracts member of the surgical team: an observational study" (paper 4) and "noise peaks influence communication in the operating room: an observational study" (paper 5). I use the opportunity of this chapter of my umbrella to detail three key aspects related to these three papers: (1) a description of the context, namely of the actual noise levels and sources in ORs, (2) a literature review about the effects of noise on performance and a range of skills that are crucial to perform well and to perform well on surgical task in particular, and (3) a focus on the mechanisms that underlie the association between higher noise levels and difficulty communicating. In this section, I discuss further the higher distracting potential of noise peaks compared to other noise measurements, also on communication. These last and third aspects relate specifically to paper 5.

Noise levels in the OR and their sources

There is an agreement in previous research to define noise in the OR as "the wrong sound at the wrong place" (Murthy, Malhotra, Bala, & Raghunathan, 1995b) or simply as an "unwanted sound" (Blomkvist, Eriksen, Theorell, Ulrich, & Rasmanis, 2005; Hodge & Thompson, 1990). A main advantage of this definition is that it excludes all wished sounds, for example the sounds produced by the surgeons discussing the case or the feedback sounds of a cautering device. The definition focuses on the distracting aspects a sound can bear for the OR teams.

Modern ORs are not quiet work environments (Healey, Primus, & Koutantji, 2007; Kracht, Busch-Vishniac, & West, 2007). Empirical studies showed *mean noise levels* up to 66.5 *Leq* (dB(A)) for orthopedic surgeries. Although the technical devices are less noisy, mean noise level during gastrointestinal surgeries were still 63 *Leq* (dB(A)) (Kracht et al., 2007). Such noise levels correspond to an exposition to average traffic (Hodge & Thompson, 1990). Although these noise levels do not present risks of hearing impairment unlike those measured in some orthopedic ORs (Love, 2003; Marsh, Jellicoe, Black, Monson, & Clark, 2011), they have extra-aural effects (e.g. on concentration). General recommendations specify that noise exposure should not exceed 40 dB(A), if tasks require high concentration (SUVA, 2012). Thus, generally, noise levels in ORs are above recommendations and international standards (Kam, Kam, & Thompson, 1994; Shankar, Malhotra, Ahuja, & Tandon, 2001).

There are two major suspected noise sources in the OR: the one associated with the equipment used and the other with conversations among staff (Hasfeldt, Laerkner, & Birkelund, 2010; Shankar et al., 2001). For this study, we will focus specifically on high noise peaks (above 70 dB(A)); such noise peaks are hardly reached by normal human speech. By contrast, equipment or behaviors associated with equipment handling and use have been associated with louder sounds: for example, the suction devices can produce up to 75-80 dB(A); a cylinder loosing gas produces up to 103 dB(A) (Hodge & Thompson, 1990). A recent study reported equipment or doors as sources of noise peaks higher than 70 dB(A) (Broom, Capek, Carachi, Akeroyd, & Hilditch, 2011); the loud sounds are explained by the frequent use of equipment made of metal in ORs, for disinfection reasons (Stringer, Haines, & Oudyk, 2008).

Noise and its effects on surgical performance and skills. A review of the literature.

Noise affects well-being and performance (Edworthy, 1997; Passchier-Vermeer & Passchier, 2000; Szalma & Hancock, 2011) also in the hospital setting (Blomkvist et al., 2005), and this includes operation rooms (OR). In this chapter, I report the actual state of research about noise effects on human performance and specific skills contributing to it. A first group of studies examined to what extent noise had an impact on objectively measurable performance. These field studies measured performance in terms of surgical outcome (e.g. post-operative complication rates). However, to reach a deeper understanding of the effects of noise on performance, it is also necessary to examine which task-related skills or functions necessary for efficient work are particularly vulnerable to noise effects, and under which conditions. Thus, this section aims at presenting studies investigating (1) the effects of OR noise on surgical outcomes and (2) studies investigating the effects of noise on physiological functioning, cognitive processes and emotional states – in first presenting basic research and then presenting studies done in the OR setting, if available.

Effects of noise on surgical outcomes

Noise has an impact on work performance in general and on surgical performance in particular: Almost two thirds of surgeons that were asked whether noise had a negative impact on their job, responded yes (Tsiou, Efthymiatos, & Katostaras, 2008). Several field studies measured noise in the OR and looked at its consequences on surgical outcomes. These studies

tend to corroborate the surgeons' perception, as several studies indeed found an association between noise during surgeries and surgical outcome.

For example, one study showed that higher general noise level in the OR was associated with an increased probability for surgical site infection (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). The results of a second similar study also indicated that louder noise levels during surgeries predicted a higher risk of surgical site infections (Dholakia et al., 2015). Another study showed a decreased complication rate (particularly in minor procedures) after a noise-reduction intervention in pediatric surgeries (Engelmann, Neis, Kirschbaum, Grote, & Ure, 2014). When interviewed about their working conditions before a medical error had occurred, medical staff reported more distractions (i.e. more noise) than usual (Grayson et al., 2005). These studies indicate that noise in the OR can indeed be a problem that needs to be assessed. In the next sections I will discuss known effects of noise in general, and in the OR setting.

Specific effects of noise on individuals

Physiological effects of noise: Individuals exposed to noise show physiological responses, such as fatigue and stress. One study found that under higher noise conditions (55 dB(A) vs 35 dB(A) of office noise), participants experienced higher fatigue (Witterseh, Wyon, & Clausen, 2004). For short term exposure, there might be individual differences in sensibility to noise: One study compared noise effects for participants high in introversion or extraversion. They found that only introvert participants that had to solve arithmetic problems in a noisy vs a quiet condition reported higher levels of fatigue under the noise condition; there was no effect for extraverts (Belojevic, Slepcevic, & Jakovljevic, 2001).

Noise seems to arouse the autonomic nervous system as evidenced by observed increases in blood pressure, heart rates and stress hormones under noise (Basner et al., 2014; Rylander, 2004). Consistent with these findings, long-term exposition to environmental noise (i.e. over several months), has been found to be associated with more cardiovascular problems (e.g. myocardial infarction (Huss, Spoerri, Egger, Röösli, & Group, 2010).

There are only few studies investigating physiological reactions to noise in the OR. Engelmann et al. (2014) measured physiological parameters of the surgeons before and after a noise reduction intervention. The intervention that was conducted reduced median noise level in the OR by about 4 dB(A) and reduced noise peaks. The results indicated a non-significant trend towards a reduction of physiological stress after the intervention. It is interesting that "wanted noise", such as music, does not have the same negative effect than unwanted noise. Music was indeed associated with *reduced* cardiovascular reactivity in a sample of surgeons that solved calculations in a laboratory experiment (Allen & Blascovich, 1994). Note that this study did not test the effect of louder noises, nor did it examine the effects of auditory stimuli on surgical tasks.

Noise also influences experienced stress levels: Like temperature, noise belongs to the environmental job *stressors* (Long, Jusoh, Ajagbe, & Ghee, 2013; Szalma & Hancock, 2011), and can increase employees' feeling of being stressed (Gladd & Saunders, 2011). For example, employees in a critical care unit experienced less demands (e.g. the quantity of work was experienced as less) and less pressure (lack of calmness, hastiness and stress) as well as less

strain (tension and irritation) during an afternoon in a room with optimal room acoustic conditions (sound absorbing ceiling) as compared to a room with bad room acoustic conditions (sound reflecting ceiling) (Blomkvist et al., 2005).

In the context of the OR, noise is as well considered as a source of stress by different authors describing the work environment of an OR, although these studies did not empirically assess the association between noise and stress (Hodge & Thompson, 1990; Shankar et al., 2001; Wetzel et al., 2006).

Cognitive effects of noise: The effects of noise on cognitive performance are of main interest, as cognitive impairments may be directly responsible for short-term performance effects under higher noise levels. Research found that noise can impair information processing, attentional processes and memory processes (Szalma & Hancock, 2011). For example, participants had more difficulties to *concentrate* under higher office noise conditions (55 dB(A) vs 35 dB(A)), (Witterseh et al., 2004). Again, introverts (medical students) reported more difficulty concentrating, under higher noise levels (88 dB(A)) than extroverts (Belojevic et al., 2001). I could not find empirical studies in the OR or related to surgical tasks that investigated the relationship of noise to concentration impairments. However, given the available evidence from other domains, the probability is high that loud noise peaks in the OR threaten the concentration needed for complex surgical tasks (Hodge & Thompson, 1990).

Besides of concentration, noise directly impairs *cognitive performance*. First, noise also impacts *memory*. There is evidence of lower performance on memory tasks that were solved in noisy conditions, as compared to silence; although the type of task and the type of noise needs to be considered (Baker & Holding, 1993). Second, one study showed that performance in a cognitive ability test (e.g. abstract reasoning test) decreased in a noisy condition (typical noise of a children's classroom) as compared to silence (Dobbs et al., 2011). Again, this effect was related to unwanted noise: Participants solving the tests in a music condition performed as well as participants in the silence condition. Other studies even showed a positive impact of noise on resolution time of an attentional tasks; however, this was at the cost of a decreased accuracy in terms of errors committed (Hygge & Knez, 2001; Szalma & Hancock, 2011).

Noise particularly impairs performance on *complex cognitive tasks*. One study showed that participants performed worse in an office noise condition vs a silence condition when solving complex cognitive tasks, but not if they performed simple cognitive tasks (Loewen & Suedfeld, 1992).

Studies investigating the relationship between noise and cognitive performance in the OR are scarce. The only study I found showed that real loud noise in an OR (mean noise was 77.32 dB(A)) had a negative impact on the performance of resident anesthesiologists for tasks that aimed at testing their short-term memory and their mental efficiency (Murthy et al., 1995b). To the best of my knowledge there are no studies that examined the association between operating room noise and complex cognitive aspects of surgical tasks, for example intraoperative decision making. However, again, we can assume that loud noise impairs complex cognitive performance also in the OR.

Emotional effects of noise: Besides its effects on physiological aspects and cognition, noise elicits an evaluative response that contributes to the annoyance associated with noise (Guski, Felscher-Suhr, & Schuemer, 1999; Zimmer, Ghani, & Ellermeier, 2008). For example, noise can trigger unpleasant affects or resentment feelings that are, like cognitive noise effects, moderated by the noise intensity or frequency (Guski et al., 1999; Passchier-Vermeer & Passchier, 2000).

The few empirical results of associations of specific emotional aspects with noise show mixed evidence for the hypothesis that noise should have a negative impact on affective states. For example, participants performing under office noise and a control condition did not show different pleasure ratings (Loewen & Suedfeld, 1992). However, participants solving tasks under noise conditions experienced higher anxiety levels compared to the participants in the quiet condition in another study. They felt higher anxiety not only at the end of the session, but as soon as they heard the noise (Smith, Whitney, Thomas, Perry, & Brockman, 1997). Indeed, another study supported the hypothesis that it is not the noise itself, but the interference caused by the noise that is responsible for noise annoyance (Zimmer et al., 2008), indicating that negative affect is a result of noise making the attainment of goals more difficult. There is also no support for the hypothesis that the affect induced by noise mediates the association between the noise and decreased cognitive performance (Hygge & Knez, 2001). However, induced negative mood before the noise exposition influenced how annoying high frequency, irregular noises were rated by the study participants (Västfjäll, 2002). In line with the findings that negative affect related to noise may be a result of noise impairing task execution, residents performing a laparoscopic task in a simulator setting were more irritated towards their collaborators and towards the noise, in a distracting condition, but did not show higher general irritation (Pluyter, Buzink, Rutkowski, & Jakimowicz, 2010). In sum, the results of these studies suggest that noise exposure is particularly related to negative affect, if the noise directly interferes with the task. This also explains why not all noise under all circumstances leads to more negative affect.

Effects of noise on sensory-motor skills and performance: Successful surgery depends on high sensory-motor skills of the surgeons. It is thus particularly important to evaluate whether noise impairs sensori-motor performance. This is indeed the case: A recent meta-analysis found medium effect sizes for the negative impact of noise on motor processes (Szalma & Hancock, 2011), this despite the small number of studies on this topic. Interestingly, other studies report positive effects of noise on motor skills, however specifically for monotonous tasks (Passchier-Vermeer & Passchier, 2000).

Studies with surgeons showed that noise had no impact on surgeons performing a surgical tasks in a simulator (Moorthy, Munz, Undre, & Darzi, 2004). Indeed, monotonous 80-85 dB(A) OR noise and music did not change objective performance (e.g. completion time, tasks accuracy). Interestingly, the authors explain these results by the absence of sudden loud noise (Moorthy et al., 2004). Another study, using as well recorded OR noise, found similar results, with no association between noise and performance on a robotic assisted task; whereas different distractors affected performance (Suh et al., 2010). This, again, is in accordance with the hypothesis that not louder noise levels per se, but aspects of noise that interfere with the

task, may influence performance. Studies about distractions (Feuerbacher, Funk, Spight, Diggs, & Hunter, 2012; Goodell, Cao, & Schwaitzberg, 2006b; Pluyter et al., 2010; Suh et al., 2010) show indeed impaired sensory-motor performance (e.g. more errors, more time resources to finish the task).

Another explanation for the absence of effects of noise on sensori-motor performance was given by Moorthy et al. (2004); they claim that surgeons can "block out" noises. Note that the participants recruited in this latter study –that showed no impact of noise on performance, possessed heterogeneous levels of experience (Moorthy et al., 2004). By contrast, studies that found negative effects of distractors on laboratory surgical sensori-motor performance were mostly conducted with junior surgeons (e.g. residents) or medical trainees (Feuerbacher et al., 2012; Goodell et al., 2006b; Pluyter et al., 2010). Indeed, studies on distractors and OR-performance showed that each time, the performance of the participant group with the less experience in surgery suffered the most under distracting conditions (Hsu, Man, Gizicki, Feldman, & Fried, 2008; Suh et al., 2010).

Impact of noise on communication

Impact of noise on communication is a particularly important aspect for this dissertation, because it implies that workplace noise may not only impair the performance of single individuals, but will also have effects on team communication and performance. I first shortly discuss the general impact of noise on communication in diverse settings. Second, I discuss more specifically issues related with communication impairments by higher noise levels in medical settings and in the OR. Third, I review some important mechanisms that may hinder or complicate communication under higher noise levels. Fourth, I discuss the particularly distracting impact of noise peaks compared to other noise measures, also on communication.

General impact of noise on communication

It is not surprising that noise impacts communication, because both use the auditory system (Barach & Weinger, 2007; Gladd & Saunders, 2011; Szalma & Hancock, 2011). Indeed, negative effects on conversations is one of the most impaired activities by aircraft noise during the day (Stansfeld & Matheson, 2003). A meta-analysis found that noise impaired performance of tasks that needed oral, but also written communication; this effect was consistent across all 17 studies included in the analysis (Szalma & Hancock, 2011). The authors explain the negative effect of noise on communication tasks by the fact that communication requires high cognitive resources and may thus be additionally impaired by noise, because noise captures attention (Szalma & Hancock, 2011).

Impact of noise on communication in medical settings

Surgery is teamwork, and requires communication within a multidisciplinary team (Nurok, Sundt, & Frankel, 2011). Many errors and mishaps in the OR are related to problems in communication (Lingard, Espin, Whyte, et al., 2004). Thus, communication may be particularly vulnerable to noise. Indeed, in the context of the OR and hospitals in general, the major detrimental effect of noise pertains to communication among the medical staff (Hasfeldt et al., 2010; Hodge & Thompson, 1990). One of the few empirical studies related to this topic

found that noise impairs phone conversations of clinic staff (Gladd & Saunders, 2011). Noise impairs the understanding of the others' speech (Barach & Weinger, 2007; Shankar et al., 2001). As a consequence, this threatens the safe transmission of information from the speaker to the listener (Solet, Norvell, Rutan, & Frankel, 2005). We can thus expect that under noise conditions, transmission of oral information suffers. To be able to continue information exchange under high noise levels, one strategy is to speak louder, to raise the voice (Barach & Weinger, 2007; Hodge & Thompson, 1990; Kracht et al., 2007; Orellana, Busch-Vishniac, & West, 2007; Shankar et al., 2001). However, when looking closer at the mechanisms of communication under higher noise levels, the issue cannot be so easily solved by simply raising the voice.

Mechanisms of impaired communication under higher noise levels

More specifically, noise has specific effects on (1) sent communication, but also on (2) received communication. I outline effects on communicating and on understanding communication in noisy environments. (1) Studies showed that under higher noise levels, communication is more likely interrupted, and senders communicate less, and different. Indeed, one study found that aircraft noise levels were significant predictors of interruptions of conversation. On third of the 164 study participants that were talking just before exposed to loudest sound used in this experiment (79 dB(A)), stopped talking at the onset of the noise (Key & Powell, 1980). In addition, 70 per cent of the participants increased their vocal effort (talked louder) when exposed to such high noise levels. Such qualitative changes in the communication under higher noise levels conditions are called Lombard reflex: the Lombard reflex describes the fact that humans speak louder when noise levels increase. They do so in order to maintain the intelligibility of their message, which means that the Lombard reflex is not only triggered by physiological processes (Junqua, 1996). The Lombard reflex induces a range of changes in the speech production, most importantly louder speech and hyperarticulation (Zhao & Jurafsky, 2009). As a summary, loud noises on the one hand lead to interruptions of communication and induce changes in communication. It is likely that both aspects are linked, as interruptions may be an alternative to effortful risings the voice. A loud speaking person is more likely to be perceived as extravert (Scherer, 1978); it thus may be that surgeons fear that if they speak much louder, they would be perceived as too much extravert or even aggressive. Applied to the OR situation studied, it may be that surgeons are more reluctant to communicate detailed explanations about what they are currently doing, if the vocal effort needed to be understood is too important. If noise is very high in the OR, they thus may limit their task-related communication to the absolute necessary. Consequently, we postulate that the amount of task-related information exchanges will decrease under more high noises peaks.

(2) For received communication, noise and music impair the understanding of communication. This is especially true when the information to be received is unpredictable or complex (Way et al., 2013). To understand unpredictable and complex information, the receiver needs a complete understanding of the words and sentences communicated; otherwise, meaning cannot be reconstructed by the listener. This means that communication content that needs to be well understood (such as task-related information, particularly novel and non-routine communication may be particularly prone to be disturbed by high noise peaks. Communication

where details are less important (for example small talk) may suffer less from noise peaks. Applied to the OR-setting, I suggest that more complex information exchanges about the current case are more likely to suffer from noise as compared to less important and more easily predictable social case-irrelevant communication.

Noise peaks are particularly disturbing

Many studies reported above that investigated effects of noise in general and in the OR operationalized noise as mean decibel levels. However, even high mean decibel levels may not be the most disturbing aspects of noise on communication. It is thus important to define which "type" of noise we study and why. Indeed, previous research showed that the characteristics of the noise moderate its impact on performance. As said, it is often not the mean noise levels that have the most influence on performance. At least for certain tasks, sounds of short duration that are aperiodic and intense (noise peaks) showed a greater impact on performance as compared to less intense, periodic and sounds of longer duration (Baker & Holding, 1993). For example, a study tested the effects of different types of noise on performance and showed that children's reading capacity was poorer when exposed to aircraft (sudden, nonmonotonic noise) compared to constant road traffic noise (Clark et al., 2006). The authors explain these results as effect of the higher variation associated with aircraft noise, compared to more constant road traffic noise (Clark et al., 2006).

We can expect that communication is also especially disturbed by sudden loud noise peaks, if the noise peaks draw on attentional resources simultaneously as communication and impair in addition the correct understanding of the communication content. In paper 5 of this dissertation, we used noise peaks to the test the impact of noise on communication in the OR. In this section, I discuss in more details the specificities of noise peaks and their effects.

The reasons for the greater effects of noise peaks that are of high intensity or varying compared to more monotonic, constant and continuous sounds may be due to the *lack of predictability* of noise peaks. Intermittent or aperiodic noises are hardly predictable (Hodge & Thompson, 1990). In the OR, noise peaks are frequent (Broom et al., 2011); one study reports over 90 noise peaks above 79 dB(A) per hour (Engelmann et al., 2014). The number of noise peaks varies with different phases of the surgery (Broom et al., 2011); they are more frequent at the beginning and the end of the procedure (Engelmann et al., 2014). Nevertheless a sudden loud noise from removed metal boxes may be perceived as less predictable by the surgical team than a continuous noise from ventilation. Exposure to noise peaks led to a higher increase in emotional arousal, measured as the skin resistance spontaneous fluctuation, than exposure to periodic loud noises, indicating indeed an effect from unpredictability (Glass, Snyder, & Singer, 1973). Noise peaks, even of short duration, elicit attention and often an orienting reaction towards the noise source. This may explain their greater disruptive effects compared to continuous noises (Szalma & Hancock, 2011).

Very loud noise peaks (in this case sudden noises that are at least 30 dB(A) above the background noise levels) may also be responsible for the so called startle reflex (Hodge & Thompson, 1990). This reflex leads to the contraction of a wide range of body muscles (that trigger for example eyeblink (Filion, Dawson, & Schell, 1998)). Although the startle reflex may

have an adaptive function in allowing the organism to react efficiently toward a threat, this reflex is maladaptive in modern contexts without threats (Yeomans, Li, Scott, & Frankland, 2002), and may negatively influence sensori-motor performance.

Many authors see noise in general as a threat for safe communication, as discussed in the previous chapter. However, when looking closer at the mechanisms that may threaten communication, if noise levels are high, there are more complex aspects to consider. Noise, especially repeated noise peaks create a feeling of urgency, which is more than the increased attention under moderate noise levels; it is important to note that the feeling of urgency is also induced for familiar noises, if they are very loud (Woodhead, 1964).

Thus, an ongoing communication can be expected to especially suffer from noise peaks, as these would distract the ongoing communication activity. Therefore, to investigate the effects of noise on communication in detailed analysis during the ongoing surgery (per five-minute interval) in paper 5, we choose to focus on noise peaks. However, note that in paper 4, we did not focus on noise peaks but on median noise levels. This choice was guided by the different research questions and the fact that our analysis on longer phases of the surgeries and assessed the effects of concentration in general.

As a conclusion, previous literature showed that noise in the OR is still an issue, and higher noise levels continue to be measured. As noise can impair a range of skills that are used in surgery, we can expect that noise disturb ideal surgical processes and thus impact in turn on patient outcome.

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Theoretical background 2: Communication in the context of the operating room (OR)

Communication in the operating room (OR) is one of the central topics of this dissertation. In two of the papers included in this dissertation, we measured communication in the OR. These papers are "Impact of case-relevant and case-irrelevant communication within the surgical team on surgical-site infection" (paper 2) and "Noise in the operating room distracts member of the surgical team: an observational study" (paper 4). In addition, it is likely that teamwork perception, discussed in paper "Do nurses always perceive teamwork as worse than surgeons? Differences between teamwork quality perception in general and in specific surgeries" (paper 1), is also related to communication aspects, as communication is an important facet of teamwork.

Teamwork and communication are an increasing preoccupation for patient safety, including in the operating room. Even if the preoccupation of practitioner and researchers in the medical domain focused more on these aspects in the last decade (Vincent, 2010), the role of teamwork in team performance was studied earlier and in other domains. Systematic empirical research about groups and teams emerged at the beginning of the 20th century, and was fostered by the concerns of team effectiveness during the second world war (cf. Goodwin, Burke, Wildman, & Salas 2008), as well as by the goal to study group dynamics. For example, Lewin investigated effects of different leadership styles on group processes (cf. Levine & Moreland, 2006). Further, teamwork research developed, especially in the domain work and organizational psychology (Levine & Moreland, 2006), generating knowledge about key aspects supporting team performance. Thus, although the main focus of this chapter will be communication in association with patient safety, I also discuss important team processes related to communication and identified outside the scope of patient safety research. Note that the approach to teams in is dissertation is related to group performance in natural groups (Levine and Moreland (1990)), in the tradition of the functional perspective (Wittenbaum et al., 2004) applied in to surgical teams.

In this chapter, I unfold some important aspects related to the study of communication during surgeries. The aim of this chapter is to highlight the role played by communication in teamwork during the intra-operative process, in other words during the duration of the surgery in the operating room. I first define "teamwork", emphasizing key features of the task and work context in the OR. Second, I review previous studies that showed that suboptimal communication was often associated with adverse events or inefficient patient care. Third, I present the communication processes within surgical teams with a focus on how efficient communication can support efficient teamwork and be a barrier to technical errors. Fourth, I review past research that emphasized the social functions of case-irrelevant communication in work teams and more specifically in the OR.

Definition and characteristics of teamwork in the operating room

There is no one definition of teamwork that covers all the possible facets of teamwork. The concept is too broad to be defined with a few sentences; rather, teamwork needs to be defined for specific research topics (Dorsay et al., 2009).

The characteristics of working teams are that the individuals share and work towards a common goal. In surgery, this goal is to perform a safe operation for the patient. In the OR, teams are placed in a situation of *high interdependency* (e.g. the surgeons rely on the circulating nurse to bring them the needed material), and the needed resources are available to perform the task (West, 2012). Surgical teams are *performance teams*, as they plan, practice, and perform (Forsyth, 2009; Sundstrom, De Meuse, & Futrell, 1990). In certain situations, surgical teams can also be seen as *action teams*, like ambulance or firefighting teams, because they may have to master unexpected situations under high time pressure. Surgical teams can be opposed for example to strategy and policy teams (e.g. an administrative board) (West, 2012). Action teams show often work on a temporary basis, with high specialized members, performing urgent and highly interdependent tasks that cannot be performed by one single team member (Klein, Ziegert, Knight, & Xiao, 2006; Marks, DeChurch, Mathieu, Panzer, & Alonso, 2005). Although not all surgical teams are action teams, as some surgeries are routine procedures, a surgical team has to be prepared to react on sudden changes and complications.

Human factors and teamwork impact surgical performance and adverse events

As in other life threatening domains such as aviation, it is crucial to know what factors contribute to an excellent performance during surgeries. The stakes are human lives, but also economic resources, because complications cost a lot of money to the healthcare system. In addition, a better insight in what predicts performance has important implications for training what should emphasize the importance of research focusing on surgical performance contributors.

An analyses of adverse events in a study analyzing more than 30’000 patients records showed that 3.7 percent of the patients suffered an adverse event, defined as treatment related harm; almost half of them were related to surgery (Leape et al., 1991). When investigating the errors that led to adverse outcomes, researchers often distinguish between technical and non-technical errors (Catchpole et al., 2006). Technical errors emerge from lack of knowledge, skills or expertise related to the specific tasks performed, whereas non-technical errors include cognitive and teamwork failures. The importance of non-technical skills and teamwork contributing to adverse events was largely ignored in the medical domain until the nineties (Gordon, Darbyshire, & Baker, 2012; Leape et al., 2009). Medical education curricula are a good indicator of the importance of non-technical skills: Ten years ago, training related to non-technical skills remained marginal (Yule, Flin, Paterson-Brown, & Maran, 2006), and were only offered on a voluntary basis (Glavin & Maran, 2003; Lighthall et al., 2003). Thus, most of the current leaders in healthcare did not receive formal training in managing teamwork skills.

There are two indicators that non-technical skills and teamwork are increasingly perceived as important factors in patient care. First, curricula to teach non-technical skills in medicine were developed (Gordon et al., 2012). Second, research showed that medical

professionals are increasingly aware of the role of problems in teamwork as contributing to adverse events (ElBardissi, Wiegmann, Dearani, Daly, & Sundt, 2007). More specifically, poor communication was the characteristic that best described poor OR teams according to professionals working in the OR, whereas good communication was the most cited characteristic to describe good teams (Undre, Sevdalis, Healey, Darzi, & Vincent, 2006). Empirical studies investigating the association between communication and performance in the OR support this view (Nagpal et al., 2010).

Although I focus on teamwork and non-technical skills in this dissertation, this does not mean that technical skills should be neglected. Both technical and non-technical skills are necessary for efficient performance in the OR.

Adverse events related to teamwork

Researchers investigated the *role of teamwork* in medicine using different research methods, including incident reports, prospective observations, simulated events and laboratory experiments (Manser, Howard, & Gaba, 2009), as well as intervention studies.

Studies measured *surgical performance* in four categories: (i) "outcomes" such as patient morbidity/mortality, but more often they assessed performance as (ii) technical errors, (iii) operating times and delays, and (iv) teamwork and/or communication failures. Note that although some studies include communication failures as a performance outcome, this will not be the case in the present dissertations, as only measurable outcome *after* the surgery will be called outcome. What happens *during* the surgery, *how* the surgical reach this outcome (and this includes communication processes) will be described as aspects of the process. Note that studies investigating the association between teamwork aspects and patient outcomes are scarce, this is explained by the rarity of adverse outcomes in surgery, especially in terms of mortality (Nurok, Sundt III, & Frankel, 2011; Wahr, Prager, Abernathy, Martinez, Salas, Seifert, Groom, Spiess, Searles, & Sundt, 2013).

Teamwork/communication and patient outcome: the crucial role of communication

The following section provides an overview on empirical studies relating communication/teamwork to patient outcomes, structured along the methodological approaches described by Manser and colleagues (Manser et al., 2009).

Evidence from incidents reports. One study found that almost a quarter of the 444 surgical errors claims dealt with by insurance companies involved at least one communication breakdown, among which 92 pertained to verbal communication, and about 50% occurred within a single discipline (Greenberg et al., 2007). Another study found similar results, with 89 of 130 adverse surgical events caused by communication breakdowns (Morris Jr et al., 2003). An interview based study found that in 43% of the adverse events presented by the surgeons interviewed were associated with communication breakdowns (Gawande, Zinner, Studdert, & Brennan, 2003).

Evidence from observational studies. Observation of teamwork and communication could be related to surgical performance. Video analyses of surgeries showed that

communication problems were involved in almost one third of events compromising patient safety and causing delays (Hu et al., 2012). Lingard, Espin, Evans, and Hawryluck (2004) analysed in details how communication can be dysfunctional in the OR. Four aspects of the communication process (occasion - when and where; content – what; audience - to whom; and purpose - why the communication took place) are vulnerable to failures and often found ineffective (Lingard, Espin, Evans, et al., 2004). Note that in this study, communication failures often were recovered and did not have visible effects on patient outcomes. This study suggests that and how communication can impact performance even without causing immediately visible effects.

Another study supports that communication was important to recover from compromising events (Hu et al., 2012). The thesis that efficient communication during surgery has compensatory functions and contributes to prevent possibly adverse events is supported by further studies (de Leval, Carthey, Wright, Farewell, & Reason, 2000). In addition to the compensatory function, communication during surgeries may have other beneficial effects. One study found that a higher frequency of intraoperative communication - including briefings and intrasurgical information sharing - was related to better patient outcomes measured 30 days after surgery (Mazzocco et al., 2009). These results are interesting, as they show that communication may be important in general, and not only during particularly difficult situations.

Evidence from training studies are growing, whereas studies focusing on the association between teamwork and outcome are less frequent than before (Manser, 2009). For example, one study found a reduction of observed technical errors after a theoretical training based on the crew resource management (CRM) principles (McCulloch et al., 2009). Training studies further investigated often specific training strategies, this will not be discussed here.

Optimal teamwork

Several papers of this dissertation examine communication *during* surgeries. Communication is obviously necessary in the OR, as the task requires not only instruments exchanges, but as well exchange of information (Healey, Undre, & Vincent, 2006a). For example, although scrub nurses often foresee which material the surgeon needs at a certain moment, (Mitchell et al., 2010), clear communication about what instruments the surgeons will need, allows the nurses to prepare them in advance (Koh, Park, Wickens, Ong, & Chia, 2011). Such a simple communication may appear trivial. But only if the underlying mechanisms related to everyday communication in surgical teams are well understood, it will be possible to understand the factors that make communication in the OR vulnerable on the one hand, and efficient on the other hand. A better understanding of processes related to communication is crucial, because communication can be trained and improved (Awad et al., 2005).

Team processes

Previous research focused on team processes associated with verbal communication (Schmutz & Manser, 2013). This research has the advantage to examine the mechanisms of teamwork and thus to point out which of them are crucial for (surgical) team to be performant.

In this section, I first present some of the main models of team processes related to the papers in this dissertation, and examine main functions of communication in supporting efficient team processes, namely communication as coordinating mechanisms, communication related to cognitive concepts, and functions of case-irrelevant (off-task) communication throughout this dissertation.

Team processes: definition and theoretical models

Among the many different models that describe team processes, I focus first on the I-P-O (input-process-outcome) models, then present the "big 5 of teamwork" and third non-technical skills for surgical teams.

Input-process-output (I-P-O) models. Team processes represent the "P" for process of the widely used Input-Process-Outcome model (Goodwin et al., 2008; Salas, Rosen, & King, 2007). They are defined as the steps a group takes to convert input into outputs by interacting with each other and their environment (Marks, Mathieu, & Zaccaro, 2001). Examples of inputs are team composition, time resources or material (McGrath, 1984), outputs are the results of the groups, but also the sustainability of the group for future performance and individual gains for group members. Part of the team processes are verbal activities (Marks et al., 2001). Processes are dynamics in groups and evolve over time (McGrath, Arrow, & Berdahl, 2000). For example, there can be different I-P-O cycles during a same task (Marks et al., 2001). In this dissertation, processes will refer to what happen during the surgery, and outcomes are the result of the surgery.

The big five of teamwork. This model describes a set of processes that are critical for efficient teamwork and performance (Salas, Sims, & Burke, 2005). Five core components of teamwork are identified, based on previous literature. The components are leadership, mutual performance monitoring, team orientation, backup behavior and adaptability. The five core components are supported by three coordination mechanisms (closed-loop communication, shared mental models and mutual trust). Although this global model has the advantage to highlight core components of teamwork, its generality is one of its major weakness. On the one hand, there is no clear specification about *how* the different coordinating mechanisms impact the core components of teamwork. In addition, the concepts cannot easily be operationalized as specific behavioral or verbal markers that can be observed. In addition, the inter-relationships between the core components and the coordinating mechanisms are likely to be influenced by processes that happen previously to task completion. Typically, the attitude of team orientation might be influenced by previous experiences of team members. Finally, different tasks might rely on different team processes, which means that the core components, the coordinating mechanisms and their inter-relationship are likely to vary strongly depending on the task or even depending on phases within same task. Nevertheless, this model identifies a limited set of important aspects and fosters the understanding and need to modelling the complex inter-relation between the different processes.

