ORIGINAL RESEARCH

Silent operating theatre optimisation system for positive impact on surgical staff-members' stress, exhaustion, activity and concentration in urological da Vinci surgeries

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ABSTRACT

Background Noise in the operating room (OR) is a stressor with far-reaching negative consequences. The Silent Operating Theatre Optimisation System (SOTOS) suppresses the noise level in the OR and improves the communication of the OR-staff. This study investigates whether SOTOS has a positive impact on the OR-staff's perceived stress, exhaustion, activity and concentration.

Methods Data were collected in a quasi-experimental study design of 32 radical prostatectomies using the da Vinci robotic-assisted system. Sixteen randomly chosen surgeries were carried out with SOTOS and 16 without. A total of 34 OR-staff-members took part, each 32 surgeries involving five planned OR-staff-members. Two points of measurement, before and after each surgery, were carried out, with a final sample of n=143 repeated measurements data. Before and after surgery, OR-staff-members completed a concentration test and a questionnaire concerning their perceived stress, exhaustion and activity levels.

Results The OR-staff felt significantly less stressed, less exhausted and more active during and after surgery when operating with SOTOS. Especially the primary surgeons, assisting surgeons and circulating nurses profited from SOTOS. SOTOS did not reveal a significant impact on the OR-staff's concentration in this study.

Conclusion For urological surgeries using the da Vinci system SOTOS constitutes a technical resource which significantly reduces perceived noise stress and exhaustion and improves the activity of primary surgeons, assisting surgeons and circulating nurses. These efficiencies likely lead to positive changes in their health and job satisfaction and are hence beneficial to the patient safety and hospital resources.

INTRODUCTION

Every day, surgical teams work in operating rooms (OR) with a noise level similar to a transport highway.[1] Depending on the type of surgery, the average noise level ranges between 51 dB(A)[2] and 81 dB(A)[3] with peaks exceeding 120 dB.[4] The main reasons for these high noise levels in the OR are staff communication, medical technical devices, dropping metal tools, slamming doors, suction system(s), alarms, the surgical saw, opening of sterile instrument packages and the air circulatory and cooling system.[2 5 6] Studies have shown that the OR-staff perceives these high noise levels as distracting, stressing and reducing their efficiency.[6–9] The OR-noise impairs the OR-staffs' concentration[10 11] which has cognitive consequences such as reduced mental efficacy, attention, short-term memory, long-term memory and working memory performance[12] and motor skill consequences such as compromised coordination, dexterity, increased complications and a higher error rate in surgery.[10 12–15] In addition, noise hinders the communication in the

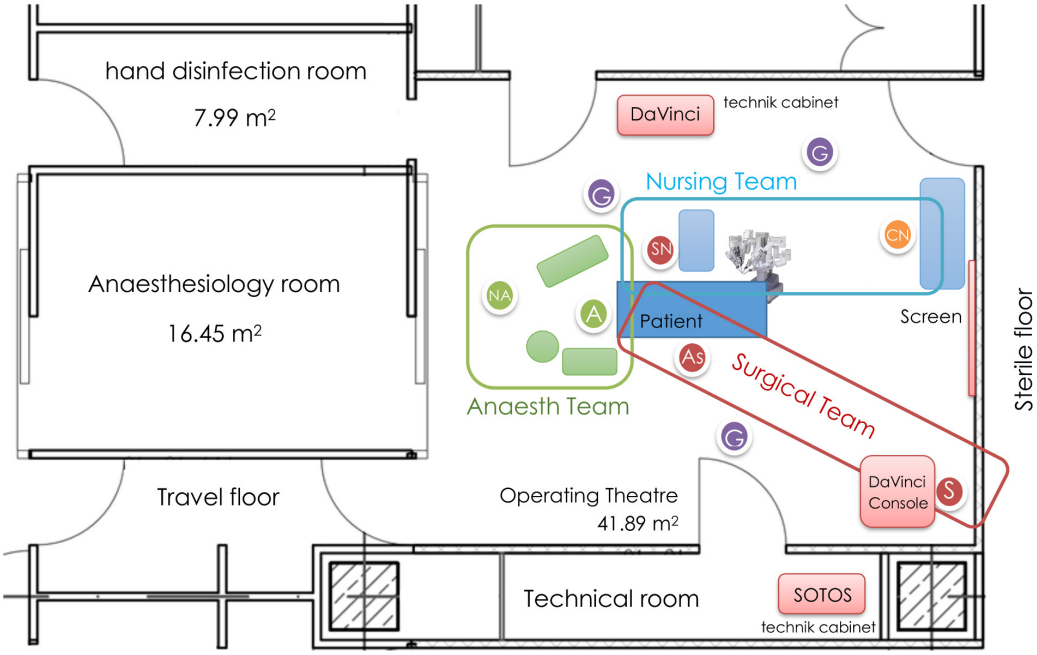

Figure 1 Operating room setting. AnaesthTeam, anaesthesia team; SOTOS, Silent Operating Theatre Optimisation System.

