NOISE PEAKS INFLUENCE COMMUNICATION IN THE OPERATING ROOM. An observational study.

Sandra Keller [1]

Franziska Tschan [1]

Guido Beldi [2]

Anita Kurmann (†)

Daniel Candinas [2]

Norbert K. Semmer [3]

[1]University of Neuchâtel, Institute for Work and Organizational Psychology; Rue Emile Argand 11; CH-2000 Neuchâtel, Switzerland tel +41 32 178 13 90; [2] Department of Visceral Surgery and Medicine, Inselspital, University Hospital of Bern, University of Bern; CH-3010 Bern, Switzerland, +41 31 632 24 03[3] University of Bern, Department of Psychology, Fabrikstrasse 8, CH-3000 Bern, Switzerland; +41 31 631 40 45

Authors' note:

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Correspondence regarding this paper should be addressed to Sandra Keller, Institute of Work and Organizational Psychology, University of Neuchâtel, Rue Emile Argand 11, 2000 Neuchâtel, Switzerland Sandra.keller@unine.ch.

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.

Keywords: Operating room; Noise; Communication; Distractors

Practitioner summary

This study investigated whether noise during surgeries influenced the communication within surgical teams. During abdominal surgeries, noise levels were measured, and communication was observed. Results showed that high noise peaks reduced the frequency of patient-related communication, but did not reduce patient-irrelevant communication. Noise may negatively affect team coordination in surgeries.

Introduction

Noise has been defined as “the wrong sound at the wrong place” (Murthy *et al.* 1995) or as an “unwanted sound” (Hodge and Thompson 1990, Blomkvist *et al.* 2005). Noise is a nuisance and negatively affects well-being and performance (Edworthy 1997, Passchier-Vermeer and Passchier 2000, Szalma and 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 *et al.* 2006), 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 *et al.* 2006, Kurmann *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 (Weaver *et al.* 2010, Kurmann *et al.* 2012, Wahr *et al.* 2013), 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).

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); a metal bowl falling on the floor generates more than 100 dB(A) (Hodge and Thompson 1990). Music can also be a source of noise in the OR, as can communication (Shankar *et al.* 2001, Hasfeldt *et al.* 2010, Way *et al.* 2013); however, 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 and 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 *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 (Rylander 2004, Basner *et al.* 2014). A link between noise levels and stress of the surgical team has been suggested (e.g.

Hodge and 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.* 1995). This result is in accordance with findings in other settings, showing that noise impairs performance on cognitive tasks (Loewen and Suedfeld 1992) because it lowers attention and concentration (Hygge and Knez 2001, Szalma and 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 and Knez 2001, Szalma and 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 and 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 and 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* (Hodge and Thompson 1990, Shankar *et al.* 2001, Tsiou *et al.* 2008, Hasfeldt *et al.* 2010, Way *et al.* 2013). Evidence from other contexts suggest indeed that noise impairs performance of tasks that rely on communication (Szalma and Hancock 2011). For example, people living close to airports report that conversation suffers most under aircraft noise (Stansfeld and Matheson 2003). Noise impairs the listener to understand the communication (Shankar *et al.* 2001, Barach and Weinger 2007), 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 *et al.* 2011, Way *et al.* 2013).

For speakers, the obvious solution with noise present is to raise the voice (Hodge and Thompson 1990, Shankar *et al.* 2001, Barach and Weinger 2007, Kracht *et al.* 2007, Orellana *et al.* 2007). Speaking louder (the so-called Lombard reflex (Junqua 1996)), was indeed the reaction of two thirds of participants exposed aircraft noise (Key and 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 and 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 closely cooperating multi-disciplinary team consisting of subteams of surgeons, anesthetists and scrub and circulating nurses (Nurok *et al.* 2011a). They all need 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 *et al.* 2011b, Tschan *et al.* 2015). Case-relevant communication facilitates situation awareness, helps building a shared mental model (Catchpole *et al.* 2008), and helps coordinating the team (Xiao *et al.* 2013). Communication failures or delays impair performance by increasing the likelihood of mishaps (Lingard 2004, Davies 2005); communication problems are a common cause of adverse events (Leonard *et al.* 2004, Christian *et al.* 2006). Thus, case-related communication is imperative for surgical teams to perform their tasks in a safe and efficient way. Besides 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 *et al.* 2006, Sevdalis *et al.* 2007, Tschan *et al.* 2015).