Non-technical skills. A third description of team processes focuses on the non-technical skills that apply specifically to surgical personnel (Yule et al., 2006). The authors identify four different skills sets as playing a key role during surgery: Communication, teamwork, leadership

and decision making. Specific non-technical skills are described for surgeons, anesthetist, and scrub nurses (Flin, 2013). Similar to the model of Salas et al. (2005), the interrelation between the different concepts are not discussed, and the description of non-technical skills help to assess individual team members, rather than the group (Robertson et al., 2014). In fact, if one surgeon shows good communication skills, this might not be enough for high team performance. Rather, successful team coordination requires several team members being involved in an optimal communication process.

Although communication is a very important aspect in all the models presented above, the models are limited as explanatory background for a better understanding of the *functions* fulfilled by communication in the OR. The models provide only few indications about the relationship of communication to other aspects, for example to leadership or to coordination. The lack of explicit description of the inter-relations makes it thus difficult to derive specific hypotheses about the relationship of communication to team performance.

Communication supports efficient team processes

Based on the literature, I identified coordination and cognitive processes as two main aspects of teamwork closely related to communication. Coordination has tangible and observable indicators, whereas team cognition refers to more abstract concepts.

Coordination

Communication is closely linked to coordination processes in surgical teams. Surgical tasks have high coordination requirements, given the high interdependence of the teams composed of different members with different levels of expertise, the complexity of the task, and the limited time resources available.

Coordination means managing interdependencies (Espinosa, Lerch, & Kraut, 2002; Krokos, Baker, Alonso, & Day, 2009). More specifically, groups have to manage interdependencies between group members, but also between tasks and tools (McGrath & Argote, 2001). How well the coordination between members, tasks and tools and within the subnetworks composed of the different aspects is done, is an important predictor of group performance (McGrath & Argote, 2001). For surgeries, some of these subnetworks are already partly defined. For example, the member-task subnetwork ("who does which task") is predefined by the roles of the different members of the surgical team (e.g. the scrub nurse hands instruments to the surgeons; the anesthetist monitors the patient during the period of narcosis). Nevertheless, explicit coordination within the subnetworks is still needed. For example, during a laparoscopic surgery, a surgeon may allocate the task of holding the camera to the scrub nurse for a few seconds. In this case, explicit communication supports coordination. In sum, communication is required and useful tool to coordinate the group process.

There is empirical evidence of communication as coordinating mechanism. One study conducted with anaesthesia teams showed how the task influences the coordination and communication needs, and also showed that performance depended on how teams managed the information demands after a critical event (Burtscher et al., 2011). The authors show the performance benefits of the accordance of coordination behavior with task requirements. They

measured information management as verbal behaviors (which shows the high overlap between coordination and communication). Surgeons managed their dependency in coordinating with the nurse to perform a specific task, for example asking them to bring in a thread they needed. It is important that the surgical team deals with the dependencies in an efficient way (Patterson, 2007).

Communication supports coordination, but efficacy depends on how the team organizes the communication. One study investigated (a) the presence or absence of key communication steps during a task (orientation, planning, and evaluation) and (b) the ideal order of apparition of these communication steps. Results showed that completeness as well as ideal sequence influenced team performance (Tschan, 1995). Thus, the content and the timely order of communication during a task should be considered.

Verbal communication also helps leaders coordinate their teams. One of the functions of leadership is indeed team coordination (Klein et al., 2006; Künzle, Kolbe, & Grote, 2010; Reader, Flin, Mearns, & Cuthbertson, 2009), and it is part of the task-oriented behaviors expected from leaders (Yukl, 1999). In a study in an intensive care unit (ICU), communication supporting team coordination was identified as one of the main leader behaviors (Reader et al., 2009), this was also found for leadership behaviors of surgeons in a OR (Parker, Yule, Flin, & McKinley, 2011b). A simulation study showed that a leadership and communication skills training led to more observed coordinating communication and positively influenced performance (Hunziker et al., 2010). Leader coordination also support effective communication within the team and can help the team to exchange information (Parker et al., 2011b).

Not only the content of communication but also how the team communicates plays a key role in coordinating. Salas and colleagues (2009) describe closed loop communication as a communication pattern particularly supportive of efficient communication. Closed loop communication means that the message is not only sent, but the sender expects a confirmation from the receiver that he or she got the message. Closed-loop communication thus describes a secure way of convening a message to ensure that the message target receives and understands the message. Thus, it can well be that specific communication patterns facilitate coordination.

Consequently, communication is a key tool for team members and leaders to coordinate while performing a task. Given the multiple interdependences, surgeries have especially high coordination needs. Verbal communication can be related to key information to perform the task or to broader aspects related to members, task or tools. Closed loop communication patterns can prevent that the last critical step in information exchange fails.

Team cognition

Team researchers developed the concept of team cognition and its refinements to understand better what influences on team performance and efficient team processes (DeChurch & Mesmer-Magnus, 2010). Similarly to individual cognition concepts, team cognition was an attempt to explain the mechanisms happening “in the black box”. Compared to coordination mechanisms, team cognition is “one level” higher, as it is “in the head” of the individuals (Gutwin & Greenberg, 2004).

Team cognition is closely associated with team processes for two reasons. First, team cognitions are tied to team processes because team processes such as coordination rely on information that are processed by several team members; second, the content of the cognition is related to the team (‘s task) (Salas, Rosen, Burke, Nicholson, & Howse, 2007).

In this section, I discuss the three most important team cognition concepts: shared mental models, situation awareness and transactive memory systems. Then, I shortly mention issues related to “wrong” team cognitions.

Shared mental models

Mental models are organized knowledge and representations of situations or task (Klimoski & Mohammed, 1994; Mohammed & Dumville, 2001). The concept of shared mental models[1] refers to mental models that are similar across team members. Shared mental models can pertain to the situation, the task, the equipment and the team (Mohammed & Dumville, 2001). Shared mental models are not considered as team processes, neither as psychological traits; rather, they are described as emergent states (Marks et al., 2001), because they change depending on the context. These authors consider shared mental models are both inputs and outputs of team processes. The development of shared mental models is supported by information sharing (see also Salas et al., 2005), but they can be as well the starting point for information sharing.

The most discussed positive effects of shared mental models on communication is related to the switch from attention demanding explicit coordination to implicit coordination. Shared mental models allow the teams to anticipate better, and implicit coordination that requires less overt communication is more likely. Interestingly, information exchanges about the current task are a component of implicit coordination (Rico, Sánchez-Manzanares, Gil, & Gibson, 2008), this implies that teams with good shared mental models may develop quantitatively different communication, as shared mental models facilitate information exchange.

Empirical research outside the OR found that updated or similar mental models supported team performance (Gurtner, Tschan, Sernmer, & Nagele, 2007; Uitdewilligen, Waller, & Pitariu, 2013; van der Haar, Li, Segers, Jehn, & Van den Bossche, 2014). The benefits of shared mental models may especially apply to stressful task performed under time pressure (Lim & Klein, 2006) or non-routine task phases (Waller, Gupta, & Giambatista, 2004). As surgical task often contain stressful phases, shared mental models may be crucial in this specific context.

Previous research examined how shared mental models influence performance. In one study, the authors found an effect of shared mental models on team processes which in turn predicted performance (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Accurate shared mental models support team coordination (Burke, Salas, Wilson-Donnelly, & Priest,

[1] I use the term shared mental model interchangeably to the term team mental model; for a discussion on overlapping and differences see(e.g. Klimoski & Mohammed, 1994)

2004; Marks, Sabella, Burke, & Zaccaro, 2002). Thus, there is increasing evidence that shared mental models are closely related to key team processes. We can reasonably assume that shared mental models also contribute to effective teamwork processes in the OR (Weller & Boyd, 2014). Interview studies showed how shared mental models can support effective team processes in the OR: Communication is crucial in this process, because it allows the surgical team members to anticipate the next steps, and in turn adapt their behavior. An example is a scrub nurse who communicates her familiarity with a specific procedure, which allows the surgeon to adapt his or her explanations accordingly (Mitchell et al., 2010). Another study showed that shared mental models are useful for coordination if a team faces changes or unexpected events (Gillespie, Chaboyer, Longbottom, & Wallis, 2010). This last aspect may be particularly valuable the context of the OR, because multidisciplinary and sometimes ad-hoc interdisciplinary teams with members of different levels of experience collaborate. In these conditions, it is crucial that team teams build shared mental models.

Team situation awareness

The concept of team situation awareness was developed based on (individual) situation awareness that I will discuss shortly. Situation awareness implies not only the perception of the current state of the situation, but also includes goals and projections about the evolution of the situation in the future (Endsley, 1995). Most authors agree that situation awareness develops when an individual observes and explores the environment (Salas, Prince, Baker, & Shrestha, 1995). Team situation awareness is the same concept on the team level. It describes the shared portion of individual situation awareness and thus the understanding of a given situation by different team members (Endsley, 1995). Communication within the team is assumed to support the development of team situation awareness (Endsley, 1995; Hazlehurst, McMullen, & Gorman, 2007; Parush et al., 2011).

One study found that communication frequency between a senior and a most junior doctor was correlated with a better feeling of involvement in the care processes by the junior doctor in a intensive care unit (Reader, Flin, Mearns, & Cuthbertson, 2011). In turn, involvement predicted better team situation awareness regarding the patient evolution (Reader et al., 2011). We can assume that communication supports team situation awareness.

Team situation awareness shares common characteristics with the shared mental models. First, both describe emergent team cognitions (Endsley, 1995; Marks et al., 2001); both refer to mental representations and both are useful to anticipate the near future and thus influence how the team will deal with what comes next. They evolve over time, as the situation evolves. Second, both shared mental models and team situation awareness emphasize that communication supports and is supported by these cognitive constructs (Endsley, 1995; Parush et al., 2011; Salas et al., 2005). However, there is no complete overlap between the concepts. Situation awareness was developed to specifically describe processes in aviation, where situations change very rapidly, and a loss of situation awareness is the reason of many accidents (Endsley, 1997; Wickens, 2002), the concept has only recently been applied to the medical domain (e.g. Reader et al., 2011). Shared mental models were developed for teams that need to develop and apply adaptive strategies, for example sports teams (e.g. Bourbousson, Poizat,

Saury, & Seve, 2011; Reimer, Park, & Hinsz, 2006) or emergency teams (Rasker, Post, & Schraagen, 2000).

Transactive memory systems

Transactive memory systems is a third team cognition concept that can be related to communication. Transactive memory systems allow the team members to know who knows what and thus to turn to the right team member when a specific piece of information or a specific competence is needed (Moreland, 1999). Wegner (1986) was the first to theorize about the use of external storage by humans to expand their own memory that takes the form of a "group mind" and studied it in couples. The construct was then applied in organizational psychology to explain why training existing teams together has performance benefits (e.g. Moreland, 1999). Indeed, the development of a transactive memory systems takes time (Forsyth, 2009).

The link between transactive memory systems and communication was d in association with the development of a transactive memory system and their use (Littlepage, Hollingshead, Drake, & Littlepage, 2008). To develop a transactive memory systems, information has to be allocated to team members, this is likely be based on communication, although the exact functions of communication in the building of transactive memory systems is not clear (Littlepage et al., 2008; Palazzolo, Serb, She, Su, & Contractor, 2006).

Corrective functions of communication

I presented the importance of communication in the development of team cognition (shared mental models, team situation awareness and transactive memory systems) that all positively influence performance. The key communication process for all three team cognition concepts is most likely explicit information sharing by communication.

However explicit information sharing may not only help teams to build shared representations and identify what the other know, but it is also important to correct inaccurate cognitions and information. Previous research showed team members often overestimate their knowledge of what the others know (Nickerson, 1999), and they overestimate knowledge about the other team member's role. One study found that also surgeons overestimated their understanding of the other's roles in the OR (Undre et al., 2006). Explicit information sharing can contribute to avoid that wrong beliefs subsist, and thus prevent errors. Decision making may especially benefit from explicit communication (Tschan et al., 2009), and explicit communication is important for mutual performance monitoring, which includes catching errors and mistakes of other team members when they occur (Salas et al., 2005). There may, however, be social factors that hinder group members from overtly communicating.

The concept of speak up describes the phenomenon of team members freely communicate their ideas or opinions or concerns (Morrison & Milliken, 2003). This is not always easy and the literature focuses on the predictors and hindrances of freely speaking up in teams. Employees are often reluctant to speak up, mainly because of the fear of taking interpersonal risks (Edmondson, 2005). Highly hierarchical organizations such as surgical

teams are especially prone to face reluctance to speak up, because hierarchy enhances the fear of being evaluated by high powerful members (Edmondson, 2005).

Speaking up is easier if psychological safety is high. Psychological safety is defined as the perception that team members have about the risk they can take in their environment (Edmondson, 2005). A team member that does not feel high psychological safety in his team may more likely withhold concern. High psychological safety does not only facilitate reporting of errors, but also the discussion about the errors, thus fostering group and organizational learning (Edmondson, 2004). Leaders' communication can support, or hinder, speaking up in a team (Edmondson, 2003).

Case-irrelevant communication

Most group and team communication research investigating group performance concentrated on task-related communication, ignoring task-irrelevant communication in teams. In the OR setting, there was, until recently, no need to specify that communication in the OR meant case-relevant communication. However, research teams in England began studying case-irrelevant communication and its effects in the OR (Healey, Sevdalis, & Vincent, 2006b; Sevdalis, Healey, & Vincent, 2007), introducing the distinction between case-relevant and case-irrelevant communication. Case-irrelevant communication includes verbal exchanges within the surgical team that do not relate the current case (Healey, Sevdalis, et al., 2006b).

In other domains, task-irrelevant communication has been discussed in relationship with as socio-emotional processes in groups (Hackman & Katz, 2010). Task-irrelevant aspects may be communicated during "banana times" when groups letting the task rest and take time to joke or engage in social activities, or relax (Forsyth, 2009).

Case-irrelevant communication in the OR, or in general, time dedicated to socio-emotional functions in groups, can distract from the task (Sevdalis et al., 2007), but socio-emotional behaviors show benefits for the team in terms of cohesion, interpersonal relationships, mutual support and team climate (Forsyth, 2009; Hackman & Katz, 2010). This, in turn, can positively influence performance. One study found an effect of humour during team meetings on performance after the meetings (Lehmann-Willenbrock & Allen, 2014). However, short term positive effects of socio-emotional behavior such as task irrelevant communication may not be found in surgeries, as there is so far no empirical evidence that positive effects of team cohesion or team climate compensate the distracting effects of case-irrelevant communication. Second, the type of task performed during surgery is radically different than meetings, making the results hard to generalize to surgical teams. Third and more importantly, banana times are described as rituals (Forsyth, 2009), and rituals often occur at specific times. Thus, the timing of case-irrelevant communication or humor might play a role in predicting their benefits or distracting effects.

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Methods

To conduct the studies included in my dissertation, we used different methodologies, often combining different of them in a same study. Questionnaires, observation, patient outcome and noise measures were used to measure the variables included in the different studies. In this section, I briefly summarize these methods, refer to the papers where the methods are described in more details and, going beyond the descriptions of the methods figuring in the papers, I add specifications about how the method was used and the data prepared.

Questionnaires

In papers 1 (perception of teamwork in the OR), 3 (team familiarity) and 4 (impact of noise on concentration), we collected the data using questionnaires. The survey process is described in each of the paper. To note is that we used two survey methods: a general survey, asking OR teams about the quality of teamwork in paper 1, and in addition, in this same paper and in papers 3 and 4, we conducted the survey in the OR, handling the OR teams personally a questionnaire at the end of their duty. This second method had on the one hand the advantage of increasing the willingness to answer the questionnaires, because the OR teams were asked personally. On the other hand, this was the ideal way to collect data about specific surgeries, for example, as in paper 4, to relate the data form the questionnaires to noise measures conducted during the same surgery.

Observation

Observations were conducted in papers 2 (impact of communication on surgical site infections) and 5 (impact of noise on communication). In paper 4 (impact of noise on concentration), observations were also used, but only to identify phases of the surgeries, without more refined behavioral coding. We used a reliable coding system, previously developed in our research team for same types of surgeries (Seelandt et al., 2014); see Appendix B for a complete version of the manuscript that describes the development of the observational coding system. An important aspect throughout papers 2, 4 and 5 is the focus on different phases of the observed surgeries. Thus, the computerized behavioral coding system was set so that it automatically time stamped all the observations. To conduct analysis per phase of the surgery (e.g. to differentiate the main part of the surgery form the preparation and closing phase, or five-minute intervals), the data preparation consisted in aggregating the observed behaviors per specific phase. More specifically, this process allowed us to count the number of behaviors that were observed in the phases identified.

Patient outcome

In papers 2 (impact of communication on surgical site infections) and 3 (team familiarity), we measured patient outcomes, respectively in a prospective and retrospective study. In surgery, patient outcome can be seen as a proxy for surgical performance. However, measuring patient outcome also means taking into account that surgical performance is not the

only known predictor of patient outcome. Patient variables have to be considered. In the papers included in this dissertation, the expertise of medical colleagues was crucial to identify and measure the patient variables that had to be included in the statistical models predicting patient outcome from intra-operative behaviors.

Noise measures

In papers 3 (team familiarity), 4 (impact of noise on concentration) and 5 (impact of noise on communication), we measured noise in dB(A) with the same sound level recorder placed above the surgical field, following the method used by Kurmann, Peter, Tschan, Muhlemann, et al. (2011). The description of the noise measures and the variables we could calculate (i.e. noise peaks equal or above 70 dB(A) and L50) based on noise measures in dB(A) are specific to the papers and described in more details in the method section of the respective papers. To note is that we also ran analysis per phase of the surgeries with variables describing noise exposure. We thus had again, as for observational data, to prepare the noise data per each phase of the surgery specifically defined.

Relating data stemming from different methodologies

Comparing process-data (i.e. per time phases of the surgery) stemming from different data sets implied a specific data preparation in the case of the data presented in my dissertation. Before relating data sets from observations and from noise measures, we in fact had to ensure that the two data sets were timely synchronized. This represented the first step of the data preparation and was crucial especially for paper 5 (impact of noise on communication), because we related both measures on a detailed basis (five-minute intervals). We applied the same procedure also for paper 4 (impact of noise on concentrations), as we used the data from the observation to identify the phases of the surgery in the noise data. Thus, in both paper, we had to ensure that the intern clock of both the observational system and the noise level recorder were synchronized; if this was not the case, we had to adapt the time on the noise data sets to the time of the observational system. In a working paper (see appendix B), we described the procedure we used to identify potential time differences between the two data sets, and to adapt the time stamps of the noise measures to the observational data set when this was the case. Once the noise and the observational data sets were timely concordant, we could begin building a data sat that related noise and observational measures, preparing process analysis per phase of the surgery.

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Abstracts of the papers presented

Disclaimer: This chapter bases on the abstracts that we wrote in the version of the papers that were submitted or ready to submit.

This chapter consists of the abstracts of the five papers included in the present dissertation. For a quick overview of the papers' content, I first present a simplified graphical representation of the different variables and their associations tested across the five papers (figure 1). Second, before presenting the abstract of the papers, I add an explanation about the specific role of each paper in the current dissertation. On the one hand, this explanation emphasizes which aspects of teamwork in the OR were central in the specific papers. On the other hand, the explanations aim at giving a red threat that describes the link between the different papers in this dissertation, and how the findings in the first papers guided the research questions that were investigated in the latest papers.

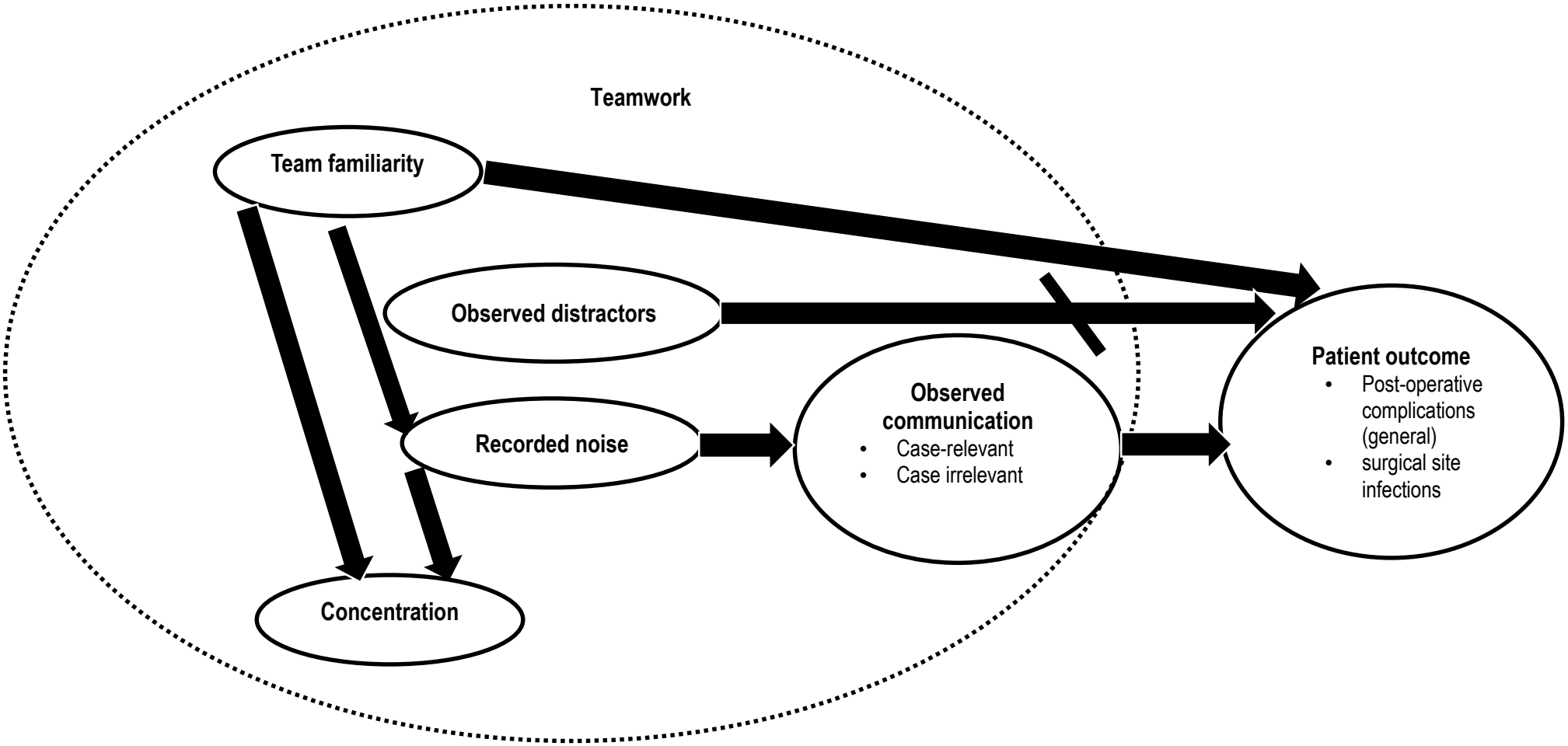

Figure 1. Overview of the main variables and their association investigated in the five papers presented

Paper 1: Do nurses always perceive teamwork as worse than surgeons? Differences between teamwork quality perception in general and in specific surgeries

This first paper in my dissertation assessed and compared how teamwork is perceived by surgeons, anaesthetists and nurses that work in the OR. More specifically, we compared perceptions of teamwork "in general" and related to specific surgeries. This was a first step towards approaching teamwork processes during specific surgeries. On the other hand, survey were the only method that could capture teamwork perception by the teams concerned, that is a complementary approach to behavioural observations.

Background. Good teamwork is important for high quality surgical performance. Previous survey-based studies found that surgeons perceived teamwork as more positive than operation room (OR) nurses. However, observational studies investigating teamwork directly in the OR showed similar or higher teamwork skills of surgeons as compared to nurses, contradicting survey results. Objectives of the studies was to investigate teamwork quality as perceived by surgeons, anaesthetists and OR nurses in the same hospital using a general survey method (Study 1), and assessing teamwork quality immediately after open visceral procedures (Study 2), with the goal to compare differences in perceived teamwork quality across professions.

Methods. Both studies took place in the same hospital. Study 1 assessed teamwork quality using the teamwork climate scale of the Safety Attitude Questionnaire. Study 2 assessed teamwork quality related to just finished surgeries from surgeons, anaesthetists and OR nurses.

Results. Results of Study 1 (132 participants) reveal a medium to high (mean = 3.6 on a scale from 1 to 5 (SD=0.65), 95% CI: 3.48-3.71) overall teamwork climate - with senior surgeons significantly more satisfied than OR nurses and junior surgeons and anaesthetists significantly more satisfied than OR nurses. Results of Study 2 (data collected immediately after 179 open visceral procedures) showed a generally high satisfaction with teamwork. Senior surgeons were significantly less satisfied with teamwork than all other professions and OR nurses were significantly more satisfied with teamwork than all other professions.

Conclusion: General survey studies assessing teamwork quality may not be representative of teamwork quality during actual surgical procedures.

Key words: Teamwork; Team climate; Surgery; Surgeons; OR nurses; anaesthetists

Paper 2: Impact of case-relevant and case-irrelevant communication within the surgical team on surgical-site infection

In this second paper, we focused on the effects on teamwork, and more specifically of communication, on patient outcome. We measured communication by observing surgeries, and thus had contrary to the first paper (perceived teamwork), a methodology that did not rely on subjective experience of the teams. This paper represents a mile stone in this dissertation, because the results indicated the importance of intra-surgical processes on a measurable patient

outcome. Thus, this paper triggered the next studies of this dissertation, where we investigated in more details the processes of teamwork during surgeries.

Background. Surgery is a classical team effort, but the impact of case-relevant and case-irrelevant communication within surgical teams on morbidity rates remains widely unknown. This study assesses the impact of intraoperative communication and distractors on surgical site infections (SSI), one of the most frequent surgical complications.

Methods. A prospective observational study was performed in 103 patients undergoing major elective open abdominal procedures. Case-relevant and case-irrelevant communication and distractors between incision and closure were observed by trained psychologists. Primary outcome parameter was SSI 30 days postoperative.

Results. A total of 21 (20.4%) SSI were diagnosed. During 459.4 hours of observation, 8,780 case-relevant and 2,584 case-irrelevant communications and 24,410 distractors were identified. Multinomial logistic regression analysis revealed that case-relevant communication during the entire procedure was associated with a significant reduction in organ/space SSI (relative odds 0.856, 95% confidence interval 0.741-0.988; P=0.033). Case-irrelevant communication during the closing phase (last 20 minutes) of the procedure was associated with a significant increase of incisional SSI (relative odds 1.170, 95% confidence interval 1.039-1.317; P=0.009). Incidence and type of distractors had no effect on SSI.

Conclusions. This study reveals a significant association between intraoperative behavior and SSI as a clinically relevant outcome parameter. Case-relevant communication is a preventive factor to protect from organ/space SSI whereas case-irrelevant communication during the last 20 minutes of the procedure is a risk factor for incisional SSI.

Key words: Teamwork; Operating room; Communication; Surgical site infections

Paper 3: Impact of team familiarity in the operating room on surgical complications

In this third paper, we again focused on patient outcome, as in the previous paper. However, we investigated the effects of team composition, a different facet of teamwork, on patient outcome and team processes. The results pertaining patient outcome supported the hypothesis that team familiarity was associated with less “superficial” complications. Equally interesting were the results pertaining the possible mechanisms that underlie the association between team familiarity and patient outcome. Higher noise levels and a reduced reported concentration measured in unfamiliar teams indicated that noise may be a hindrance to concentration. In the further studies, we more specifically focused on this questions.

Background. The quality of surgical performance depends on the technical skills of the surgical team as well as on non-technical skills, including teamwork. The present study evaluated the impact of familiarity among members of the surgical team on morbidity in patients undergoing elective open abdominal surgery.

Methods. A retrospective analysis was performed to compare the surgical outcomes of patients who underwent major abdominal operations between the first month (period I) and the last month (period II) of a 6-month period of continuous teamwork (stable dyads of one senior and one junior surgeon formed every 6 months). Of 117 patients, 59 and 58 patients underwent operations during period I and period II, respectively, between January 2010 and June 2012. Team performance was assessed via questionnaire by specialized work psychologists; in addition, intraoperative sound levels were measured.

Results. The incidence of overall complications was significantly higher in period I than in period II (54.2 vs. 34.5 %; P = 0.041). Postoperative complications grade <3 were significantly more frequently diagnosed in patients who had operations during period I (39.0 vs. 15.5 %; P = 0.007), whereas no between-group differences in grade ≥3 complications were found (15.3 vs. 19.0 %; P = 0.807). Concentration scores from senior surgeons were significantly higher in period II than in period I (P = 0.033). Sound levels during the middle third part of the operations were significantly higher in period I (median above the baseline 8.85 dB [range 4.5–11.3 dB] vs. 7.17 dB [5.24–9.43 dB]; P<0.001).

Conclusions. Team familiarity improves team performance and reduces morbidity in patients undergoing abdominal surgery.

Key words: Team familiarity; Operating room; Post-operative complications

Paper 4: Noise in the operating room distracts member of the surgical team: an observational study

The aim of this fourth paper was to assess to what extent noise can impair self-reported concentration. As in the first paper, we distinguished between the professional teams present during long abdominal surgeries. This allowed us to take into account that surgeries can be divided into different phases. The phases are all associated with a different workload for the specific teams.

Background. Noise pollution in operation rooms is a concern, as noise is known to impair performance, most likely because it is a source of distractions. In the OR setting, high noise pollution may distract OR personnel particularly in phases of high concentration demands.

Method. Noise was measured during 167 open abdominal surgeries; distinguishing three phases (opening, main phase, and closing), noise was related to reports of being distracted by main and secondary surgeons, scrub nurses and anesthetists who participated in the surgeries.

Results. Noise pollution was higher than recommended levels for concentrated work. Adjusted for duration and surgical type, results showed that second surgeons felt more distracted when noise pollution was high in the main phase; anesthetists felt more distracted when noise pollution was high during the closing phase. Main surgeons' and scrub nurses' reports of being distracted was not related to measured noise.

Conclusions. In phases with higher concentration demands, noise pollution was particularly distracting for second surgeons and anesthetist, corresponding to their specific task demands (anaesthetists) and experience (second surgeons). Reducing noise levels in all phases of surgeries should be considered.

Key words: Noise; Concentration; Phases of surgery

Paper 5: Noise peaks influence communication in the operating room: an observational study

This fifth paper focuses on communication as a dependent variable. On the one hand, as we already found that communication was associated with patient outcome, it was crucial in a second time to investigate to what extent case-relevant and case-irrelevant communication could be fostered and hindered. On the other hand, we had found that noise impaired concentration. In this paper, we thus combined these two aspects, by investigating how communication, an attention demanding task, was impacted by noise. In this paper, we ran detailed analysis, investigating the effects of noise on communication five-minute interval per five-minute interval. We also took into account different phases of the surgery, as senior and junior surgeons may not face the same reactions towards noise. Thus, this paper investigated in detail communication and distraction as they occur during long abdominal surgeries.

Background. Noise peaks are powerful distractors. This study focuses on the impact of noise peaks on surgical teams' communication during 109 long abdominal surgeries.

Method. We related measured noise peaks during five minute intervals to the amount of observed communication during the same interval.

Results. We showed that noise peaks are associated with less case-relevant communication; this effect is moderated by the level of surgical experience; case-relevant communications decrease under high noise peak conditions among junior, but not among senior surgeons. However, case-irrelevant communication did not decrease under high noise level conditions; rather, there was a trend to more case-irrelevant communication under high noise peaks. The results support the hypothesis that noise peaks impair communication because they draw on attentional resources rather than impairing understanding of communication.

Conclusions. As case-relevant communication is important for surgical performance, exposure to high noise peaks in the OR should be minimized especially for less experienced surgeons.

Key words: Operating room; Noise; Communication; Distractors

Papers

In this chapter, I present the papers included in my dissertation. I specify for each paper, if the paper has been published or is at an earlier stage toward the publication process. For copy right reasons related to the papers already published, I present the papers in a page layout that is not the page layout of the journals that published the papers. The page layout I used differ from one manuscript to the other, as I used the layout that best fit the different journal guidelines.

Paper 1. Do nurses always perceive teamwork as worse than surgeons? Differences between teamwork quality perception in general and in specific surgeries

Müller, P., Tschan, F., Keller, S., Seelandt, J. C., Beldi, G., Elfering, A., . . . Semmer, N. K. (2015). *Do nurses perceive teamwork as worse than surgeons? Differences between teamwork quality perception in general and in specific surgeries*. Manuscript submitted for publication.

ABSTRACT

Objectives

To assess and compare perception of teamwork quality of surgeons, anesthetists and nurses.

Good teamwork is important for high quality surgical performance. Previous survey-based studies found that surgeons perceived teamwork as more positive than operation room (OR) nurses. However, observational studies investigating teamwork directly in the OR showed similar or higher teamwork skills of surgeons as compared to nurses, contradicting survey results.

Objectives of the studies was to investigate teamwork quality as perceived by surgeons, anaesthetists and OR nurses in the same hospital using a general survey method (Study 1), and assessing teamwork quality immediately after open visceral procedures (Study 2), with the goal to compare differences in perceived teamwork quality across professions.

Methods

Both studies took place in the same hospital. Study 1 assessed teamwork quality using the teamwork climate scale of the Safety Attitude Questionnaire. Study 2 assessed teamwork quality related to just finished surgeries from surgeons, anaesthetists and OR nurses.

Results

Results of Study 1 (132 participants) reveal a medium to high (mean = 3.6 on a scale from 1 to 5 (SD=0.65), 95% CI: 3.48-3.71) overall teamwork climate - with senior surgeons significantly more satisfied than OR nurses and junior surgeons and anesthetists significantly more satisfied than OR nurses. Results of Study 2 (data collected immediately after 179 open visceral procedures) showed a generally high satisfaction with teamwork. Senior surgeons were significantly less satisfied with teamwork than all other professions and OR nurses were significantly more satisfied with teamwork than all other professions.

Conclusion

General survey studies assessing teamwork quality may not be representative of teamwork quality during actual surgical procedures.

Key words: Teamwork, Team climate, Surgery, Surgeons, OR nurses, anaesthetists

INTRODUCTION

Good interprofessional teamwork in the operating room (OR) is one of the key components of high surgical performance (Catchpole, Mishra, Handa, & McCulloch, 2008; Mazzocco et al., 2009; Schmutz & Manser, 2013): After technical problems, teamwork issues are the most common contributory factor for adverse events in surgeries (Gawande et al., 2003).