OR.[7 10–12] OR-team-members have to raise their voices to communicate accurately over the noise,[7] which can be exhausting. Instead of the usual speaking volume of 55 to 65 dB(A), approximately 70 to 85 dB(A) are needed in the OR.[4 11] Speaking loudly accelerates the soaking through of the medical masks, leading to an increase of potential germ transference in the OR-environment.[16] These communication problems especially apply to surgeries using the robotic-assisted da Vinci system that enables minimal-invasive surgery. This system consists of four robotic-assisted arms at the OR table remote-controlled by the primary surgeon via a free-standing console standing apart from the OR table (figure 1). The da Vinci system produces additional noise and communication problems,[15] as the primary surgeon faces the console which causes an audial, visual and physiological barrier between the primary surgeon and the remaining OR-staff.[17] The Silent Operating Theatre Optimisation System (SOTOS) was invented to suppress noise levels, improve communication and in turn lead to OR-optimisations measured in this study.[16]

The SOTOS

The SOTOS (V.2.1, University Medical Center Göttingen, Germany)[16] consists of headsets (headphones with microphones) that are linked wirelessly or via cable to a central control unit. During surgery, each OR-staff-member wears a headset leading to a 50% to 75% decrease in the perceived sound level through active and passive noise-cancelling.[16] Remaining non-communication noise is overshadowed by music played through the headphones—type and volume of which is regulated individually. Each OR-staff-member hears selected acoustic signals from the OR, which include other OR-staff-members' voices and OR-machine signals. SOTOS offers the possibility to build acoustical subgroups, for example, the primary surgeon as team leader can be heard by everyone whereas he or she can choose the OR-staff-members he/she needs to hear. This way, irrelevant communication and signals can be blocked. As soon as any OR-staff-member starts to speak, the music tunes to the lowest perceptible volume level for the whole acoustical group so the staff-member's voice is clearly heard. The microphones enable an undisturbed, relaxed communication because there is no need to raise one's voice. The SOTOS hearing systems induced a noise reduction directly at the ear of the team member of 21 or 31 dB (which corresponds to a perceived reduction of the ambient noise by 50% and 75%, respectively). Within the SOTOS, a multi-stage volume limiter is built in to filter unpredictable acoustic artefacts and to safely limit the continuous volume.[16] With these technical features and structural set-up, SOTOS goes beyond other wireless speaker systems tested in simulated robotic OR.[18] As SOTOS reduces high noise levels and improves communication,[16] it seems likely that the application of SOTOS favourably affects the OR-staffs' stress, exhaustion, activity and concentration levels. This could in turn favour their efficiency, health and the patient's safety. These assumptions are supported by psychological theory and empirical research presented in the following.

Noise as a stressor

Noise in the OR is a biophysical stress stimulus[6 10 19 20] that is especially disruptive because it is intermittent (loud and quiet phases alternating during the surgery) and not controllable by the OR-team-members.[12 21]

There are further stressors in the OR such as the surgical task itself (eg, difficulty and duration of the surgery), disruptions, time pressure, shift work, people traffic in the OR, new techniques and personal attributes (eg, responsibility, anxiety, experience).[5 20 22] Such stressors can interact and therefore exacerbate each other, for example, negative effects of noise become stronger when an additional, unanticipated task is required[11] or when the task complexity increases.[15 21]

According to the transactional stress model,[23] the same stressor can lead to a different stress reaction depending on the individual. The model states that individuals (unconsciously) judge all stimuli in their environment. In the primary appraisal, the demands of a stimulus are ranked as irrelevant, positive or stressing for the person's well-being. In the secondary appraisal, one's own (genetic, physical, social and psychological[23]) resources to cope with the demands of the stimulus are estimated. If the primary and secondary appraisals are imbalanced, for example, if an OR-staff-member appraises his or her coping resources as not suitable to cope with the OR-noise stimuli, stress occurs and shows in harm/loss, threat or challenge to the staff-member. Such an imbalance can produce short-term negative consequences like exhaustion and loss in concentration and/or long-term negative consequences like psychological and physical diseases.[24] With SOTOS, the OR-staff would have a technical resource that changes the (perceived) noise level in the OR, eases the communication and thus works as a problem-oriented coping strategy. With said OR-noise reduction, the OR-staff is likely to appraise the remaining OR-noise level as irrelevant. This balance would lead to positive short-term consequences like more activity with a coincident decrease in negative consequences as defined above.[24] The following hypotheses can be derived:

H1 to H4: Before surgery, the perceived stress (H1), activity (H2), exhaustion (H3) and concentration (H4) levels do not differ among the OR-staff-members who will work with the SOTOS and those who will work without the SOTOS in the upcoming surgery.

