# Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres

Jan Lehrke[1] Margarete Boos[1] Andreas Cordes[1] Conrad Leitsmann[2] Martin Friedrich[3]

[1] Department of Social and Communication Psychology, Georg-Elias-Mueller-Institute of Psychology, University of Goettingen, Georg-August-Universität Göttingen, Gottingen, Germany
[2] Department of Urology, University Medical Center Goettingen, Universitätsmedizin Göttingen, Goettingen, Niedersachsen, Germany
[3] Department of Thoracic and Cardiovascular Surgery, University Medical Center Goettingen, Universitätsmedizin Göttingen, Goettingen, Niedersachsen, Germany

Thorac Cardiovasc Surg

**Address for correspondence** Jan Lehrke, MSc, Department of Social and Communication Psychology, Georg-Elias-Mueller-Institute of Psychology, University of Goettingen, Georg-August-Universität Göttingen, Gosslerstrasse 14, Gottingen 37073, Germany (e-mail: jan.lehrke@uni-goettingen.de).

## Abstract

**Background** Noise in operating theaters (OT) exceeds safety standards with detrimental effects on the health and performance of OT crews as well as patient safety. One of the reasons for these effects is the stress response to noise, which could be minimized by the Silent Operating Theater Optimisation System (SOTOS), a noise-reductive headset solution.

**Methods** This study evaluates the effects of the SOTOS on the stress perceived by OT crew members, operationalized through *stress level* and *exhaustion*. Twenty-one heart surgeries and 32 robot-assisted prostatectomies at the University Medical Center Goettingen, Germany were examined. Twenty-six surgeries were conducted with and 27 without the SOTOS. The SOTOS-effect is defined as a more beneficial stress course from before to after surgery, when comparing the experimental group with and control group without SOTOS.

**Findings** Eighty-one OT workers were investigated. The linear multilevel models revealed significant interactions between treatment and time of measurement on stress level ($F[1, 406.66] = 3.62$, $p = 0.029$) and exhaustion ($F[1, 397.62] = 13.12$, $p = 0.00017$). Nevertheless, there was no a significant main effect of surgery type on stress level ($F[1, 82.69] = 1.00$, $p = 0.32$) or on exhaustion ($F[1, 80.61] = 0.58$, $p = 0.45$). Additionally, no significant three-way interaction including surgery type, for stress level ($F[1, 406.66] = 0.32$, $p = 0.29$) or exhaustion ($F[1, 397.62] = 0.03$, $p = 0.43$), was found.

**Interpretation** An SOTOS-effect was confirmed: the development of stress over the course of an operation was beneficially modified by the SOTOS. Both surgery types are perceived as similarly stressful, and the staff benefits equally strongly from the intervention in both settings.

**Keywords**
- SOTOS
- noise reduction
- technology
- cardiovascular diseases
- operating theater
- surgery
- surgical staff
- stress
- exhaustion
- communication

**received**
September 27, 2021
**accepted after revision**
November 22, 2021


Georg Thieme Verlag KG,
Rüdigerstraße 14,
70469 Stuttgart, Germany

**DOI** https://doi.org/10.1055/s-0041-1741059.
**ISSN** 0171-6425.

## Introduction

Operating theater (OT) crews face various stressors, such as time pressure, distractions, or physical demands.[1] While most stressors are inherent part of the profession, others, including noise, seem avoidable. Empirical findings support the argument that noise pollution is an issue in OTs,[2–4] with safety standards concerning noise, postulated by the World Health Organization, being exceeded regularly.[3] The sources of noise in the OT are predominantly human actions like slamming doors or dropping tools, human communication, and technical devices, like suction systems, alarms, or air conditioning systems.[3]

High noise levels are associated with reduced cognitive and psycho-motoric performance.[5] Concentration, for instance, is negatively correlated to the frequency of noise and its volume.[5,6] Noise negatively affected outcomes of surgical procedures.[7,8] In robot-assisted laparoscopic procedures, it was shown that the more complex the task, the more severe the adverse effects of noise.[8]

Further to the effects of noise on performance, research showed that regular exposure to high noise levels is associated with deteriorated health.[9] The most serious effects include the development of different cardiovascular diseases.[10,11] Additionally, health problems such as burnout, exhaustion, and fatigue among staff are connected to noise,[12] which can, in turn, increase absenteeism rates in hospitals.[13]

Concerning the adverse effects on performance, two explanatory pathways are considered in the existing literature, among which only the second is a potential explanation for the adverse health effects as well. The first explanatory pathway constitutes that high noise impairs communication which represents a source of error in the OT.[14,15] Studies showed that noise leads to disruptions and obfuscation of information, resulting in impaired intelligibility and disturbed speech discrimination. In response to the noise levels, the staff is forced to raise their voices, further amplifying the noise level.[16] The issue is aggravated by the fact that intermittent noise, which is present in OTs,[2] decreases performance more strongly than constant noise.[5] An explanation for this observation is that intermittent noise leaves less opportunity for behavioral habituation.[17] Furthermore, the high information density, which reflects the complex processes of a highly technical and specialized operation, can already be a challenge in itself. Research showed that humans are limited in their capacity to process information, which includes verbally shared information.[18]