Several studies have surveyed OR personnel to assess teamwork climate. They showed that surgeons, OR nurses and anaesthetists were not only aware of the importance of collaboration in the OR (ElBardissi et al., 2007; Gawande et al., 2003), but they liked working in teams (Flin, Fletcher, McGeorge, Sutherland, & Patey, 2003; Flin, Yule, McKenzie, Paterson-Brown, & Maran, 2006). However, perception of the quality of collaboration (Awad et al., 2005; Lingard, 2011) was different between professions. In one study, surgeons perceived high quality teamwork with other surgeons and OR nurses; whereas OR nurses perceived teamwork with the surgeons as less positive (Flin et al., 2006). Similar results were found in a multicenter study where 87% of the surgeons, but only 48% of the OR nurses rated collaboration quality between surgeons and OR nurses as good (Makary et al., 2006; Sexton, Makary, et al., 2006). Anaesthetists perceived teamwork with surgeons as lower than with OR nurses or to other members of the anesthetic sub-team (Flin et al., 2003; Sexton, Makary, et al., 2006).

In sum, it is a consistent finding that surgeons express more satisfaction with teamwork than anaesthetists or OR nurses (Fleming, Smith, Slaunwhite, & Sullivan, 2006; Helmreich & Davies, 1996; Schaefer & Helmreich, 1994; Sexton, Makary, et al., 2006; Sexton, Thomas, & Helmreich, 2000; Undre et al., 2006). Based these findings, the authors of the cited studies expressed concerns about the quality of interprofessional cooperation during surgeries (Flin et al., 2006; Makary et al., 2006; Sexton, Makary, et al., 2006). Note however, that all studies cited asked participants to provide their general, overall assessment of teamwork climate, they were not asked to judge the collaboration in specific surgeries.

Several explanations have been offered for the divergent perceptions of teamwork climate by surgeons and OR nurses. First, existing hierarchical and status differences may shape collaboration (Helmreich & Schaefer, 1994; Sexton et al., 2000) Status inequality in teams creates more negative emotions and lower satisfaction for low status members (Anderson, Kraus, Galinsky, & Keltner, 2012). Second, negative and stereotypic perceptions among the different professions may play a role (Amaravadi, Dimick, Pronovost, & Lipsett, 2000; Lingard, Garwood, & Poenaru, 2004). One study reported that nurses tended to see surgeons as "self-centred antagonistic primadonnas, motivated largely by frustration" whereas surgeons tended to see nurses as "record-keeping employees, motivated by fear of reprisal" (Lingard, Espin, Whyte, et al., 2004) (p. 697). Third, conflicts and disruptive behaviors in teams lower satisfaction: In a survey study, more than 70% of nurses and surgeons reported "frequent" disagreements between surgeons and OR nurses (Coe & Gould, 2008); and disruptive behavior was more often shown by surgeons than by OR nurses (Rosenstein & O'Daniel, 2006). Fourth, divergent conceptions of teamwork and different expectations for collaboration may lie behind the contrasting perceptions: One study found that nurses tended to perceive surgeries as carried out by a single team, whereas surgeons and anaesthetists saw surgery as a collaboration between

several specialized sub-teams (Undre et al., 2006). Finally, nurses and surgeons seem to have different communication styles (Leonard, Graham, & Bonacum, 2004), which may lead to misunderstandings and problems in collaboration.

In sum, steep hierarchies, negatively toned stereotypes, experienced conflicts, and different expectations concerning specific aspects of collaborative behaviour, as well as different communication styles may shape the perception of teamwork climate.

Interestingly, observational studies that use a different methodology and assess the quality of teamwork directly in the OR, tend to contradict the results obtained by general surveys. Three observational studies assessed non-technical skills (which include measures of teamwork quality) separately for surgeons, anaesthetists, and OR nurses. One study failed to find differences between professions for observed teamwork skills (Robertson et al., 2014), but the two other studies found that surgeons had significantly higher teamwork skills than anaesthetists or nurses (Catchpole et al., 2008; Mishra, Catchpole, Dale, & McCulloch, 2008). Observational studies in the OR also failed to confirm the high frequency of open disagreements and conflicts between surgeons and OR nurses that could be expected from survey study results (Coe & Gould, 2008; Lingard, Garwood, et al., 2004). Although disagreements during surgeries were observed, most of them were resolved without tensions (Booij, 2007). Exceptions were disagreements related to organizational issues, such as scheduling and planning; these resulted more often in open conflicts. The low number of tensions and conflicts observed in the OR led authors to conclude that "communication among OR team members is more subtle and complex than the openly combative style that is the stuff of OR myth" (p. 237) (Lingard, Reznick, Espin, Regehr, & DeVito, 2002).

Objective: Comparing general and surgery-related teamwork perception

Together, existent research points to a contradiction in the perception of teamwork in the OR setting: Results based on survey studies indicate that collaboration in the OR may be difficult and conflicts are frequent, and suggests that these difficulties are more clearly perceived by nurses. Conversely, studies observing teamwork directly in the OR did not find differences in teamwork between professions or show that surgeons are particularly proficient in teamwork. It is therefore likely that general survey studies do represent different aspects of teamwork to those in observational studies focusing on specific procedures. However, the contradictory findings presented are based on studies from different hospitals. It is thus conceivable that the differences found are due to different social climates in these hospitals.

The main objective of this study is to compare assessments of teamwork quality among OR personnel (1) based on a general survey and (2) based on assessments of teamwork quality directly after surgical procedures. We did this in the same hospital including the same subspecialty group in both studies.

METHODS

Study setting

Both studies took place in the same surgical department of a middle sized European University Hospital. Study 1 included surgeons, OR nurses and anaesthetists across all surgical disciplines (with the exception of the obstetrics); Study 2 data was collected immediately after

open visceral procedures. Both studies were approved by the hospital internal ethical review board.

Participants and procedure Study 1.

Data for Study 1 were collected as part of a general survey study investigating work and cooperation in the surgical department. All surgeons, anaesthetists, and OR nursesreceived a paper based survey. They returned the survey either in a sealed box placed in a highly frequented area or sent it back to the first author using a pre-stamped envelope. The study was anonymous.

Participants and procedure Study 2.

Data for Study 2 were collected in the visceral surgery department in the same hospital over a period of two years. Immediately after 179 open visceral procedures, and before leaving the OR, surgeons, anaesthetists and OR nurses answered (individually and privately) a short questionnaire pertaining to the procedure just finished. Participants were assured that their answers would be treated confidentially. They indicated their role (senior/junior surgeon, anaesthetists, nurse), but did not provide names.

Measures.

Measures Study 1

In Study 1, we collected demographic data (gender; age groups [up to 30 / 31-50 / above 50 years old], employment in percentage of a full time equivalent, and tenure at the current job (less than 1 /1-5, >5 -10, more than 10 years). Participants indicated if they regularly participated in visceral surgeries.

Teamwork was measured with the 6-item teamwork climate scale that is part of the Safety Attitude Scale (Operation Room Version) developed and tested by Sexton and colleagues (Sexton, Holzmueller, et al., 2006). Items were translated into German and back-translated by a native speaker. A sample item is: “The doctors and nurses here work together as a well-coordinated team”. Answering format was a Likert-type scale ranging from 1 (do not agree at all) to 5 (agree very much). Cronbach’s alpha for the scale was .87.

Measures Study 2

We measured teamwork quality immediately after each procedure with a single question. We chose a one-question solution in order to obtain a high response rate – responding to the questionnaire took less than one minute and was thus accepted, particularly relevant, after long procedures. Surgeons and OR nurses were asked “How was the collaboration within the (sterile) surgical team?”; anaesthetists were asked “how was the collaboration with the (sterile) surgical team?” Answering format was a Likert-type scale ranging from 1 (very bad) to 7 (very good). Participants indicated their profession and role in the OR (senior or junior surgeon; anaesthetist; OR nurse).

Statistics

In both studies, we used means and standard deviations for descriptive statistics. In Study 1, we used analyses of variance with Bonferroni corrected P values for comparisons

between professions. In Study 2, to compare teamwork quality within specific surgeries between professions, we ran an analysis of variance with repeated measures to assess the overall effect, and paired-sample t-tests for comparison between professions. P-values < 0.05 (two-tailed) were considered significant; we report 95% confidence intervals. Analyses were done using IBM SPSS software (Version 22) (IBM, 2013).

RESULTS

Results study 1.

The sample consisted of 132 participants; (35 certified surgeons, 18 junior surgeons, 17 anaesthetists and 61 OR nurses). Overall return rate was 56.9% (surgeons: 49.1%, anaesthetists: 36.2%, nurses: 81.3%). One anaesthetist and three nurses did not respond to the team-climate questionnaire; the final sample is 127 participants. Fifty eight respondents indicated regular participate in visceral surgeries (10 senior surgeons, 5 junior surgeons, 11 anaesthetists, and 32 nurses).

OR personnel in this hospital perceived team climate in the OR as medium to high with an overall mean of 3.6 (SD=0.65), 95% CI: 3.48-3.71. Comparisons among professions (Table 1) yielded significant differences. Pairwise comparisons (Bonferroni corrected) across professions showed that senior surgeons were significantly more satisfied than nurses (P<0.001), but also significantly more satisfied than junior surgeons (P=0.02). Anaesthetists were significantly more satisfied than nurses (P=0.037).

The comparison between respondents working in the visceral versus in other surgical specialties (Table 2) showed no significant differences in team-climate perception (P=0.873), and no significant interaction effects between professions and surgical specialty (P=0.782), indicating that the perception of teamwork in the visceral versus other specialties was not different across professions. Bonferroni corrected pairwise comparisons for the professions across surgical specialties (visceral/other) showed that for the visceral domain, senior surgeons and anesthetists were significantly more satisfied with teamwork climate than OR nurses.

Table 1: Demographics, perception of team climate across professions for the whole surgical department

		Perception of team climate in the OR 95% CI					Demographic characteristics			
Profession	n	M	SD	lower bound	upper bound	Differences between professions [a]	% male	Age group	% full –time employed	Tenure at current job
Senior surgeon	35	4.04	0.37	3.92	4.21	Senior > Junior (P=0.020) Senior > Nurses (P<0.001)	91.4%	≤30: 0% 31-50: 85.7% >50: 14.3%	100%	< 1 year: 28.6% 1-5 years:42.9% >5-10 years:14.3% >10 years:14.3%
Junior surgeon	19	3.55	0.89	3.12	3.99	Junior < Senior (P=0.020)	84.2%	≤30: 31.6% 31-50: 68.4% >50: 0%	100%	< 1 year: 42.1% 1-5 years:57.9% >5-10 years:0% >10 years:0%
Anaesthetist	17	3.74	0.53	3.46	4.03	Anaesthetists > Nurses (P=0.035)	70.6%	≤30:5.9% 31-50: 76.5% >50: 17.6%	82.4%	< 1 year: 17.6% 1-5 years:47.1% >5-10 years:29.4% >10 years:5.9%
OR-Nurse	61	3.29	0.56	3.15	3.45	Nurses < Senior (P<.001) Nurses < Anaesthetists (P=0.037)	8.5%	≤30: 16.92% 31-50: 67.8% >50: 15.3%	73.8%	< 1 year:3.3% 1-5 years: 44.3% >5-10 years: 23.0% >10 years: 29.5%
Overall	132	3.60	0.65	3.48	3.71					
P Value		< 0.001					< 0.001	0.021	0.001	< 0.001

[a] Bonferroni corrected

Table 2: Perceived teamwork climate of other surgical departments and the visceral department

Team Climate Other Surgical Specialties							Team Climate Visceral Surgery					
				95% CI						95% CI		
Profession	n	M	SD	lower bound	upper bound	Significant differences between professions [a]	n	M	SD	lower bound	upper bound	Significant differences between professions [a]
Senior surgeon	25	4.03	0.12	3.81	4.26	Senior > Junior (P=0.029) Senior > Nurses (P<0.001)	10	4.08	0.18	3.72	4.44	Senior > Nurses (P<0.001)
Junior surgeon	13	3.56	0.16	3.25	3.88	Junior < Senior (P=0.029)	5	3.53	0.26	3.02	4.04	
Anaesthetist	5	3.69	0.26	3.18	4.20		11	3.77	0.17	3.43	4.12	Anaest. > Nurses (P=0.023)
OR-Nurse	26	3.40	0.11	3.17	3.62	Nurses < Senior (P<0.001)	32	3.22	0.10	3.02	3.42	Nurses < Senior (P<0.001) Nurses < Anaest. (P=0.023)
Overall	69	3.67	0.09	3.50	3.84		58	3.65	0.09	3.47	3.84	

a Bonferroni corrected

Note: M = Mean, SD = Standard Deviation CI = Confidence Interval

Results study 2.

Data were collected immediately after 179 open visceral procedures. Return rate was 93.3% (167/179) for senior surgeons; 96.7% (173/179) for junior surgeons; 96.7% (173/179) for anaesthetists and 100% (179/179) for OR nurses. Reasons for not returning the questionnaire were unexpected early departures from the OR by senior or junior surgeons, and work overload of anaesthetists in the final phase of the surgery.

Table 3: Perception of teamwork pertaining to a specific procedure

				95% CI		
Profession	n	M	SD	lower	upper	
Senior surgeon	167	5.46	1.32	5.26	5.67	senior surgeons < junior surgeons (P=.001); senior surgeons < anaesthetists (P< 0.001); senior surgeons < nurses P<0.001)
Junior surgeon	173	5.84	0.84	5.72	5.97	junior surgeons > senior surgeons (P=0.001); junior surgeons < nurses (P=0.005)
Anaesthetist	173	5.81	0.93	5.67	5.95	anaesthetists > senior surgeons (P<0.001); anaesthetists < nurses (P=0.006)
OR-nurse	179	6.10	0.87	5.98	6.23	nurses > senior surgeons (P<.0.001); nurses > junior surgeons (P=0.005); nurses > anaesthetists (P=0.006);

Note: Likert scale ranging from 1 (very poor teamwork) to 7 (very good teamwork);
M = Mean, SD = Standard Deviation CI = Confidence Interval

To illustrate the differences between professions in both studies, we split the perceived team climate score used in Study 1 at the overall median (3.67), and defined those at or above the median as highly satisfied with team climate. A majority (88.6%) of the senior surgeons, 55.6% of junior surgeons, 68.8% of the anaesthetists, but only 31.0% of OR nurses were classified as highly satisfied (Chi2 (3) =30.63: P<.0.001), see Figure 1.

For Study 2, we split the perceived teamwork quality at the overall median (5.87) and defined those at or above the median as highly satisfied with teamwork. Analyses revealed that 58.3% of senior surgeons, 62.4% of junior surgeons, 69.4% of anaesthetists, and 72.5% of OR nurses were highly satisfied with teamwork; see Figure 2.

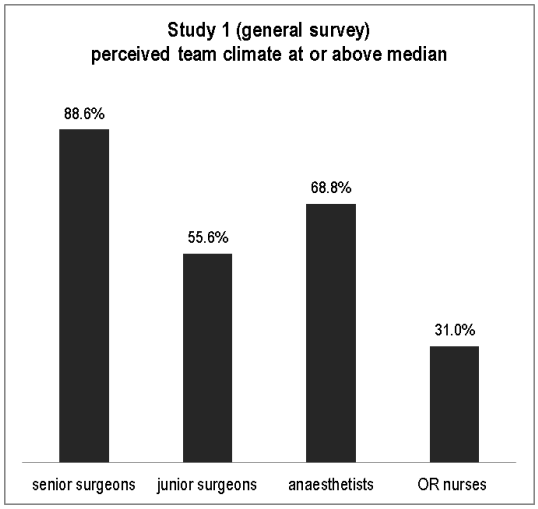

Figure 1: Per cent within a profession indicating at or above median team climate (general survey)

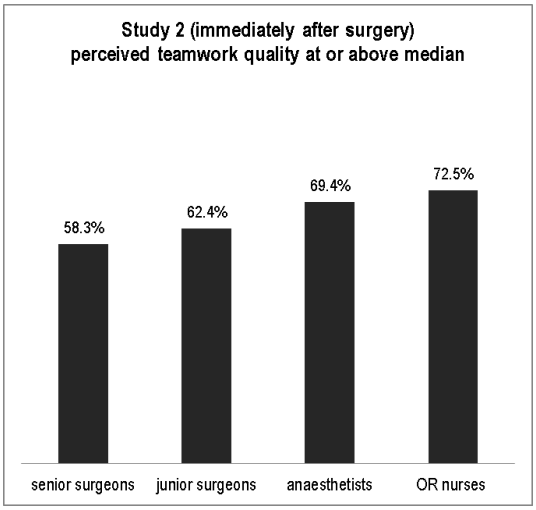

Figure 2: Per cent within a profession indicating at or above median teamwork quality (immediately after surgery)

Figure 1 and *Figure 2*. Perceived teamwork as at or above median across professions

DISCUSSION

To our knowledge, this is the first study comparing general perceptions of team climate with perceptions of teamwork quality immediately after a surgical procedure. Study 1 replicates findings of previous studies (Fleming et al., 2006; Helmreich & Davies, 1996; Schaefer & Helmreich, 1994; Sexton, Makary, et al., 2006; Sexton et al., 2000; Undre et al., 2006) showing that nurses were the least, senior surgeons the most satisfied, with junior surgeons and anaesthetists in between. In contrast, Study 2 showed that senior surgeons were the least, and OR nurses the most satisfied with actual teamwork in the OR, assessed immediately after the procedure. Results of Study 2 are more in line with results of observational studies (Catchpole et al., 2008; Mishra et al., 2008).

Both studies were conducted in the same hospital and included the same subspecialty group. We did not collect person data and can thus not directly compare individual answers. It is however safe to assume that the participant pool largely overlaps. This is particularly likely for senior surgeons and OR nurses, because both report long tenure in this hospital (Table 1). The results can therefore not be explained by changes in team composition between the two studies. Furthermore, the diverging results cannot be attributed to a specific team-climate in the visceral team of the hospital, because there were no differences between the surgical subspecialties (Study 1, Table 2).

The results show that perceptions of team climate assessed using a general survey do not necessarily represent everyday collaborative experiences in the OR. The results of Study 2 do not confirm that collaboration during surgeries was perceived as problematic – means are above 5 on a 7 point scale. In addition, Study 2 does not confirm that nurses are less satisfied with teamwork than surgeons, quite the contrary. Measures of team climate obtained by general surveys may not represent collaboration quality during surgeries.

There are several possible explanations for the contradicting results. They are based on the assumption that Study 1 and Study 2 measure different aspects of teamwork, because the methodology used was different: Research on survey methodology showed that the scope and the time frame implied by a question influences results (Tourangeau, Rips, & Rasinski, 2000). The scope for Study 1 is general; so participants had to "mentally integrate" their answers based on memories of many different teamwork experiences over an extended period of time. Their responses reflected a general perception, based on collaborative experiences that include surgeries, but also include other collaborations (Beyea, 2007). In Study 2, the scope and time frame of the question was narrow, as the participants reported directly after a surgery (Tourangeau et al., 2000). We thus contend that results of Study 2 more accurately represented the perceived quality of teamwork during surgical procedures, whereas the results of Study 1 represented a more generalized view of team climate in and around the OR.

How can we explain that nurses are less satisfied with team climate than surgeons in Study 1, but not in Study 2?

Legitimate and illegitimate status differences. Previous studies interpreted the lower satisfaction of nurses with steep hierarchies (Sexton et al., 2000; Undre et al., 2006). Although studies found low status group members to be less satisfied than high status members (Anderson et al., 2012), status differences may be acceptable if they are seen as legitimate (Ellemers, Wilke, & Van Knippenberg, 1993; Weber, Mummendey, & Waldzus, 2002). During surgeries, the roles of surgeons and OR nurses are well defined, and the leadership role of the surgeon is not only uncontested (Henrickson Parker, Yule, Flin, & McKinley, 2011; Lingard, Reznick, DeVito, & Espin, 2002;

Parker, Yule, Flin, & McKinley, 2011a) but actually expected (Parker, Flin, McKinley, & Yule, 2013). In contrast, the expectations regarding non-technical skills of OR nurses are anticipating needs and "thinking ahead of the surgeon", but not being a leader (Mitchell & Flin, 2008; Mitchell & Flin, 2012). The hierarchy in the OR is an expression of different roles during surgery and is not debasing nurses, per se. The fact that the clear hierarchy in the OR did not imply low satisfaction of the nurses in Study 2 may be due to the legitimate character of this hierarchy.

Not all aspects of hierarchies are perceived as legitimate. Hierarchies in collaborations outside of the OR can contain aspects that nurses might not consider legitimate. Organizational problems often require short term adaptations (Gillespie et al., 2010; Nestel & Kidd, 2006). For example, scheduling of surgeries changes frequently and often at short notice; they are the main source of tensions between surgeons and nurses (Booij, 2007; Coe & Gould, 2008; Lingard, Garwood, et al., 2004; Riley & Manias, 2006). If surgeons decide on scheduling issues on medical grounds, this is likely be considered legitimate. However, if nurses see the physicians' way of prioritizing as guided by personal preferences rather than medical reasons, they might regard such decisions as not legitimate (Lingard, Reznick, DeVito, et al., 2002). Organizational problems such as these are likely to lower the perception of general teamwork climate specifically for nurses.

Taken together, the contradicting results in Study 1 and Study 2 may be explained by the fact that the higher status of surgeons is perceived as more legitimate during surgery, but that hierarchies may not be perceived as equally adequate and legitimate with regard to collaborations outside of the OR.

Interprofessional perceptions. A second explanation of the contradictory results refers to stereotypic interprofessional perceptions (Lingard, Reznick, DeVito, et al., 2002). Research on survey methodology shows that stereotypic perceptions influence answers to general survey questions more than answers to questions about specific events (Schwarz, 2007, 2012). Study 1 is thus more likely to reflect stereotypic perceptions. Stereotypes attribute higher academic ability and higher leadership competences to surgeons, but higher teamwork and communicative competences to nurses (Ateah et al., 2011). The results of Study 1 are in line with such stereotypes. The answers in Study 2 are based on interactions between specific surgeons and nurses who work together, so stereotypes are less likely to bias the answers.

How can we explain that surgeons are less satisfied with teamwork than nurses in Study 2?

Although all team members report high satisfaction with teamwork in Study 2, it is interesting that senior surgeons were significantly less satisfied than all other professions, and that OR nurses were significantly more satisfied than all other professions in the same surgery. This result points to the possibility that different aspects of collaboration shape the perception of teamwork for nurses and surgeons. Good teamwork can be seen as related to either social-emotional aspects of team interactions (e.g. agreeable communication), or to good task-related cooperation (Arrow, McGrath, & Berdahl, 2000; Valentine , Nembhard , & A.C., 2012). Previous research suggested that surgeons may base their judgement of good teamwork on task-related collaboration: Surgeons found OR nurses most helpful, if they could anticipate task-related needs (Makary et al., 2006), and surgeons reported being concerned if they perceived OR nurses as less competent (Gillespie et al., 2010), and cooperating less smoothly (Koh, Park, Wickens, Ong, & Chia, 2011; Korkiakangas, Weldon, Bezemer, & Kneebone, 2014). It could well be that lower scores of senior surgeons reflect suboptimal task-related collaboration.

Nurses, on the other hand, may base their perception of teamwork more on socio-emotional and interpersonal aspects. The high satisfaction of nurses with teamwork in this study could therefore be an indication of generally low disruptive behavior in the OR (Coe & Gould, 2008). This is in line with recent observational studies that question the stereotypical view that conflicts are very common during surgical procedures (Booij, 2007; Coe & Gould, 2008; Lingard, Garwood, et al., 2004).

Those interpretations are speculative, because we did not assess the background of teamwork perceptions. Future research should evaluate the background of perceptions of teamwork in the OR in combining observational methods with self-report.

Strengths and limitations

The main strength of this study is that it allows comparing results from largely overlapping participants in the same hospital, using two different data collection methodologies. Another strength is the very high response rate in Study 2. A limitation of the study is that we collected all data in only one hospital, and, for Study 2, in only one subspecialty group. As team climate is influenced by local aspects and varies considerably between hospitals (Sexton, Makary, et al., 2006); the results of this study cannot be generalized. However, Study 1 replicates results of earlier surveys around the globe, and results of Study 2 are similar to those of observational studies in other hospitals. Nevertheless, more studies are needed to generalize the results.

A second limitation is the relatively low response rate in Study 1 for surgeons and for anaesthetists.

CONCLUSIONS

In conclusion the current study shows that results from general surveys assessing team climate in surgery may not adequately reflect the quality of collaboration during actual surgical procedures. This conclusion does not imply, however, that one of the two methods is more valuable, but they answer different questions. General surveys shed light on the perceived degree of interdisciplinary integration and mutual understanding, specific surveys represent experienced teamwork in specific surgeries; both aspects are important for overall performance. The current study also implies that we do not know enough about how teamwork quality is actually experienced during surgeries. Future research should combine observations of team processes and relate these to self-reports of members of the surgical team. This could help clarify mutual expectations, and could lead to the development of interventions that satisfy the different collaboration needs in interdisciplinary surgical teams (Awad et al., 2005; Lingard, Garwood, et al., 2004).

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Paper 2: Impact of case-relevant and case-irrelevant communication within the surgical team on surgical-site infection

Tschan, F., Seelandt, J. C., Keller, S., Semmer, N. K., Kurmann, A., Candinas, D., & Beldi, G. (2015, early view). Impact of communication within the surgical team on surgical site infections. British Journal of Surgery. doi:10.1002/bjs.9927.

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ABSTRACT

Background and objectives

Surgical site infections (SSI) are the most common complications after surgery. An influence of communication and distractors during surgery on patient outcomes has been suggested, but there is limited evidence. Aim of this prospective observational study was to assess the relationship between intraoperative communication within the surgical team and SSI and between intraoperative distractors and SSI.

Methods

This prospective observational study included 167 patients undergoing elective, open abdominal procedures with a mean duration of 4.6 hours. For each procedure, intraoperative case-relevant and case-irrelevant communication and intraoperative distractors were continuously observed on site. The influence of communication and distractors on SSI after surgery was assessed using logistic regressions, adjusting for risk factors.

Results

A total of 24 (14.4%) SSI were diagnosed. Case-relevant communication during the procedure was independently associated with reduced incidence of organ/space SSI (propensity score-adjusted odds ratio was 0.86, [95% CI 0.77-0.97]; P=0.014). Case-irrelevant communication during the closing phase of the procedure was independently associated with increased incidence of incisional SSI (propensity score-adjusted odds ratio was 1.29, [95% CI 1.08-1.57]; P=0.006). Distractors had no association with SSI.

Conclusions

More case-relevant communication is associated with reduced organ/space SSI, and higher levels of case-irrelevant communication during closure are associated with incisional SSI.

Key words: Teamwork; Operating room; Communication; Surgical site infections

INTRODUCTION

Surgical site infections (SSI) are the most common complications in surgery, with highest incidence rates after open abdominal procedures (Cardo et al., 2004; Sax et al., 2011). Despite attempts to reduce SSI through evidence-based practices, their incidence remains high (Beldi, Bisch-Knaden, Banz, Muhlemann, & Candinas, 2009; Mu, Edwards, Horan, Berrios-Torres, & Fridkin, 2011). Most established risk factors for SSI refer to characteristics of the patient (e.g. comorbidities, obesity) and the procedure (e.g. grade of contamination, duration) (Mangram, Horan, Pearson, Silver, & Jarvis, 1999). Only few studies explored the impact of the behaviour of the surgical personnel on SSI (Beldi et al., 2009; Haynes et al., 2009; Pittet et al., 2006). These studies focused primarily on compliance with hygiene-related protocols and antiseptic procedures (Beldi et al., 2009; Pittet et al., 2006), and on the introduction of checklists (Haynes et al., 2009), but not on effects of teamwork and communication in the operating room (OR).

Prospective observational studies during routine surgeries emphasize the importance of good intrasurgical teamwork and cooperation. Communication failures can be observed in almost every procedure (Lingard, Espin, Whyte, et al., 2004), and poor teamwork was linked to more procedural errors (Catchpole et al., 2008). More information sharing during surgery and briefings were related to less complications and less mortality (Mazzocco et al., 2009). With one notable exception (Mazzocco et al., 2009), the endpoints of studies investigating teamwork and communication in the OR were not clinical outcomes. Thus, there is still little direct evidence of a relationship between intraoperative communication and patient complications (Nagpal et al., 2010).

Communication within the surgical team can be case-relevant or case-irrelevant (e.g., small talk). Case-relevant communication assures the exchange of information (Mazzocco et al., 2009) and supports the team in developing a common understanding of the task (Westli, Johnsen, Eid, Rasten, & Brattebo, 2010). A common understanding, in turn, makes it easier for team members to anticipate developments and to align their actions accordingly. As a result, team coordination should be smoother (Hazlehurst, McMullen, & Gorman, 2007; Weaver et al., 2010), and performance should improve. Case-irrelevant communication during surgery is more ambiguous; it may promote a positive work environment in the OR (Nurok, Evans, et al., 2011), but it also can divert the attention of the surgical team from its main task, and it has been found to impair team performance (Feuerbacher, Funk, Spight, Diggs, & Hunter, 2012; Wheelock et al., 2015).

Case-relevant and case-irrelevant communication may have different effects in different phases of a surgery. Case-relevant communication is likely to be beneficial throughout the surgery. Case-irrelevant communication is more likely to occur during routine activities, such as the closing phase (Katz, 1981); it may thus distract surgeons while they are suturing –which in turn may increase the risk specifically for incisional infections.

In addition to communication, distractors (e.g. noises, traffic) may also compromise performance (Sevdalis, Healey, & Vincent, 2007; Wheelock et al., 2015). Previous studies found that more distractors and higher noise levels were related to poorer teamwork in the OR (Kurmann, Peter, Tschan, Mühlemann, et al., 2011; Wheelock et al., 2015), and that more "lapses in discipline"

(operationalized as traffic, noise, and visitors) were related to a higher incidence of SSI (Beldi et al., 2009).

Primary goal of this prospective observational study was to test the impact of communication within the surgical team on SSI for major elective open abdominal surgeries. Specifically, we tested the effect of case-relevant and case-irrelevant communication during the whole surgical procedure, as well as during closure of the abdominal wound on deep/organ and incisional SSI. Secondary goal was to test the effect of distractors within the operating room on the incidence of SSI.

METHODS

Study design and sample

Inclusion criteria were elective open abdominal surgery that were expected to last at least one hour, and availability of observers. Exclusion criteria were laparoscopic and emergency procedures, and pre-existing SSI. The surgeries included represent the surgeries performed in the visceral department and include procedures of the upper and lower gastrointestinal tract and hepatobiliary procedures. All procedures were open surgeries with median or oblique laparotomies.

The surgical procedures were observed by a team of trained work psychologists; using a reliable observational system (Seelandt et al., 2014).

Surgeries were selected as follows: Each week, the observer team indicated to the study coordinator of the hospital all days for which observers were available. The coordinator then chose procedures that met the inclusion criteria for those dates. If more than one surgery met the inclusion criteria, the first procedure of the day was chosen. For 225 days indicated, 171 surgeries were available and observed. Four observed procedures were eliminated before analysis because two patients withdrew consent for the follow-up interview, one patient died within the 30-day follow up period, and one surgery lasted less than 30 minutes. Thus, 167 procedures were analysed.

The surgeries were performed in a Swiss university hospital. They took place in one of three equally spaced and identically equipped operating rooms (OR), all of them equipped with a high-efficiency particulate air (HEPA) filter vertical laminar air flow ventilation system. The surgical teams were composed of at least one board certified surgeon, at least one resident, one student, one scrub nurse, one or two circulating nurses, at least one anaesthesiologist and one nurse anaesthetist.

The Internal Review Board of the Hospital approved the study. All patients were informed about data collection. Consent from all staff was obtained.

Patient and surgery data

Preoperative preparation of the patient was performed according to the standards of the clinic and includes hair clipping outside of the OR, skin disinfection using povidon-iodine based solution, administration of antibiotics 60 to 30 minutes before the incision, and repetition of the dosage after 6 hours of surgery. Drain placements including stomach tubes, suturing technique, and postoperative care were performed according to clinical standards.

Characteristics of the patient (age, sex, smoking last 30 days, excessive alcohol use, body mass index, diabetes, oral steroid use, malignant condition, ASA class (American Society of

Anesthesiologist physical status classification), and of the surgical procedure (wound contamination grade, type of surgery, duration of surgery, bowel preparation, blood transfusion during surgery and whether or not a drain was placed) were extracted from the patient file, the surgery report and the anaesthesia report. It was also calculated whether the duration of the surgery was above standard values (i.e., the 75th percentile) for each type of surgery, because this is part of the National Nosocomial Infection Control Surveillance (NNIS) Risk Index, which estimates risks for infections of different surgeries (Cardo et al., 2004).

Primary study endpoint – SSI

Independent and trained infection control practitioners assessed the occurrence of SSI according to standards defined by the Center of Disease Control and Prevention (Emori et al., 1991). This protocol also includes a follow-up phone call 30 days after surgery. If SSI was suspected, consultants or general practitioners were asked to confirm and to classify it. SSI were grouped as superficial incisional, deep incisional, or organ/space SSI. In line with other authors (Beldi et al., 2009; Blumetti et al., 2007), superficial and deep incisional SSI were combined into one category.

Assessment of communication and distractors

Case-relevant and case-irrelevant communication as well as distractions during the procedure were assessed by direct observation. Trained work psychologists observed the surgeries using an event-coding observational system that has been shown to be reliable (Seelandt et al., 2014). Observers were located in the OR, about 1.5m from the operation table, facing the lead surgeon. The observations started when the patient was wheeled into the OR, and ended with the last suture. Analyses refer to the time between incision and the last stitch of closure.

Each exchange of communication within the sterile team (surgeons and scrub nurses), and between the sterile team and anaesthesiology was time-stamped and coded as either case-relevant or case-irrelevant. An exchange of communication was defined as one or several verbal statements related to the same theme and not interrupted by pauses (Seelandt et al., 2014).

Case-relevant communication was defined as exchange about the patient in surgery or the procedure performed. This includes i) communication about current or future actions and explanations (e.g., the surgeons talk about the next steps of the procedure); ii) leadership statements (e.g., the surgeon demands insertion of a stomach tube); and, iii) case-related teaching (e.g. the surgeon replies to a question on the use of a specific instrument) (Seelandt et al., 2014). Case-relevant communication is expressed as mean per hour for the entire procedure.