H5: During surgery, OR-staff-members working with SOTOS feel less stressed than OR-staff-members working without SOTOS.

H6 to H9: After surgery, OR-staff-members who worked with SOTOS feel less stressed (H6), less exhausted (H7), more active (H8) and more able to concentrate (H9) than OR-staff-members who did not work with SOTOS.

METHOD

Design, procedure and participants

A quasi-experimental field study was conducted to ensure high external (ie, user) validity for SOTOS. Data were collected from March to June 2017 during a total of 32 urological prostatectomies using the robotic-assisted surgery da Vinci system (Intuitive Surgical Inc, Sunnyvale, USA) in the surgical ward of the University Medical Center Göttingen (UMG). The four dependent variables (DVs)—stress, activity, exhaustion and concentration of the OR-staff—were tested in a 2×2 repeated measurements design with a between-factor condition (SOTOS vs control) and a within-factor measurement time point (pre-surgery vs post-surgery). A total of 16 surgeries were carried out using the SOTOS-condition with the SOTOS applied by each OR-staff-member during the surgery. Staff-members listened to pop-rock music and their communication was recorded via SOTOS. SOTOS was not applied in the 16 control-condition surgeries. However, neck-microphones were worn by OR-staff-members during the control-condition surgeries to record their communication and to give them a similar feeling of a technical device on their head to reduce the possibility of a Hawthorne effect (modification in performance of participants due to awareness of being observed[25]). The conditions were randomly assigned to test days and the OR-staff-members were informed in the morning of the surgery. The staff consisted of five members per surgery: the primary surgeon, assisting surgeon, scrub nurse, circulating nurse and anaesthesiologist. The local OR setup is shown in figure 1. Due to the work schedule of the UMG, a total of 34 OR-staff-members participated 1 to 20 times (M=4.21, SD=4.04) in the study. Counting each participation as a person with dependent pre–post data, a final sample of n=160 was expected. Due to other prioritised obligations in the hospital, the anaesthesiologist measurements were missing on 17 test days. Thus, a final sample of n=143 was reached (SOTOS-condition: n=71; 39% female; control-condition: n=72; 42% female).

All measurements were executed under supervision of one or two test conductors from the psychological and medical research team and each OR-staff-member was required to give informed consent before taking part in the study. The pre-surgery measurements taken at 07:00 a.m. started with the staff putting on a portable ECG, followed by filling in the pre-surgery questionnaire of the respective condition and performing the concentration test KTL-R (*Konzentrations-Leistungs-Test – Revidierte Fassung*).[26] At about 08:30 a.m. the surgeries began with the first surgical cut and ended with the last cutaneous suture around 12:30 p.m. During the surgeries, the staff's physiological reactions were recorded via ECG, and task-related and team-related occurrences in the OR were protocolled by a study conductor. The following post-surgery measurements at 01:00 p.m. were collected by the post-surgery questionnaire of the respective condition, another test form of the KTL-R[26] and the return of the ECGs. Because of prior emergencies, two surgeries were delayed and were therefore excluded from further analyses.

Test material

The test material was conceptualised to fit the tight schedule of the UMG and minimise restrictions on the staff's workflow. The pre-surgery and post-surgery questionnaires took 5 to 10 minutes each. They were specifically designed for the SOTOS evaluation by the research team using original items as well as items from existing questionnaires[27–29] (all items in German language). The items concerned demographic data and the following items relevant to this study: The DV stress indicated by the OR-staff-members' perceived stress level in the pre-surgery and post-surgery questionnaire (How stressed do you feel right now?) and their perceived perioperative stress level asked in the post-surgery questionnaire (How stressed on average did you feel during surgery?). The stress items were answered on a 5-point Likert scale from *1*=not at all *to 5*=extremely.

To measure the DVs activity (energetic, indefatigable) and exhaustion (tired, worn out), the corresponding scales *'Aktivität'* (activity) and *'Erschöpfung'* (exhaustion) of the Leipziger Stimmungsbogen,[28] each containing six items, were used in the pre-surgery and post-surgery questionnaires.

The OR-staff's concentration was measured pre-surgery and post-surgery with the KLT-R version for adults,[26] which offers forms A and B. The KLT-R contains nine blocks with 20 arithmetic problems each. Participants have 2 min to work on a block before switching to the next one. To shorten time, the study authors decided to give the OR-staff three blocks per measurement time point; this meant the concentration test took 6 min each pre-surgery and post-surgery. In sum, there were six different KLT-R forms to rotate throughout the study from pre-surgery to post-surgery time points. Results of the concentration tests were analysed regarding the total amount of processed items (*TI*) and the error percentage (*EP*).