The second explanatory pathway is concerned with the stress-inducing effect of noise. According to the transactional stress theory,[19] stress results from processes in which an individual appraises an event as harmful, threatening, or challenging (primary appraisal), and simultaneously assesses the potential resources he/she can oppose to that situation (secondary appraisal) as insufficient. The appraisal processes are crucial to the concept of stress, allowing certain stimuli to be perceived as stressful by one person but not by another. This subjective aspect can also be found in the definition of noise. Consequently, sound only becomes noise through an individual appraisal process where a person subconsciously decides which sounds are perceived as noise, opening the possibility that a specific sound may be perceived as noise by one person while others perceive it as just sound. Hence, noise is a predominantly psychological phenomenon rather than a physical one.[20] As the definition of noise includes a negative—primary—appraisal,[20] stating that exclusively unpleasant sounds are perceived as noise, one may argue that noise stimuli are likely to be stressors that means that part of the preconditions in the stressor definition (primary appraisal) is inherently satisfied for any noise stimuli. Whether noise acts as a stressor depends exclusively on the secondary appraisal, in which a person relates his/her coping resources to the potential stressor[19]—in this case noise. Therefore, all stimuli can be stressors, but noise is predisposed to be one. Additionally, both constructs react similarly to the subjective feeling of control. It is this sense of control over potentially stressful situations or over the sound which is the determining factor of whether something is perceived as stressful or not.[21]

This argument is backed up by the similar consequences of noise and stress. As shown above, noise leads to cardiovascular diseases[10,11] and so does stress. One review, encompassing 27 studies indicates that work stressors are linked to a moderately elevated risk of stroke and a higher incidence of coronary heart diseases.[22] Waterland et al found a direct connection between noise and stress: noise itself elicited stress reactions on a subjective and physiological level.[23] Furthermore, growing evidence indicates that acute and chronic noise can affect the hypothalamic pituitary adrenocortical axis function, which is a known stress pathway.[24]

The evaluated intervention is a solution called the Silent Operating Theater Optimisation System (SOTOS). It is a noise reduction methodology and information management system which was developed specifically for the OT.[25] The significant noise reduction[26] is expected to reduce stress and, therefore, improve health and performance outcomes. Based on the transactional stress model, where individuals rely on their resources to cope with stressors, the SOTOS may be regarded as such a resource. Consequently, individuals should be able to better cope with the stressors they encounter, entailing an overall reduction in their stress perception. Additionally, the SOTOS can change the transaction between the individual and the environment to the benefit of the individual as less noise is perceivable, also enabling a stress reduction. This paper focuses on the connection between the intervention and stress. Therefore, it is hypothesized that the SOTOS positively modulates the development of stress from before to after surgery compared with a control group without the system. This effect will be referred to as the SOTOS-effect hereafter. Furthermore, it is expected that heart surgeries are in general differently stressful than radical prostatectomies since they also require different audio-visual processes within the OT crew. As explained in the methods section, prostatectomies have an additional noise issue; therefore, a stronger SOTOS-effect in prostatectomies is expected.

 

## Methods

### Study Design and Participants

To investigate the conjectured effects, a quasi-experimental field study with an experimental and a control group was conducted. The objective was to test the SOTOS in its organizational environment. All 54 surgeries took place in the University Medical Center Goettingen (UMG) during regular workdays, and OT crews were randomly assigned to a treatment condition. Due to the limited number of 81 OT workers on shift, the randomized assignment of test subjects to treatment groups was practically unfeasible. The necessary adaptation of the procedure to the shift plan meant that some subjects participated more often than others, which resulted in repeated measurements in different frequencies for different individuals. The OT crews worked together in their regular composition. In each OT crew during surgery, a primary surgeon, an assisting surgeon, a scrub nurse, a circulating nurse, an anesthesiologist, and a perfusionist (only in heart surgeries) were present. All participants signed a declaration of consent for their participation and allowed the anonymous usage of data for research. The ethics committee of the UMG approved the heart surgery series on January the 8th in 2015 (radical prostatectomies: August 17th in 2015).

Two study arms, one for direct heart surgeries and one for robot-assisted laparoscopic radical prostatectomies, were conducted. To minimize the disruption to the diligent conduct of the surgeries, all conducted measurements were planned to be as short and as easily applicable as possible. The latent variable stress is operationalized by the manifest variables stress level and exhaustion, which constitute the two dependent variables. The three independent variables are treatment (experimental vs. control), time of measurement (pre and post), and surgery type (heart surgery vs. radical prostatectomy), leading to a $2 \times 2 \times 2$ design. The key research question was whether any positive effects of treatment could be found for these dependent variables.

### Procedures

The first study session between April 2015 and March 2016 comprised 22 heart surgeries. Only bypass and valve replacements using conventional extracorporeal circulation were included in the study. The second session between March and end of June 2017 consisted of 32 robot-assisted prostatectomies. Exclusively similar radical prostatectomies with the da Vinci system (Surgical Intuitive, Inc., Mountain View, CA, United States) were considered. Combining both study sessions, a total of 81 individuals participated in the study.

For collecting measurements, a paper-and-pencil questionnaire was employed that included items for all psychological and demographical variables. To minimize measurement biases, all examined surgeries were the first surgery of the day. The surgery began after the first round of measurement at around 8.30 AM in prostatectomies and around 9.00 AM in heart surgeries. During heart surgeries, the coordinators recorded significant markers of the surgical process, e.g., skin incision, start of extracorporeal perfusion, cross-clamping. In prostatectomies, it was the skin cut, da Vinci docking, bladder neck incision, and da Vinci undocking. In each surgery types, a log of incidents was maintained. Prostatectomies ended around 12.30 PM and heart surgeries at around 12.50 PM. The post-testing was conducted immediately afterward.