We contend that case-relevant communication demands more attention than case-irrelevant communication for two reasons: First, case—relevant communication typically is more complex. Second, not paying attention or not understanding, case-irrelevant communication typically is inconsequential, whereas it may have adverse consequences with regard to case-relevant communication. Thus, paying close attention to the more complex case-relevant communication, and making sure that it is understood correctly is necessary for the team to achieve the goal. 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 and 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 and Holding 1993). Research on emotional (Guski *et al.* 1999, Passchier-Vermeer and Passchier 2000), cognitive (i.e. reading ability) (Clark *et al.* 2006) and physiological effects of noise (Allen and 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) (Goodell *et al.* 2006, Pluyter *et al.* 2010, Suh *et al.* 2010, Feuerbacher *et al.* 2012), noise levels alone were not associated with worse performance in another 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).

The work environment in the OR is complex and includes many technical, and often noisy, devices. It is thus not surprising that mean noise levels in gastrointestinal surgery were as high as 63 dB(A) (Kracht *et al.* 2007). Noise peaks are also very frequent in the OR (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 focused on 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 (Goodell *et al.* 2006, Pluyter *et al.* 2010, Feuerbacher *et al.* 2012). 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 and 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. Nine surgeries were excluded because of technical errors related to the sound meter (the noise recording device was not set up correctly to record dB(A), or the recordings were incomplete, because the duration of the surgery exceeded the recording capacity of the device); one surgery was excluded because it was terminated after a laparoscopic diagnosis. 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, a junior surgeon, a resident and/or a medical student, at least one anaesthetist; one scrub nurse and at least one circulating nurse. Senior surgeons held a degree in general surgery as well as a specialty degree in visceral surgery; the latter requires at least 10 years of postgraduate training. Junior surgeons held a degree in general surgery and were in training towards the specialty degree in visceral surgery; thus, all junior surgeons had between 6 and 10 years of postgraduate training.

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 for each second, and time-stamped. In line with other studies, we used a dB(A) filter, because the dB(A) measurement scale is best adapted to the human perception of relative loudness (Hodge and Thompson 1990, Murthy *et al.* 1995) The sound level recorder was placed in a holder on the main operative lamp, about 1.5 meters above the operative field (Kurmann *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, Gladd and Saunders 2011, Engelmann *et al.* 2014). 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 always the responsible surgeon of the resection and reconstruction phase. We did not distinguish whether the senior surgeon was performing the main phase of the surgery or assisted 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 phase 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 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, the clock of the sound level meter differed from real time, which needed to adjust the synchronization between the computer observational system time and the sound level meter time. To assure the correct temporal alignment of noise measures and observations, we identified at least three observed loud noises and matched these with noise-peaks measured by the sound recording device.Based on 25 surgeries (23 % of the sample) and two independent raters; the intraclass-correlation coefficient for the time-matching procedure was very high (0.99), indicating excellent inter-rater agreement.

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), 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 analysis

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 *et al.* 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 hr 22 min (SD = 1 hr 38 min), range was between 1 hr 14 min and 7 hr 21 min; 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 junior surgeon in charge, significantly more noise-peaks above 70 dB(A) per hour were observed than in the 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.

Influence of noise-peaks on intra-surgical communication

Hypotheses were tested based on 5399 five-minute intervals nested in 109 surgeries. Descriptive statistics and intercorrelations among the study variables are displayed in Table 2 and 3.

To assess whether multilevel modeling is appropriate, we estimated a null model without predictors. For case-relevant communication, the null model showed that the variances were significant on Level 1 (the five-minute interval: 1.53; SE = .03) as well on Level 2 (the surgery level: 0.25 SE = 0.04); the variance explained on Level 1 was 86%. For case-irrelevant communication, the null model showed that the variances on Level 1 (0.8; SE = .02) as well on

Level 2 (0.1 SE = 0.02) were significant; the variance explained on Level 1 was 88%. Thus, multilevel modeling is thus justified (Hox 2010).