Case-irrelevant communication was coded if members of the sterile team i) talked about topics unrelated to the patient or the procedure or ii) joked or laughed (Seelandt et al., 2014). Case-irrelevant communication is expressed as mean per hour for the entire procedure and as count during the skin closing phase. The closing phase was defined as the last 20 minutes of the procedures, because this is the minimal duration required for suturing the abdominal fascia and suturing the skin in the institution for median or oblique laparotomies. This duration is independent of the duration of the whole procedure.

Distractor coding included the following events: i) noise events produced by a member of the non-sterile team (e.g., loud noises when opening packages); ii) traffic in the OR (operationalized by counting doors to the OR that were opened); and, iii) side-conversations in the OR (non-sterile personnel in the OR, including the anaesthesiologist, scrub nurses, technicians, and visitors engaging

in conversations with each other, except if those conversations were very quiet). Noise events, door openings, and side-conversations were each expressed as mean per hour.

To assess inter-observer agreement, 29 of the surgeries (17.4%) were simultaneously observed by two observers. Cohen's weighted kappa was used to assess inter-observer agreement, based on 5-minute intervals. All kappas were higher than 0.70, which is considered substantial agreement (Landis & Koch, 1977).

Statistical analyses

The prespecified primary outcomes were incisional or organ/space SSI. Descriptive information is expressed in frequencies and percentages for categorical variables, in means and standard deviations for continuous variables. To assess associations of SSI-rates with patient characteristics, surgery characteristics, communication, and distractors, univariate logistic regression analyses were performed. Because the number of outcome events (SSI) was small, conventional multivariate analysis with all baseline characteristics as covariates is not feasible. We therefore used the propensity score covariate adjustment technique (Austin, 2011; da Costa, Gahl, & Juni, 2014). The variables included in the propensity score were selected based on a priori considerations; they are displayed in Table 1.

Probability values and 95% confidence intervals (CI) are two-tailed. SPSS(V22) software was used for analyses.(IBM, Released 2013) Because no prior research provided expected effect sizes for the type of surgeries investigated, sample size considerations were based on Peduzzi et al.'s recommendations (Peduzzi, Concato, Kemper, Holford, & Feinstein, 1996), assuming an overall infection rate of 15-20%.

RESULTS

Mean duration of the 167 observed procedures was 4.59h (SD = 2.07). SSIs were diagnosed in 24 (14.4%) patients; 14 (8.4%) were deep/organ space SSI, and 10 (6.0%) incisional SSI. Descriptive statistics and results of univariate logistic regressions relating patient characteristics and surgery characteristics to SSI are shown in Table 1. No patient characteristic or surgery type was significantly related to SSI. Among the surgical risk factors, blood transfusion during surgery was a significant univariate risk for incisional as well for organ/space SSI (Table 1).

Case-relevant and case-irrelevant communication and SSI

Separate univariate analyses showed that case-relevant communication throughout the procedure was significantly associated with a lower risk for space/organ SSI. Case-irrelevant communication during the whole procedure and during the closing phase was a significant univariate risk factor for incisional SSI. The results are displayed in Table 2.

To take known risk factors for SSI into account, we performed adjusted logistic regression analysis by including the propensity score (Table 2). As ASA-score information, which is part of the NNIS Risk Index, was missing for three surgeries (which all were no SSI surgeries); the adjusted logistic regression analysis is based on 164 procedures

Table 1. Patient and surgery characteristics. Descriptive statistics and univariate relationships to incisional and organ/space SSI

	Overall (N=167)	No SSI (n=143)	Organ/space SSI (n=14)	relative odds, 95% CI	P	Incisional SSI (n=10)	relative odds, 95% CI	P
Patient characteristics								
[a] Age, y, (SD)	61.48(14.51)	60.88(14.64)	63.14(14.32)	1.01 (0.97-1.05)	0.580	67.6(12.45)	1.04 (0.98-1.1)	0.163
[a] Sex, male, n (%)	90(53.9)	77(53.8)	7(50)	0.86 (0.29-2.57)	0.783	6(60)	1.29 (0.35-4.75)	0.706
[a] Smoking last 30 days, n (%)	40(24)	37(25.9)	1(7.1)	0.22 (0.03-1.74)	0.152	2(20)	0.72 (0.15-3.53)	0.682
[a] Excessive alcohol use, n (%)	32(19.2)	27(18.9)	3(21.4)	1.17 (0.31-4.49)	0.817	2(20)	1.07 (0.22-5.35)	0.930
[a] BMI > 27, n (%)	61(36.5)	52(36.4)	6(42.9)	1.31 (0.43-3.99)	0.632	3(30)	0.75 (0.19-3.03)	0.686
[a] Diabetes mellitus, n (%)	30(18)	27(18.9)	2(14.3)	0.72 (0.15-3.39)	0.674	1(10)	0.48 (0.06-3.93)	0.492
[a] Medication: Oral steroid use, n (%)	18(10.8)	15(10.5)	1(7.1)	0.66 (0.08-5.38)	0.695	2(20)	2.13 (0.41-10.99)	0.365
[a] Malignant condition, n (%)	118(70.7)	98(68.5)	12(85.7)	2.76 (0.59-12.83)	0.197	8(80)	1.84 (0.37-9)	0.453
[a] ***Surgery characteristics***								
[a] Type of surgery								
[a] Upper GI-tract, n (%)	30(18)	29(20.3)	1(7.1)	0.3 (0.04-2.41)	0.258	0(0)	NA	
[a] Liver / Pankreas, n (%)	88(52.7)	73(51)	9(64.3)	1.73 (0.55-5.4)	0.349	6(60)	1.44 (0.39-5.32)	0.586
[a] Lower GI-tract, n (%)	33(19.8)	27(18.9)	3(21.4)	1.17 (0.31-4.49)	0.817	3(30)	1.84 (0.45-7.59)	0.398
[a] Other, n (%)	16(9.6)	14(9.8)	1(7.1)	0.71 (0.09-5.83)	0.749	1(10)	1.02 (0.12-8.69)	0.983
[a] Bowel preparation, n (%)	12(7.2)	131(91.6)	1(7.1)	0.84 (0.1-6.98)	0.872	0(0)	NA	
[a] Operative time (h) (mean, SD)	4.59(2.1)	4.42(1.85)	5.48(2.31)	1.26 (0.99-1.67)	0.064	5.76(3.78)	1.32 (1-1.74)	0.047
[a] Blood transfusion during surgery, n (%)	41(24.6)	29(20.3)	7(50)	3.93 (1.28-12.09)	0.017	5(50)	3.93 (1.07-14.5)	0.040
[a] Drain placed, n (%)	137(82)	115(80.4)	13(92.9)	3.17 (0.4-25.22)	0.277	9(90)	2.19 (0.27-18.02)	0.466
[a] ASA class >2, n (%)	108(64.7)	94(65.7)	7(50)	0.49 (0.16-1.48)	0.205	7(70)	1.14 (0.28-4.62)	0.852
[a] Duration > 75th percentile (no/yes), n (%)	111(66.5)	91(63.6)	12(85.7)	3.43 (0.74-15.92)	0.116	8(80)	2.29 (0.47-11.17)	0.307
[a] Wound contamination > 2, n (%)	15(9)	14(9.8)	1(7.1)	0.71 (0.09-5.83)	0.749	0(0)	NA	

a Included into propensity score; CI: Confidence Interval; BMI: Body Mass Index; ASA: American Society of Anesthesiologists physical status classification system; SSI: Surgical Site Infection; GI: Gastro-Intestinal

Table 2. Communication and distractors during surgeries. Descriptive statistics, univariate and propensity score adjusted relationship to incisional or organ/space SSI

	Overall	No SSI	Organ/Space SSI					Incisional SSI				
	(N=167)	(n=143)	(n=14)	Univariate relative odds (95% CI)	P	Adjusted relative odds (95% CI)	P	(n=10)	Univariate relative odds (95% CI)	P	Adjusted relative odds (95% CI)	P
Communication												
Case-relevant communication p. h., mean(SD)	19.20(6.5)	19.40(6.7)	15.40(3.2)	0.90(0.81-0.99)	0.030	0.86 (0.77-0.97)	0.014	21.61(4.9)	1.05(0.96-1.16)	0.296	1.08 (0.95-1.23)	0.239
Case-irrelevant communication p.h. whole procedure, mean (SD)	6.17(4.3)	5.98(3.74)	5.68(6.12)	0.98 (0.85-1.13)	0.78	1 (0.86-1.17)	0.955	9.53(7.79)	1.13 (1.02-1.26)	0.023	1.19 (1.04-1.36)	0.012
Case-irrelevant communication during closure, mean (SD)	3.11(3.2)	2.87(2.9)	2.92(3.3)	1.01(0.83-1.22)	0.939	0.98 (0.81-1.2)	0.869	6.90(4.5)	1.31(1.12-1.53)	0.001	1.29 (1.08-1.55)	0.006
Distractors												
Noise events p.h, mean (SD)	10.17(4.4)	10.35(4.4)	8.25(3.3)	0.87(0.75-1.02)	0.088	0.84 (0.71-1.01)	0.057	10.33(4.7)	1.00(0.86-1.16)	0.993	0.97 (0.82-1.15)	0.723
Door openings (traffic) p.h mean, (SD)	31.77(6.3)	31.81(6.6)	31.79(4.6)	1.00(0.92-1.09)	0.990	0.99 (0.9-1.09)	0.787	31.15(5.7)	0.98(0.89-1.09)	0.749	0.93 (0.83-1.05)	0.245
Side conversations p.h mean, (SD)	10.54(5.2)	10.46(5.4)	9.88(3.3)	0.98(0.87-1.09)	0.684	0.98 (0.87-1.1)	0.674	12.57(4.9)	1.07(0.96-1.19)	0.222	1.08 (0.95-1.23)	0.229

The adjusted model shows that more case-relevant communication during the whole procedure (events per hour) was associated with a decreased incidence in organ/space SSI (adjusted odds ratio 0.86 [95% CI 0.77-0.97]; P=0.014). To illustrate the effect, we plotted case-relevant communication per hour for patients with no SSI, organ/space SSI, and incisional SSI (Figure 1A), and compared the infection rate of surgeries below and above the mean of case-relevant communication (Figure 1B).

Regarding incisional SSI, the adjusted model for case-irrelevant communication throughout the procedure (events per hour) showed that more case-irrelevant communication overall was related to a higher incidence of incisional SSI (adjusted odds ratio 1.19 [95% CI 1.04-1.36]; P=0.012); and, in particular, more case-irrelevant communication during closure was related to a higher incidence of incisional SSI (adjusted odds ratio 1.29 [95% CI 1.08-1.55], P=0.006). To investigate whether the effect was due to case-irrelevant communication overall or to case-irrelevant communication during the closing phase, a logistic regression model was performed, adjusting the effect of case-irrelevant communication during closure for the propensity score as well as for case-irrelevant communication before the closure phase. The results show that more case-irrelevant communication during closure remained significantly related to a higher risk of incisional SSI (adjusted odds ratio 1.23 [95% CI 1.01-1.50]; P=0.048); whereas case-irrelevant communication before closure was not a significant predictor (adjusted odds ratio 1.09 [95% CI 0.92-1.29]; P=0.308). To illustrate the effect, we plotted case-irrelevant communication during closure for patients without SSI, organ/space SSI, and incisional SSI (Figure 2A), and compared the infection rate of surgeries below and above the mean of case-irrelevant communication during closure (Figure 2B).

Perioperative distractors and SSI

None of the observed distractors (noise events, door openings, side conversations) was significantly related to incisional or organ/space SSI in univariate or propensity score adjusted logistic regression analyses (see Table 2).

A B

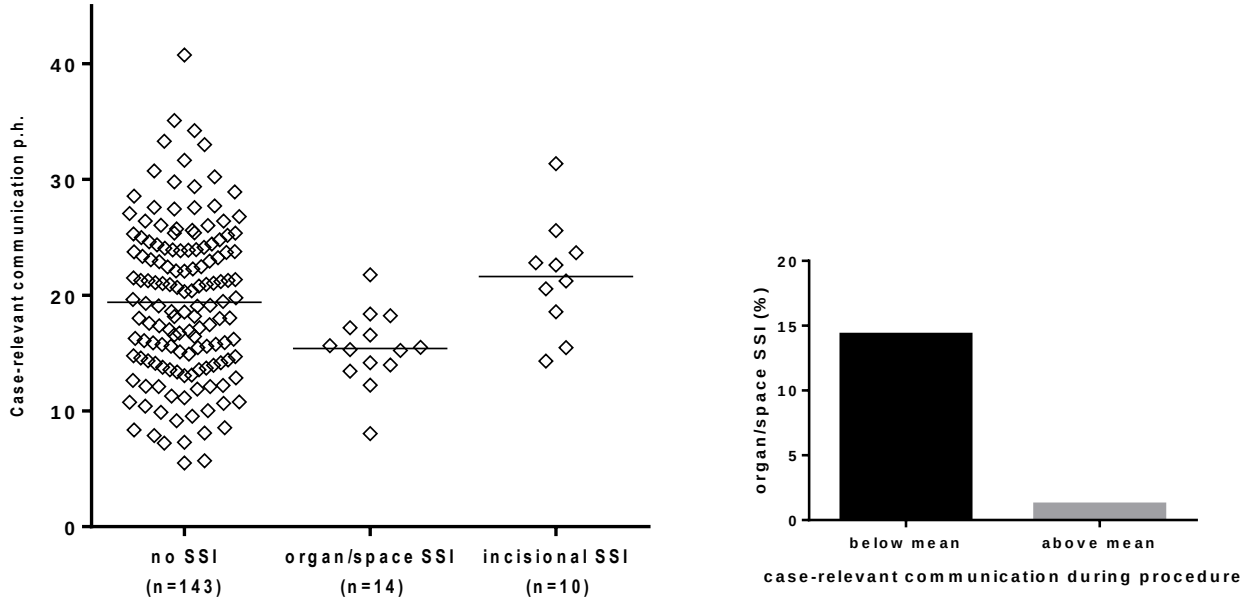
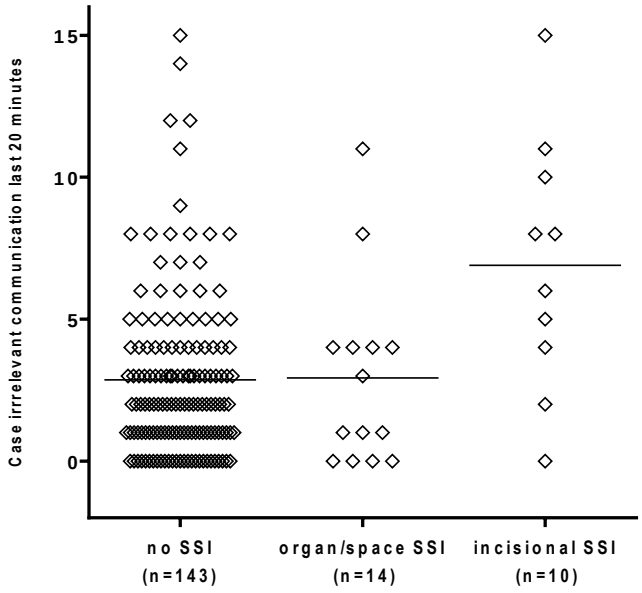


Figure 1. (A) Plot of case-relevant communication per hour (p.h.) for surgeries with no SSI, organ/space SSI or incisional SSI. Horizontal lines represent the mean. (B) Plot of organ/space SSI (%) separately for patients with case-relevant communication below and above the mean.

A



B

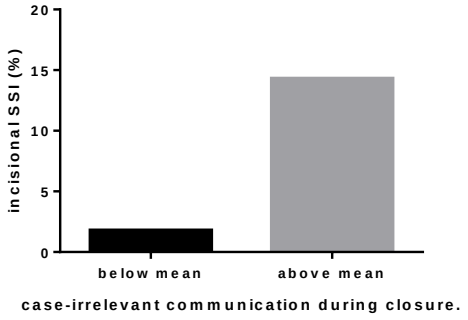


Figure 2. (A) Plot of case-irrelevant communication in the last 20 minutes of surgeries with no SSI, organ/space SSI or incisional SSI. Horizontal lines represent the mean. (B) Plot of superficial SSI (%) separately for patients with case-irrelevant communication during closure below and above the mean.

DISCUSSION

In this study, more case-relevant communication during the whole procedure was associated with lower risk of organ/space SSI, whereas more case-irrelevant communication during the closing phase was associated with increased risk of incisional SSI. Distractors were not associated with SSI.

Case-relevant communication assures the exchange of information (Healey, Undre, & Vincent, 2006b; Wong et al., 2011), and less sharing of information has been found to be related to more complications (Mazzocco et al., 2009). Exchanging case-relevant information may foster a shared understanding of the task within the team. Indeed, studies from medicine and other fields show that task-related communication helps team members to cooperate more smoothly (Youngson & Flin, 2010); this is likely to be particularly important during difficult phases of the surgery (Mazzocco et al., 2009). Smooth cooperation implies that the surgeons do not have to switch attention between their primary task and the need to assure team coordination, thus avoiding "micro-interruptions". In addition, persistent misunderstandings and loss of information have frequently been observed in surgery (Gillespie, Chaboyer, & Fairweather, 2012; Lingard, Espin, Whyte, et al., 2004); they may be attenuated by exchanging more case-relevant communication during the procedure.

Things are more complex for case-irrelevant communication. Case-irrelevant communication may improve team climate. Relaxed communication and the use of humour are seen as an important part of team-building processes in the OR (Catchpole et al., 2008) (Weigl, Antoniadis, Chiapponi, Bruns, & Sevdalis, 2015). However, case-irrelevant communication may also divert the attention from the primary task and may impair performance (Sevdalis et al., 2007; Wheelock et al., 2015). Our results support the distracting effect of case-irrelevant communication under specific circumstances: Case-irrelevant communication predicted *incisional* SSI; these are likely produced during closure, and it was case-irrelevant communication during closure that was responsible for this effect.

During closure, the most difficult part of the surgery is over, and what is left are routine activities for most team members (i.e., clearing and removing equipment). During routine phases, teams are more likely to engage in case-irrelevant talk (Katz, 1981), which may increase the probability of minor errors for several reasons. First, performing a manual task while engaging in an unrelated communication is a form of multitasking, which may increase the likelihood of errors (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Second, negative effects of demanding tasks often manifest themselves only *after* the period of high workload (Hockey, 1997), because attentiveness often decreases when people start to relax. For example, residents working long hours have more car accidents on their way home (Krauss, Chen, DeArmond, & Moorcroft, 2003). Third, although supervised by an experienced surgeon, closing the abdominal wall is often performed by a junior surgeon, for whom suturing is not yet a routine task (Raval et al., 2011; Stenvik et al., 2006). In contrast to experienced surgeons, who can shield themselves quite well from distractors (Moorthy, Munz, Undre, & Darzi, 2004; Wiegmann, ElBardissi, Dearani, Daly, & Sundt, 2007), performance of junior surgeons, including manual performance, tends to degrade in distracting environments (Feuerbacher et al., 2012; Gallagher, Satava, & O'Sullivan, 2015; Goodell, Cao, & Schwaitzberg, 2006a; Hsu, Man, Gizicki, Feldman, & Fried, 2008). Lower concentration may induce less careful suturing,

more damaged tissue, or too much tension in the sutures, thus raising the risk of incisional SSI. Fatigue may be an additional aggravating factor (Denisco, Drummond, & Gravenstein, 1987).

Our results confirm the findings of an earlier study showing that lapses in discipline raise the risk of SSI (Beldi et al., 2009). They refine these results by identifying the most sensitive phase (closing phase) for this effect. It is, however, not clear why only case-irrelevant communication affected the surgeons in the closing phase, and other distractors did not. We suspect that is because communication conveys meaning to a greater extent than other distractors. Meaningful noise is difficult to ignore (Engelmann et al., 2014), and is more likely to impair concentration and coordination (Wheelock et al., 2015).

In a more general vein, this study adds to the growing evidence that teamwork quality in the OR is related to patient outcomes (Nagpal et al., 2010). A shared understanding of important characteristics of the situation is a central aspect of good teamwork, as suggested by findings that surgeries performed by familiar teams result in fewer complications (Brown, Parker, Quinonez, Li, & Sundt, 2011; Kurmann et al., 2014). Our results suggest that case-related communication may be an efficient way to achieve this common understanding. However, there is an alternative explanation that one cannot rule out empirically: It is possible that it was not case-related communication that improved team coordination but that case-related communication is simply a marker of good teamwork quality. This alternative explanation would imply that improving teamwork quality would result in better communication, whereas our explanation implies that improving communication would result in better teamwork quality.

Using behaviour observation as a method, and simultaneously assessing case-relevant and case-irrelevant communication as well as distractors constitutes a strength of this study. Our method allowed us to separately assess communication during the closing phase of the procedure. Furthermore, whereas most other studies investigated procedures lasting less than two hours (Healey, Sevdalis, & Vincent, 2006a), this study focused on long, open abdominal surgeries, which carry the highest risk of SSI. A strength of this study is also the focus on everyday behaviour in the OR, rather than on gross communication failures (Gawande et al., 2003; Greenberg et al., 2007). We found that general, ordinary aspects of communication measurably affect SSI. This supports previous findings that intraoperative behaviours that are not dramatic, yet lack optimal focus, may cause minor errors that often go unnoticed (Beldi et al., 2009).

Our study is limited by the fact that a controlled random design was not feasible; instead, we adopted a prospective design. However, reverse causation is not a plausible explanation for our results, because we assessed SSI after the surgery and we excluded pre-existing SSI cases. Another limitation is that we did not observe intervening variables between communication and SSI, so the exact mechanisms linking communication events to SSI need to be addressed in further research. Because this was a single-site study in a teaching hospital, and only elective open abdominal surgeries were included, generalization of the results is limited. Many influencing factors, including team climate, and thus probably also communication, may vary considerably between hospitals (Sexton, Makary, et al., 2006). Future research should replicate the study and extend it to other surgical procedures under other conditions.

CONCLUSION AND IMPLEMENTATION

This study related intraoperative communication to SSI as measurable patient complications because they are the most frequent complication in surgery. The results highlight the importance of intraoperative communication. Case-relevant communication during the whole procedure appears to reduce the risk of organ/space SSI, while case-irrelevant communication during the closing phase seems to increase the risk of incisional SSI. However, we do not suggest that surgical teams abstain from all case-irrelevant communication during the closing phase. Case-irrelevant communication can foster a positive team climate (Catchpole et al., 2008), and it is understandable that the surgical team relaxes after a long and difficult procedure (Katz, 1981). Prohibiting case-irrelevant communication might create tension and frustration, which may have detrimental effects. It may be more appropriate for teams to adapt behaviour to the situation by allowing a short period of tension release or a break (Engelmann et al., 2011) before the closing phase begins, but then calling for renewed focus on the task of closure.

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Paper 3. Impact of team familiarity in the operating room on surgical complications

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ABSTRACT

Background and objectives

The quality of surgical performance depends on the technical skills of the surgical team as well as on non-technical skills, including teamwork. The present study evaluated the impact of familiarity among members of the surgical team on morbidity in patients undergoing elective open abdominal surgery.

Methods

A retrospective analysis was performed to compare the surgical outcomes of patients who underwent major abdominal operations between the first month (period I) and the last month (period II) of a 6-month period of continuous teamwork (stable dyads of one senior and one junior surgeon formed every 6 months). Of 117 patients, 59 and 58 patients underwent operations during period I and period II, respectively, between January 2010 and June 2012. Team performance was assessed via questionnaire by specialized work psychologists; in addition, intraoperative sound levels were measured.

Results

The incidence of overall complications was significantly higher in period I than in period II (54.2 vs. 34.5 %; $P = 0.041$). Postoperative complications grade \3 were significantly more frequently diagnosed in patients who had operations during period I (39.0 vs. 15.5 %; $P = 0.007$), whereas no between-group differences in grade C3 complications were found (15.3 vs. 19.0 %; $P = 0.807$). Concentration scores from senior surgeons were significantly higher in period II than in period I ($P = 0.033$). Sound levels during the middle third part of the operations were significantly higher in period I (median above the baseline 8.85 dB [range 4.5–11.3 dB] vs. 7.17 dB [5.24–9.43 dB]; $P \setminus 0.001$).

Conclusions

Team familiarity improves team performance and reduces morbidity in patients undergoing abdominal surgery.

Key words: Team familiarity; Operating room; Post-operative complications

INTRODUCTION

The quality of surgical performance depends not only on the technical skills of the surgical team but also on good collaboration and effective teamwork. The operating room is a very complex environment and is associated with significant morbidity: up to 60 % of all adverse events occur in the operating room, with up to 33 % resulting in permanent disability and up to 13 % resulting in deaths [1–3]. Surgeries may therefore be even more vulnerable to suboptimal teamwork than other fields. Previous work demonstrated that noise levels, which are a potential indicator of team activity, are associated with postoperative complications [4].

The introduction of checklists has influenced teamwork by structuring some processes in the operating room at the beginning of a procedure [5, 6]. Nonetheless, other studies identified breakdowns in collaboration during critical situations that were noticeable to external observers [7, 8]. Interactions among members of the surgical team may be subtle, and they occur throughout the duration of an operation. Thus, there seems to be a need to optimize interactions among members of a surgical team throughout an operation in order to improve team performance and reduce patient morbidity.

The aim of the present study was to assess whether close collaboration reduces the incidence of surgical complications. In particular, we hypothesized that team familiarity (common experience as team members) between one senior and one junior surgeon (fellowship teams) improves team performance and thereby reduces the risk of postoperative complications in patients undergoing open abdominal surgery.

METHODS

Patients

A total of 117 patients undergoing elective major abdominal surgery between January 2010 and June 2012 were included in this case–control study. The inclusion criterion was an elective open abdominal operation performed by one of the stable dyads composed of one senior and one junior board-certified surgeon. The exclusion criteria were laparoscopic and emergency procedures and pre-existing surgical site infection (SSI). All patients who underwent operations during the specific periods and who met the inclusion criterion were analyzed. Data were prospectively collected and stored in an electronic database. Postoperative patient care visits were performed daily during the hospital stay. All patients were contacted by study nurses 30 days or more after surgery to complete a standard questionnaire to detect SSIs according to guidelines from the Centers for Disease Control and Prevention [9]. If a patient was diagnosed with a suspected SSI, consultants or general practitioners were asked to confirm the finding and to classify the SSI. This study has been reviewed and approved by the Internal Review Board of the University Hospital Bern, Bern, Switzerland.

Teams and psychological assessment

A fellowship system was introduced in 2008 at the Department of Visceral Surgery and Medicine, University Hospital Bern. Fellowship teams consist of one senior and one junior board-certified surgeon and are newly formed every 6 months, starting in January or

July. During these 6-month periods, elective operations, preoperative and postoperative patient care visits, and outpatient follow-ups are performed by the fellowship team. Five senior surgeons led 16 fellowship teams. Period I was defined as the first month of each 6-month teamwork period, and the last month of each period was designated period II.

For a total of 26 operations (16 operations in period I and 10 operations in period II), every member of the surgical team completed a standardized questionnaire. This was done before staff left the operating room in order to evaluate the quality of teamwork and to report the difficulty level of the operation. Questionnaires were designed by specialized work psychologists and were confidential. Team members responded to questions about the perceived difficulty of the operation, stress during the operation, quality of team collaboration within the surgical team, and the ability to concentrate on the operation. Single items were assessed with a 7-point Likert scale in which a score of 1 indicated disagreement and a score of seven indicated full agreement. The cut-off for categorical variables was set by the mean value of each item. Analyses were run separately for questionnaire values of the entire surgical teams and of the senior surgeons (team leaders) responsible for the operation.

Measurements of sound levels

Intraoperative sound levels were recorded during 26 surgical procedures in two operating rooms of the same size with identical equipment, as described previously [4]. A sound-level measuring device (PCE 353, PCE GmbH & Co.KG, Meschede, Germany) was placed directly above the operative field in a fixed holder on the operative lamp. The noise intensity was registered digitally every second in decibels (dB[A]). To eliminate the influence of general background noise, the baseline was set to the lowest decibel level measured during surgery for each patient. Results are given in medians above the baseline [4].

The operative time of each procedure was divided into three parts: first third: resection, middle third: reconstruction, and last third: closure. The middle third of each operation was defined as crucial for evaluating teamwork; this part of the operation includes highly difficult steps, such as reconstruction and close teamwork between the junior and senior surgeons. Whereas during the first and the last third of the operation the senior surgeon was not always present.

Surgical technique

All patients received preoperative antibiotic prophylaxis. Before incision, a team time-out procedure using a standardized checklist was performed [10]. Hepatobiliary and pancreatic resections were performed with a transverse upper laparotomy, and surgeries of the upper and lower gastrointestinal tract were performed with a median laparotomy. The underlying disease defined the extent of resection. In all patients, abdominal closure was performed with a running suture of PDS (polydioxanone) Loop (Ethicon Sarl, Neuchâtel, Switzerland).

Complications were classified based on the type of therapy required to treat the complication and were defined as grade <3 or grade ≥3 [11, 12]. Surgical site infections that occurred up to 30 days after surgery were assessed according to the criteria developed by the U.S. Centers for Disease Control and Prevention [9]. Superficial SSI involved only the skin and subcutaneous tissue and excluded stitch abscesses. Deep SSI involved deeper soft tissues, such as the fascia and muscle, at the site of incision. Organ-space SSIs involved any organ or space.

Outcome parameters

The primary outcome parameter of this study was the number of overall postoperative complications that occur- red in patients who underwent operations during period I or period II within one 6-month period of fellowship teamwork. Secondary outcome measures were SSI, assessment of team performance, intraoperative sound levels, duration of operation, and hospitalization time.

Statistical analysis

Univariate analysis was performed with Fisher's exact test for categorical variables. Continuous variables were compared with Student's t test and are presented as medians and ranges. Two-way analysis of variance (ANOVA) was performed to analyze sound levels during the operation. P values were two-sided, and $P < 0.05$ was considered the threshold for statistical significance (NCSS 2007 for Windows; NCSS, Kaysville, UT).

RESULTS

The present study included 59 patients who underwent operations during period I and 58 patients who had operations during period II. Complete follow-up information was obtained for 115 patients (98.3 %); two patients died during the 30-day follow-up because of multi-organ failure. The baseline characteristics of the two patient groups were comparable (Table 1). Operative procedures classified as ''other'' included adrenalectomy, multivisceral resection, retroperitoneal resection, and ventral hernia repair, including adhesiolysis. No between-group differences were found in the median duration of hospital stay (period I: 11 days; range 4–51 days; period II: 12 days, range 4–56 days; P = 0.524).

A significantly higher incidence of overall complications was detected during period I than during period II (54.2 vs 34.5 %; P = 0.041; Table 2). The grading of complications is shown in Table 3. The incidence of SSI was significantly higher in period I than in period II (40.7 vs. 22.4 %; P = 0.046). Incisional superficial SSI occurred in 16 patients (27.1 %) who underwent operation during period I and in 6 patients (10.3 %) who underwent operation during period II (P = 0.131). Incisional deep SSI occurred in one patient in each group (1.7 vs. 1.7 %; P = 1.000), and organ-space SSI was diagnosed in nine patients in each group (15.3 vs. 15.5 %; P = 1.000). A combination of different types of SSI was found in two patients who received operations during period I (3.4 %) and in three patients (5.2 %) who received operations during period II.

Table 1
Baseline characteristics and operative procedures (Kurmann et al., 2014, p. 3049)

	Period I $n = 59$	Period II $n = 58$	P value*
Age, years[a]	61 (22–93)	61 (27–89)	0.261[b]
Male gender	34 (57.6)	35 (60.3)	0.851
Female gender	25 (42.4)	23 (39.7)	
BMI (kg/m^2)[a]	23 (16.1–42)	23.6 (17.3–46.8)	0.535[b]
ASA score[a]	3 (1–3)	3 (2–4)	0.065[b]
Diabetes	13 (22.0)	6 (10.3)	0.131
CVD	17 (28.8)	15 (25.9)	0.836
COPD	9 (15.3)	13 (22.4)	0.353
Malignant disease	46 (78.0)	47 (81.0)	0.820
Type of surgery			
Hepatobiliary/pancreas	35 (59.3)	33 (56.9)	0.852
Upper GI	5 (8.5)	6 (10.3)	0.762
Lower GI	11 (18.6)	9 (15.5)	0.806
Other	8 (13.6)	10 (17.2)	0.617
Blood loss, ml[a]	300 (10–5,500)	500 (50–3,000)	0.661[b]
Duration of operation, min[a]	240 (90–570)	265 (90–660)	0.082[b]

Values in parentheses are percentages unless indicated otherwise

BMI body mass index, *ASA* American Society of Anesthesiologists, *CVD* cardiovascular disease, *COPD* chronic obstructive pulmonary disease, *GI* gastrointestinal tract

* Fisher's exact test unless indicated otherwise

[a] Values are medians (range)

[b] Student's *t*-test

Table 2
Surgical outcomes (Kurmann et al., 2014, p. 3049)

	Period I $n = 59$	Period II $n = 58$	P value*
Postoperative complications	32 (54.2)	20 (34.5)	0.041
Complication grade <3	23 (39.0)	9 (15.5)	0.007
Complication grade ≥3	9 (15.3)	11 (19.0)	0.807
SSI	24 (40.7)	13 (22.4)	0.046
Re-operation	4 (6.8)	5 (8.6)	0.743

Values in parentheses are percentages

SSI surgical site infection

* Fisher's exact test

Table 3
Grading of surgical complications (Kurmann et al., 2014, p. 3050)

	Period I $n = 59$	Period II $n = 58$	P value*
Grade 1	5 (8.5)	1 (1.7)	0.207
Grade 2	18 (30.5)	8 (13.8)	0.044
Grade 3a	6 (10.2)	5 (8.6)	1.000
Grade 3b	3 (5.1)	4 (6.9)	0.717
Grade 4a	–	–	–
Grade 4b	–	–	–
Grade 5	0 (0)	2 (3.4)	0.244

Values in parentheses are percentages

* Fisher's exact test

Concentration scores from senior surgeons, which were assessed with a 7-point Likert scale on the psychological questionnaire, were significantly higher during period II than during period I (37.5 % for period I vs. 88.9 % for period II; P = 0.033; Table 4). No difference between the two periods was found regarding difficulty of operation, stress during operation, or team collaboration within the surgical team.