### The SOTOS

Treatment is the first independent variable and constitutes a between factor with two expressions: the experimental group with the SOTOS (version 2.1)[25] and the control group without the system. Crew members in the experimental group are provided with wireless or wired headsets (on-ear/in-ear), including microphones. This way, background noise is filtered through active and passive noise canceling, while the microphones allow staff to communicate without the need to raise their voices. The on-ear headphones cover the whole ear's auricle and lead to a 70% decrease in perceived sound volume, where up to 17 dB are attributable to passive noise canceling. The active noise reduction contributed a total reduction of 33 dB, which is perceived as a 90% reduction in perceived sound volume. SOTOS offers individual audio channels which allow the user to listen to music. While doing so, the crew member is still addressable through the integrated ducking mechanisms. This mechanism lowers the music within 0.6 seconds to the lowest perceptible volume possible (reduction by 40 dB), as soon as a member of the crew starts speaking.[25]

The signal selection is a feature of the SOTOS, which allows connecting specific subgroups in the OT. The selection depends on a matrix of connections that can be programmed into the system and defines a communication structure within and between defined subgroups in the OT. It is, for instance, possible that specific subgroups communicate only within their group, leading to less distraction in the whole crew. The all-in-mode was used in radical prostatectomies as a default setting. During heart surgeries, a task-based communication matrix was implemented.[25] To control for confounding variables, the test subjects in the control group were given a neck-worn microphone setup which physically resembled the SOTOS setup but does not offer any of its functionality. To make sure the application of the SOTOS device is compatible with high hygienic standards in the OT, all body-near systems were disinfected after use and stored in a clean container until the next operation. A hygienic examination of swabs of the SOTOS taken before every surgery proved that no hygienic problems arose from the use of this technology.

### Time of Measurement

Time of measurement is the second independent variable and constitutes a within factor, with two expressions, and refers to the time the dependent variables were measured (pre- and post-surgery). This factor was included to capture the development within the dependent variables. All test subjects provided data points before and after a specific surgery, which constitutes a case.

 

#### Surgery Type

Surgery type is the third independent variable and represents a between factor, with two expressions: heart surgery and radical prostatectomy. The difference between surgery types refers not only to the targeted organ but also to the surgical approach. Heart surgeries are direct surgeries on the patient, whereas the radical prostatectomies are robot-assisted laparoscopic through the da Vinci system.[27] To establish valid results, only similar surgeries in terms of length and procedure qualified for this study. Within the heart surgeries, the main prerequisite to qualify for the study was an extracorporeal circulation with a minimal length of 90 minutes. For urological surgeries, only radical prostatectomies operated with the da Vinci system qualified for the study.[27] This procedure involves an additional noise issue. The robotic system is managed from a console by a specially trained surgeon. To operate the system, the surgeon must face the console, which distances him/her physically from the rest of the crew. This creates an auditive and visual barrier and leads to an impairment of communication within the crew.[28] While communicating, the surgeon can only speak into the console and must raise his/her voice to be heard and, at the same time, having problems understanding the communication outside of the console. Additionally, the surgeon cannot rely on visual communication cues due to the visual barrier.[29]

### Outcomes

#### Stress Level

Stress level is the first dependent variable. This variable represents the first manifest variable for the latent construct stress. The variable is based on the subjective experience of feeling stressed and was measured as part of the general questionnaire before and after surgery with one item: "How stressed do you feel in the present moment?" Answers were given on a five-point Likert scale.

#### Exhaustion

Exhaustion represents the second manifest variable. To measure the perceived amount of exhaustion before and after surgery, the exhaustion subscale of the Leipzig Mood Questionnaire in German[30] was used. The six items of the exhaustion subscale ask for the present perception of six adjectives linked to exhaustion. Answers were given on a five-point Likert scale.

### Statistical Analysis

Data were analyzed with the SPSS software (IBM Corp., Armonk, NY, United States) and R (version 4.0.3). For the age variable, arithmetic means ($M$) and standard deviations (SD) were presented and compared for the control and treatment condition. For the categorical variables, gender and role, frequency distributions were analyzed. As this study is a field study, the participants participated according to their shift schedule. For each surgery, the participants formed a crew. The members of each crew were not fixed between surgeries. Consequently, participants may be members in several crews as a result of work schedules, which were not controlled for in the experiment. This led to a complex pattern of dependencies between the observations. By design, observations were nested within participants, due to the repeated measures, and participants were further nested within crews, as one participant was part of different crews. This resulted in an incomplete crossing of participants between crews and, hence, between treatment conditions. These dependencies were addressed by using linear mixed-effects regression with crossed random intercepts for participants and crews. Satterthwaite approximations for the fixed effects $F$-tests were applied.

All hypotheses were investigated with the linear multilevel approach and presented via analysis of variance tables. $p$-Values in the text were halved for the directed hypotheses H1 and H3, allowing for one-tailed testing. For all statistical tests, an α-level of 0.05 was set as a default ($\alpha = 0.05$). For the hypotheses that relied on a change in an observed variable, the change is referred to as the difference between post- and pre-scores, i.e., the pre-score is subtracted from the post-score.