To test whether noise peaks affect communication, we separately assessed effects of noise peaks on case-relevant and case-irrelevant communication. We included the Level-2 control variable (duration of the surgery) and the variable representing noise peaks in the same interval as the main predictor variable in Model 1 (Tables 4 and 5). We subsequently added the following control-variables: a) communication in the previous five-minute interval (Model 2 in Tables 4 and 5); and b) noise-peaks in the previous five-minute interval (Model 3 in Tables 4 and 5). 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 4 in Tables 4 and 5) as well as the interaction term between noise-peaks in the same interval and the surgeon in charge (Model 5 in Tables 4 and 5).

Hypothesis 1 stated that noise peaks would impair case-relevant communication. Results are displayed in Table 4 (Models 1 to 3). 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. Model 5 in Table 4 shows that the interaction term 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. 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 noise peaks were associated with *more* case-irrelevant communication in the same interval (Tale 5, Model 1; 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, Table 5) but was only marginally significant when noise peaks during the prior five-minute interval were added (Model 3 in Table 5). 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.

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). Previous studies have shown negative effects of noise exposure on technical aspects of surgical performance (Murthy *et al.* 1995); 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 (Kurmann *et al.* 2011, Engelmann *et al.* 2014, Dholakia *et al.* 2015). Reducing communication is one of the reactions people show in noisy environments (Key and Powell 1980), and studies in other fields also showed that noise particularly impaired novel and complex communication (Way *et al.* 2013).

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. 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 show good performance even under distracting conditions (Hsu *et al.* 2008, Suh *et al.* 2010). However, it has to be noted that the phases of responsibility of senior and junior surgeons also differ in task complexity. The phase under responsibility of the main surgeon may be perceived as a higher risk phase, and this may also have influenced the link between noise and communication.

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. The team may therefore be more relaxed, and this may be particularly important for the last phase of the surgery, when one is about to finish. In line with these considerations, there is evidence of more case-irrelevant communication as well as more noise during closure as compared to the main phase of the surgery (Broom *et al.* 2011, Tschan *et al.* 2015). However, preparing and closing can 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 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 (Kurmann *et al.* 2011). 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. 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. An enhancing effect on case-irrelevant communication does seem theoretically plausible. 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 *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 *et al.* 2011a), 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).

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 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 sensorimotor 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.

Another limitation that is due to the naturalistic setting of this research is that the phases of responsibility of the senior vs the junior surgeon overlap with phases of different task complexity, we can therefore not unambiguously attribute the effect found to surgeon experience. In this study, we defined senior and junior surgeons based on their specialty degrees, but we do not have more specific information regarding the years of experience and the number of surgeries performed. This would be necessary for a more thorough study of expertise levels and sensitivity toward distractions.

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 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 real surgeries, thus analysing the interplay of noise and communication. The combination of observational data and noise measures is another strength, because it 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, not only case-relevant communication. However, this study found that only the more complex communication, and only communication in a phase that is under the responsibility of a less experienced group member, was impaired under noise. If the effect of noise were purely auditory, noise would have interfered with all types of communication in all phases of the team process.

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 may impair task-related teamwork in the OR. The results of this study support the need for noise-reducing programs in the OR. Although it is not possible to eliminate all noises, noises in the OR can be significantly reduced by behavioral interventions, for example by clamping the sucker if it is not needed (Engelmann *et al.* 2014). Another possibility to reduce noise is to ask manufacturers of noisy equipment to technically reduce noise emissions, and it may also be possible to use less noisy equipment, for example using step stools made of reinforced plastic rather than metal.

Because it may not be realistic to eliminate all noise-peaks in the OR, interventions could also aim at the communication behavior in the OR with the goal to assure that information is shared and understood. Interventions aimed at improving communication such as structured call outs (Weller *et al.* 2014), closed loop communication (Härgestam *et al.* 2013) or general team and communication training (Armour Forse *et al.* 2011) may contribute to assuring information exchange in the OR even under high noise. Such trainings may be of particular use for junior surgeons, because they seem to be more disturbed by noise than senior surgeons. Besides noise reduction programs, it is thus important to help junior surgeons to develop strategies not only to cope with a distracting environment, but also to assure case-relevant communication.