Table 4
Quality of teamwork in the operating room within the surgical team (Kurmann et al., 2014, p. 3050)

	Period I $n = 16$	Period II $n = 10$	P value*
The team[a] defined the operation as difficult ≥5	9 (56.3)	5 (50.0)	1.000
The senior surgeon defined the operation as difficult ≥5[b]	9 (56.3)	7 (77.8)	0.401
The team[a] defined the operation as stressful >3	12 (75.0)	5 (50.0)	0.234
The senior surgeon defined the operation as stressful >3[b]	8 (50.0)	3 (33.3)	0.677
The team[a] defined the team collaboration as good ≥5	15 (93.8)	10 (100)	1.000
The senior surgeon defined the team collaboration as good ≥5[b]	10 (62.5)	5 (55.6)	1.000
The team[a] was able to concentrate on the operation >4	15 (93.8)	9 (90.0)	1.000
The senior surgeon was able to concentrate on the operation >4[b]	6 (37.5)	8 (88.9)	0.033

Values in parentheses are percentages. Cut-offs represent mean values of each item on a 7-point Likert scale

[a] Mean value of the entire team

[b] One missing value in period II

* Fisher's exact test

Median sound levels above baseline during the middle third of each operation were significantly higher during period I than during period II (median 8.85 dB [range 4.5–11.3 dB] vs. 7.17 dB [range 5.24–9.43 dB]; P < 0.001; 0.234 Fig. 1). Median sound levels above baseline during the entire operation (from incision to closure) were not significantly different between the two periods (data not shown). No differences in median sound levels were detected during the first third and the last third of the operation between the two periods (Online supplementary Figs. 1, 2).

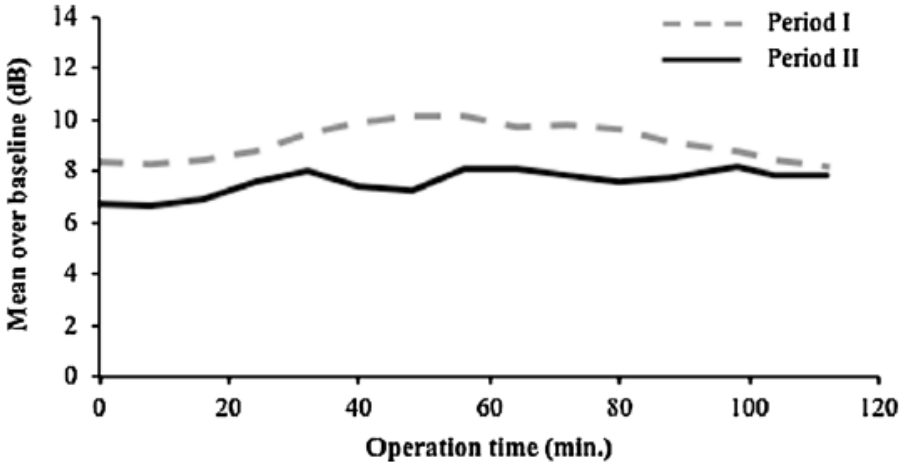

Figure 1. Mean sound levels above baseline during the middle third of the operations were significantly higher I period I than in period II ($P < 0.001$; two-way analysis of variance [ANOVA] (Kurmann et al., 2014, p. 3050)

DISCUSSION

In the present study, working on fellowship teams whose members were more familiar (period II, the last month of the six-month teamwork period) was associated with reduced morbidity after major abdominal surgery

Team familiarity (common experience as team members) has been found to play a critical role in good collaboration in the operating room [13, 14]. Working on the same team allows team members to gain mutual experience and to develop routines [13, 14]. Teams can improve their performance over time, particularly as team members gain experience in collaborating [13, 15]. Common experience allows teams to perform better work under pressure when operations become more difficult, thereby enabling them to better react to unexpected surgical problems [7, 8]. Previous studies have revealed that working on fixed teams was associated with a shorter duration of operative time, but these analyses did not include patient outcomes [14, 16, 17]. The present study demonstrates the impact of team familiarity on clinically relevant outcome parameters.

The present results are clearly different from the so-called ‘‘July effect,’’ in which team performance influences mortality rate throughout the academic year; new residents arrive in July. However, the potential association between resident exchange and mortality rate remains controversial [18–22]. Rather, the July effect may be caused by the introduction of novice residents who are unfamiliar with the clinical workflow, and not a lack of team experience. The present study, however, focused directly on the impact of teamwork experience within surgical teams consisting of senior and junior board-certified surgeons on clinical out- come parameters. Therefore, this study more likely highlights the synergistic effects of cumulative teamwork experience than the lack of experience in the clinical workflow that is expected of residents in their first months of clinical work.

The present study also revealed that the main surgeon’s mental concentration was higher in more familiar teams during period II, which may explain the observed effect. In the

operating room, distractions that occur in and around the surgical field affect concentration. These distractions can impair surgical performance and result in a higher error rate [23]. Senior surgeons have to deal with various distractions, train junior surgeons, lead the entire surgical team, and simultaneously focus on a complex procedure. Training less- experienced surgeons is a crucial task for senior surgeons. The increase in the knowledge and skills of junior surgeons and the increasing sense of routine in the more experienced teams may enable the senior surgeon to better concentrate on the operation. The lower overall concentration score reported by the main surgeon compared to the entire team further indicates that especially the main surgeon is faced with various distractions during the procedure because of the above-mentioned additional demands.

Noise in the operating room was previously shown to be associated with an elevated incidence of SSI [4]. The present study recorded lower noise levels in the operating room staffed by familiar teams during the middle third of the operation, which is likely the most difficult part of the entire operation. Low noise levels may indicate smoother teamwork because of more efficient communication, less tension, and a better emotional climate, all of which have been associated with better patient outcome [2]. Obviously, there are many other factors that influence noise levels in the operating room (e.g., doors opening; phones ringing; alarms going off), and very low noise levels may well indicate a cold and uncooperative atmosphere. However, if our observation of an association between team familiarity and noise levels is supported by future studies, and if other influences on noise can be controlled, high noise levels might be considered an indirect, if very gross, indicator of problems in team cooperation.

Breakdown of collaboration in the operating room is relatively frequent and enhances the risk of postoperative complications [1, 2, 24]. Establishing consistent surgical teams for everyday procedures seems to be clinically relevant; team familiarity was previously reported to have a threefold greater impact on the duration of the procedure than the experience of the main surgeon [14]. Team training under artificial situations has been attempted in order to improve surgical performance. However, changes in clinical practice, such as the use of checklists, have been shown to reduce surgical morbidity, often with larger effects than team training [5, 6, 25, 26]. Thus, teamwork in surgery may benefit more greatly from structural changes, including the introduction of stable teams, than from additional training.

A strength of the present study is the correlation of team familiarity and other indicators of team behavior with a clinically relevant outcome parameter. Interestingly, mortality and the incidence of severe complications were comparable between the two surgical periods in the present study. These observations cannot be explained by specific patient- or procedure-related issues alone. Low-grade complications seem to be ideal for evaluating team performance, as they are potentially associated with repeated minor breaks or errors in workflow.

One of the limitations of the present study is its single-center, non-randomized design. In addition, this case–control study investigated only team familiarity between senior and junior surgeons. Team performance in the operating room encompasses various teams, such as the surgical team, the anesthesia team, and the nurses. Additional assessment of teamwork quality and sound measurements were analyzed only in 26 procedures because of the limited

availability of specialized work psychologists. The study is also limited by its retrospective design and the limited sample size. Given the results from this study, these limitations warrant a prospective observational trial.

In conclusion, the present investigation has demonstrated the beneficial impact of team familiarity on com- plication rate, a clinically relevant outcome parameter. This finding may be explained by a scenario in which a senior surgeon operating with a more-familiar team has a greater ability to concentrate on the operation than a surgeon operating with a less-familiar team. However, this specific finding needs to be confirmed in a prospective fashion that includes the investigation of other teams in other institutions.

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Paper 4. Noise in the operating room distracts member of the surgical team: an observational study

Keller, S., Tschan, F., Semmer, N. K., Holzer, E., Kurmann, A., Candinas, D., Brink. M., Beldi, G. (2015). Noise in the operating room distracts member of the surgical team: an observational study. Manuscript ready to submit. My co-authors and myself will work on minor modifications of this paper, and soon submit it for publication.

ABSTRACT

Background and objectives

Noise pollution in operation rooms (OR) may distract the surgical teams. Especially during phases of high complexity, noise is expected to jeopardize concentration. However, the phases of high complexity are related to task specificities and experience level and may thus vary across the professional teams working in the OR setting

Study Design

Noise exposure was measured during 110 open abdominal surgeries; distinguishing three phases (opening, main phase, and closing), noise was related to reports of being distracted by main and secondary surgeons, scrub nurses and anesthetists who participated in the surgeries.

Results

Noise pollution was higher than recommended levels for concentrated work. Adjusted for duration and surgical type, results showed that second surgeons are more likely to report being distracted when noise pollution was high in the main phase; and anesthetists are more likely to report being distracted when noise pollution was high during the closing phase. Main surgeons' and scrub nurses' concentration was not impaired by measured noise, during none of these phases.

Conclusions

In phases with higher concentration demands, noise pollution was particularly distracting for second surgeons and anesthetist, corresponding to their specific task demands (anaesthetists) and experience (second surgeons). Reducing noise levels particularly in the main and closing phase of the surgery may reduce concentration impairments.

Keywords: Noise; Concentration; Phases of surgery

INTRODUCTION

Aim of this prospective observational study is to relate noise pollution levels in different phases of long open abdominal surgeries to reports of being distracted of main and second surgeons, anaesthetists and scrub nurses.

Exposure to noise, defined as unwanted sound, has negative effects: it can lead to more exhaustion (Witterseh et al., 2004), elicit stress responses (Basner et al., 2014; Rylander, 2004), impair sensori-motor performance (Szalma & Hancock, 2011), interfere with communication (Stansfeld & Matheson, 2003), and impair cognitive performance, for example through distraction (Baker & Holding, 1993). Operation Rooms (OR) are noisy environments (Katz, 2015) with noise pollution levels that regularly exceed international recommendations for concentrated work (Healey, Primus, & Koutantji, 2007; Kam et al., 1994; Shankar et al., 2001). There is evidence that noise affects surgical performance; noise pollution was associated with higher levels of patient complications (Dholakia et al., 2015; Grayson et al., 2005; Kurmann, Peter, Tschan, Muhlemann, et al., 2011). In a survey study, the majority of surgeons, anesthetists and OR nurses reported being disturbed by noise during surgeries (Tsiou et al., 2008). Higher noise levels led to increased interactional irritation of surgeons (Pluyter et al., 2010) and noise impaired their auditory performance (Way et al., 2013). However, surgeons who were exposed to different types and levels of noise in short term experimental studies did not show performance impairments for manual tasks (Moorthy et al., 2004; Suh et al., 2010), but noise was related to a higher error rate in a laparoscopic task (Moorthy, Munz, Dosis, Bann, & Darzi, 2003). A recent study analyzing noise peaks and communication on a five-minute by five-minute base showed that noise impaired task-related communication in the OR (Keller et al., submitted). For anesthetists, effects of noise have repeatedly been found: Noise exposure impaired anesthetist's mental efficiency and short-term memory (Murthy, Malhotra, Bala, & Raghunathan, 1995a) and decreased their speed of response to patient changes (Stevenson, Schlesinger, & Wallace, 2013).

Most of the empirical findings relating noise to surgical performance are based on short term experimental research. Effects of noise may be different if performance has to be maintained over a long period of time under elevated noise levels, and if additional stressors are present (Moorthy et al., 2003). It was indeed particularly prolonged exposure to noise that was related to reduced attention and impaired performance (Clark & Sörqvist, 2012).

Noise may impair performance because noise distracts and interferes with the ability to concentrate (Belojevic et al., 2001; Habibi, Dehghan, Dehkordy, & Maracy, 2013; Szalma & Hancock, 2011). In one study, surgeon auditory performance (correctly understanding a communication) under noise exposure was only impaired if the surgeons had to perform a manual task at the same time, or if the auditory content was novel and unexpected (Way et al., 2013). In another study, the combination of noise and other stressors led to highest performance impairments (Moorthy et al., 2003). Thus, noise is most likely to have a negative impact on performance when task complexity is high (Loewen & Suedfeld, 1992). During surgeries, task complexity varies. Periods of high complexity differ in the surgical phases opening – main phase – and closure (Tsiou et al., 2008; Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt, 2010) for the OR personnel. For surgeons, the main phase of the surgery is the most complex phase and generates the highest cognitive workload (Parker, Flin,

McKinley, & Yule, 2014). For anesthetists, the closure phase is particularly demanding, because patient emergence is induced during this phase (Broom et al., 2011; Jenkins, Wilkinson, Akeroyd, & Broom, 2015; Parker et al., 2014). Several authors have indeed discussed the potentially important effect of distractions if they happen in critical phases of the surgery (Broom et al., 2011; Jenkins et al., 2015; Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt, 2010).

In many hospitals, the main surgeon is present during high complexity periods; he or she may come only for such periods, and leave when they are over; this study therefore defines phases of high complexity on the basis of the main surgeon being present.

Aim of this study was to identify whether elevated noise levels in the OR in different periods of the procedure led to distractions of surgeons, anesthetists or scrub nurses.

METHODS

This prospective observational study took place in the visceral surgical department of a middle sized European University Hospital between November 2010 and July 2013. It combines noise exposure measurements during surgeries with questionnaire data related to the same surgeries. Questionnaire data were collected from main and second surgeons, anesthetists and scrub nurses before leaving the OR.

Inclusion criteria were elective surgeries planned as open abdominal procedures with an expected duration of minimally 60 minutes and maximally 7 hours (the limit of the sound meter recording capacity was 8 hours); the availability of the sound meter, and the availability of observers to collect questionnaires. Data were collected for 119 surgeries; nine surgeries had to be excluded because of technical problems with the sound meter, the final sample is 110 surgeries. The local ethical board of the hospital approved the study.

Sound pressure levels (noise) in the OR, were measured with a digital sound level meter (TES-1352H (©, TES Electrical Electronic Corp., Taipei, Taiwan, R.O.C.)). A-weighted sound pressure levels (SPL) were recorded each second and stored on the device for offline analysis. The sound meter was placed on the main operative lamp above the surgical team, to capture noise as heard by the sterile surgical team. The recording was time stamped, the sound level for each second between incision and closure was used for analyses. Noise levels were calculated for each phase of the surgery.

Although measuring sound pressure level is relatively easy, it is more difficult to assess noise levels, because they fluctuate over time. A common measure of noise background levels for a given exposure time is the median noise level (L_{50}), which is the level of noise that is exceeded during 50 percent of exposure time. This measure has been used in previous OR related studies (Hodge & Thompson, 1990; Tsiou et al., 2008). For this study, we also chose L_{50} to describe noise exposure, focusing on the noise levels exceeded in 50% of the duration of the respective phase for each surgery. In contrast to e.g. the Leq (energetic average sound pressure level) this metric has the advantage, that it is relatively insensitive to suddenly occurring high level noises that are not representative for the measurement period.

Assessment of being distracted was the main outcome variable in this study and was measured on an individual basis as the subjective self-reported distraction during the surgery. This was assessed with one question in the questionnaire, using a 1 to 7 scale with two opposite

poles: "During this surgery, I could work in a very *concentrated way (1)* to …I felt *very distracted (7)*. Respondents were classified as distracted if they indicated a level of distraction of four or higher; they were classified as concentrated, if they indicated a level of distraction of three or less.

Phases of the surgery were distinguished based on the presence of the main surgeon (Kurmann et al., 2014), as his or her presence likely indicates a high complexity period. In the surgical department where the study took place, second surgeons (holding a general surgery degree and working towards a specialty degree) are the responsible surgeons for less complex periods. They often start the surgery until the target organs are ready for resection (*Phase 1*). The main phase (*Phase 2)* starts when the main surgeon joins the team. He or she was always present during the middle part of the procedure. Unless there are special events or requirements, the main surgeon leaves before closing (most often around the last sponge count); if this happens, the third, and final phase starts *(phase 3)*. For some procedures, the main surgeon was present throughout the procedure; in this case, the whole surgery was considered to be phase 2. If the main surgeon was present from the beginning but left before closure, we coded no phase 1 for those surgeries. If the main surgeon joined for phase two and stayed to the end of the surgery, we coded no phase 3.

Observers were present throughout the entire surgery. They installed the sound meter before the patient was wheeled in the room, noted time of incision, time of closure, as well as time of arrival and departure of the main surgeon, and they administered the questionnaires. After their duty, but before leaving the OR, each member of the surgical team was asked to fill in a short questionnaire that measured the reported distraction. Each person responded individually, the responses were not shared with the team. Confidentiality was assured by the observers.

Statistical analyses were performed using SPSS® for Windows ® version 22 software (IBM, Armonk, New York, USA), $P < 0.05$ (two-tailed) was considered statistically significant; 95% confidence intervals are reported. The difference of noise levels across phases between different types of surgeries was tested with a repeated measurement ANOVA, pairwise comparisons were based on the Least Square Difference method. Influences of noise levels on self-reported distraction were assessed using univariable logistic regression for univariable effects and adjusted logistic regression for effects adjusted for type of surgery as well as for duration of the phase.

RESULTS

Sample characteristics:

The total sample consisted of 110 surgeries, of those, 53 were hepatobiliary surgeries, 19 upper gastro-intestinal tract surgeries, 26 lower gastro-intestinal tract surgeries, 12 other visceral surgeries, and one surgery was not finished as planned, because it was terminated after a diagnostic laparoscopic procedure. Mean duration of the operations from incision to closure was 4.34h (SD = 1.65h); median = 4.27h; duration ranged between 1.2h and 7.3h.

Response rate for the distraction self-report questionnaires was 91.8% for the main surgeons; 76.4% for the second surgeon; 95.5% for the anesthetists, and 96.4% for the scrub nurses. According to the cut-off criteria (higher than 3/7), 38.6% of the main surgeons, 42.9% of the second surgeons, 16.2% of the anesthetists, and 11.3% of the scrub nurses complained being distracted during the surgery.

In 91 of the 110 surgeries, the main surgeon joined the team for the main phase and left after the main phase. In 4 surgeries, the main surgeon was present throughout the surgery, in 13 surgeries, the main surgeon was present from the beginning, but left after the main phase; in 2 surgeries, the main surgeon joined for the main phase and stayed until the end of the surgery. Duration of the different phases and noise levels are reported in Table 1.

Noise level in different phases and types of surgery

Noise levels (L_{50}) were significantly higher in the main phase as compared to the preparation phase (t=-9.42, df 92. P<.001), and significantly higher in the closing phase as compared to the preparation phase (t=-7.990, df 86. P<.001), noise levels were not significantly different between the main phase and the closing phase (t=-1.899, df = 97, P=.060) (Table 1). Noise levels between surgery types were not significantly different (Table 2), with one exception: In the main phase, hepatobiliary surgeries were significantly louder than lower GI-tract surgeries (P=.008).

Table 1
Duration and noise levels for different phases of surgeries

				95% CI				95% CI	
	N	mean duration [h]	SD duration [h]	lower	higher	L50 [db(A)]	SD [db(A)]	lower	higher
Phase 1: Preparation	93	1.17	0.776	1.01	1.32	54.52	1.55	54.21	54.84
Main phase	110	2.45	1.49	2.38	2.94	55.84	1.73	55.51	56.16
Phase 3: Finishing and closing	104	0.81	0.69	0.68	0.95	56.34	1.93	55.96	56.34

Table 2
Type of surgery, and mean noise level (L_{50}) in different phases

Surgery type	Upper GI tract		Hepatobiliary		Lower GI tract		Other	
	M	95% CI	M	95% CI	M	95% CI	M	95% CI
Phase 1 noise level [dB(A)]	54.49	(53.76 -55.23)	54.88	(54.44 -55.32)	53.79	(53.1 -54.49)	54.39	(53.24 -55.54)
Main phase noise level [dB(A)]	56.00	(55.25 -56.75)	56.30	(55.83 -56.76)	55.21	(54.56 -55.86)	55.44	(54.45 -56.42)
Phase 3 noise level [dB(A)]	56.69	(55.8 -57.59)	56.22	(55.67 -56.77)	56.38	(55.56 -57.21)	56.85	(55.59 -58.11)

Note: Noise level is expressed in L_{50} for each phase, M refers to the arithmetic mean of the L_{50} values

Noise and reported distraction

Table 3 lists Noise levels for main surgeons, second surgeons, anesthetists, and scrub nurses who reported concentration or distraction; for main surgeons, data are given for the main phase only, as they were present during this phase only. Table 4 contains univariable results and results adjusted for duration of phase and surgery type for all three phases, based on logistic regression analyses. The results show that noise levels did not affect self-reported distraction for main surgeons nor for scrub nurses in any phase of the surgery. For second surgeons, reported distraction was significantly related to higher noise levels, but only in the main phase, not in the opening or closing phase. Adjusting for phase duration and surgery type did not change this result. For anaesthetists, reported distraction was significantly related to higher noise levels only in the closing phase of the surgery, but not in the opening and main phase. Adjusting for phase duration and type of surgery did not change this result. Figure 1a and 1b illustrate noise levels for second surgeons reporting concentration versus distraction in the main phase and for anaesthetists reporting concentration versus distraction in the closing phase.

Table 3
Noise level in phase 1-3 for main and second surgeons, anaesthetists, and scrub nurses reporting low vs high distraction levels

Target	Main surgeons		Second surgeons		Anaesthetists		Scrub nurses	
	concentrated	distracted	concentrated	distracted	concentrated	distracted	concentrated	distracted
Phase 1 L_{50} noise level [dB(A)]	-[a]	-[a]	54.05 (1.63)	54.47 (1.13)	54.51 (1.40)	54.27 (1.72)	54.59 (1.41)	54.31 (1.79)
Main phase L_{50} noise level	55.88 (1.62)	55.85 (1.86)	55.34 (1.64)	56.20 (1.42)	55.82 (1.74)	56.09 (1.52)	55.86 (1.68)	55.71 (1.91)
Phase 3 L_{50} noise level	-[a]	-[a]	56.20 (1.83)	56.38 (2.00)	56.14 (1.85)	57.20 (1.90)	56.36 (1.93)	56.05 (1.41)

Note: high self-reported distraction: > 3. [a]Main surgeon is not present in this phase

Table 4
Relationship of noise level and reported distraction; univariable and adjusted for duration of surgery and type of surgery

	Main surgeons		Second surgeons		Anestethists		Scrub nurses	
	univariable OR; 95% CI; P	adjusted OR; 95% CI; P	univariable OR; 95% CI; P	adjusted OR; 95% CI; P	univariable OR; 95% CI; P	adjusted OR; 95% CI; P	univariable OR; 95% CI; P	adjusted OR; 95% CI; P
Phase 1 distracted	-[a]	-[a]	1.26 (0.915-1.77); 0.169	1.31 (0.91-1.88); 0.151	0.90 (0.610-1.339); 0.616	0.96 (0.58-1.61); 0.584	0.928 (0.59-1.46); 0.745	0.969 (0.58-1.61), 0.904
Main phase distracted	0.989 (0.78-1.25); 0.924	0.895 (0.69-1.17); 0.412	1.476 (1.07-2.03); 0.017	1.45 (1.04-2.01); 0.029	1.108 (0.81-1.52); 0.522	1.044 (0.73-1.49); 0.811	0.951 (0.67-1.35); 0.782	0.951 (0.68-1.36); 0.811
Phase 3 distracted	-[a]	-[a]	1.068 (0.84-1.36); 0.588	1.075 (0.84-1.38); 0.566	1.367 (1.02-1.83); 0.036	1.395 (1.01-1.93); 0.045	0.922 (0.66-1.29); 0.638	0.865(0.61-1.22); 0.412

Note. OR: Odds Ratio, 95% CI: 95% Confidence interval: -[a]Main surgeons were not present in this phase

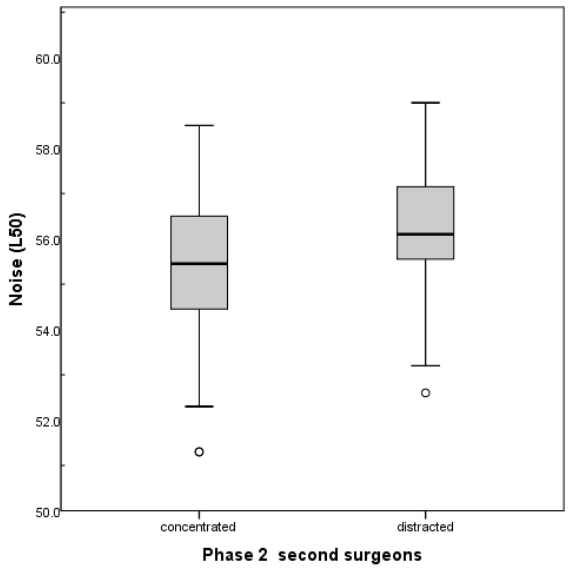

Figure 1a (second surgeons)

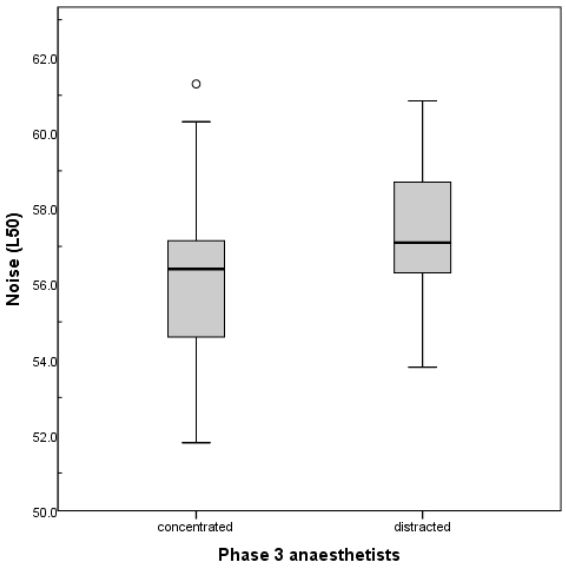

Figure 1b (anaesthetists)

Figure 1a. Boxplot illustration of noise level for second surgeons reporting being able to work concentrated or being distracted in phase 2.
Figure 1b. Boxplot illustration of noise level for anaesthetists reporting being able to work concentrated or being distracted in phase 3.

DISCUSSION

This study confirmed that noise pollution in the OR is a real concern.

First, recommendations for maximum noise levels when people have to perform tasks requiring high mental concentration is 55 dB(A) (Berger, Royster, Royster, Driscoll, & Layne, 2003; Engelmann, Neis, Kirschbaum, Grote, & Ure, 2014). In the current study, this recommended level was exceeded in at least 50% of the time in the main and the closing phase, and this applied for all surgical types included. Other studies reported either similar (Tsiou et al., 2008), or even higher noise pollution (Healey et al., 2007; Ryherd et al., 2012) in the OR. Note that the mean duration of the main phase was about two hours and thirty minutes, and the mean duration of the last phase was about 50 minutes; this implies that exposure time to noise above recommended levels was considerable.

Second, noise level was not stable across the different phases of the surgery. In the current study, the main and closing phases were noisier than the opening phase. This result corresponds to several previous studies that reported increasing noise levels during surgeries or reported a particularly high noise pollution in the last phase of a surgery (Broom et al., 2011; Ginsberg et al., 2013; Jenkins et al., 2015; Kurmann, Peter, Tschan, Muhlemann, et al., 2011; Tsiou et al., 2008). It also implies that noise pollution is highest in the phases of high mental workload for surgeons (main phase) or for anesthetists (finishing and closing) (Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt, 2010).

Surgeons, anesthetists and nurses reported whether they were distracted at the end of their presence in the OR, referring to the total time they were present. It is possible that participants subjectively "averaged" noise levels over the whole time they were present; it seems more likely, though, that their judgements were most strongly influenced by moments of especially high distraction. Thus, only noise in the main phase influenced second surgeons' reported distraction, and only noise in the last phase influenced anesthetists' reported distraction. This indicates that indeed, noise pollution in high mental workload phases is particularly harmful.

In hospital settings such as the one studied (university hospital), the main phase of the surgery may be particularly straining for two reasons. First, second surgeons are present from the beginning of the surgery; at the time the second phase starts, they have already spent more than an hour operating. Second, they are in a training situation. If they are not yet very familiar with the procedure, they have to concentrate on performing the surgery and on learning on how to perform the surgery during the main phase. If they are already well trained in the surgery, they have to perform the surgery under close supervision from the main surgeon. These factors can be additional stressors in the main phase.

For anesthetists, emergence is one of the most intense phases of their work. To allow for concentrated work during this phase, several authors have discussed the suggestion of a "sterile cockpit" period - a period that is explicitly declared as high workload during which distractions should be limited (Broom et al., 2011; Jenkins et al., 2015; Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt, 2010; Wahr, Prager, Abernathy, Martinez, Salas, Seifert, Groom, Spiess, Searles, Sundt, et al., 2013). Explicitly restricting distraction during the closing phase may be particularly important, because the closing phase is a more routine phase for surgeons and nurses, as the operating team has finished their main task

at that time. Therefore, they start relaxing (Katz, 1981; Tschan et al., in press), and may fail to take into account that this is a phase of especially high concentration for anesthetists. In addition, anesthetists may be particularly vulnerable to noise distractors, because part of their task is vigilant surveillance. Anesthetists have to react to patient changes rapidly, and an important information base for them are auditory sources (such as pitch changes in surveillance sounds, as well as auditory alarms) (Stevenson et al., 2013). Thus, anesthetists cannot use a strategy of blocking out noises to protect themselves from noise pollution, because such a strategy might impair their vigilance.

Interestingly, scrub nurses and main surgeons' assessment of distraction were not related to noise levels. For scrub nurses, this can be explained by the fact that for them, none of the three intraoperative phases is characterized by very high mental workload, if no extraordinary events occur. Rather their mental workload is highest during the preparation of the surgery (Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt, 2010).This reasoning is supported by the fact that in the current study, only 11.3% of scrub nurses were classified as distracted, based on their self-report.

Main surgeons may not report higher levels of distractions in the main phase of the surgery because of their higher experience. Highly experienced surgeons have been found to be able to block out distractors (Moorthy et al., 2004), and studies investigating the effect of distractors other than noise revealed that it was the less experienced surgeons who showed the most performance impairments under distracting conditions (Hsu et al., 2008; Suh et al., 2010). However, this does not mean that surgeons are totally oblivious to noise distractions – in another study, almost 60% of surgeons reported that loud noises have the potential to disturb them (Tsiou et al., 2008).

A strength of this study is that noise measures and subjective measures of reported distraction in the same surgeries were combined. Previous studies in the OR did assess subjective noise annoyance and objective noise measures, but did not combine them. Note that the question used in this study did not ask about whether one was distracted by noise, but rather asked about general distraction during the surgery. Thus, the answers are most likely not biased by the knowledge that noise influences concentration. Another strength is that this study distinguished different phases of the surgery, and thus could assess the impact of noise in periods of high mental workload. A limitation of the study is that only duration and surgery type were included as potentially confounding variables. It cannot be excluded that noise as well as reported distraction were influenced by a third, unmeasured variable. It was also not possible to measure surgical performance during the different phases in this study. Finally, the definition of phases on the basis of the main surgeon being present may not fully correspond to the complexity of tasks demands; for instance, the main surgeon might stay during periods of lower complexity for reasons of teaching. However, other definitions of phases (e.g., based on time) would entail similar problems, and a definition based directly on complexity was beyond the expertise of the observers. Note, however, that the presence of the main surgeon during less complex periods would lead to an underestimation of the effects of complexity, and therefore is not likely to invalidate our results.

Noise levels in the OR settings are higher than recommended for high concentration work, and noise during high mental workload periods interferes with the concentration of OR

personnel. If possible, noise should be reduced to recommended levels or below. Noise reduction is indeed one of the key safety design principles recommended in healthcare (Reiling, 2006).

Many noises stem from technical devices used in the OR (Ginsberg et al., 2013; Tsiou et al., 2008). Suppliers of technical devices should be asked to find technical solutions for reducing unwanted noise from the devices. Another source of noise is behavior. It might be helpful to remind OR personnel regularly of engaging in conscious attempts to limit unnecessary noises, particularly in the last phase of the surgery, when part of the team may be starting to relax. Note, however, that general "rules of silences" are not very likely to be successful for surgeries as long as the ones studied here; rather, periods of "silence" should alternate with well-timed periods of relaxing and chatting, which may help energize the team and maintain a good climate and high morale (37). Noise reduction programs in hospitals in general (MacLeod, Dunn, Busch-Vishniac, West, & Reedy, 2007), and in OR's specifically (Engelmann et al., 2014), showed that mean reductions of 3 to 5 dB can be achieved. Note that an increase of 3 dB represents doubling the acoustic energy, and an increase of 6 dB is perceived as about 50% increase in volume (South, 2004), so noise reductions of a few dB are already very worthwhile.

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Paper 5: Noise peaks influence communication in the operating room: an observational study

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ABSTRACT

Noise peaks are powerful distractors. This study focuses on the impact of noise peaks on surgical teams' communication during 109 long abdominal surgeries. We related measured noise peaks during five minute intervals to the amount of observed communication during the same interval. Results show that noise peaks are associated with less case-relevant communication; this effect is moderated by the level of surgical experience; case-relevant communications decrease under high noise peak conditions among junior, but not among senior surgeons. However, case-irrelevant communication did not decrease under high noise level conditions; rather, there was a trend to more case-irrelevant communication under high noise peaks. The results support the hypothesis that noise peaks impair communication because they draw on attentional resources rather than impairing understanding of communication. As case-relevant communication is important for surgical performance, exposure to high noise peaks in the OR should be minimized especially for less experienced surgeons.

INTRODUCTION

Noise has been defined as "the wrong sound at the wrong place" (Murthy et al., 1995a) or as an "unwanted sound" (Blomkvist et al., 2005; Hodge & Thompson, 1990). Noise is a nuisance and negatively affects well-being and performance (Edworthy, 1997; Passchier-Vermeer & Passchier, 2000; Szalma & Hancock, 2011); this has also been shown in healthcare settings (Blomkvist et al., 2005), including in surgery (Katz, 2014).

Modern operating rooms (ORs) are not quiet work environments (Healey et al., 2007; Kracht et al., 2007); noise levels in ORs range between 58 and 67 dB(A) (Kracht et al., 2007) (Healey, Sevdalis, et al., 2006b), which is well above international standards for concentrated work (Kam et al., 1994; Shankar et al., 2001). Such noise levels are everything but a secondary concern in the OR, and negative consequences of noise are often assumed.