## Results

After the elimination of one heart surgery due to technical problems, 21 instead of 22 heart surgeries were investigated, whereas the observation of all 32 scheduled urological surgeries was conducted as planned. In total, 81 individuals participated in these 53 surgeries. The average age of the participants was 38.02 years (SD = 9.66), while 43 participants were male (53.1%) and 38 were female (46.9%). However, we analyzed our hypotheses with a multilevel method which leads to $N = 262$ observations because the participants were observed multiple times during different surgeries. A data point consists of a set of two questionnaires one being filled out before surgery and one after. Concerning the dependent variables of stress level and exhaustion, ►**Table 1** offers an overview with means, adjusted $M$, and $SD$.

In heart surgeries, we measured a mean sound pressure level of 62.75 dB(A) (SD = 6.25) in the experimental group and 63.90 dB(A) (SD = 6.64) in the control group. For the radical prostatectomies, the mean sound pressure level was 61.97 dB(A) (SD = 3.96) in the experimental group and 65.36 dB(A) (SD = 4.60) in the control group.

Since the test assumptions were not violated and the groups showed no significant differences concerning age, gender, and role, a linear multilevel approach was calculated for each manifest variable. Treatment, time of measurement, and surgery type were integrated as fixed effect factors, whereas the personal code and the crew code were integrated as random effect factors. The results for stress level are shown in ►**Table 2**, whereas the results for exhaustion are displayed in ►**Table 3**. Tables show $p$-values for two-tailed tests.

There was a significant interaction between time of measurement and treatment on stress level, $F(1, 406.66) = 3.62$, $p = 0.029$. ►**Fig. 1** presents the results as a graph. Both conditions start with similar stress level means. Subjects in the experimental group show a stronger stress level reduction compared with the control condition.

 

**Table 1** Means and standard deviations of each dependent variable

| DV | total ($n = 262$) | | exp. ($n_{exp.} = 129$) | | | control ($n_{control} = 133$) | | |
|---|---|---|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | $M_k$ | *M* | SD | $M_k$ |
| Stress level pre | 2.5 | 1.1 | 2.5 | 1.0 | 2.4 | 2.5 | 1.1 | 2.5 |
| Stress level post | 2.4 | 1.0 | 2.2 | 0.9 | 2.1 | 2.5 | 1.1 | 2.4 |
| Exhaustion pre | 2.3 | 0.9 | 2.4 | 0.9 | 2.3 | 2.3 | 0.9 | 2.2 |
| Exhaustion post | 2.5 | 0.9 | 2.4 | 0.8 | 2.3 | 2.7 | 1.0 | 2.6 |

Abbreviations: DV, dependent variable; Exp., experimental; M, mean; SD, standard deviation.
*Note.* *n* refers to cases, not individuals.
$M_k$ = adjusted mean by multilevel modeling.

**Table 2** Stress level: type III analysis of variance table with Satterthwaite's method

| Fixed factors | SS | MS | $df_{num}$ | $df_{den}$ | *F* | *p* |
|---|---|---|---|---|---|---|
| Time | 4.08 | 4.08 | 1 | 406.66 | 6.46 | 0.011* |
| Treatment | 2.09 | 2.09 | 1 | 45.77 | 3.31 | 0.075 |
| Surgery type | 0.63 | 0.63 | 1 | 82.69 | 1.00 | 0.32 |
| Time*Treatment | 2.29 | 2.29 | 1 | 406.66 | 3.62 | 0.058 |
| Time*Surgery type | 4.91 | 4.91 | 1 | 406.66 | 7.78 | 0.0055* |
| Treatment*Surgery type | 0.18 | 0.18 | 1 | 45.77 | 0.29 | 0.60 |
| Time*Treatment*Surgery type | 0.20 | 0.20 | 1 | 406.66 | 0.32 | 0.57 |

Abbreviations: den, denominator; df, degrees of freedom; MS, mean square; Num, numerator; SS, sum of squares; Time, time of measurement.
*Note.* Multilevel model for stress level.
*$p \leq 0.05$, two-tailed.

**Table 3** Exhaustion: type III analysis of variance table with Satterthwaite's method

| Fixed factors | SS | MS | $df_{num}$ | $df_{den}$ | *F* | *p* |
|---|---|---|---|---|---|---|
| Time | 5.57 | 5.57 | 1 | 397.62 | 14.67 | 0.00015* |
| Treatment | 2.15 | 2.15 | 1 | 45.37 | 5.66 | 0.022* |
| Surgery type | 0.22 | 0.22 | 1 | 80.61 | 0.58 | 0.45 |
| Time*Treatment | 4.98 | 4.98 | 1 | 397.62 | 13.12 | 0.00033* |
| Time*Surgery type | 1.39 | 1.39 | 1 | 397.62 | 3.65 | 0.057 |
| Treatment*Surgery type | 0.01 | 0.01 | 1 | 45.37 | 0.02 | 0.88 |
| Time*Treatment*Surgery type | 0.01 | 0.01 | 1 | 397.62 | 0.03 | 0.87 |

Abbreviations: den, denominator; df, degrees of freedom; MS, mean square; Num, numerator; SS, sum of squares; Time, time of measurement.
*Note.* Multilevel model for exhaustion.
*$p \leq 0.05$, two-tailed.

No significant main effect of surgery type on stress level was found, $F(1, 82.69) = 1.00$, $p = 0.32$. The mean stress level of radical prostatectomies does not differ significantly from the heart surgeries.

There was no significant interaction between time of measurement, treatment, and surgery type on stress level, $F(1, 406.66) = 0.32$, $p = 0.29$. ►**Fig. 2** presents the results as a graph. In conclusion, the effect of treatment on stress level is not significantly different in prostatectomies compared with heart surgeries. The interaction between time of measurement and treatment does not differ between the surgery types.