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Table 1. Noise levels and communication frequency overall and in phases of responsibility of the senior or junior surgeons

	Overall (N=109)		Senior surgeon responsible (N=102) [1]		Junior surgeon responsible (N=102) [1]			
	M	SD	M	SD	M	SD	t(101)[2]	p
Duration	4hr 22 min	1hr 38min	2hr 37min	1hr 29min	1hr 51min	1hr 03min	3.86	p < 0.001
Mean noise level 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)	21.47	6.49	23.42	8.12	19.16	9.79	3.74	p < 0.001
Case-irrelevant communication (Mean per hour)	6.67	4.36	5.65	4.91	7.47	8.38	-1.96	p = 0.052

Notes: M=mean; SD = Standard Deviation; hr=hour min = minutes

[1] in 7 surgeries, the senior surgeon was present throughout the entire procedure

[2] comparison of the phases of responsibility of senior vs junior surgeon

Table 2. Means, standard deviations, minimum and maximum values of study variables

	M	SD	Min	Max
Duration of surgery (in hours and minutes)	4:22h	1:38h	1:14	7:21h
Number of noise peaks per 5-min interval	2.82	5.10	0	66
Number of case-relevant communication per 5-min interval	1.85	1.33	0	8
Number of case-irrelevant communication per 5-min interval	0.55	0.94	0	9

Note: N=109 surgeries; M = Mean; SD = Standard Deviation; Min = Minimum; Max = Maximum

Table 3: Intercorrelations between level 1 variables

	1	2	3	4	5	6	7
1. Duration of surgery (in hours)	-						
2. Noise peaks per 5-min interval (sum)	-0.03						
3. Case-relevant communication prior 5-min interval (sum)	0.04**	-0.07***	-				
4. Noise peaks prior 5-min interval (sum)	-0.02	0.37***	0.06***	-			
5. Surgeon responsible (junior = 0, senior = 1)	0.03*	-0.06***	0.14***	-0.06***	-		
6. Case-irrelevant communication prior 5-min interval (sum)	-0.05***	0.03*	-0.05**	0.03*	-0.01		
7. Case-relevant communication same 5-min interval (sum)	0.05***	-0.08***	0.29***	-0.08***	0.14***	0.04**	-
8. Case-irrelevant communication same 5-min interval (sum)	-0.05***	0.03*	0.02	0.02	-0.01	0.32***	-0.04**

Note. *p < 0.05, ** p < 0.01. *** p < 0.001; N=5399 5-minute intervals

Table 4. Influences on case-relevant communication (five-minute intervals)

Predictor variables	Dependent variable: case-relevant communication in 5-minute intervals														
	Model 1			Model 2			Model 3			Model 4			Model 5		
Fixed effects	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t
Intercept	1.75	0.15	11.56***	1.42	0.13	11.20***	1.45	0.13	11.41***	1.30	0.13	10.00***			
Level 2															
Duration of surgery (in hours)	0.03	0.03	0.97	0.03	0.03	1.04	0.03	0.03	1.02	0.03	0.03	0.95			
Level 1															
Noise peaks per 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***
Random effects															
VAR Intercept Level 2			0.25			0.16			0.16			0.16			0.16
VAR Intercept Level 1			1.52			1.49			1.48			1.46			1.46

Note. *p < 0.05. ** p < 0.01. *** 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 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 5. Influences on case-irrelevant communication (five-minute intervals)

	Dependent variable: case-irrelevant communication per 5-min interval														
Predictor variables	Model 1			Model 2			Model 3			Model 4			Model 5		
Fixed effects	B	SE	t	B	SE	t	B	SE	t	B	SE	t	B	SE	t
Intercept	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	-1.62	-0.02	0.02	-1.62	-0.02	0.02	-1.62	-0.02	0.02	-1.58			
Level 1															
Noise peaks per 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[1]							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
Random effects															
VAR Intercept Level 2			0.10			0.05			0.05			0.05			0.05
VAR Intercept Level 1			0.80			0.76			0.76			0.76			0.76

Note. *p < 0.05. ** p < 0.01. *** 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 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 Captions

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).