To identify each staff-member's pre-surgery and post-surgery questionnaire, pre-KLT-R and post-KLT-R and yet maintain their anonymity, they were asked to write a self-constructed repeatable personal code on each document.

Demographics and control variables

All demographic data were captured in the pre-surgery questionnaire. Demographic data included age, gender, work experience, noise sensitivity, SOTOS experience and professional role in the OR. Additionally, each OR-staff-member was asked to rate the difficulty of the surgery using a 5-point Likert scale (1=very difficult to *5*=very easy) in the post-surgery questionnaire. The duration of surgery (from first surgical cut to last cutaneous suture) was protocolled by the study conductor. These eight variables were determined by the study authors because they might influence the effects of SOTOS on the DVs and thus needed to be tested to achieve clear results. It is known, for example, that older (more experienced) people adapt better to stress situations and that primary surgeons tend to feel more stressed than assistant surgeons.[22] The effects of SOTOS can also be skewed by OR-staff who might need more time to get used to SOTOS before it can reveal a positive impact, as it is a new technical device.

Statistical analyses

Descriptive data were calculated for each variable using SPSS V.24 (IBM Germany, GmbH, Ehningen, Germany). *T*-tests were used to analyse whether there were any differences in the means (*M*) of demographic data between the with-SOTOS-condition and without-SOTOS-condition due to the lack of randomisation of staff-member assignment to the OR-teams.

Inferential statistics to test the hypotheses were carried out with the statistic software R-Studio V.1.1.423 (RStudio, Boston, USA). To analyse the effects of the two factors on the DVs, linear multilevel models were used. They account for the intrapersonal dependencies between pre-surgery and post-surgery questionnaire data as well as for the dependencies between the test-days, as some OR-staff-members participated more than once. Condition and measurement time points were implemented as fixed effects and the participants (per their personal code) and test days as random effects. Repeated measures of analysis of variances (ANOVA) were calculated based on the multilevel models. Significant interactions were further decoded via contrasts. Relevant for this study were main effects of the condition and interactions. One exception was the perioperative stress variable, as it was assessed post-surgery and the measurement time point was left out.

Concerning the hypotheses, the ANOVAs should reveal an interaction effect for current stress, exhaustion and error percentage in the concentration test showing lower values for the with-SOTOS-condition post-surgery. Stress during surgery should be lower in the with-SOTOS-condition. The ANOVAs for activity and total amount of processed items in the concentration test should demonstrate an interaction with higher values in the with-SOTOS-condition post-surgery. No difference for any DV is expected pre-surgery, as the start position is the same for both conditions.

RESULTS

The cut-off for statistical significance was $\alpha=0.05$. P values are reported rounded to two decimal places (Significance levels were set to $^{*}p\leq0.05$, $^{**}p\leq0.01$, $^{***}p\leq0.001$).

Descriptive statistics

Demographic data

On average, participants were 36.73 years old (*SD*=8.42 years), 59% male, worked for 11 years and 1 month in their job (*SD*=9 years, 5 months), reckoned themselves to be less sensitive to noise than others

Table 1 Means and SDs for dependent variables

	Total		SOTOS		Control	
DV	M	SD	M	SD	M	SD
Stress pre*	2.42	1.01	2.44	0.97	2.41	1.05
Stress post*	2.44	0.95	2.28	0.90	2.60	0.99
Stress peri*	2.45	0.97	2.32	0.91	2.57	1.02
Exhaustion pre*	2.48	0.84	2.55	0.84	2.41	0.85
Exhaustion post*	2.59	0.90	2.45	0.80	2.72	0.97
Activity pre*	3.04	0.77	2.99	0.77	3.09	0.77
Activity post*	2.88	0.83	2.97	0.89	2.79	0.76
EP pre†	17.76%	15.73%	18.43%	17.01%	17.10%	14.45%
EP post†	16.92%	16.69%	19.68%	20.18%	14.23%	11.95%
TI pre†	29.59	12.54	28.73	11.27	30.43	13.71
TI post†	31.04	12.49	30.28	11.22	31.79	13.67

*Likert scale: 1=not at all, 2=slightly, 3=moderately, 4=very, 5=extremely.
†Indicators for concentration: EP=error percentage, TI=total amount of processed items (out of 60).
DV, dependent variable; SOTOS, Silent Operating Theatre Optimisation System.