There was a significant interaction between time of measurement and treatment on exhaustion, $F(1, 397.62) = 13.12$, $p = 0.00017$. ►**Fig. 3** presents the results as a graph. Both conditions start with similar exhaustion means. Subjects in the experimental group show no relevant change in exhaustion, whereas a rise is observed in the control condition.

No significant main effect of surgery type on exhaustion was found, $F(1, 80.61) = 0.58$, $p = 0.45$. The exhaustion mean of radical prostatectomies does not differ significantly from heart surgeries.

There was no significant interaction between time of measurement, treatment, and surgery type on exhaustion,

 

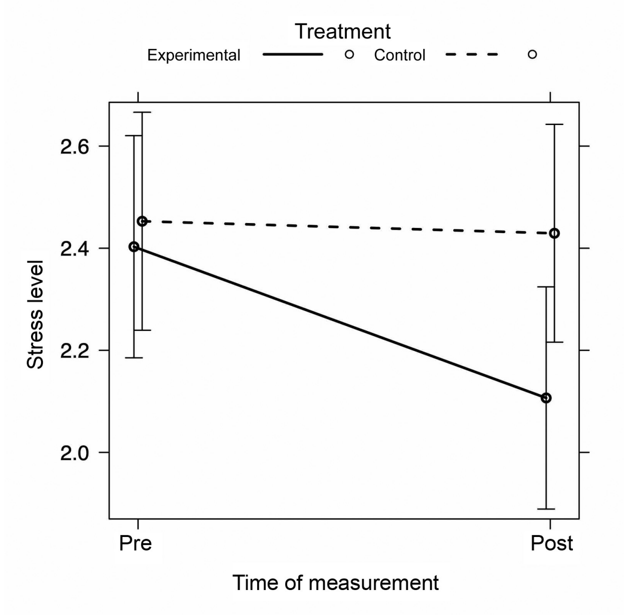


**Fig. 1** Time of measurement*treatment effect plot for stress level. Means before and after surgery displayed for the experimental and control condition. $N = 262$. Error bars represent 95% confidence intervals.

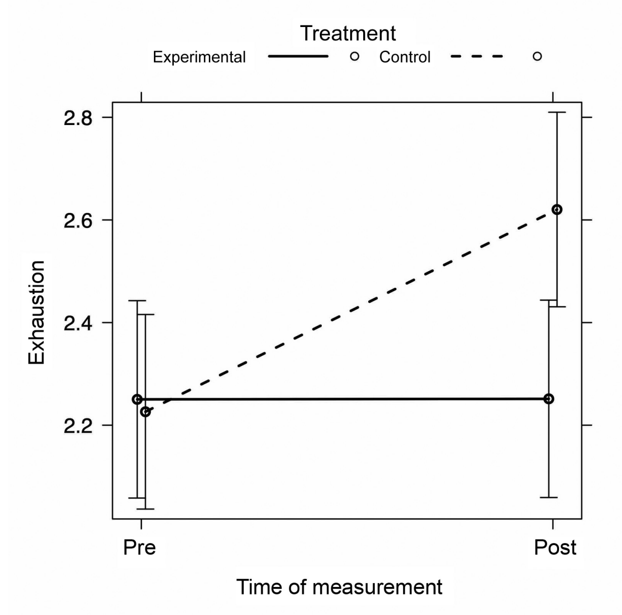


**Fig. 3** Time of measurement*treatment effect plot for exhaustion. Means before and after surgery displayed for the experimental and control condition. $N = 262$. Error bars represent 95% confidence intervals.

$F(1, 397.62) = 0.03$, $p = 0.43$. ►**Fig. 4** presents the results as a graph. In conclusion, the effect of treatment on exhaustion is not significantly different in prostatectomies than it is in heart surgeries. The interaction between time of measurement and treatment does not differ between the surgery types.

## Discussion

The results show that both outcome variables are positively affected, i.e., reduced or less elevated, in the SOTOS condition compared with the control condition. The stress level of the groups differs in so far as the control group displayed a stable