Past research focused mainly on the consequences of noise on individual performance of OR personnel (e.g. on concentration), or on patient outcomes (Healey, Sevdalis, et al., 2006b; Kurmann, Peter, Tschan, Muhlemann, et al., 2011). To our knowledge, no study has yet assessed the consequences of *changing* noise levels on the ongoing *team processes*. The present study contributes to filling this gap by assessing the impact of loud noise peaks on communication activities within the surgical team. We focus on communication because good teamwork is important for surgical performance (Kurmann et al., 2012; Wahr, Prager, Abernathy, Martinez, Salas, Seifert, Groom, Spiess, Searles, Sundt, et al., 2013; Weaver et al., 2010), and because sharing information and the exchange of patient-relevant communication within the surgical team has been found to be related to fewer patient complications (Mazzocco et al., 2009; Tschan et al., 2015, early view).

Sources and Effects of Noise in the OR

Sources of loud noises in the OR have been associated to technical equipment and the handling of equipment (Broom et al., 2011). For example, a suction device can produce up to 75-80 dB(A); or a metal bowl falling on the floor generates more than 100 dB(A) (Hodge & Thompson, 1990). Communication can also be a source of noise in the OR (Hasfeldt et al., 2010; Shankar et al., 2001), but normal human speech hardly reaches 70 dB(A). In this study, we thus focus on high noise peaks above 70 dB(A).

Effects of Noise on (Surgical) Performance

Loud auditory stimuli are necessarily processed by the attentional system, it is thus difficult to ignore noise (Edworthy & Hellier, 2000). Surgeons are well aware of noise in the OR: Two thirds of surgeons assumed that noise in the OR negatively influenced their work (Tsiou et al., 2008). OR staff also perceived more than the usual level of distractions and noise before an adverse event occurred (Grayson et al., 2005). Empirical field studies linking noise to surgical outcomes corroborated these results: Higher noise levels in the OR were associated with an increased probability for surgical site infections (Kurmann, Peter, Tschan, Muhlemann, et al., 2011); and a noise-reducing intervention led to a decreased complication rate (Engelmann et al., 2014). Although both studies established a link between noise and surgical outcomes, they did not investigate the possible processes involved. Noise may affect individual

performance by distracting concentration, and/or affect performance by impairing team communication. We discuss both aspects.

Noise and individual performance. Noise influences individual performance through several processes. First, noise has *physiological* effects. Noise arouses the autonomic nervous system; it increases in blood pressure, heart rates and stress hormones (Basner et al., 2014; Rylander, 2004). A link between noise levels and stress of the surgical team has been suggested (e.g. Hodge & Thompson, 1990; Shankar et al., 2001; Wetzel et al., 2006), and an empirical study showed indeed that a reduction of noise in the OR was associated with a reduction of physiological stress parameters (e.g. cortisol values) of surgeons (Engelmann et al., 2014).

Second, noise impacts *cognitive performance*. Noises of more than 75 dB(A)) had a negative impact on the performance of resident anesthesiologists who were asked to perform memory and mental efficiency tasks (Murthy et al., 1995a). This result is in accordance with findings in other settings, showing that noise impairs performance on cognitive tasks (Loewen & Suedfeld, 1992) because it lowers attention and concentration (Hygge & Knez, 2001; Szalma & Hancock, 2011). Although participants were faster to solve attentional tasks under noisy conditions in one study, the accuracy of performance was worse compared to a silent condition (Hygge & Knez, 2001; Szalma & Hancock, 2011).

Third, noise impairs *sensory-motor task performance*, which is particularly important in the OR setting. A recent meta-analysis found medium effects sizes for the negative impact of noise on motor processes (Szalma & Hancock, 2011).

Fourth, noise influences *emotional reactions*. Morrison *et al.* (2003) found more annoyance among nurses in a noisy pediatric intensive care unit, and Blomkvist et al. (2005) showed that noise reduction in a critical care unit lowered tension and irritation levels among the personnel. Experimental studies also showed that noise was associated with more anxiety (Smith et al., 1997) and displeasure (Loewen & Suedfeld, 1992). Pluyter et al., (2010) had surgical residents perform a laparoscopic task under distracting conditions, including noise. Participants reported a higher level of irritation towards the sources of the distraction (i.e., noise and the (intentionally clumsy) assistant). Of note, it seems that negative emotions in a noisy environment often are not due to the physical properties of the noise but are rather a reaction on the disruption of efficient performance caused by noise levels (Zimmer et al., 2008).

Noise effects on communication. One of the main concerns regarding noise in the OR are its effects on *communication* (Hasfeldt et al., 2010; Hodge & Thompson, 1990; Shankar et al., 2001; Tsiou et al., 2008; Way et al., 2013). Evidence from other contexts suggest indeed that noise impairs performance of tasks that rely on communication (Szalma & Hancock, 2011). For example, people living close to airports report that conversation suffers most under aircraft noise (Stansfeld & Matheson, 2003). Noise impairs the listener to understand the communication (Barach & Weinger, 2007; Shankar et al., 2001), and thus threatens the complete and accurate transmission of information from speaker to listener (Solet et al., 2005). In everyday and routine conversations, listeners may infer missing information from the context; thus, noise is especially harmful for comprehending communication when the information to be received is unpredictable or complex (Kurmann, Peter, Tschan, Muhlemann, et al., 2011; Way et al., 2013).

For speakers, the obvious solution with noise present is to raise the voice (Barach & Weinger, 2007; Hodge & Thompson, 1990; Kracht et al., 2007; Orellana et al., 2007; Shankar

et al., 2001). Speaking louder (the so-called Lombard reflex (Junqua, 1996)), was indeed the reaction of two thirds of participants exposed aircraft noise (Key & Powell, 1980). However, the remaining third of study participants interrupted their communication under noise, which can be explained by the fact that noise captures attention (Szalma & Hancock, 2011). In sum, noise impairs the transmission of information, and does more so if the information is complex. Noise forces speakers to either raise their voice or to interrupt the communication.

Noise and communication in surgery. Surgery is performed by a multi-disciplinary team (Nurok, Evans, et al., 2011) that needs to communicate during the procedure. Case-relevant communication (talking about the patient or the procedure), is a key factor for team coordination and has been found to influence surgical performance (Mazzocco et al., 2009; Nurok, Sundt III, et al., 2011; Tschan et al., 2015, early view). Case-relevant communication facilitated situation awareness, helped building a shared mental model (Catchpole et al., 2008), and helped coordinating the team (Xiao, Parker, & Manser, 2013). Communication failures or delays impair performance by increasing the likelihood of mishaps (Davies, 2005; Lingard, 2004); communication problems are a common cause of adverse events (Christian et al., 2006; Leonard, Graham, & Bonacum, 2004). Besides of case-related communication, communication in the OR can also be case-irrelevant (e.g. social talk). Case-irrelevant communication during surgeries has been studied as a distractor that can interfere with the surgical task, but it also fulfills social functions in the team (Healey, Sevdalis, et al., 2006b; Sevdalis et al., 2007).

We contend that case-relevant communication demands more attention than case-irrelevant communication, because it is more complex and team members need to correctly understand it. Given that noise draws attentional resources, we can expect that noise in the OR interferes particularly with case-relevant communication. Case-irrelevant communication may be less affected by noise, because it is not essential for the task that team members correctly understand it in all details.

Based on these considerations, we state the following hypothesis:

Hypothesis 1: Noise impairs case-relevant communication during surgeries in the sense that under high noise, surgical teams engage in less case-relevant communication.

Noise Characteristics: Noise levels versus noise peaks

The auditory system reacts more strongly to changes in sound levels than to continuous sounds (Rylander, 2004). Sudden changes, for example noise peaks, induce an orienting reflex and a startling response (Hodge & Thompson, 1990). Because changes in noise levels are particularly distracting, previous research suggested that noise peaks (sudden, particularly loud noises) impact performance more than constant noise (Baker & Holding, 1993). Research on emotional (Guski et al., 1999; Passchier-Vermeer & Passchier, 2000), cognitive (i.e. reading ability) (Clark et al., 2006) and physiological effects of noise (Allen & Blascovich, 1994) all suggest stronger effects for noise peaks than for steady noise levels. This is corroborated by results of studies using simulated surgical tasks. Whereas studies using distractors consistently found negative effects on performance (e.g. more errors, longer time to finish the task) (Feuerbacher et al., 2012; Goodell et al., 2006b; Pluyter et al., 2010; Suh et al., 2010), noise levels alone were not associated with worse performance in a similar study (Moorthy et al., 2004). The authors of this latter study argue that the absence of noise peaks could in part explain the absence of effects of noise on performance (Moorthy et al., 2004).

In the OR, noise peaks are very frequent (Broom et al., 2011); one study reported over 90 peaks above 70 dB(A) per hour (Engelmann et al., 2014). The number of noise peaks varied with different phases of the surgery (Broom et al., 2011); they were more frequent at the beginning and at the end of the procedure (Engelmann et al., 2014). Given the frequency of noise peaks and their particularly high potential for distractions, we used noise-peaks above 70 dB(A) in this study.

Experience level as a Moderator of the Negative Effects of Noise (Peaks)

Experience levels of surgeons may moderate the impact of noise on performance. Moorthy *et al*. (2004) claim that especially experienced surgeons are more able to "block out" noises and that experienced surgeon's behavior and performance is less influenced by noise or noise peaks than junior surgeon's behavior and performance. Most studies that found negative effects of noise and distractors on surgical performance were conducted with less experienced junior surgeons or medical students (Feuerbacher et al., 2012; Goodell et al., 2006b; Pluyter et al., 2010). Studies that included participants with different levels of expertise showed that less experienced surgeons were more likely distracted than experienced surgeons (Hsu et al., 2008; Suh et al., 2010). These results are in line with other research showing that noise has more negative effects as task complexity increases (Loewen & Suedfeld, 1992). Because task complexity also depends on experience, noise peaks should impact junior surgeons more than senior surgeons.

Based on these considerations, we state the following hypothesis:

Hypothesis 2: Noise peaks impair case-relevant communication more when less experienced (junior) surgeons (vs senior surgeons) are in charge of the surgery.

METHODS

Sample

Inclusion criteria were major, elective open abdominal surgeries with a planned duration of at least one hour, and the availability of observers. The initial sample consisted of 119 procedures. 9 surgeries were excluded because of errors with the technical handling of the sound meter (e.g. the noise was measured in dB(C) instead of dB(A) or the recordings were not complete, because the duration of the surgery exceeded the recording capacity of the noise recording device) and we also excluded one surgery that was finished after a laparoscopic diagnosis; thus, the final sample was 109 surgeries. The surgeries were performed in two operating rooms of similar size and identical equipment at a university hospital in Switzerland. Procedures included 19 surgeries of the upper gastro-intestinal tract; 29 hepato-biliar surgeries, 23 surgeries of the pancreas, 26 lower gastro-intestinal tract surgeries, and 12 other visceral surgeries (e.g. open hernia, adhesiolysis).

The surgical teams were composed of a senior surgeon (approximately 20 years of experience), a junior surgeon (a resident working towards a specialized surgical degree), one very junior resident and/or a medical student, at least one anaesthetist; one scrub nurse and at least one circulating nurse.

The local ethics committee of the hospital approved the study.

Apparatus.

Noise levels in the OR were recorded using a TES-1352H (©, TES Electrical Electronic Corp., Taipei, Taiwan, R.O.C.) digital sound level recorder. The sound pressure level was recorded as dB(A) for each second, and time-stamped. The sound level recorder was placed in a holder on the main operative lamp, about 1.5 meters above the operative field (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). This location was in the center of the OR and allowed noise measures similar to those the surgeons were exposed to.

Procedure

When a surgery was scheduled for observation, the observers installed the noise device before the patient was wheeled into the OR. Observers were present in the OR for the whole procedure. They were seated about 2.5 m away from the operating table on the left side of the patient, facing the senior surgeon and observed communication as well as distractors (see below). After the surgery, the noise levels meter recordings were transferred to a computer. To relate noise measures to communication measures, the surgical procedure was divided in five-minute intervals between incision and closure, noise peaks and communication for each five-minute interval were calculated as described in the next section.

Measures

Duration of the surgery was measured as time elapsed between incision and the last stitch of closure.

A noise peak was recorded for each second the noise level reached 70 dB(A) or higher in any given five-minute interval of the surgery, similar to the practice of other studies (Broom et al., 2011; Engelmann et al., 2014; Gladd & Saunders, 2011). Noise peaks were rather infrequent, which would yield extremely small coefficients in regression analyses. In order to avoid reporting numbers with too many decimals, we divided noise peaks values by 10. This transformation expresses noise pollution as 10-percent increments of noise peaks - it does not change statistical significance levels.

Communication within the sterile surgical team (including communication on between the surgical team and the anesthetists) was observed using a reliable behavioral observational system (Seelandt et al., 2014). Inter-observer agreement was assessed based on 12 (11%) surgeries observed simultaneously by two independent observers. ***Case-relevant communication*** events were defined as uninterrupted communication related to the current patient or the current surgical procedure; they included (i) patient-relevant communication (e.g. talking about the patient or the procedure); (ii) teaching (e.g. explaining the steps of the procedure) or (iii) instructions (e.g. asking the anesthetist to insert a gastric tube) (Seelandt et al., 2014). Inter-observer agreement for case-relevant communication was 0.83, 0.86, and 0.94 (Cohen's Kappa) for patient-relevant communication, teaching, and instructions, respectively. Case-relevant communication was expressed as the sum of patient-relevant communication, teaching and instructions for each five-minute interval between incision and closure. ***Case-irrelevant communication*** was defined as (i) patient-irrelevant communication (talking about

something unrelated to patient or procedure, e.g. about the next patient or duty hours), and (ii) humor (joking, laughter) (Seelandt et al., 2014). Inter-observer agreement was 0.78, 0.89 (Cohen's Kappa), for patient-irrelevant communication and humor, respectively. Case-irrelevant communication was expressed as the sum of patient-irrelevant communication and humor for each five-minute interval of the surgery.

Observed loud noise events. In addition to the noise peaks measured by the sound recording device, observers noted and time-stamped particularly loud noises as noise distractors. Inter-observer agreement for loud noise events was 0.86 (Cohen's Kappa).

Experience levels of the surgeon in charge were defined based on the presence of the senior surgeon, in order to distinguish phases of responsibility of the senior or of the junior surgeon. In most surgeries (102/109), surgeon group composition changed during the procedure (Kurmann et al., 2014): The junior surgeon was in charge of the preparatory phase (Parker et al., 2014) until the target organs were ready for resection. The senior surgeon joined the team after the preparatory phase for the main phase; he or she was in charge of the resection and reconstruction. We did not distinguish whether the senior surgeon was performing the main phase of the surgery or assisting the junior surgeon during this phase. The senior surgeon often left after the main phase. The closure phase included lavage, placing of tubes, and closure of the abdominal wall, and was again under the responsibility of the junior surgeon. If the senior surgeon was present during the preparatory phase, the closure or during both, we considered these phases in charge of the senior surgeon. Junior surgeons are less experienced, and being in charge of parts of the surgery is a highly complex task for them, even if objectively, the phase of the highest task complexity is the phase of the surgery with the senior surgeon present.

Data preparation

Matching noise measures and observed communication events. Noise measures and observations were both time-stamped, allowing for matching the data sets by time. However, for 25 surgeries, the time of the sound recording device and the computer was off by a couple of minutes, due to technical problems. For theses surgeries, we controlled the correct temporal alignment of noise measures and observations by identifying at least three observed loud noises. Those were matched with noise-peaks measured by the sound recording device. Inter-rater agreement (intraclass correlation coefficient) for this time-matching procedure between two independent observers, based on all 25 surgeries, was 0.99.

Five-minute intervals. Noise data and observational data were aggregated for consecutive five-minute intervals, starting with the time of incision and then matched. The final data set thus included - for each five-minute interval between incision and closure - the noise peaks above 70 dB(A) in 10% increases (see above), the number of case relevant and case irrelevant communication events; and whether the senior or the junior surgeon was in charge. Lag-one measures of noise peaks and case-relevant and case-irrelevant communication (i.e. noise peaks and communication in the prior five minutes) were calculated.

Data analyses

Aim of data analyses was to test the impact of noise peaks on case-relevant and case-irrelevant communication, based on five-minute intervals for the whole surgery and for phases

the senior and junior surgeons were in charge separately. Because the data set is nested (five-minute intervals within surgeries), we used multilevel modelling (Hedeker, Gibbons, & Flay, 1994). Noise peaks, case-relevant communication and case-irrelevant communication per five-minute interval were Level 1 variables, surgeries were Level 2 variables. Noise peaks and case-relevant as well as case-irrelevant communication in the prior five-minute interval were Level 1 control variables. Surgeon in charge was the Level 1 variable used to express experience levels. Duration of the surgery was a Level 2 control variable. Analyses were conducted using IBM SPSS statistics 21 (IBM, 2013).

RESULTS

Descriptive results

We first report surgery characteristics and descriptive statistics (Table 1). Mean duration between incision and closure was 4.37h (SD = 1.64), range was between 1.23h and 7.35h; total observation time was about 450 hours. The phase of high task complexity with the senior surgeon in charge was significantly longer than the phase with the junior surgeon in charge. Mean overall noise levels (Leq in dB(A)) were not significantly different between phases the senior or the junior surgeon was in charge. However, in phases with the less experienced junior surgeon in charge, significantly more noise-peaks above 70 dB(A) per hour were observed than in the high complexity phase with the senior surgeon in charge. In the phase with the senior surgeon in charge, more case-relevant communication per hour were observed than if the junior surgeon was in charge. There was a non-significant trend towards more case-irrelevant communication per hour in the phase with the junior surgeon in charge.

Table 1. Description of noise and communication during the surgeries and the phases where the senior respectively the junior surgeon are in charge

	Overall (N=109)		Senior surgeon in charge (N=102) [1]		Junior surgeon in charge (N=102) [1]			
	M	SD	M	SD	M	SD	t(101)	p
Duration (hours)	4.37	1.64	2.62	1.49	1.85	1.05	3.86	$p < 0.001$
Leq (dB(A))	59.53	1.44	59.57	1.73	59.72	1.67	-0.83	$p = 0.410$
Noise peaks equal or above 70 dB(A) (Mean per hour)	34.20	19.88	31.35	25.38	43.48	37.59	-3.04	$p = 0.003$
Case-relevant communication (Mean per hour)	23.15	7.97	23.42	8.12	19.16	9.79	3.74	$p < 0.001$
Case-irrelevant communication (Mean per hour)	6.08	5.38	5.65	4.91	7.47	8.38	-1.96	$p = 0.052$

[1] *Note* that in 7 surgeries, the senior surgeon was present all the time, and thus, the duration of the absence of the main surgeon and the noise during this phase is calculated only for the surgeries characterized by a phase of absence of the senior surgeon. The senior surgeon was considered as present all the time if present for at least during 99% of the time of the surgery.

Table 2. Means, standard deviations and intercorrelations of study variables (N = 5399 five-min intervals)

	M	SD	Min	Max	1	2	3	4	5	6	7	8
1. Duration of surgery (in hours)	4.37	1.64	1.23	7.35	NA	NA	NA	NA	NA	NA	NA	NA
2. Noise peaks per same 5-min interval (sum)	2.82	5.10	0	2.2	-0.08	NA	-0.08**	0.37**	-0.06**	0.03*	-0.08**	0.03*
3. Case-relevant communication prior 5-min interval (sum) [2]	NA	NA	NA	NA	NA	NA	NA	-0.06**	0.14**	-0.05**	0.29**	0.02
4. Noise peaks prior 5-min interval (in 10%) [1]	NA	NA	NA	NA	NA	NA	NA	NA	-0.06**	0.03*	-0.08**	0.02
5. Surgeon in charge (junior = 0, senior = 1) / at Level2, percent of time the senior surgeon was present during the entire surgery	NA	NA	NA	NA	0.09	0.01	NA	NA	NA	-0.01	0.14**	-0.01
6. Case-irrelevant communication prior 5-min interval (sum) [1]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04**	0.32**
7. Case-relevant communication same 5-min interval (sum)	1.85	1.33	0	8	0.04	-0.14	NA	NA	0.11	NA	NA	-0.04**
8. Case-irrelevant communication same 5-min interval (sum)	0.54	0.94	0	9	-0.18	-0.04	NA	NA	0.24**	NA	0.13	NA

Note. Above the diagonal, level1 correlations. Under the diagonal, level 2 correlations

[1] The Mean, standard deviation and level2 statistics of variables describing events that happened in the prior five-minute interval are given in the same table next to the variables that describe the events in the same five-minute interval.

Influence of noise-peaks on intra-surgical communication

Hypotheses were tested based on 5399 five-minute intervals nested in 109 surgeries. Intercorrelations among the study variables are displayed in Table 2. Assessment of Intraclass correlation coefficient (ICC) indicated a significant amount of variance both at the five-minute interval (Level1) and between surgeries (Level 2); this justifies the use of multi-level modeling (Hox, 2010). To test whether noise peaks affect communication, we separately assessed effects of noise peaks on case-relevant and case-irrelevant communication. We started with a null model without predictors to assess the proportion of variance on the five-minute interval and the surgery level. We then included the Level-2 control variable (duration of the surgery) (Model 1.1 and 1.2), and added the variable representing noise peaks in the same interval as the main predictor variable (Model 1.2 and 2.2). We subsequently added the following control-variables: a) communication in the previous five-minute interval (Model 1.3 and 2.3); and b) noise-peaks in the previous five-minute interval (Model 1.4 and 2.4). To test hypothesis 2 (noise peaks impair communication more if the inexperienced surgeon is in charge), we added a dummy variable representing whether the senior or the junior surgeon was in charge (Model 1.5 and 2.5) as well as the interaction term between noise-peaks in the same interval and the junior vs senior surgeon in charge (Model 1.6 and 2.6).

Hypothesis 1 stated that noise peaks would impair case-relevant communication. Results are displayed in Table 3 (Models 1.1 to 1.4). The null-model showed that 14% of the variance was at the surgery level, implying that a large proportion of the variance was at Level 1. Noise peaks in the same interval were related to a significant decrease in case-relevant communication (95% Confidence Interval (CI) [-0.78, -0.38]). This relationship remained significant after including the control variables. Hypothesis 1 is supported.

Hypothesis 2 stated that the relationship between noise peaks and case-relevant communication would be stronger when the less experienced surgeon was in charge. The interaction between surgeon in charge and noise peaks was significant, indicating that the effect of noise peaks on case-relevant communication differed by experience level of the surgeon in charge (95% CI [.04, 1.18]). Figure 1 illustrates this effect and shows that more noise peaks were associated with a decrease of case-relevant communication only when the less experienced surgeons were in charge (simple slope = -0.73, z = -5.00, $p<0.001$) but not when the senior surgeon was in charge (simple slope = 0.06, z = 0.42, p=0.673). This supports hypothesis 2.

We did not expect noise peaks to impair case-irrelevant communication. However, as Table 4, Model 2.2 shows, noise peaks were associated with *more* case-irrelevant communication in the same interval (95% CI [0.06, 0.35]) when no covariates at Level 1 were included into the model. The effect remained significant when case-irrelevant communication during the prior five-minute interval was introduced (Model 2.3, Table 4) but was only marginally significant when noise peaks during the prior five-minute interval were added (Model 2.4 in Table 4). Although we did not postulate that the relationship between noise-peaks and case-irrelevant communication would be moderated by surgical phase, we tested this interaction, which did not yield a significant result.

Table 3. Multilevel models to predict case-relevant communication per same 5-min interval

	Null model 1.0			Model 1.1			Model 1.2			Model 1.3			Model 1.4			Model 1.5			Model 1.6		
Variable	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t
Intercept	1.83	0.05	35.39***	1.68	0.15	11.12***	1.75	0.15	11.49***	1.42	0.13	11.20***	1.44	0.13	11.41***	1.29	0.13	10.00***			
Level 2																					
Duration of surgery (in hours)				0.03	0.03	1.02	0.03	0.03	0.94	0.03	0.03	1.04	0.03	0.03	1.02	0.03	0.03	0.95			
Level 1																					
Noise peaks per same 5-min interval[1]							-0.58	0.1	-5.66***	-0.5	0.1	-4.92***	-0.37	0.11	-3.48*	-0.33	0.11	-3.11*			
Case-relevant communication prior 5-min interval										0.18	0.01	13.73***	0.18	0.01	13.58***	0.17	0.01	12.33***			
Noise peaks prior 5-min interval[1]													-0.42	0.11	-3.84***	-0.39	0.11	-3.57***			
Surgeon in charge (junior = 0, senior = 1)																0.31	0.04	8.43***			
Noise peaks per same 5-min interval x Surgeon in charge																			0.79	0.2	3.98***
-2 X Log (lh)			17862.55			17866.56			17733.51			17667.64			17655.48			17589.78			17575.33
Difference of -2X Log						4.01			-133.05***			-65.87***			-12.16***			-65.70***			-14.45***
Df						1			1			1			1			1			1
VAR intercept level 2 (SE)			0.25 (0.04)			0.26 (0.04)			0.25 (0.04)			0.16 (0.03)			0.16 (0.03)			0.16 (0.03)			0.16 (0.03)
VAR intercept level 1 (SE)			1.53 (0.03)			1.53 (0.03)			1.53 (0.03)			1.49 (0.03)			1.48 (0.03)			1.46 (0.03)			1.46 (0.03)

Note. *p < 0.05. *** p < 0.001.

[1] Noise peaks episodes are not so frequent as to yield high numbers. As a consequence, coefficients become very small (e.g., 0.0001). In order to avoid reporting numbers with so many decimals, we divided noise peaks values by 10, this transformation does not change anything in terms of statistical significance, but expresses the effects as 10 percent increments of noise peaks.

Table 4. multilevel model to predict case-irrelevant communication per 5-min intervals

	Null model 2.0			Model 2.1			Model 2.2			Model 2.3			Model 2.4			Model 2.5			Model 2.6		
Variable	B	SE	T	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t
Intercept	0.56	0.03	16.74***	0.72	0.1	7.27***	0.69	0.1	7.00***	0.52	0.07	6.91***	0.51	0.07	6.87***	0.55	0.08	7.06***			
Level 2																					
Duration of surgery (in hours)				-0.03	0.02	-1.65	-0.03	0.02	-1.62	-0.02	0.02	-1.62	-0.02	0.02	-1.62	-0.02	0.02	-1.58			
Level 1																					
Noise peaks per same 5-min interval[1]							0.2	0.07	2.71*	0.15	0.07	2.06*	0.14	0.08	1.84†	0.13	0.08	1.74†			
Case-irrelevant communication prior 5-min interval										0.26	0.01	19.52***	0.26	0.01	19.50***	0.26	0.01	19.39***			
Noise peaks prior 5-min interval													0.03	0.08	0.36	0.02	0.08	0.28			
Surgeon in charge (junior = 0, senior = 1)																-0.05	0.03	-2.03			
Noise peaks per same 5-min interval x Surgeon In charge																			0.19	0.14	1.34
-2 X Log (lh)			14346.81			14350.01			14346.01			14003.69			14006.82			14008.18			14008.44
Difference of -2X Log						+3.2			-4*			-342.32***			+3.13			+1.36			+‘0.26
Df						1			1			1			1			1			1
VAR intercept level 2 (SE)			0.10 (0.02)			0.10 (0.02)			0.10 (0.02)			0.05 (0.01)			0.05 (0.01)			0.05 (0.01)			0.05 (0.01)
VAR intercept level 1 (SE)			0.80 (0.02)			0.80 (0.02)			0.80 (0.02)			0.76 (0.01)			0.76 (0.01)			0.76 (0.01)			0.76 (0.01)

Note. *p < 0.05. *** p < 0.001. † p< 0.1.

[1] Noise peaks episodes are not so frequent as to yield high numbers. As a consequence, coefficients become very small (e.g., 0.0001). In order to avoid reporting numbers with so many decimals, we divided noise peaks values by 10, this transformation does not change anything in terms of statistical significance, but expresses the effects as 10 percent increments of noise peaks.

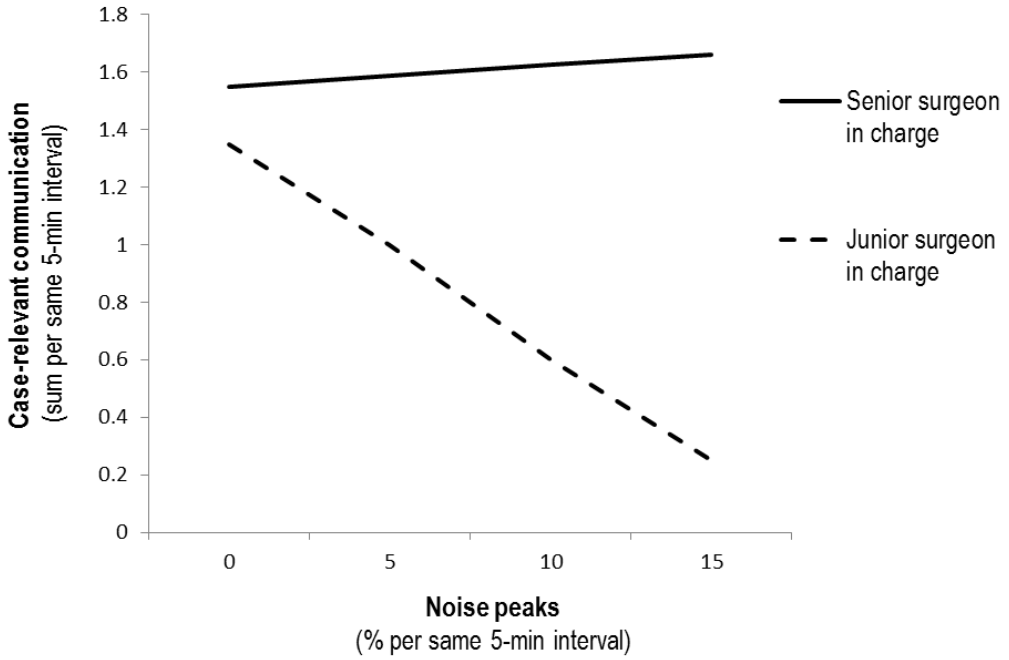

Figure 1. Interaction effect of noise peaks (in percentage per same five-minute interval) (x-axis) on case-relevant communication (sum per same five-minute interval) (y-axis) as moderated by the phase of the surgery (senior surgeon in charge vs junior surgeons in charge).

DISCUSSION

We investigated the relationship between noise in the OR and communication within the surgical team, on the basis of five-minute intervals during long, open, abdominal surgeries.

Noise effects on case-relevant communication. Our results supported the hypothesis that loud noise peaks reduced case-relevant communication within the surgical team. Noise peaks thus impair case-relevant communication. This is important because previous research has linked more case-relevant communication to fewer patient complications (Mazzocco et al., 2009; Tschan et al., 2015, early view). Previous studies have shown negative effects of noise exposure on technical aspects of surgical performance (Murthy et al., 1995a); the results of this study show that noise directly interferes with the team process by reducing case-relevant communication, which is a key aspect of team coordination. This study helps to better understand a potential mechanism through which noise may affect performance of the surgical team, given that noise has been shown to negatively affect surgical outcomes (Dholakia et al., 2015; Engelmann et al., 2014; Kurmann, Peter, Tschan, Muhlemann, et al., 2011). Reducing communication is one of the reactions people show in noisy environments (Key & Powell, 1980), and studies in other fields also showed that noise particularly impaired novel and complex communication (Way et al., 2013), such as case-relevant communication during a surgical procedure.

However, the results of this study do not allow to simply conclude that noise peaks impair case-relevant communication throughout the surgery, as the effect was only present in the phase the less experienced junior surgeon was in charge of the surgery, and when the senior surgeon was not in the OR. This is in line with other studies showing that less experienced surgeons are more sensitive to distractions and that more experienced surgeons can more easily block out noises (Moorthy et al., 2004), keep up concentration, and they show good performance even under distracting conditions (Hsu et al., 2008). On the one hand, the results are reassuring: the most experienced surgeon is responsible for the most difficult part of the surgery, and noise peaks did not influence case-related communication in this phase. On the other hand, our results raise concerns with regard to the working environment for junior surgeons. From a surgical-technical perspective, preparing and closing the abdominal wall is less complex than the main phase of the surgery. However, preparing and closing may well be complex for a less experienced surgeon. In addition, note that during the phase the junior surgeon is in charge, there is one team-member less in the room, and the junior surgeon is assisted by an even less experienced resident. Errors and mishaps can also occur in this phase, and lower case-related communication may contribute to them. In addition, noise pollution is greater in the phases of responsibility of the junior surgeon, as noise peaks were significantly more frequent in those phases. This has been found in other studies (Kurmann, Peter, Tschan, Muhlemann, et al., 2011) and is most likely related to the preparation of technical devices in the OR at the beginning of the procedure, and clearing up activities towards the end of the surgery. Junior surgeons thus face cumulative difficulties – more frequent exposure to noise peaks, less experienced team members, being the team leader and still having to master a complex task for junior surgeon's experience levels.

Noise effects on case-irrelevant communication. We did not expect noise peaks to reduce case-irrelevant communication. In accordance with our expectations, noise-peaks did

not reduce case-irrelevant communication. However the contrary occurred – more noise peaks were related to more case-irrelevant communication in the same five-minute interval. This finding is somewhat tentative, as the effect is only marginally significant after entering noise peaks of the previous interval into the model. Note, however, that noise peaks in the previous five minutes are not a significant predictor, and the fit (-2 X log likelihood) is best for Model 2.3, in which the effect of current noise is significant. An enhancing effect on case-irrelevant communication does seem theoretically plausible, however. First, case-irrelevant communication is less complex than case-relevant communication, it therefore demands less attentional resources and may be upheld even under noise. Second, noise peaks are more frequent when apparatus are installed or put away (Broom et al., 2011; Kurmann, Peter, Tschan, Muhlemann, et al., 2011); thus noise peaks may be highest when task coordination demands within the surgical team are lower, leaving time for more social communication. However, although case-irrelevant communication may be functional for a good team climate within the surgical team (Nurok, Evans, et al., 2011), it can also be an additional distractor for the surgical team (Feuerbacher et al., 2012; Wheelock et al., 2015). This is particularly important, because a previous study found that more case-irrelevant communication towards the end of the surgery was related to a higher risk of incisional surgical site infections (Tschan et al., 2015, early view).