(M=2.04, SD=0.90) and were rather experienced with the SOTOS (M=2.48, SD=0.76). On average, the surgery took 4 hours and 9 min (SD=0.52 hour, Min=1.5 hour, Max=6.0 hour) and was perceived as average difficult (M=3.01, SD=1.00). T-tests comparing the means of the two conditions revealed no inequality of demographic data except experience with the SOTOS. Participants in the with-SOTOS condition had worked significantly more often with the SOTOS ($t(138) = 2.01$, p=0.05). Due to the low significance of these differentiation values, it was assumed that, despite the lack of randomisation, the conditions had equal preconditions in the study.

Dependent variables

An overview of the means and SDs of the DVs is given in table 1.

Inferential statistics

The effects of the condition and the measurement time point on the DVs, given by the multilevel model based repeated measures ANOVAs, are shown in figure 2.

Current stress

The ANOVA revealed a significant interaction for current stress (F(1, 209)=5.46, p=0.02*). Contrasts showed that the stress level did not differ between the conditions before surgery (z=0.51, p=0.61). After surgery, those working in the with-SOTOS-condition felt significantly less stressed than those in the without-SOTOS control-condition (z=3.32, p=0.00***).

Perioperative stress

A significant main effect of condition indicated that during surgery, those working in the with-SOTOS-condition felt significantly less stressed than those working in the without-SOTOS control-condition (F(1, 27)=7.98, p=0.01**).

Exhaustion

The ANOVA for exhaustion showed a significant interaction of condition × measurement time point (F(1, 235)=10.98, p=0.00**). Contrasts revealed that the OR-staff-members working in the with-SOTOS condition felt significantly less exhausted after surgery compared with those in the without-SOTOS control-condition (z=3.94, p=0.00***). Also, the conditions did not differ before surgery (z=−0.47, p=0.64). Furthermore, those working in the without-SOTOS control-condition reported feeling significantly more exhausted post-surgery than pre-surgery (z=3.33, p=0.00***), while those working in the with-SOTOS condition did not report a shift in their exhaustion levels (z=−1.36, p=0.17).

Activity

Concerning the OR-team members' perceived activity levels, a significant interaction was found (F(1, 236)=6.21, p=0.01**). Contrasts indicated that those working in the with-SOTOS condition felt significantly more active after surgery than those working in the without-SOTOS control-condition (z=−2.87, p=0.00**) and that the conditions did not differ pre-surgery (z=0.44, p=0.66). It was also revealed that the without-SOTOS control-condition participants felt significantly less active after than before surgery (z=−3.41, p=0.00***) but the with-SOTOS condition did not shift in activity from pre-surgery to post-surgery (z=0.13, p=0.90).

Error percentage in the KLT-R

Neither a significant main effect nor an interaction of the factors concerning the EP was found in this study.

Total amount of processed items in the KLT-R

The measurement time points had a significant main effect on the TI, showing that for post-surgery both