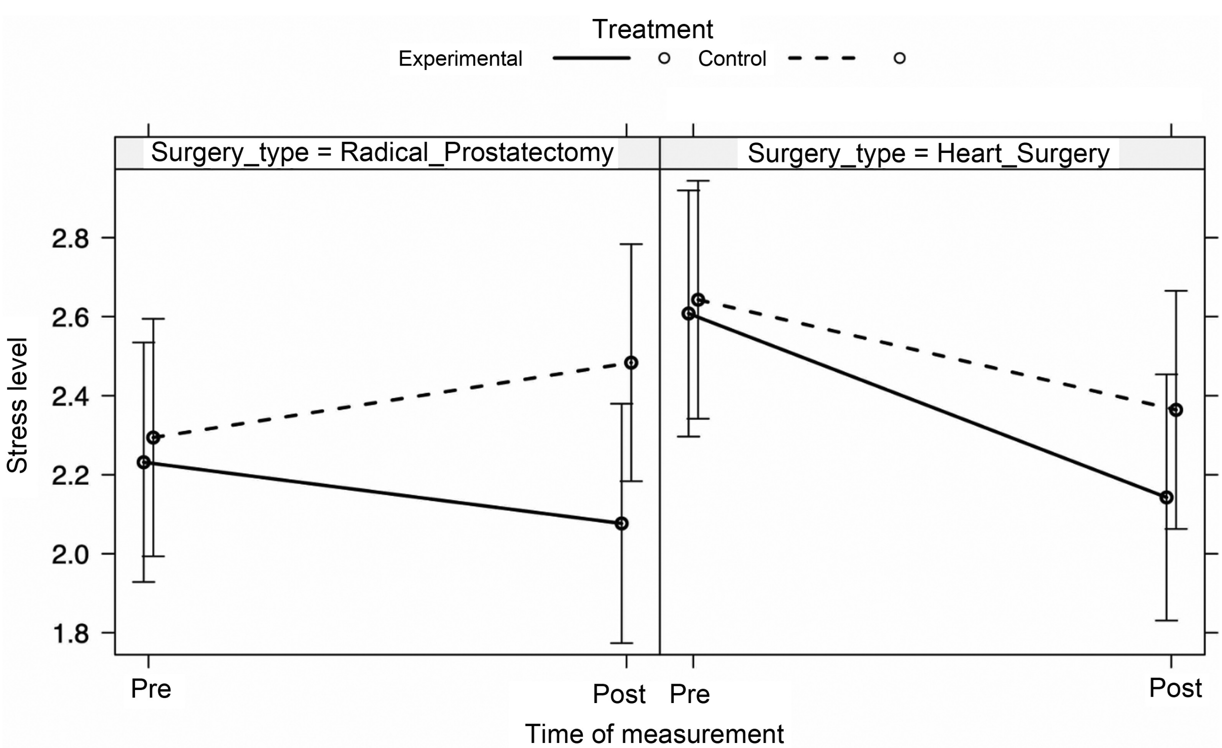


**Fig. 2** Time of measurement*treatment*surgery type effect plot for stress level. Means before and after surgery displayed for treatment conditions. Left plot = radical prostatectomy. Right plot = heart surgery. $N = 262$. Error bars represent 95% confidence intervals.

 

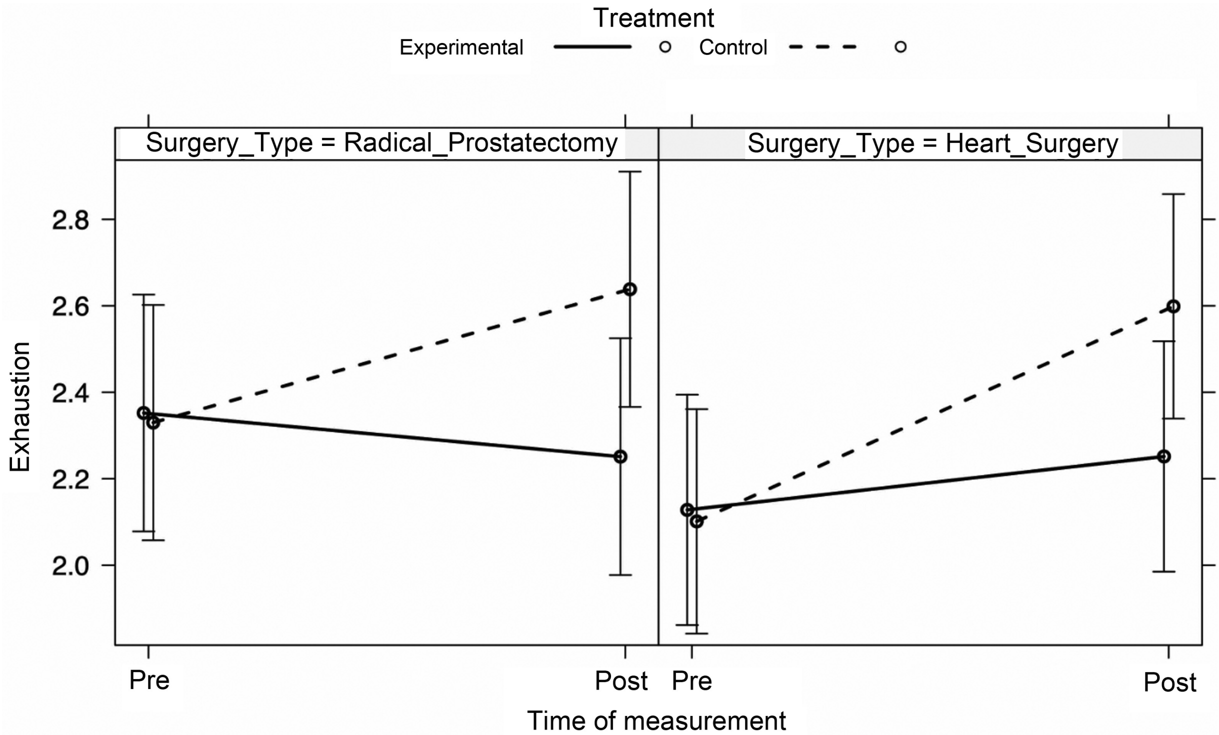


**Fig. 4** Time of measurement*treatment*surgery type effect plot for exhaustion. Means before and after surgery displayed for treatment conditions. Left plot = radical prostatectomy. Right plot = heart surgery. *N* = 262. Error bars represent 95% confidence intervals.

course in which the mean did not change from pre to post, whereas a decrease in stress level from pre to post was found in the experimental group. This development is compliant with our hypothesis and constitutes a benefit for the OT staff. The reaction observed in the exhaustion variable also conforms to our hypothesis. Whereas a rise of exhaustion is found in the control group, the experimental group mean remained almost unchanged from before to after surgery. In the end, the control group was more exhausted than the experimental group. This is interpreted as a successful implementation of the SOTOS with positive stress modulation effects.