Noise impairs complex communication. Taken together, our results suggest that noise peaks do not impair all communication, but only interfere with complex (case-relevant) communication. This supports the contention that noise indeed draws on attentional resources that would be needed for a complex conversation. Under noise, attention would have to be divided between fighting off the disturbance of noise, performing a sensori-motor task (surgery), and at the same time communicating about the current state of the procedure and coordinating the team. By contrast, case-irrelevant communication is more compatible with noise, because it requires less attention.

Strengths and limitations. One of the limitations of the study is that it is confined to one field of surgery (visceral). Noise pollution varies with the type of surgery (Kracht et al., 2007); the concentration on visceral surgeries therefore limits the generalization of the results. Because this is an observational study, we cannot establish a causal link between noise peaks and communication without doubt. There is a possibility of a third, unmeasured variable influencing both, noise peaks and communication. The result should therefore be replicated in a more controlled study, for example an experimental simulator study. A further limitation is the coding of communication. While we could reliably distinguish between case-relevant and case-irrelevant communication, we could not assess the specific content of communication or its characteristics in terms of hesitations, incomplete sentences, etc.. Such analyses could show more clearly how and what aspects of communication are influenced by noise peaks. Another limitation is the placement of the sound meter at the main operating lamp. When the lamp is moved during the surgery, the sound meter is moved too, and thus does not measure exactly from the same position in the room during the whole procedure. However, the range of lamp movements during a surgery is limited.

This study also has strengths. To our knowledge, it is the first study relating noise peaks within rather short intervals (5 minutes) to case-relevant as well as case-irrelevant communication during surgeries, and thus analysing the interplay of noise and communication during the surgical procedure. The combination of observational data and noise measures

allows assessing how noise peaks affect different aspects of communication. It thus contributes to the growing interest of influences on teamwork in the operating room. Another strength of the study is that noise and communication were analyzed for each five-minute interval, controlling for influences of both aspects in prior five-minute intervals. This time-frame allows studying more immediate effects of noise on communication than assessing noise levels for entire surgeries.

CONCLUSIONS AND IMPLICATIONS

A first, theoretical conclusion is that noise peaks interfere with processes that require attention because they drain attentional resources, and not because noise and communication both channel through the auditory system. If the latter was the case, all communication should have been impaired by noise peaks, however, this study found that only the more complex communication, and only in a phase that is challenging for a less experienced group member, was impaired under noise.

Surgical performance depends on good teamwork, and this study showed that high noise peaks can negatively influence task-related communication processes which are crucial for team coordination, noise peaks thus impair task-related teamwork in the OR. Although it is not possible to eliminate all noises in the OR, and ORs may remain noisy environments, intervention studies have shown that noise in the OR can be somewhat reduced (Engelmann et al., 2014). Results of our study suggest that such noise-reducing interventions should be promoted.

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Overall discussion

The papers presented in this dissertation built on previous research to investigate aspects in the OR identified as influencing performance and teamwork. The studies focused on specific research questions pertaining teamwork (paper 1, perceived teamwork), team familiarity (paper 3, impact of team familiarity on post-operative complications), concentration (paper 4, impact of noise on concentration), noise (paper 4, impact of noise on concentration and paper 5, impact of noise on communication), distraction (paper 2, impact on communication on surgical site infections) and communication (paper 2, impact of communication on surgical site infections and paper 5, impact of noise on communication) *during* surgeries. The first main goal of the papers taken together was to investigate to what extent the intra-operative processes predict post-operative patient outcome (paper 2, impact of communication on surgical site infections, and paper 3, impact of team familiarity on post-operative complications). The second main goal was to focus on intra-operative processes, and the impact of distractions on concentration and communication during the time of the surgical procedure (paper 4, impact of noise on concentration and paper 5, impact of noise on communication).

The papers included in this dissertation have strengths and limitations. These aspects are already discussed in each of the specific papers. Thus, this chapter emphasizes on the one hand the key results, and the caution regarding their interpretations. On the other hand, the present discussion draws a possible future research line

Direct observation is necessary.

The different studies show that intra-surgical processes are an important aspect to consider. First, in paper 1 (perception of teamwork), we showed that quality of teamwork assessed *after* specific surgeries did not yield the same results as if teamwork quality was assessed in a general survey. This study points to the fact that research focusing on intra-operative processes reveals "how teamwork works" and thus assesses facets of teamwork that cannot be detected using a general survey methodology. It is thus important to observe the surgical process, as done in papers 2 (impact of communication on surgical site infections) and paper 5 (impact of noise on communication).

A potential pathway : Noise peaks influence intra-surgical communication – communication influence patient outcomes.

Second, intra-operative processes observed *during* surgeries, in particular communication, predicted surgical site infections in abdominal surgeries (paper 2, impact of communication on surgical site infections). Whereas case-relevant communication was associated with a lower probability of surgical site infections, case-irrelevant communication during the closure of the abdominal wall was associated with a higher probability of surgical site infections. This result is in line with previous studies that also found a link between intra-surgical processes variables and patient outcome (Mazzocco et al., 2009). Whereas communication had an impact on surgical site infections, observed distractors did not show an

impact on surgical site infections. However, looking closer at the impact of specific distractors on intra-surgical processes, we found that noise peaks influenced communication (paper 5, impact of noise on communication); in other words, noise peaks are particularly distracting auditory stimuli. This is important and interesting, because although observed distractors did not show a direct impact on surgical site infections, distractors as measured noise peaks influenced communication and noise had also an impact on surgical site infections (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). A mediating effect can be supposed: Noise may influence patient outcomes through its influence on communication.

Effects of noise and communication depend on phases of surgeries

A further transversal aspect present across the different papers of this dissertation is the focus on phases of the surgeries, an emerging topic in the literature (Parker et al., 2014). We found that depending on the phase of the surgery, communication had a different impact on surgical site infections; with case-irrelevant communication particularly predictive of surgical site infections in the phase of closing of the abdominal wound. Similarly, noise had a different impact on communication and reported concentration depending on the phase of the surgery. Whereas observed communication (paper 5, impact of noise on communication) and reported concentration (paper 4, impact of noise on concentration) of senior surgeons were not affected by noise, communication and reported concentration of junior surgeons varied depending on noise. It is likely that the different cognitive load across the phases (Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, & Sundt III, 2010) is at the base for these effects. As experience levels influence cognitive load, more experienced surgeons seem to be less sensitive to noise and distracted communication (paper 5, impact of noise on communication). Thus, our results from a field study are in line with findings of laboratory studies that also found an increased sensitivity of less experienced surgeons towards distractions (Hsu et al., 2008; Suh et al., 2010)

Limits of the studies

The results that I describe in this dissertation cannot be generalized to all surgical settings. We conducted the studies in a single surgical unit specialized for abdominal surgeries. Although this is a "classical" limitation of such studies, it is important to remind that work processes and rules - including social rules, may vary across surgical units, hospitals, countries and cultures. It is thus necessary to replicate the studies in other hospitals and different surgeries. Another limitation pertains to the measures of distractions and communication. The used methodology of on-site observations did not allow us to assess the precise content of the communication, nor communication quality. For example, important theoretical constructs such as closed-loop communication were not measured. Assessing surgical processes based on video and audio recording would yield more specific information. However, we can reasonably suppose that if surgical teams are distracted, not only the quantity of the information exchanged suffer, but also the quality of these verbal exchanges.

We faced a similar limitation pertaining observed distractors. Counting observed distractions, we did not take into account that within the broad category of "observed distractors", there were qualitative differences that could be studied in a more precise way in

further analysis. Thus, whereas the question of the generalizability of the results could be resolved only if the results of our studies can be replicated in other surgical settings, there might be a possibility to conduct more analysis of observed communication and distractions. In the next paragraph, I draw a possible future research line based on these considerations.

Future research

Analyzing communication and distraction in a more precise way would be, given the results reported in this dissertation, a first research priority. To analyze the nature and effect of noise and distractors more precisely, the actual behavioral coding system allows further analyses. In fact, observers wrote a comment about the nature of each distractor observed. Based on these comments, distractors can be categorized based on different criteria that allow to distinguish the distracting potential of different distractors observed. Appendix C presents a working paper that we prepared for such a categorization. In a future research, we can build on this categorization of distractors and investigate their impact on intra-operative processes and patient outcome. As more experienced (senior or main) surgeons seemed to be less sensitive to noise and distractors, it would also be interesting to investigate the mechanisms responsible for this effect. More specifically, this would mean exploring if experienced surgeons developed conscious strategies to deal with distractors or if they block out distractors on an automatic basis, and finally to what extent some specific distractors have the potential to distract even experienced surgeons.

Some further interesting research may be beyond the limits of the actual observational system. However, pertaining communication, we could adapt the coding system developed by Seelandt and colleagues (Seelandt et al., 2014) to focus more precisely on indicators of communication quality, such as closed loop communication. Another possibility is investigating more precisely who is communicating information to whom, and during which phase of the surgery. For example, junior surgeons receiving a lot of information from the senior surgeon during specific phases of the surgery might help them stay concentrated and support shared mental model building across surgeons. Such analyses would also allow to identify if shorter phases of the surgeries, based on communication content and turn taking and to look if there are some patterns that are more efficient that other.

To conclude, this dissertation showed that intra-operative teamwork behavior, and more specifically communication, impacted on patient outcome. In a "distractor" perspective, I contributed to explore what distract surgical teams form efficient teamwork processes. Although conducted in one surgical unit, these results are promising and raise further questions that are related to teamwork processes in surgical teams and the nature of events that indeed distract them. The future research paths presented here pertain only a few aspects that should be investigated deeper. There are many more aspects that are likely to contribute to efficient teamwork processes and error prevention, and they also would deserve attention. However, generating knowledge about which behaviors should be fostered and which should be inhibited during the intra-surgical process, and when (in which phase of the surgery), is alone not enough to contribute to patient safety in the OR. On the other hand, future research has also the

responsibility to concentrate on the training of safe behaviors in the everyday praxis and to evaluate how these behaviors can best be supported and strengthen (Salas et al., 2008). Combining these two perspectives, future research should pursue the goal of improving patient safety.

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Appendix A: Observational coding system

This appendix describes the categories in the observational tool used to conduct the studies in paper 2 (impact of communication on surgical site infections), paper 4 (impact of noise on concentration) and paper 5 (impact of noise on communication). The paper that report in details the development of the observational tool and containing the description of the categories described below is published and its reference is the following: Seelandt, J. C., Tschan, F., Keller, S., Beldi, G., Jenni, N., Kurmann, A., . . . Semmer, N. K. (2014). Assessing distractors and teamwork during surgery: developing an event-based method for direct observation. BMJ quality & safety, 918-929. doi:10.1136/bmjqs-2014-002860.

Codes Behaviour

Code	Indikatoren	Beispiele
Türe	1mal Türe beinhaltet Öffnen und Schließen bleibt die Türe über einen längeren Zeitraum geöffnet, wird ein 2. mal Türe kodiert wenn diese wieder geschlossen wird; zudem wird ein Kommentar eingefügt, dass die Türe längere Zeit offen war notieren, wenn Türe gewissen Zeitraum offen bleibt Achtung: meistens gibt es 4-5 Türen pro OP Notieren, welche Türe geöffnet wird (PFLE/ANA/Nebenop), wenn möglich an erster Stelle im Kommentar	
Other (comment!)	Radio an/aus Vertreter oder Techniker kommt/geht Licht an/aus Ultraschall an/aus Navigationsgerät an/aus Alles, was nicht auf der Liste steht Kann wirklich möglichst viel sein (Protokoll des Geschehens)	Team arbeitet sehr konzentriert Team arbeitet sehr ruhig, praktisch keine Kommunikation Wenn Techniker/Vertreter und einer der CHIs über neues Gerät sprechen (und es nur um das Gerät geht!!); bitte auch notieren, ob die anderen dabei weiterarbeiten oder nicht Wenn es sehr stark blutet Anästhesie fragt sterile Pflege/Pflege mit wie welcher Menge sie die Wunde gespült hat Wenn ANAS Blut oder NACL mit Druck reinpressen (Beutel in Gestell, Beutel wird mechanisch „ausgedrückt“
Distractor (comment!)	Alles, was das OP-Team potentiell ablenken/stören könnte und weiter unten nicht spezifiziert ist Distractor kommt eher von aussen, weil sie das sterile Team ablenken können	Etwas fällt laut auf den Boden Pflege reisst Packungen laut auf Apparate werden umgestellt

	Unbedingt kommentieren, was es für einen distractor ist Alle Distraktoren notieren; und nicht alle 2min kodieren wie z.B. Parakomm. Wenn der Distraktor kontinuierlich ist, und es geht um die gleiche Handlung geht, die weniger als 2 min dauert, nur ein Mal kodieren falls Distraktor leise, dann als other kodieren	Lautes Ein- und Ausräumen von Instrumenten/Materialien
		Türe zu Nebenop offen, man hört Geräusche von nebenan
		Sterile Pflege und Pflege suchen laut im Müll nach einem verschwundenen Bauchtuch
		Geräte werden aufgeräumt
		Pfleger stellt während OP Frage zur postoperativen Lagerung
		Person, die nicht zum sterilen Team gehört, spricht jemanden aus dem sterilen Team an (Pflege fragt nochmals Chirurgen wie sie Schnellschnitt beschriften soll)
		Wenn beispielsweise Gerät von Pfle **vorbereitet** wird und dabei Geräusche von sich gibt Wenn Chi1 kommt, den Kopf reinstreckt und laut zu reden beginnt Anästhesie spricht „aus dem Nichts“ das OP-Team an
Interruption / Delay (comment!)	Wenn steriles Team die Handlung unterbrochen bzw. diese verlängert wird, ohne dass man bestimmte Kategorie codieren kann Komplettes steriles Team unterbricht die Handlung unbedingt im Kommentar angeben, was es ist und wie lange diese Interruption dauert (Sekunden/Minuten): jeweils zu Beginn und am Ende einer Unterbrechung „Interruption“ kodieren; beim Daten säubern anhand der 2.Kodierung berechnen, wie lange die Unterbrechung gedauert hat; die Dauer der Unterbrechung dann bei der 1. Interruption-Kodierung beim Kommentar	Chirurg telefoniert mit Labor wegen Schnellschnittresultaten, wobei das restliche Team nicht weiterarbeitet
		Neuer Apparat wird hereingebracht, da plötzlich geröntgt werden muss, Unterbruch der OP
		Während der OP-Tisch verstellt wird, kann das OP-Team nicht weiterarbeiten (wenn es nicht nur 2 Sekunden dauert)
		OP-Team muss warten bis Anästhesie die Magensonde eingeführt hat

	einfügen, anschließend 2.Interruption-Kodierung rausschmeißen. Beginn und Ende kodieren	Anästhesie muss zuerst auf einen Alarm reagieren bevor sie den Patienten umlagern kann, OP-Team kann nicht weitermachen
		Es werden Fotos von der OP gemacht
		Chirurg muss Bauchtuch in der Wunde suchen, kann nicht normal weiterarbeiten
Aufmerksamkeitsreaktion	Jemand vom sterilen Team (inkl. STE) hebt den Kopf, orientiert sich nach aussen Häufig nach distractor Blick nach aussen zu Objekt	Blick auf die Uhr
		Blick zur Tür
		einer der Chirurgen dreht sich um
		Assistent schaut der Pflege beim Aufräumen zu
Telefon, Beeper, Alarm (comment!)	Jeweils in der Comment box erläutern, was es war und ob es operationsbezogen war Feedback der Kaustik nicht als Telefon, Beeper, Alarm kodieren!!! dieser Code beinhaltet nur eingehende Telefonate Wenn ALARM ANA: notieren, ob dieser rot oder gelb ist!	Das Telefon klingelt und jemand möchte den Chirurgen sprechen
		Jemand vom Labor ruft wegen den Schnellschnittresultaten an
		Alarm bei den Anästhesisten
		Alarm beim Röntgengerät
Sterilalert	Wenn die Sterile Pflege oder eine andere Person wegen Gefährdung der Sterilität warnt	Unsteriler Besucher/Pflege zu nahe am Operationstisch
		Chirurg kommt mit unsterilen Apparaten in Kontakt
Sterilhandlung (comment!)	Handlungen, die der Sterilität dienen Hängt häufig mit arrival/departure zusammen	Wechseln der Handschuhe
		Aermel werden angezogen
		etwas wird abgeklebt
		Immer, wenn jemand neu eingekleidet wird
		wenn der Patient vorbereitet wird: Person wird desinfiziert, abgedeckt, es wird ein Tuch als Schutz zur ANA angebracht

Bauchtücher zählen	Sterile Pflege und Pflege zählen die Bauchtücher ab **Kommentieren**, wenn dies **nonverbal** geschieht	Tupfer/Bauchtücher werden gezählt Tupfer werden oft bei laparaskopischen Eingriffen benutzt
Sicherheit-Ueberprüfungen (comment!)	Sicherheitssüberprüfungen werden gemacht bezieht sich auf alles, was speziell präventiv ist zwischen STE und PFLE	Instrumente werden gezählt Ueberprüfung, ob bestimmtes Gerät funktioniert Zeigen von Flaschen an die STE Flüssgkeitsbilanz: wird geschaut, wie viel Blut Patient verloren hat
Zwischenfall (comment!)	Besondere Zwischenfälle potentiell schwerwiegender als interruption unbedingt kommentieren/beschreiben nach der Beobachtung mit jemandem vom Chirurgen-Team besprechen Beginn und Ende kodieren	Jemand schneidet sich es fehlt ein Bauchtuch Bei einer Magenverkleinerung ist das Ventil an einem Instrument zu, weshalb das Team bei dem laparaskopischen Eingriff nichts mehr sehen kann Reanimation
Arrival – Departures (comment!)	Bezieht sich auf Schichtwechsel, Pausen und Uebergaben des sterilen OP-Teams; das Anästhesieteam sowie die Pflege werden nicht kodiert Hinweis für die Kodierung: CHIs kommen häufig in den OP, schauen wie weit Team ist, gehen dann nochmals raus. Das ist noch kein Arrival. Wenn CHI/STE/ASSI/STUDI endgültig kommen, haben sie beim Betreten des OPS die Arme ausgestreckt vor dem Bauch, und warten darauf, steril angezogen zu werden - erst dann kodiert man Arrival, wenn sie gewaschen reinkommen; notieren wenn CHIS beim Betreten des OPS grüssen Sobald sich jemand steril/unsteril macht; auch wenn jemand aus STE-Team in die Pause geht Achtung: wenn jemand den OP verlässt, kommt häufig auch ein Platzwechsel vor	Sterile Pflege wird abgelöst OP wird vorbereitet, kurz vor dem Eingriff kommt Chirurg
Platzwechsel surgery team	Innerhalb des Teams wird der Platz gewechselt Achtung: wenn es einen Platzwechsel gibt, hängt das häufig mit arrival/departure zusammen	Chirurg wechselt mit dem 2.Chirurgen die Seite
Hektik, Stress, Unruhe (comment!)	Handlungen werden schneller, es ist stressing und unruhig Personen aus dem Team wirken nervös	Chirurg bewegt sich hektisch Chirurg wirkt angespannt

	es muss klar ersichtlich sein, dass Hektik herrscht Wenn es andauert, alle 2min kodieren Negative gefärbt	Ein Röntgenapparat wird hereingebracht, der Chrirurg muss vorher die Wunde versorgen, der Anästhesist den Patienten stabilisieren; parallele, hektische und schnelle Bewegungen Chirurg kommt nicht an gewünschte Stelle, muss sich beeilen, da es stark blutet
Material in Raum bringen	Die Zudienung (nicht bei ANA) kommt mit etwas in den Händen (ausser Telefon und Blätter) in den Raum Material für OP; deutliche Materialübergabe Türe immer noch dazu codieren!! Kurz dazuschreiben, was gebracht wurde	Zudienung bringt Bauchtücher.
Zudienung gibt Steril Material	Die Zudienung händigt der STE irgendwas aus Achtung: beim Zunähen sind das sehr oft Fäden, das macht die letzte Phase des Beobachtens deutlich spannender Kurz dazuschreiben, was gebracht wurde	Zudienung gibt STE Fäden zum Nähen.

Codes Communication

Code	Indikatoren	Beispiele
Teaching – explaining (comment!)	eher allgemein gehalten, nicht nur speziell auf aktuellen Fall bezogen Jemand aus dem engen OP-Team erklärt einer anderen Person (intern/extern) etwas über die Operation/Prozedur kommt eher selten vor	Chirurg erklärt Assi anhand einer Skizze, wie er beim Nähen vorgehen muss Chirurg klärt Assi über die Besonderheiten eines seltenen Tumors auf

	Jemand wird angeleitet/instruiert “extra so viel sagen, weil der andere weniger weiss” Wenn es andauert, alle 2min kodieren	Chirurg erklärt der Pflege wie man mit einem bestimmten Instrument die Leber zurückhält
		Chirurg erklärt uns (den Beobachtern), was er macht
		Chirurg erklärt Assistent etwas über Blutungen bei Magenverkleinerungen
		Chirurg zeigt Assistent und Studenten, wie man bei einem laparaskopischen Eingriff beispielsweise den Magen abmisst
Problem solving discussion	Problembezogene Diskussion, es wird nicht einfach etwas erklärt, sondern gemeinsam überlegt/gedacht Es muss sehr deutlich als Konzentration auf die Problemlösung zu erkennen sein Wenn es andauert, alle 2min kodieren	Das Team schaut sich ein Röntgenbild an
		Diskussion über ein CT
		Chirurg konsultiert telefonisch einen Kollegen, anschliessend gemeinsame Diskussion über Lösung
		Chirurg möchte ein neues Gerät ausprobieren, weiss nicht, wie es funktioniert. Gemeinsam schaut sich das komplette Team das neue Instrument an und diskutiert über dessen Anwendung
		Neue Gerätschaft wird gemeinsam aufgebaut. Die Beteiligten überlegen gemeinsam, wo welches Teil hingehört
Tension (comment!)	Bezieht sich auf spitze Bemerkungen bis hin zu offenen Konflikten unbedingt angeben, ob es schwach-mittel-heftig war	Es fehlt ein Bauchtuch, sterile Pflege sagt, dass sie den Chirurgen so lange nicht bedienen werde, bis das ausstehende Tuch gefunden ist

	Achtung: wenn es tension gibt, besonders darauf achten, ob eine release tension folgt und auch kleine Anzeichen davon kodieren Wer war beteiligt? Wenn es andauert, alle 2min kodieren	Sterile Pflege entschuldigt sich für ausstehendes Bauchtuch, Assistent erwidert, dass es hierfür kein Pardon gebe
		Chirurg ist ungeduldig, nimmt Assistenten Instrument aus der Hand
		Assistant möchte etwas von steriler Pflege, sie widerspricht ihm und weist ihn zurück, da sie gerade Bauchtücher zählen muss
		Sterile Pflege beauftragt ihre Ablösung im Müll nach einem fehlenden Bauchtuch zu suchen
		Assistent schiebt zwei Bauchtücher mit dem Fuss beiseite, sterile Pflege kommentiert spitz, dass sie dies gesehen hätte
Release – Tension (comment!)	Leichte Bemerkungen, Erleichterung, Witze, Lachen Wer war beteiligt? Wenn es andauert, alle 2min kodieren	Jemand macht einen Witz, das Team lacht
		Bei einer Magenverkleinerung wird ein Witz über einen übergewichtigen Hund gemacht
Verbalization (comment!)	Alles, was zu geteilten mentalen Modellen beiträgt CHI/ASSI (selten Studi oder STE) erklärt etwas über aktuelle OP oder in Bezug auf den aktuellen Patienten Handlungsleitend	Jemand fragt etwas über die OP, der Chirurg gibt darüber Auskunft, das ganze Team bekommt es mit
		Der Chirurg fragt Anästhesisten, ob der Urin klar ist
		Chirurg diktiert Schnellschnitt
	Verbalisierungen zwischen Pflege/Zudienung und steriler Pflege werden nicht als solche kodiert, sondern unter "other" mit einem Kommentar	Chirurg teilt der Anästhesie mit, wann er beginnen möchte und wie lange der Eingriff ca. dauern wird

	Verbalisierungen, welche wir kodieren, sollten im "engen" OP-Team stattfinden (CHI, ASSI, STE, ANA) Notieren, wer etwas sagt Wenn es andauert, alle 2min kodieren; aber nur, wenn es um dasselbe Thema geht	Der Chirurg plant und teilt mit, welche Geräte er benötigen wird
		Chirurg sagt laut die Zeit an
		Chirurg nennt die weiteren Schritte/das weitere Vorgehen
		Chirurg erklärt, weshalb er bestimmte Kontrollen macht und warum ihm dies so wichtig erscheint
		Sterile Pflege fragt, ob Patientin Hepatitis hat
		Chirurg telefoniert mit Kollegen, sie unterhalten sich über OP, restliches Team bekommt die Informationen mit Wenn CHI etwas vor sich hinmurmelt. Im Kommentar notieren, dass CHI gemurmelt hat Wenn Techniker anwesend sind und deren Kommunikation mit CHIs inhaltsspezifisch für OP ist
Surgery team External (comment!)	Das OP-Team kommuniziert mit Externen Sobald CHIs mit externen Personen kommunizieren, unabhängig davon, worüber sie kommunizieren Wenn es andauert, alle 2min kodieren Wenn mit externer Person über aktuelle OP/aktuellen Patienten gesprochen wird, zusätzlich noch Verbalisierung kodieren Wenn Externe das sterile Team „überfallen“ und damit ablenken, dann **auch** distractor kodieren Wenn über die OP gesprochen wird, dann zusätzlich Verbalization kodieren; aber niemals not patient relevant, da der Code surgery team external alles schon beinhaltet	Von draussen wird Chirurgen eine Frage gestellt
		Externer steht neben dem zweiten Chirurgen und stellt Fragen zur OP
		Externer Arzt und Chirurg diskutieren über nächste Operation
		Wenn einer der CHIs telefoniert und die anderen weitermachen (nicht Parakomm kodieren!)

	- Die Lagerungspfleger ->werden NICHT als surg. team ext. kodiert, solange dass sie kommen, weil es geplant ist und man braucht ihre spezifische Kompetenzen für den nächsten Schritt. Der Patient muss intraop. umgelagert werden. Da sind sie wie die Techniker, die mithelfen und arbeitsbezogene Gespräche mit den Chis führen. -> werden als surgery team ext. kodiert, wenn sie vorbeikommen, weil es spontan ein Problem gibt oder was wurde vorher nicht gut gemacht. Da sind sie etwa wie die externe chirurgen, die spontan kommen sollen, weil die chis Ratschläge brauchen. Zudem können sie als externe da etwas ablenken, weil sie nicht geplant kommen, und die Lagerpfle hantieren um den Tisch und kommunizieren mit den chis.	
Not Patient Relevant Communication	OP-Tem spricht klar verständlich nicht über den Patienten, sondern über andere Themen oder auch andere Patienten, es sind keine externen Personen im Gespräch involviert Wenn es andauert, alle 2min kodieren	Chirurgen unterhalten sich über bevorstehendes Wochenende Chirurgen diskutieren Krankheitsgeschichte eines anderen Patienten Chirurg befragt Pflege zu ihrem Wochenenddienst und ihre Urlaubspläne Es wird über die nächste Operation gesprochen
Timeout	jeweils nur zu Beginn der OP wird separat kodiert und nicht mehr als other	
Handover[3]	Der ablösenden Person wird erklärt, worum es geht Eher bei der steriler Pflege, sehr selten bei CHIs (nicht unter den PFLEs) Wenn bei CHIs, dann häufig, wenn interdisziplinäre Teams operieren (z.B. Viszeralchirurgen und plastische Chirurgen) Schichtwechsel bei STEs zwischen 15-15.30 Uhr; hier auch besonders aufmerksam sein wegen der Fragebogen!!	jemand geht in die Pause und wird abgelöst
Leadership/Anweisung	CHI/CHI2 (Assi selten) weist jemanden klar und laut an etwas zu tun oder zu lassen Deutliche Anweisung	Chirurg gibt Anweisung an Anästhesisten den Patienten umzulagern

[3] Code nochmals unter die Lupe nehmen

	Kann interne und/oder externe Personen betreffen Unbedingt kommentieren	Chirurg verlangt das Telefon
		Chirurg weist Anästhesie an die Magensonde einzuführen
		Chirurg weist sterile Pflege an (nochmals) die Bauchtücher zu zählen
		Chirurg gibt Anweisung einen Kollegen anzurufen
Parallellkommunikation (comment!)	Es wird Parallelkommunikation codiert, wenn eine Gruppe AUSSER dem sterilen Team so laut spricht, dass das potentiell ablenken könnte. Es reicht eine Gruppe. Wichtig dabei ist: • das Gespräch ausserhalb muss so laut oder so animiert sein, dass es ein potentieller (sprachlicher) Distractor sein könnte. Leise Unterhaltungen werden NICHT codiert • es müssen NICHT parallel mehrere Gespräche stattfinden, in dem Sinne ist der Code Parallelkommunikation etwas irreführend – und man muss sich das gut merken • Parallelkommunikation wird als eigener, SPRACHLICHER DISTRACTOR definiert, es ist deshalb nicht mehr nötig, das auch als distractor noch speziell auszuweisen. Also nur	Pflege und sterile Pflege sprechen über Bauchtücher, während sich das OP-Team über den Eingriff unterhält
		Nebengespräch bei den Anästhesisten
		Telefon nach draussen

	Parallelkommunikation codieren, nicht auch distractor • Gespräche bei ANA werden als Parallellkommunikation kodiert unabhängig vom Inhalt und wenn sie gewissen Geräuschpegel haben, also potentiell ablenkend sind • Parallellkommunikation findet parallel zur Tätigkeit der CHIs statt, kommt eher von "aussen" (ausserhalb des CHI-Teams) Im Kommentar an erster Stelle zuerst schreiben, WER sich unterhält (PFLE, ANA,…), wenn möglich Wenn es andauert, alle 2min kodieren	Wenn sich STE und PFLE in gewisser Lautstärke über etwas anderes unterhalten als den Patienten/ihre Tätigkeit
Other	Alles, was sonst noch spannend ist	Team arbeitet sehr konzentriert Chirurg wirkt im Moment etwas zittrig Sie sind am Nähen, wahrscheinlich sind sie bald fertig

Appendix B: Timely Matching of recorded noise and observed behavior

This appendix is a working paper that was not published but used as an internal documentation source to prepare the data set containing noise measures.

Working paper

Timely matching of recorded noise and observed behaviors during the duration of a surgery: description and validation of a matching system

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University of Neuchâtel, 2013 05.

We would like to thank Anna Püschel for her contribution in testing the matching system presented in this working paper and Nadja Jenni for the corrections of the German spelling and grammar.

Abstract

Background of this working paper: To timely relate noise measures recorded during surgeries with behaviors observed during the same surgeries, we needed to correct the time imprecisions of our measurement method. Indeed, it was important that an event observed at a given time could be linked with the noise measured at exactly the same time.
Aim: The aim of this working paper is (1) to give a description of how we proceeded to timely match observational data with noise data stemming from a same surgery and (2) to present how we proceeded to validate the system developed.
Method: Two independent raters matched observational data and noise data from 26 surgeries and an intraclass coefficient correlation was calculated on the basis of the time differences found by each rater.
Results: The matching system developed was usable and the intraclass coefficient was good enough to assure its reliability.

Introduction

As measured in the operating room (OR), a higher level of noise was found to be related with surgical site infections (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). Other laboratory studies, examining the relation between noise and performance on surgical tasks, could as well find a link between noise and impaired performance (e.g. more errors, longer time to solve the task) (Moorthy, Munz, Dosis, Bann, & Darzi, 2003; Szafranski, Kahol, Ghaemmaghami, Smith, & Ferrara, 2009). Even if not directly linked with a reduced performance, noise could as well impair communication (Hodge & Thompson, 1990; Kracht et al., 2007; Shankar et al., 2001) and is assessed as detrimental for their job by a majority of surgeons (Tsiou et al., 2008). Although its negative consequences were largely discussed, past research showed that the operating room can be a quite noisy work environment, where noise can exceed the international standards (Shankar et al., 2001). Different noise sources were identified as responsible for higher levels of noise, such as the technological equipment (Hasfeldt et al., 2010). Second, noise was also related to specific behaviors, which are not directly part of the current task, such as moving trolleys, door slamming or conversations among staff (Shankar et al., 2001). This stresses the importance of collecting more knowledge about which noise sources could be potentially avoided or reduced, and which not. However, few study tried to relate noise levels with systematic observations conducted with help of a validated coding system, focusing on distracting events that were already identified as such in the specific literature. Basing on noise and observational data, we would like to further examine these aspects. In order to timely relate the occurrence of possibly loud observed events and higher noise, we needed a system to assure the time correspondence between the timely stamped noise and observational data we collected.

In this working paper, we present how we could timely match data collected with a noise recording device placed in the OR, and measuring the noise level for every second of the surgery, with time stamped observational data, collected over the whole time of the surgery as well. It should be noted that the data were collected as part of a broader project investigating teamwork and distracting events in the OR, and not only with the aim of relating noise measured with observed distracting events. The noise data consisted of noise recorded with a noise measuring device. The noise recorder (a TES-1352H©, TES Electrical Electronic Corp., Taipei, Taiwan, R.O.C.) recorded noise second-by second (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). The noise meter was settled on A-level, which is the measurement commonly used in noise studies (Murthy et al., 1995b) and corresponds to the sensitivity of the human hear. Thus, we obtained a time stamped noise measure for every second of the surgery. The observational data was collected using a validated observing system (Seelandt et al., 2011), designed to code on-site behaviors and communications observed in the OR. Every event coded was time stamped, indicated the hour, minute and second when the code was entered in the computer.

Yet, the inner clock of the noise recording device was not synchronized with the inner clock of the computers used to conduct the observations. A first issue was the fact that the noise level device could not be adjusted to summer time, but this could be easily overcome (see next section). We met a second and more problematic issue: the inner clock of the computers, as well as the inner clock of the noise recording device, was inconstant across the time. As the noise device had to be set on the operating lamp before the patient came, the beginning of the noise measure did neither correspond to the beginning of the surgery. At the end of the surgery, the noise device could be switch off only after the departure of the patient, which happened a moment after the last stitch was sewn. This means that we had to find out, for each observed surgery, which was the time difference between the time indicated on the noise data and the time indicated on the observational data (e.g. if the noise device indicated 08:00:00 at a moment, the observational data indicated 08:04:30 at the same moment). Only knowing this exact difference could allow us to "match"[4] the two different data sets from the same surgery, and further allow us to timely relate the events observed with the noise measured.