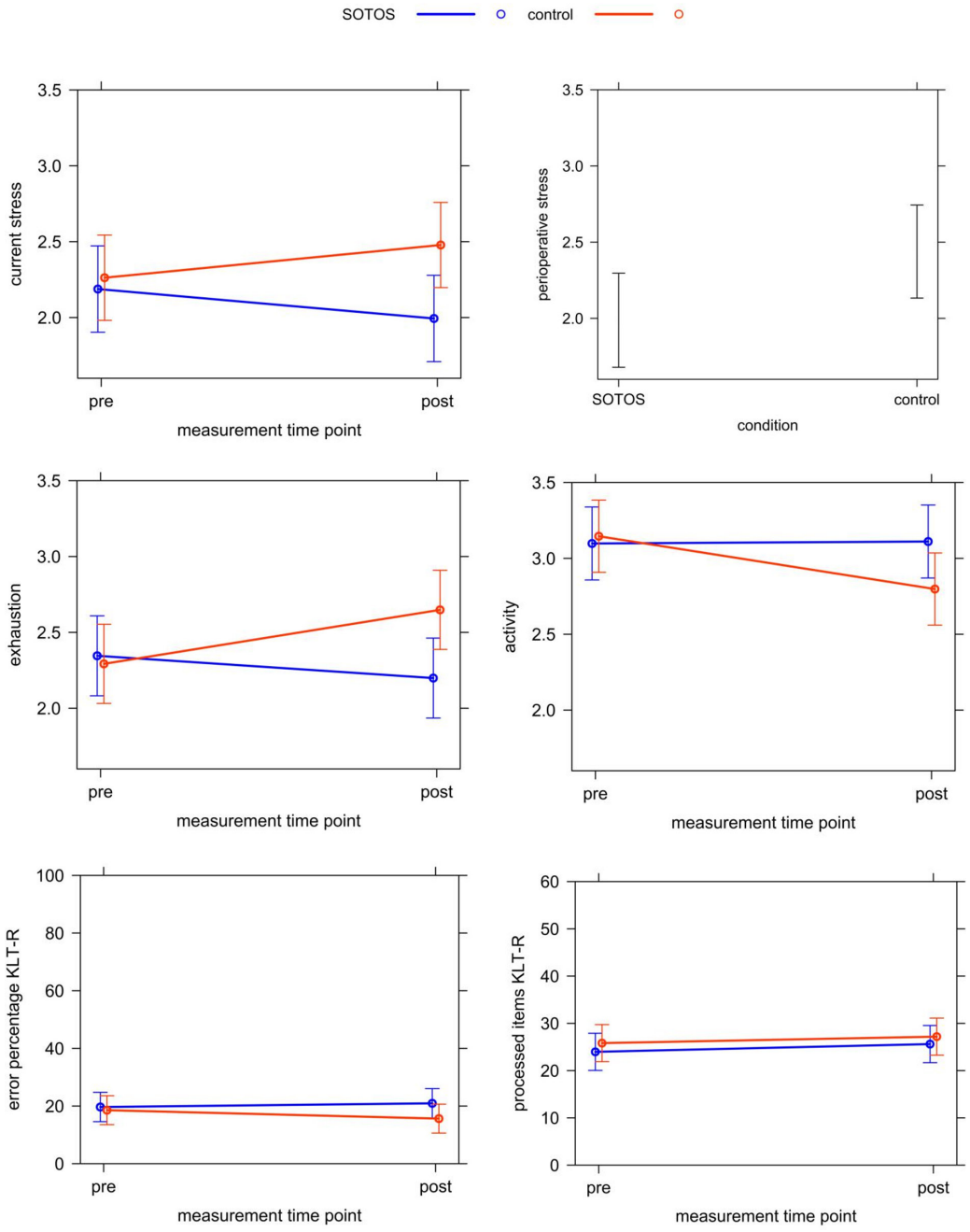

Figure 2 Significant interaction of the factors condition and measurement time point concerning the current stress, exhaustion and activity of the OR-staff. Significant effect of the condition on the perioperative stress of the OR-staff. No interaction concerning the dependent variables error percentage and total amount of processed items measured with the KLT-R concentration test. KTL-R, Konzentrations-Leistungs-Test – Revidierte Fassung; OR, operating room; SOTOS, Silent Operating Theatre Optimisation System.

conditions processed more items than pre-surgery ($F(1, 203)=12.18$, $p=0.00^{***}$). However, the condition neither led to a main effect on the amount of processed items (TI) nor interacted with the measurement time point concerning the TI in this study.

Explorative statistics

It was further examined if the demographic data as well as the duration and difficulty of the surgery interacted with the previously reported significant effects of SOTOS on the DVs. The variables were included as a third factor in the multilevel model and results were analysed for significant two-way interactions of the factor condition with the third factor and three-way interactions. Duration and difficulty of the surgery as well as age, gender, work experience and noise sensitivity of OR-staff-members did not have any impact on the effects of SOTOS. But the level of experience with SOTOS led to a significant three-way interaction concerning exhaustion ($F(1, 230)=4.29$, $p=0.04^{*}$): Participants with high previous SOTOS experience

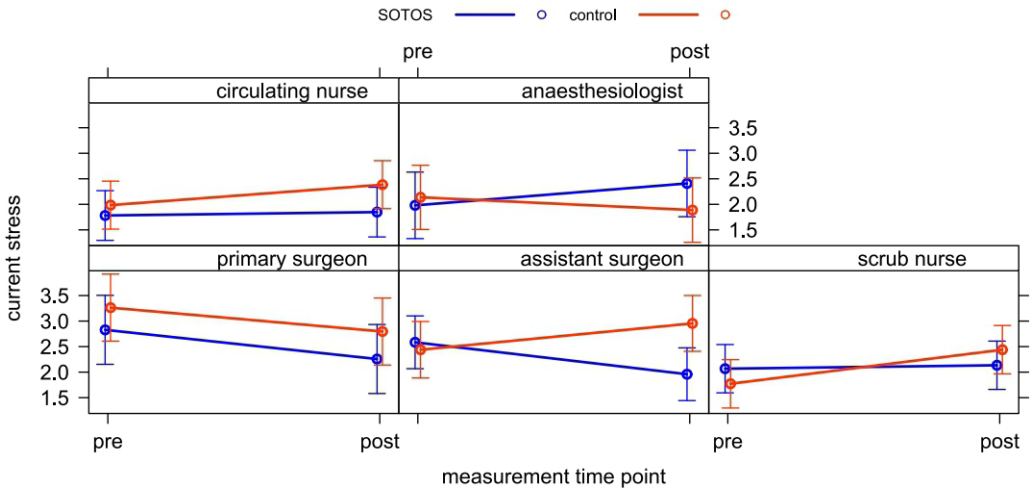

Figure 3 Significant three-way-interaction of condition, measurement time point and professional role concerning the current stress of the OR-staff-members. OR, operating room; SOTOS, Silent Operating Theatre Optimisation System.