In the context of the transactional stress model (see Introduction), the system may offer a problem-focused coping strategy to members of staff.[19] Specifically, possessing such a tool may already influence the primary appraisal since less perceived noise is present during the surgery. The secondary appraisal may also be modified because the system provides a resource to cope with the situation, as the SOTOS may strengthen the feeling of control over the situation. This interpretation is in line with previous research that found indications that control reduces the probability of a negative appraisal in both steps of the transactional stress model and can thereby reduce stress.[21] Another argument for the beneficial effects of the SOTOS is that a continuous sound level is offered through the music option.[25] This way, the perceptions of the highly stress-inducing intermittent noise passages[5] during surgery are minimized. It has to be kept in mind that different staff members may experience different stress levels due to their responsibilities. For example, it is plausible that the second nurse is much less stressed during the procedure than the primary surgeon. It is not known yet how strongly this effect varies over the roles, but our linear multilevel model takes individual differences in stress level into account while assessing the effect of the SOTOS.

An additional explanation for the found effects could lie in the tools for information management offered through the SOTOS. As humans are limited in their capacity to hold and process information,[18] the SOTOS could address this issue. The quiet, individual audio environment, clearly separated from external noise, enables a targeted distribution of information within the SOTOS and, potentially, provides additional stress relief. Further research concerning the effect of the SOTOS on communicational patterns is needed to clarify an SOTOS-effect in this area.

The results also show that heart surgeries were not different from urological surgeries in terms of their stressfulness. This finding validates the setup of the study since any strong differences in stress between the considered surgery types may call the comparability of the contexts into question. It can be assumed that in both contexts experts are working in their field of expertise, which aligns the manifest variables between the surgery types.

Due to the visual and acoustical barrier,[28] a more grave communication problem was expected in urological surgeries. Consequently, a stronger SOTOS-effect was anticipated in the prostatectomies, as the functional communication offered through the system is expected to positively impact the primary appraisal within the transactional stress theory.[19] Nevertheless, the empirical findings did not support this hypothesis. OT crews in both surgery types benefited equally from the treatment. A potential explanation for the finding could be the fact that the da Vinci system may indeed entail a greater noise issue but at the same time offer a stress-relieving effect. However, this effect appears to merely counter the greater noise issues, as no significant differences in general stress levels were found. The SOTOS seems to be equally useful in both surgery types.

Given the practical demands of the UMG—such as the shift plan—and the fact that the experiment was conducted as a field study, the chosen methodological approach proved to be sufficiently robust. While the tested sample at the UMG is part of the population of OT staff the SOTOS system is targeting, it is possible that the representativeness of the samples is insufficient, as subjects could not be randomly allocated to the treatment and control conditions. To account for this possibility, descriptive analyses were conducted and verified that although no randomized allocation was possible, the two groups had similar properties in terms of age, gender, and role distribution. The two treatment groups can, thus, be regarded as representative subsamples.

A key strength of our study is the high external validity. Since the UMG allowed the integration of all measurements into the regular working day of the OT staff, the SOTOS was investigated in a natural context. To avoid the most common cause for the loss of external validity, i.e., small sample sizes, a total of 262 cases were integrated into the analyses with a total of 81 different subjects. The obtained effects are expected to be replicable within other OT crews in other hospitals. The replication of this study with a different sample may shed further light on the applicability of the SOTOS to other hospitals and types of surgery.

Another advantage of this study was the opportunity to investigate different types of surgery. Since no systematic differences in stress were found between the surgery types, the integration of both investigated types into one dataset is justified. The internal validity is adequate because all measures were conducted in a standardized way with the same timing. Within the practical constraints, all possible confounding variables were eliminated, controlled, or balanced out. Due to these measures, the risk of biased results in this study is likely to be low.

Overall, the SOTOS constitutes an assistive technology, which can be successfully implemented in the OT. This study found a positive SOTOS-effect: The test subjects benefited from the system as the experimental group showed a significantly steeper decrease in stress level from pre to post compared with the control group and exhaustion increased exclusively in the control group, whereas in the experimental group a stable course was found that means that after surgery the experimental group was less stressed. These findings indicate that the SOTOS changes the primary and secondary appraisals of the OT staff members according to the transactional stress theory[19] and that the SOTOS can be interpreted as a resource for the OT staff, which can help them cope with the high noise levels and information density in the OT. Concerning the comparison of the general stress perception of OT crews between surgery types, no difference was found. Furthermore, the SOTOS-effect was found to be the same in both types of surgeries that were studied. It can be concluded that the system has beneficial effects on OT staff and can be successfully integrated into surgical contexts. More research is required to explore the potential health and communication benefits of the SOTOS.

**Data Availability Statement**

Data are available upon reasonable request. Please contact the corresponding author for data availability.

**Authors' Contribution**

J.L. contributed to the statistical analyses, the interpretation of the findings, and writing of the manuscript. M.B. contributed to the overall design and conduct of the study, management processes, and writing of the manuscript. A. C. contributed to the statistical analyses and writing of the manuscript. C.L. contributed to the management processes, implementation of the treatment in radical prostatectomies, and writing of the manuscript. M.F. contributed to the overall design of the study, management processes, writing of the manuscript, and supervision of the technical aspects and implementation of the treatment. All authors read and approved the final report and verify the underlying data and contributed to the data collection and implementation of the treatment.