In the next section, we present how the different steps for the preparation of the noise data look like, and how we matched this data to identify the time difference between the noise and the observational data. This is a quite detailed description as this document was used as a work document to prepare the data[5]. At the end of the description of the matching process, the training that a second rater went through is described, before giving a measure of validity of the system.

[4] The terms *match* and *matching* will refer to the process of identifying which noise recorded could be linked with which event observed. This process will be used in order to find the time difference between the two data sets.
[5] The description was originally written in German, as the data were coded in this language and some of the coders German speakers.

Table 1. Matching procedure

<table>
<tr><td>1. Vorbereitung der Dezibeldaten</td><td>Nach der Lärmmessung im Operationsraum werden die Daten vom Lärmpegelmessgerät auf den Computer übertragen. Die Daten werden dann in einem Excel spread sheet gespeichert (siehe Abbildung 1). In der einen Spalte steht das Datum und die Uhrzeit (Stunde, Minute, Sekunde) und nebenan werden die Lärmmessungen angezeigt (jeweils für die entsprechende Uhrzeit). Somit haben wir für jede Sekunde des Eingriffs eine Messung des Lärms. Die unten beschriebene Prozedur muss für jeden einzelnen Eingriff wiederholt werden.

<table>
<tr><td>No.s Date Time SPL</td><td></td></tr>
<tr><td>1 2012/05/23 07:15:11 43.4</td></tr>
<tr><td>2 2012.05.23 07:15:12 48.1</td></tr>
<tr><td>3 2012.05.23 07:15:13 51.5</td></tr>
<tr><td>4 2012.05.23 07:15:14 56.9</td></tr>
<tr><td>5 2012.05.23 07:15:15 52.9</td></tr>
<tr><td>6 2012.05.23 07:15:16 51.2</td></tr>
</table>

Abbildung 1: Beispiel eines Abschnitts aus originalen Lärmdaten, sowie sie vom Lärmpegelmessgerät gegeben werden</td></tr>
<tr><td></td><td>Sind die Daten vollständig?</td><td>Schauen, dass das File der Dezibeldaten einem Beobachtungsfile entspricht (Achtung: manchmal haben wir 2 OPs am selben Tag beobachtet, darum auch die Initialen des Patienten berücksichtigen). Dann das Dokument als .xlsx abspeichern.</td></tr>
<tr><td></td><td>Wurde der Lärm richtig gemessen?</td><td>Schauen, ob die Dezibeldaten gut aussehen: Die Messungen sollten zwischen 50 und 100 DB oder 30 und 90 DB verstreut sein und die Lärmmessung sollte die Dauer des Eingriffs abdecken (manchmal versagt das Dezibelgerät). Wenn etwas nicht stimmt, in der Übersichtstabelle notieren, was das Problem ist. Dann entscheiden, ob die Beobachtung unbrauchbar ist. Aus dem csv-file ein excel-file machen.</td></tr>
<tr><td></td><td>Spalten trennen</td><td>Aus der einen Spalte, die alle Informationen enthält, mehrere Spalten machen: Select the first column, à Data, à Text to columns, "tab" und "space" ankreuzen.</td></tr>
<tr><td></td><td>Für die Sommerzeit korrigieren</td><td>Wenn die Beobachtung während der Sommerzeit stattgefunden hat, muss eine Stunde mehr berechnet werden, damit wir im Dezibelfile etwa die gleiche Zeit wie im Beobachtungsfile haben. Daten mit Sommerzeit: 2010: 28. März- 31. Oktober // 2011: 27 März-30.Oktober // 2012: 25. März-28 Oktober. Dies hilft nachher zum Matchen. Wenn der Eingriff in der Sommerzeitperiode liegt, eine Spalte mit dem Titel „plus eine 1 Stnd“ einfügen; dieser Spalte ein Zeitformat geben, und dann in der ganzen Spalte überall 01:00:00 einfügen (dabei den Finger auf ctrl gedrückt halten, damit die Zeit 01:00:00 kopiert wird, anstatt 01:00:00, 02:00:00, 03:00:00, etc.). Dann eine nächste leere Spalte einfügen und die Sommerzeit berechnen: Die Formel für die erste Zelle ist hier „=C2+D2“ (dann einfach für die ganze Spalte kopieren). Die Daten sollten dann wie auf Abbildung 2 dargestellt, aussehen.</td></tr>
</table>

No.s	Date	Time	plus 1h	sommerzeit	SPL
1	23.05.2012	07:15:11	01:00:00	08:15:11	43.4
2	23.05.2012	07:15:12	01:00:00	08:15:12	48.1
3	23.05.2012	07:15:13	01:00:00	08:15:13	51.5
4	23.05.2012	07:15:14	01:00:00	08:15:14	56.9
5	23.05.2012	07:15:15	01:00:00	08:15:15	52.9
6	23.05.2012	07:15:16	01:00:00	08:15:16	51.2

Abbildung 2: Beispiel aus den Lärmdaten, wo die Trennung der Zeitspalten und die Anpassung an die Sommerzeit gemacht wurden

Graph herstellen

Dann die Spalten mit der richtigen Zeit komplett auswählen sowie diejenigen, mit den Lärmmessungen pro Sekunde. Aus diesen Daten ein „line Graph" herstellen (x-Achse zeigt die Zeit an, und y-Achse die Messung in Dezibel) (siehe Abbildung 3).

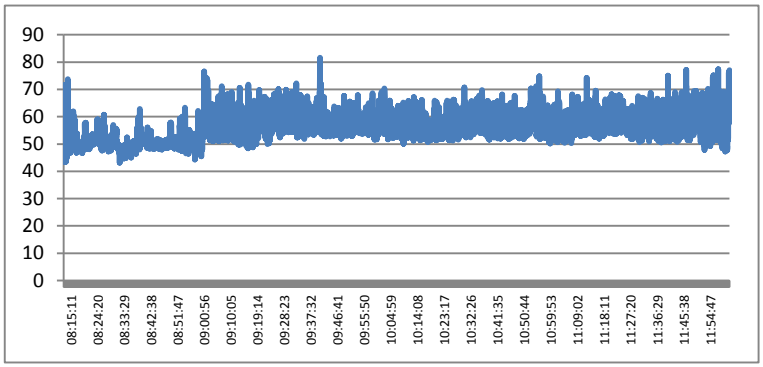


Abbildung 3: Beispiel eines Graphs mit der Zeit eines Eingriffs bei der x-Achse und der Lärmpegel (DB) bei der y-Achse.

2. Matchings

Aus dem hergestellten Graph können die Beobachtungsdaten mit den Dezibeldaten gematcht werden, damit man den Zeitunterschied zwischen den beiden herausfinden kann.

Nur die **Lärmpeaks** (ab 70 DB) anzeigen

Graph kopieren und auf einem zweiten Worksheet (im selben Excelfile) kopieren. Die y-Achse anpassen, damit die Lärmmessungen unter 70 DB nicht angezeigt werden (siehe Abbildung 4). Es erleichtert die Arbeit, wenn man nur die Peaks sieht, und die einsamen Peaks von den Peaks, die in Gruppen auftreten, unterscheiden kann. Diese Regel ist dennoch flexibel: wenn zu wenige Peaks angezeigt werden, darf die Grenze beispielsweise auf 65 DB gesetzt werden; wenn es wiederum zu viele Peaks gibt, die nicht mehr voneinander unterschieden werden können, darf die Grenze auf beispielsweise 75 DB erhöht werden.

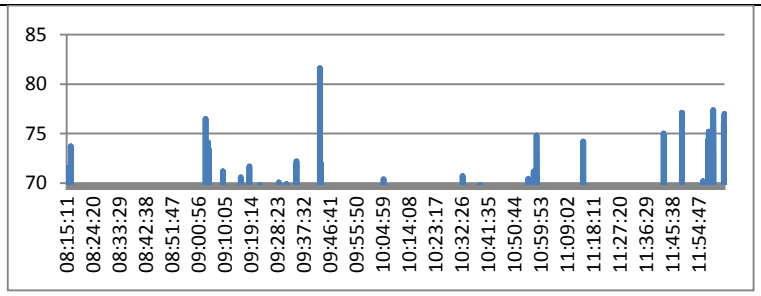
<table>
<tr><td></td><td> 

Abbildung 4: Beispiel eines Graphs, wo nur die Lärmpeaks ab 70 DB angezeigt werden, mit der Zeit bei der x-Achse und der Lärmpegel (DB) bei der y-Achse.</td></tr>
<tr><td>Lärmpeaks anhand Beobachtung erklären</td><td>Ich würde zuerst mit den grössten und einsamen Peaks beginnen. Im Beobachtungsfile schauen, ob ein bestimmtes, wahrscheinlich lautes Ereignis etwa zu dieser Zeit stattgefunden hat (ein Böckli hat Lärm gemacht, etwas ist zu Boden gefallen und hat viel Lärm verursacht, etc.). Die not patient relevant communication und release tension, sowie die Kommunikationen im Allgemeinen eher auf der Seite lassen, wenigstens diese nicht als Ankerpunkt betrachten; man darf aber als Hinweis aufschreiben, wenn Lärmpeaks vielleicht durch not patient relevant communication oder release tension erklärt werden können. Siehe Abbildung 5 für eine graphische Vorstellung des Vorgehens.

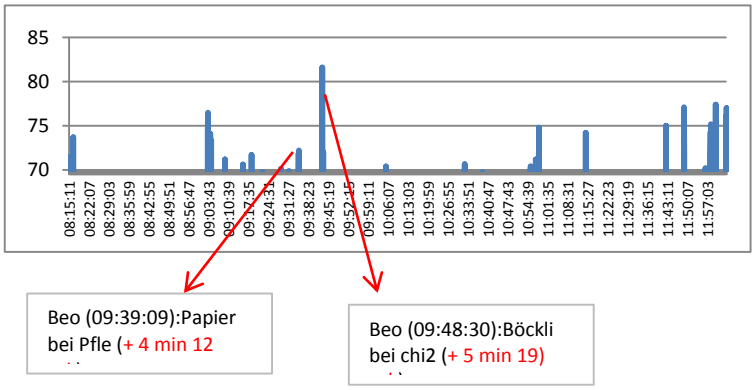
 

Abbildung 5: Beispiel eines Graphs, wo bereits 2 Lärmpeaks anhand der entsprechenden Beobachtung gematcht werden konnten.</td></tr>
<tr><td>Zeitunterschiede zwischen Lärmdaten und Beobachtungsdaten herausfinden</td><td>Wenn man denkt, die Quelle des Peaks identifiziert zu haben, weitere Peaks betrachten und schauen, ob diese auch erklärt werden können, und ob die Zeitunterschiede zwischen Beobachtungen und Dezibeldaten jeweils ungefähr die gleichen sind (wir kodieren laute Ereignisse im Beobachtungsfile eher innerhalb der nächsten 1 min. 30 sek. nachdem diese zu hören waren). Es müssen mindestens 5 gute Peaks erklärt werden können.</td></tr>
<tr><td>Hinweise zum Matchen</td><td>- Manchmal sind ganz viele Lärmpeaks am Ende der Dezibeldaten (also gegen Ende des Eingriffs), weil laut aufgeräumt wird. Man kann sich dann auf die kurzen Zeitphasen OHNE Lärmpeaks fokussieren und im Beobachtungsfile schauen, ob wir zwischen zwei "Gruppen" von "lautes Aufräumen" Kodierungen auch eine Phase OHNE diesen Kommentar identifizieren können.
- Bei Unsicherheit, der Graph der Dezibeldaten anschauen, dieses Mal nicht nur mit den Lärmpeaks über 70 DB, sondern alle. Am liebsten den Graph der ersten Seite (wo wir die Spalten mit der Zeit und Dezibel aufbereitet haben) anschauen, und diesen breiter machen, damit man die Linien genauer sieht. Dann den Graph mit der Beobachtung vergleichen: man muss das Gefühl haben, dass es stimmt (beispielsweise ist es nicht gut, wenn das Dezibelgerät lange 50 DB anzeigt und in der Beobachtung drei Mal nacheinander "lautes Aufräumen" steht. Man sollte dann nach einem anderen Zeitunterschied weitersuchen.</td></tr>
</table>

	- Bei Unsicherheit mit einem Match, unbedingt die Zeit der Dezibeldaten an die Beobachtung anpassen, wie im entsprechenden Unterkapitel beschrieben, und noch einmal die Beobachtung mit den Dezibeldaten visuell vergleichen. Wenn der angenommene Zeitunterschied nicht passt, mit weiteren Zeitunterschieden testen. - Wenn man Mühe mit einem File hat: Am besten das File einen Moment zur Seite legen und es später noch einmal versuchen. Wenn es wirklich nicht geht, schreiben, dass es nicht geht. Es ist allerdings möglich, dass die Beobachtungen zu wenige Hinweise geben, um einen genug guten Match zu erhalten.
Überprüfen, ob die folgenden **Kriterien** eines guten Matchens gewährleistet sind	- ***5 Gute Peaks*** haben, die einem lauten Ereignis (kodiert im Beobachtungsfile) entsprechen - Die ***Zeit des Last Stitch und die Zeit der letzten Lärmmessung im Dezibelfile*** anschauen. Sich fragen, ob das Matching realistisch ist (bzw. der letzte Punkt im Beobachtungsfile kann nicht VOR dem Ausschalten des Geräts kodiert werden, und nach dem Last Stitch läuft immer eine Zeit, bis das Gerät ausgeschaltet wird. - Für jede "Erklärung" des Peaks, bzw. den Kommentar aus dem Beobachtungsfile aufschreiben, was den Zeitunterschied zwischen Beobachtungspunkt und Zeit im Dezibelgerät ist (z.B. + 5 min 30 sek). Den Unterschied zwischen dem Beobachtungspunkt, der am nahesten vom aufgenommenen Lärm im Dezibelfile und dem Beobachtungspunkt, der am weitesten vom aufgenommenen Lärm ist, darf ***nicht über 1 min. 30 sek.*** sein. Denn es ist wenig wahrscheinlich, dass wir Ereignisse später als 1 min. 30 sek., nachdem wir einen Lärm gehört haben, kodieren (siehe Beispiel OP 2011 08 09). (Ausnahmen sind die Aufräumphasen und das Montieren eines Geräts, die mehrere Minuten dauern und somit nicht genau kodiert werden können).
Zeitunterschied **aufschreiben**	Zeitunterschied (der ungefähr mittlere Wert) aller gefundenen Unterschiede nehmen. Beispielsweise schreibt man, dass die Zeit des Dezibelgeräts 1 min. 30 sek. vor der Zeit der Beobachtungsdaten geht, wenn man die folgenden 5 Zeitunterschiede zwischen jeweils einem Lärmpeak und einem lauten Code gefunden hat (01:39, 01:22, 01:10, 01:45, 01:34). Achtung: auf die Richtung des Zeitunterschieds aufpassen (manchmal geht das Dezibelgerät VOR und manchmal geht das Dezibelgerät NACH der Zeit des Beobachtungsfiles). Daneben schreiben, wie schwierig das Matching war.
Anpassung der Zeit der Lärmdaten an die Zeit der Beobachtungsdaten	Da wir dann die Daten in einen SPSS Format umwandeln wollen, sollte die Anpassung der Zeit der Lärmdaten an die Zeit der Beobachtungsdaten in einer standardisierten Weise gemacht werden. Darum wird (1) ein neues Worksheet geöffnet (sheet3 im selben Excel File). (2) Der ganzen Datenblock des sheet1 (also die Zeit, die Anpassung an die Sommerzeit, wo diese gemacht wurde und die Lärmdaten pro Sekunde), wird auf sheet3 kopiert. Die erste grüne Zeile (Titel der Spalten), muss immer die gleiche sein (aus einem anderen File kopieren) und wenn es um eine "Winter OP" geht, die Spalten "plus 1h" und "Sommerzeit" einfach leer lassen, damit wir nachher die Berechnungen immer zwischen den Spalten A und I haben. Die Lärmmessungen müssen in die Spalte I verschoben werden (3) Die Zeit der Daten anpassen: in der Spalte F wird der Zeitunterschied geschrieben (bis zum Ende der Spalte kopieren). In der Spalte G wird die neue Zeit gerechnet, anhand der Spalte mit der alten leicht „verzerrten“ Zeit des Dezibelgeräts (die an die Sommerzeit angepasste Zeit nehmen, wenn es um Sommerzeit-Daten geht). Achtung: man muss dann mit der Formel gut schauen, ob man *minus oder plus* den Zeitunterschied rechnen soll. Dies hängt davon ab, ob die Zeit des Dezibelgeräts vor oder nach der Zeit der Beobachtungsdaten geht.
Einfügen der **5 Minuten Zeitintervalle** der Lärmdaten	Dieser Schritt ist für die weiteren statistischen Analysen nötig. Allerdings wurden die Beobachtungsdaten in 5-Minuten Intervalle unterteilt, indem kodiert wurde, ob ein Ereignis während dem 1., 2., 3., etc. 5-Minuten Intervalls des Eingriffs kodiert wurde. Mit den Lärmdaten wird das gleiche gemacht: in der Spalte H wird für jede Lärmmessung geschrieben, ob die Lärmmessung während dem 1., 2., 3., etc. 5-Minuten Intervalls des Eingriffs erfolgt hat. Um dies zu machen, haben wir die 5-Minuten Intervalle immer nach dem gleichen Beispiel eingefügt, weil es jeweils 300 Sekunden pro 5 Minuten hat. Bei den ersten 5 Minuten nach dem Schnitt wurde somit immer 300 Mal die Zahl „1“ kopiert, etc. Die Anzahl 5-Minuten Intervalle muss genau die gleiche sein wie im Beobachtungsfile, und gegen Ende der Lärmdaten überprüfen, ob der letzte 5-Minuten Intervall zur gleichen Zeit wie der letzte fünf-Minuten Intervall im Beobachtungsfile kodiert wurde. Ab diesem Zeitpunkt können somit die Daten für die Auswertungen in SPSS gebraucht werden, und mit dem Programm zeitlich gematcht werden. Siehe Abbildung 6 für ein Beispiel, wie die Lärmdaten am Ende der Vorbereitung aussehen sollten.

		<table><tr><th>No.s</th><th>Date</th><th>Time (winter)</th><th>plus 1h</th><th>Summer time</th><th>Zeitunterschied mit Beo</th><th>Zeit angepasst an Beo</th><th>5 min Intervalle</th><th>SPL</th></tr><tr><td>1</td><td>23.05.2012</td><td>07:15:11</td><td>01:00:00</td><td>08:15:11</td><td>00:05:00</td><td>08:20:11</td><td>0</td><td>43.4</td></tr><tr><td>2</td><td>23.05.2012</td><td>07:15:12</td><td>01:00:00</td><td>08:15:12</td><td>00:05:00</td><td>08:20:12</td><td>0</td><td>48.1</td></tr><tr><td>3</td><td>23.05.2012</td><td>07:15:13</td><td>01:00:00</td><td>08:15:13</td><td>00:05:00</td><td>08:20:13</td><td>0</td><td>51.5</td></tr><tr><td>4</td><td>23.05.2012</td><td>07:15:14</td><td>01:00:00</td><td>08:15:14</td><td>00:05:00</td><td>08:20:14</td><td>0</td><td>56.9</td></tr><tr><td>5</td><td>23.05.2012</td><td>07:15:15</td><td>01:00:00</td><td>08:15:15</td><td>00:05:00</td><td>08:20:15</td><td>0</td><td>52.9</td></tr><tr><td>6</td><td>23.05.2012</td><td>07:15:16</td><td>01:00:00</td><td>08:15:16</td><td>00:05:00</td><td>08:20:16</td><td>0</td><td>51.2</td></tr></table> *Abbildung 6*: Beispiel eines Abschnitts von Lärmdaten, so wie sie aussehen sollen, nachdem die Zeit an die Zeit der Beobachtung angepasst wurde und die 5-Minuten Intervalle eingefügt wurden.
3.	**Training zum Matching**	Nachdem die oben beschriebene Methode entwickelt wurde, wurde eine zweite Person für das Matching-System geschult. Wichtig ist, dass beide Rater on-site Beobachtungen im Operationsraum durchgeführt hatten, und somit eine klare Vorstellung haben, wie laut manche Ereignisse sein können.
	Halber Trainingstag	Die Schulung bestand aus einem halben Tag, wobei die Methode (1) erklärt und (2) ein Matching gemeinsam bearbeitet wurde und zwei weitere Matchings der geschulten Person zum Trainieren überlassen wurden. Diese ersten Versuche wurden in der Berechnung der Intraclass Coefficient nicht inbegriffen.
	Trainingsprozess und Verfeinerung der Matchingskriterien und Hinweisen	Nach dem halben Trainingstag durfte die geschulte Person weitere Matchings alleine übernehmen, die getrennt vom ersten Rater bereits gematcht worden waren. Überall, wo die geschulte Person nicht den gleichen Zeitunterschied wie der erste Rater fand oder, wo die Matchings nicht genug vollständig und eindeutig waren, wurde ein allgemeines Feedback gegeben. Dabei wurden die Kriterien eines guten Matchings verfeinert und die Hinweise zum Matchen entwickelt. Nach dem Feedback durfte die geschulte Person nach einem anderen Zeitunterschied suchen und dann zählte der zweite Versuch für die Rechnung der Intraclass correlation.
4.	**Rechnung der Inter-rater Reliabilität der Matchings**	Um sicher zu stellen, dass die oben beschriebene Matchingsmethode reliabel ist, wurde ein Teil der Dezibeldaten mit den jeweils entsprechenden Beobachtungsdaten doppelt gematcht, bzw. von zwei verschiedenen Ratern (der erste Rater und die geschulte Person). Insgesamt wurden 26 Beobachtungsdaten mit Lärmdaten doppelt gemacht. Aus den gefundenen Zeitunterschieden, welche folgendes Zeitformat haben (e.g. 00:05:30 Zeitunterschied), wurde eine Intraclass coefficient (ICC) gerechnet. Der ICC beträgt .99.

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Appendix C: Recoding observed distractors

This appendix is a non-published working paper that we used and will continue using to categorize observed distractors in order to conduct further and more detailed analysis.

Working paper

Recoding distractors classified in a non-specific category of distracting events as part of an on-site coding system used in the context of the operating room: description and testing of a coding system

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We would like to thank Anna Püschel for her help in establishing reliability scores

Abstract

Aim: The aim of this working paper is to describe (1) the coding system of the distractors observed in the operating room (OR) based on a validated observational system (Seelandt et al., 2011) and (2) the validating process of this system..
Method: Establishing a coding-system of comments to the disctractor category and double coding to establish interrater reliability.
Results: We could show the feasibility of the recoding of the distractors and validate the system we used.

Introduction

When distracted while executing surgical tasks on a simulator, surgeons or medical students made more errors and need more time to solve the task (Feuerbacher et al., 2012; Goodell et al., 2006b; Pluyter, Buzink, Rutkowski, & Jakimowicz, 2010; Szafranski et al., 2009). This research emphasizes the importance of the potential negative effects of distractors on performance in the operation room (OR). Interestingly, these studies used many different types of distractions (e.g. mathematical calculations to solve parallel to the surgical task (Goodell et al., 2006b); music or sub-optimal handling of the laparoscopic device (Pluyter et al., 2010); distracting communications in the background (Feuerbacher et al., 2012; Pluyter et al., 2010; Szafranski et al., 2009)), indicating that there is no agreed upon definition of distractors. There is evidence that these different kinds of distractors do not have the same impact on performance. For example, in the same experimental setting, one study showed that noise recorded in the OR had an impact on performance, but visual distractions or vibrations did not (Szafranski et al., 2009). Another study claims that verbal distractors (interrupting questions and sidebar conversations), were more likely to be timely related to errors compared to other types of distractors (e.g. a phone ringing or noise coming from a metal tray falling onto the floor (Feuerbacher et al., 2012). These results emphasize the importance of studying the differential impact of different distracting events on performance, instead of "grouping" them in a single distractor category.

The on-site observational system of Seelandt and colleagues includes distracting events observed during surgeries (Seelandt et al., 2011). It already distinguishes between the following categories of distracting events: (1) not patient related communication among the surgical team (e.g. the surgeons speak about the next patient), (2) side conversations outside of the sterile team (e.g. the anaesthetists communicate among each other about how much blood the patient lost) (3), phone ringing, alarms, or beepers (e.g. the laboratory calls up to give the results of their analysis of a piece of tissue that was previously sent for analysis), (4) surgery team external communication (e.g. an external surgeon comes to the OR to ask a question about another patient), (5) incidents (e.g. a surgeons cuts his finger and the surgery is shortly interrupted), (6) doors opening and (7) non-specific noise distractors (e.g. a nurse loudly opens a packaging of sterile sponges).

We focus on non-specific noise distractors. When observing a non-specific noise distractors, the observers were advised to write a comment specifying the distractor. This allows to identify *what* was potentially distracting. These qualitative descriptions make it possible to refine the non-specific distractor category in developing and applying a coding system.

In this working paper, we first present theoretical and practical considerations that guided the development of the criteria to build specific sub-categories of noise-distractors. Second, we describe the sub-categories. Finally, we present the validation of the coding.

Developing the sub-categories of noise-distractors

We developed sub-categories based on theoretical considerations and by practical limitations of the data available. The aim of the categorization is to have more fine-grained knowledge on distractor origin and content, but also to relate noise-distractors to decibel-based noise-levels used in the study. This means that the noise intensity produced by the different distractors was an important criterion in the reflexion that led to the development of the categorization system.

Criteria 1: Origins of distractors

Most of the distractors observed on-site related to the tasks and behaviors of the different sub-teams (circulating nurses, anaesthetists) and were thus "scattered" in the OR and over time. Thus, collecting more information about which sub-team working in the OR is involved in which potential distractor, and when, will allow us to relate the distractors to the specific tasks of sub-teams. To our knowledge, there is no previous study examining this relationship. As we assume that distractors occurring nearer to the surgeons have more distracting potential because of their increased visibility and audibility for the sterile team, it is important to know the origin of the distractors.

We thus developed categories that indicate "*where*" the distracting event coded came from. Comments during the site-observation mention the group of people involved in the apparition of the distractor (e.g. a nurse is loudly opening a packaging). As the different sub-teams (surgeons, anaesthetists, circulating nurses) work in their specific part of the OR (e.g. typically, the anaesthetists work by the patient's head), the coding allows to establish where (incluiding a "geographic" perspective), the distractor came from.

Criteria 2: Type of noise

The second aspect taken into account is the *characteristics of the noise* of potentially distracting events. We focused on (a) particularly loud noises and (b) on the distinction between verbal and other distractors for the following reasons:

a) Previous research showed that higher levels of noise were related with surgical site infections (Kurmann, Peter, Tschan, Muhlemann, et al., 2011). We therefore distinguish particularly loud distractors from other distracting events, as these should be responsible for higher levels of peaks of noise.

b) The question of the potential greater distracting potential of verbal distractors is explicitly discussed in other research fields than the operating room (Banbury & Berry, 1998; Enmarker, 2004; Hygge, Boman, & Enmarker, 2003). In the OR, verbal distractors (e.g. interrupting questions followed by sidebar conversations) were indeed found to be related with errors in a greater extent than other distracting events (e.g. such as an object falling onto the floor (Feuerbacher et al., 2012)).

For these reasons, we included the loudness of the distractors, its verbal or non-verbal character and its duration into the coding system.

Criteria 3: Meaning related to the distractor

The *meaning* of the task associated with the distractor could be a moderator of its distracting impact on the surgeons (Cohen & Spacapan, 1984). Indeed, if the distractor is perceived as an unavoidable part of the execution of an important task, it may be assessed as less distracting. In the same vein, the controllability of the distractor may also plays an important role in its distracting potential (Kjellberg et al., 1996). Therefore, we distinguish distracting events that indicate whether the distractor is a part of an important task "here and now" (e.g. the opening of packaging containing material needed for the progress of the surgery) from distractors associated with not immediately necessary activities (e.g. the tidying of the room). Indeed putting away instruments and cleaning up is not immediately useful as part of the actual surgery despite of the fact that it is a necessary task for the planning of the occupation of the OR. Moreover clearing and tidying activities could be perceived as less controllable by the surgical team and thus as more distracting, as they do not supervise these activities. In contrast, surgeons can influence activities directly related to the surgery (e.g. which instrument they need at a given moment). Thus, we differentiated between distractors related to immediately necessary tasks vs. tasks that could be postponed. We thus coded whether a distractor was related to tidying up the OR.

Criteria 4: Distractors as requiring an active response

We further distinguished distractors that required an *active response* from the surgical team. The study of Feuerbacher et al. (2012) showed that the verbal distractors, which were associated with the most errors were those requiring an active response from the surgeon. Moreover, these kinds of distracting events are described as involving conscious dual-tasking (e.g. operating while responding to a question asked by a nurse about the kind of material need), rather than ignoring a noise that is known to be irrelevant to the primary task (e.g. hearing a noise from a dropped object) (Beaman, 2005).

Table 1. Description of the categorization system[6]

Each unspecific distractor was coded into one of the following events.

Anleitung zur Kodierung der Distraktoren

Kategorie-Nummer	Welche Distraktoren?	Erklärung über die Kategorie	Beispiele	Kriterien
1	Distraktoren bei den **Pflegen** und den **sterilen Pflegen.** Ursache: die **Vorbereitung von Material**, das UNMITTELBAR für den Eingriff gebraucht wird	Für die Chirurgen kommen diese Distraktoren aus dem Bereich der OP, wo die Pflege und die sterile Pflege arbeiten. Diese Distraktoren "passieren" in der direkten Nähe vom OP Tisch, die Chirurgen haben meistens die Möglichkeit zu sehen, woher sie kommen und sie sind vor allem verursacht, weil die Pflege (Pfles)/sterile Pflege (Stes) etwas (nützliches) "hier und jetzt" für die Chirurgen vorbereiten	- Packungen werden geöffnet - Packungen werden weggeworfen gerade nachdem Pfle zu Ste etwas gegeben hat (es gehört irgendwie noch zur Vorbereitung von Material) oder nachdem Bauchtücher gezählt wurden (wir wissen es sind die Packungen der Bauchtücher) oder nach einer Sterilhandlung (es sind wahrscheinlich die Packungen der Kittel der Chirurgen, die weggeworfen werden) - Geräte werden bei Pfle eingerichtet - Ste vorbereitet die Metalstangen für die Montierung des Thompsons	where meaning noise type (no-)response
2	Alle Distraktoren, die im Bereich der **Anästhesie** auftreten, ausser den Böcklis	Anhand der Daten, die vorhanden waren, hatten wir zu wenige Informationen zur Verfügung, um die Distraktoren mit spezifischen Aufgaben im Zusammenhang zu setzen. Zudem nehmen die Chirurgen wahrscheinlich nicht genau wahr, was diese Distraktoren verursacht (unter anderem wegen dem Vorhang)	- Anästhesisten machen Packungen auf - Schublade bei der Anästhesie wird besonders laut zugemacht	where (no-)response
3	**Böcklis,** unabhängig davon, wo der Böckli Lärm gemacht hat	Das Verschieben der Böcklis macht ein Geräusch, das meistens eher laut und kurzfristig ist	- Assistenzarzt (Assi) verstellt sein Böckli - Die Anästhesisten (Anas) bringen einen Böckli, um den OP Feld besser sehen zu können	type (no-)response

[6] The description of the re-categorization system is written in German, the language of the coders

4	**Aufräumen** vom Material bei den Pflegen und sterilen Pflegen, das nicht mehr gebraucht wird	Die Pfles und Stes räumen das Material das sie nicht mehr benötigen, regelmässig auf. Vor allem gegen Ende der OP, wird viel aufgeräumt, und die Geräusche können besonders laut werden, da Material aus Stahl weggeräumt wird. Das Aufräumen gegen Ende der OP findet nicht mehr in unmittelbarer Nähe des OP-Tisches statt und die Chirurgen sehen somit nicht woher die Distraktoren kommen.	- Pfles räumen auf - Geräte werden weggeräumt - Pfles beschäftigen sich mit Kisten, wo dann das gebrauchte Material gelegt werden muss - Pfles pressen Papiere im Müll zusammen - etwas wird in den Müll weggeworfen und es sind KEINE Packungen, die gerade aufgemacht wurden	where meaning noise type (no-)response
5	Chirurgen werden **angesprochen**	Anästhesisten und pfles sprechen die Chirurgen während der OP öfters an um Informationen zu bekommen oder zu geben. Obwohl der Informationsaustausch mit der OP zu tun hat, kann das die Chirurgen potenziell ablenken, weil sie sich für einen Moment auf das Gespräch konzentrieren müssen. Die Chirurgen werden manchmal wie aus dem "nichts" angesprochen, was den Distraktor unvorhersehbar macht.	- Anästhesist stellt dem chirurgischen Team eine Frage - die Pflege fragt noch Mal wie sie Schnellschnitt beschriften soll - Eine Pfle AUS NEBENAN fragt ste nach etwas und dies wurde als Distraktor kodiert	noise type response
6	**Andere** Distraktoren	Alles, was nicht zu den anderen Kategorien passt. Wenn es zu wenige Informationen hat, was es für ein Distraktor ist, beispielsweise steht im Kommentar nur "pfle, ana".	- Pfle stösst gegen etwas - ein Instrument fällt zu Boden bei Chis - Eine Schublade bei der Pfle wird laut zugemacht - Alle lautlose Distraktoren wie jemand winkt oder Klopft an die Tür, oder Ana schaut über OP Tuch - "Roller" der schmutzigen Bauchtücher - Lärm aus nebenop - Pfle sucht nach etwas im Schrank (und wir wissen nicht worum es geht)	
	Tipps	- Ste mit instrumenten→ wird als andere distraktoren kodiert (Ste) - Pfle mit Instrumenten→ wird als Aufräumen kodiert, solange dass es im Kontext passt. Allerdings macht die Pfle Lärm mit Instrumenten nur, wenn sie den Raum aufräumt - Pfle mit Boxe → wird als aufräumen kodiert		

Inter-rater reliability

To test the inter-rater reliability, two independent raters recoded the 938 distractors observed during 20 surgeries, based on the comments written by the observers. It is important to note that both raters had experience as on-site observations the OR, and thus had a clear idea about the events occurring in the OR. The measure of agreement Cohen's Kappa was calculated. Overall Kappa was .88.

Conclusion

In this working paper, we presented the theoretical and practical considerations behind the -categorization system for the comments related to the non-specific category "distractors" coded during on-site observations in the OR. The high reliability score (Cohen's kappa = .88) is based on 998 distractors comments observed in 20 surgeries, coded by two independent researchers. We conclude that the coding of open comments can be done reliably.

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