were less exhausted post-surgery if they had worked in the with-SOTOS condition than in the without-SOTOS control-condition. Furthermore, the professional role of the OR-staff-members significantly affected the impact of SOTOS on their reported current and perioperative stress (but not on exhaustion and activity). A significant three-way interaction for current stress was found ($F(4, 194)=2.51$, $p=0.05$*) and analysed with contrasts (figure 3): The primary surgeons were less stressed in the with-SOTOS condition than in the without-SOTOS control-condition, which revealed a significant conditional main effect ($z=2.41$, $p=0.02$*). The assisting surgeons were less stressed post-surgery in the with-SOTOS condition compared with the without-SOTOS control-condition, shown by a significant conditional interaction ($z=3.23$, $p=0.00$**). A significant interaction of condition and professional role indicated that the perioperative stress was also perceived differently by the professional roles ($F(4, 227)=4.38$, $p=0.00$**) (figure 4). Contrasts revealed that the primary surgeons ($z=3.94$, $p=0.00$***) and the circulating nurses ($z=2.97$, $p=0.00$**) felt significantly less stressed during surgery when they worked in the with-SOTOS condition compared with the without-SOTOS control-condition.

DISCUSSION

Principal findings

Consistent with our hypotheses H1 to H4, the ANOVAs multilevel model-based repeated measures showed that the with-SOTOS condition and without-SOTOS control-condition did not differ pre-surgery in the staffs' perceived stress (H1), activity (H2), exhaustion (H3) and concentration levels (H4). The results show clear positive effects of the SOTOS: OR-staff-members reported feeling significantly less stressed during surgery (H5) and after surgery (H6) if they worked with SOTOS. Further analyses revealed that

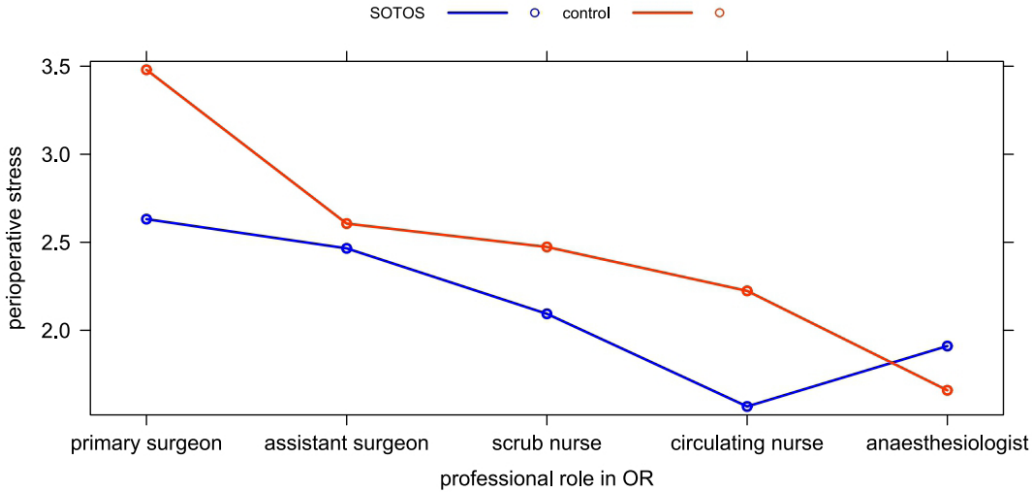

Figure 4 Significant interaction of condition and professional role concerning the perioperative stress of the OR-staff-members. OR, operating room; SOTOS, Silent Operating Theatre Optimisation System.

this effect is influenced by a staff-member's professional role in the OR. Apparently, the SOTOS constitutes an especially beneficial technical resource and problem-oriented coping strategy for the primary surgeon, assisting surgeon and circulating nurse. Through SOTOS the primary surgeon can overcome the audial, visual and physiological barrier produced by the spatially separated da Vinci console from the OR table. Knowing this benefit might also have led to less stress before surgery felt by the primary surgeons, because they knew communication with other OR-team-members and thus leadership and control would be easier. In terms of the Lazarus Model,[23] this could also mean that without SOTOS, primary surgeons might have anticipated degradation in control, hearing and/or communication during the surgery. But with SOTOS the primary surgeons appraised the high OR-noise level and communication problems as irrelevant because their experience has taught them to cope with it. The assisting surgeons also benefit from the noise reduction and the eased communication within the surgical team through SOTOS and feel less stressed after a with-SOTOS surgery. In contrast to the primary surgeons, they do not anticipate the SOTOS advantage before surgery, probably because they are challenged with less responsibility, stand closer to and face the OR table and can therefore see the other team members. Also, test results show the circulating nurse also feels less stressed with SOTOS. This is probably due to the noise reduction and the resulting lower necessity of enquiries. With the primary surgeon in mind, it could be suggested that the farther away from the OR table the stronger the advantage of SOTOS becomes, as it eases the communication.