**Funding**

The study did not receive external funding. Therefore, the authors are independent of any funders. All authors had full access to the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

## References

1 Arora S, Hull L, Sevdalis N, et al. Factors compromising safety in surgery: stressful events in the operating room. Am J Surg 2010; 199(01):60–65
2 Fritsch MH, Chacko CE, Patterson EB. Operating room sound level hazards for patients and physicians. Otol Neurotol 2010;31(05): 715–721
3 Hasfeldt D, Laerkner E, Birkelund R. Noise in the operating room–what do we know? A review of the literature. J Perianesth Nurs 2010;25(06):380–386
4 Katz JD. Noise in the operating room. Anesthesiology 2014;121 (04):894–898
5 Szalma JL, Hancock PA. Noise effects on human performance: a meta-analytic synthesis. Psychol Bull 2011;137(04):682–707
6 Seidman MD, Standring RT. Noise and quality of life. Int J Environ Res Public Health 2010;7(10):3730–3738
7 Kracht JM, Busch-Vishniac IJ, West JE. Noise in the operating rooms of Johns Hopkins Hospital. J Acoust Soc Am 2007;121(5 Pt1):2673–2680
8 Siu KC, Suh IH, Mukherjee M, Oleynikov D, Stergiou N. The impact of environmental noise on robot-assisted laparoscopic surgical performance. Surgery 2010;147(01):107–113
9 Burns KN, Sun K, Fobil JN, Neitzel RL. Heart rate, stress, and occupational noise exposure among electronic waste recycling workers. Int J Environ Res Public Health 2016;13(01):E140

 

10 Babisch W. Cardiovascular effects of noise. Noise Health 2011;13 (52):201–204
11 Münzel T, Schmidt FP, Steven S, Herzog J, Daiber A, Sørensen M. Environmental noise and the cardiovascular system. J Am Coll Cardiol 2018;71(06):688–697
12 Joseph A, Ulrich R. Sound control for improved outcomes in healthcare settings. Center Health Design 2007;4:1–15
13 Cohen A. Industrial noise and medical absence, and accident record data on exposed workers. Paper presented at the International Congress on Noise as a Public Health Problem. Washington DC: US Environmental Protection Agency (Report EPA 550/9-73-0008); 1974:441–453
14 Lingard L, Espin S, Whyte S, et al. Communication failures in the operating room: an observational classification of recurrent types and effects. Qual Saf Health Care 2004;13(05):330–334
15 Woolf SH, Kuzel AJ, Dovey SM, Phillips RL Jr. A string of mistakes: the importance of cascade analysis in describing, counting, and preventing medical errors. Ann Fam Med 2004;2(04):317–326
16 Stringer B, Haines TA, Oudyk JD. Noisiness in operating theatres: nurses' perceptions and potential difficulty communicating. J Perioper Pract 2008;18(09):384, 386–391
17 Loeb M. Noise and Human. Efficiency: John Wiley & Sons; 1986
18 Saaty TL, Ozdemir MS. Why the magic number seven plus or minus two. Math Comput Model 2003;38(3–4):233–244
19 Lazarus RS, Launier R. Stressbezogene Transaktionen zwischen Person und Umwelt. In: Nitsch JR, ed. Stress: Theorien, Untersuchungen, Maßnahmen. Bern: Huber; 1981:123–259
20 Molnar M. Lärm als psychischer Stressor. Sichere Arbeit 2005; 2005(02):10–13
21 Glass DC, Siger JE, Friedman LN. Psychic cost of adaptation to an environmental stressor. J Pers Soc Psychol 1969;12(03):200–210
22 Kivimäki M, Kawachi I. Work stress as a risk factor for cardiovascular disease. Curr Cardiol Rep 2015;17(09):630
23 Waterland P, Khan FS, Ismaili E, Cheruvu C. Environmental noise as an operative stressor during simulated laparoscopic surgery. Surg Laparosc Endosc Percutan Tech 2016;26(02):133–136
24 Ising H, Braun C. Acute and chronic endocrine effects of noise: review of the research conducted at the Institute for Water, Soil and Air Hygiene. Noise Health 2000;2(07):7–24
25 Friedrich MG, Boos M, Pagel M, et al. New technical solution to minimise noise exposure for surgical staff: the 'silent operating theatre optimisation system'. BMJ Innov 2017;3(04):196–205
26 Leitsmann C, Uhlig A, Popeneciu IV, et al. The Silent Operation Theatre Optimisation System (SOTOS©) to reduce noise pollution during da Vinci robot-assisted laparoscopic radical prostatectomy. J Robot Surg 2021;15(04):519–527
27 Tewari A, Peabody J, Sarle R, et al. Technique of da Vinci robot-assisted anatomic radical prostatectomy. Urology 2002;60(04): 569–572
28 Schiff L, Tsafrir Z, Aoun J, Taylor A, Theoharis E, Eisenstein D. Quality of communication in robotic surgery and surgical outcomes. JSLS 2016;20(03):1–5
29 Kawase T, Yamaguchi K, Ogawa T, et al. Recruitment of fusiform face area associated with listening to degraded speech sounds in auditory-visual speech perception: a PET study. Neurosci Lett 2005;382(03):254–258
30 Hinz A, Hessel A, Brähler E. Der Leipziger Stimmungsbogen. Z Differ Diagn Psychol 2002;23(01):55–65

 