Though the stress reduction is especially significant for the three aforementioned professional functions, the SOTOS seems to work as a technical resource and coping strategy for the whole OR-team as they all report feeling more active and less exhausted after surgery when they work with the SOTOS. This confirms hypotheses H7 and H8 and supports the theory that SOTOS reduces short-term negative consequences. However, as our results do not show that concentration levels are significantly enhanced through SOTOS, hypothesis H9 must be rejected. Participants in both conditions processed more items in the concentration tests post-surgery than pre-surgery. This indicates their ability to concentrate may have aroused from the surgery or from normal increase of diurnal alertness. OR-staff-members' concentration does not differ between the conditions because they focus all their concentration during surgery to ensure patient safety at all times. Nevertheless, they likely spend more resources to maintain their concentration in the without-SOTOS control-condition because they also report their activity decreases and their exhaustion and stress levels increase.

Strengths, weaknesses and impact of the study and future research

This quasi-experimental field study was conducted to test the effects of SOTOS when used in da Vinci surgeries. Its effects are particularly important to patient safety. It might be criticised that the internal validity of the results in this field study are impaired, as the lack of randomisation makes control of variables more difficult to realise. This study used multilevel modelling to deal with these limitations. Another consequence of our field study is that staff organisation meant some participants took part in more than one surgery, which can lead to statistical artefacts like more SOTOS experience in the with-SOTOS condition: the more often staff-members work in the with-SOTOS condition, the more experience they gain with the SOTOS. In terms of statistical generalisation, it would have been better to have 143 pre-surgery and post-surgery data from 143 OR-staff-members than from 34. As this is not realistic, future research that combines data from different surgeries and/or from different hospitals would be helpful. In this current field study there were missing data from some anaesthesiologists, which should be avoided if possible in future studies to get clearer results regarding their professional role. Furthermore, future research should retest the effect of SOTOS on concentration using either another concentration test or the full KLT-R. As the authors decided to take just three out of nine blocks of the test to save time, the inner consistency is reduced. Also, mathematical skills of participants are suspected to influence the results in the KLT-R. Future research will also explore how SOTOS works in surgeries other than da Vinci surgeries when the whole team is in close, direct proximity to the OR table, like in heart surgeries. If the results are similar, they could be more reliably transferred to all sorts of surgeries. SOTOS should also be tested during surgeries performed at other times of the day than mornings to see whether effects are different, when the OR-team is likely more tired.

Consistent noise cancelling can keep important unexpected and especially safety-relevant acoustic signals in the background or even make them imperceptible. This could lead to the risk of an unintentionally triggered or defective electric knife on the operating table causing burns. This also applies to safety-relevant alarms. Noise cancelling, and even the best noise cancelling currently available, does not lead to an absolute shutdown of the acoustic perception—but only to a reduction (halving (20 dB) or quartering (30 dB)).

Shrill noises can still be perceived, even at greater distances to the emitting source. Within the SOTOS matrix, acoustic information, available on the audio buses is relayed to the relevant team members, especially when it relates to safety-relevant aspects. SOTOS is therefore not only a noise-reducing intercom but manages communication to increase safety.

CONCLUSION

Concentration and communication impairments within the OR-staff pose a potential threat to patient safety.[22] Also, the OR-staff are at risk of physical and psychological health issues from the consequences of elevated noise levels,[19 30 31] which could contribute to absenteeism and efficiency fluctuations[32] that might result in economic and/or human resource problems for the hospital. SOTOS reduces the (perceived) noise in the OR and eases receiving and transmitting communication. SOTOS works as a technical resource and helps the OR-team to cope with the demands of the surgery as well as the demands of the da Vinci system. The OR-team is less stressed (especially the surgical team and the circulating nurse), more active and less exhausted, which in turn benefits their physical and mental health.[19 31] These advantages are likely also beneficial to their work satisfaction[32] and hence patient safety[22] and the hospital in the long run. We conclude that SOTOS offers meaningful human resources and medical advantages in urological da Vinci surgeries.

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Competing interests MGF is the inventor of the SOTOS and all included features. The SOTOS is patented and the patent holder is the University Medical Center Göttingen, Germany (DE102015205463, PCT/EP2016/056659).

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