Evaluation of a Noise Reduction and Information Management System on Noise, Stress, Communication and User Acceptance of Crews in the Operating Room and the Medical Laboratory

Dissertation

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to Alicja Magdalena Lehrke – to jest nasza dissertacja

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Words are just hints at reality. So, what and who you are to me is not really wordable. I can write love. Now you think that you have an idea. But you don't. Still, let me use those little words and try to hint at reality: You are one of my homes. My first home in this crazy world. You made it less crazy for me. More cosy, more gemütlich. I remember soccer in the garden, pasta at the dinner table, talks, attention, hugs, love, pushes in the direction of life and adventure. As long as I breathe, I will never forget what you have done for me. Even in times of my teenage trouble, when I was pure chaos, you persisted by my side. I was searching for my way, and I was not easy. I have not found the way, but I found out that all kinds of ways can be loved. Knowing that I will be fine, that we will be fine, because we are striving for truth & love in this world – together. You comforted me when I was small and unsure or afraid. I will feel that forever and I thank you for that. This way I take my fear by one hand, my loved ones by the other and together we go into this wonderful thing called life. This here is our team effort. Thank you for this special teamwork. I love you Mamusia, Papa and Luca.

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Abstract

This dissertation evaluates the noise reduction and communication management system, called the Silent Optimisation System (SOS), in operating theatres (OT) and medical laboratories. It is investigated whether the SOS reduces noise (H1) and stress (H2). Furthermore, it was of interest if the system enhances communication (H3) and if it is accepted by its users (H4). A conclusion concerning these four psychological hypotheses is drawn on the foundation of the three articles, that were created in the framework of this dissertation, and the previous studies concerning the SOS.

The theoretical background includes the working definitions, theories, and models. It will be shown that noise levels exceed recommendations by the World Health Organisation and that the consequences of noise are detrimental to health and performance. One potential explanation for the negative consequences of noise is that noise functions as a stressor. Stress as a concept is introduced and psychological models are presented as they explain how the SOS may reduce stress. Since communication is another affected variable, this construct and different communication functions in the OT are explained. Studies showed that noise and stress can impair communication. Other potential solutions for the noise situation in those working settings are addressing the issue suboptimally, which is why the SOS is evaluated through an investigation of the derived hypotheses, detailed in the three articles.

In the first article the SOS in the OT is examined. In total, 81 individuals filled out questionnaires before and after each of 21 heart surgeries and 32 robot-assisted radical prostatectomies included in the study. Results revealed a SOS effect, as the group using the system showed a significant stress and exhaustion reduction.

In the second article the SOS during heart surgeries is investigated. The communication of 46 crew members during 22 heart surgeries was recorded, transcribed, segmented, and coded. The results showed no noise differences between treatment conditions in the room. The crew using the system spoke less, which might favour a lower microbial load relevant for the rate of surgical site infections (SSI). The SSI rate was descriptively lower in the experimental group. Additionally, the case-relevant communication (CRC) proportion was not higher in general in the experimental group but in the

critical phase 4. The SOS also did not lower the case-irrelevant-communication (CIC) proportion in the last phase of surgery. Nevertheless, the found pattern may have beneficial effects in terms of reducing distractive effects while promoting performance and team climate.

In the third article the SOS in the medical laboratory is assessed. Results showed that the SOS did not reduce noise in the room, but that it successfully reduced noise for the workers using the system. The SOS also reduced stress on all subjective measures, but not on the physiological parameter cortisol. The acceptance of the system was rated as mostly high by the participants.

Finally, the evaluation revealed that the system reduces noise for the working crews, but the noise level in the room is not affected. As the users are the primary object of the evaluation it can be concluded that the SOS is a noise reduction tool (H1). The hypothesised stress reduction was achieved by the SOS (H2). It must be mentioned that all subjective measures reacted beneficially, whereas the two physiological stress measurements did not. More research is needed to examine whether a suboptimal measurement approach was causative for not revealing the expected small effect or if the SOS has no effect on the physiological parameters. The communication was not enhanced in the hypothesised manner (H3). Nevertheless, the SOS shows an effect on communication which may be worth investigating. The system led to less communication which might have a reducing effect on SSIs, and it enabled technical high-quality communication via its technical properties. The found higher CRC proportion in the critical phase and the constant level of CIC may have beneficial effects on performance and team climate. As the stress reducing effect was evident, a new hypothesis was developed, which stated that the SOS might reduce stress via its newly found communication pattern. The acceptance of the SOS was high across studies (H4). In the end, the SOS did defend its claim to be a noise reduction and communication management tool, with stress reducing effects and high acceptance.

Zusammenfassung

In dieser Dissertation wird ein System zur Lärmminderung und zum Kommunikationsmanagement, das so genannte Silent Optimisation System (SOS), in Operationssälen (OP) und medizinischen Laboren evaluiert. Es wird untersucht, ob das SOS Lärm (H1) und Stress (H2) reduziert. Außerdem war von Interesse, ob das System die Kommunikation verbessert (H3) und ob es von den Mitarbeiter*innen akzeptiert wird (H4). Eine Entscheidung über die vier psychologischen Hypothesen wird auf Grundlage von in drei Artikeln gewonnenen Ergebnissen und den bisherigen Studien des SOS-Projekts getroffen.

Der theoretische Hintergrund umfasst die Arbeitsdefinitionen, Theorien und Modelle. Es wird gezeigt, dass die Lärmpegel die Empfehlungen der Weltgesundheitsorganisation übersteigen und dass Lärm negative Auswirkungen auf die Gesundheit und die Leistungsfähigkeit hat. Eine mögliche Erklärung dafür ist, dass Lärm als Stressor wirkt. Das Konzept Stress wird erläutert und es werden psychologische Modelle vorgestellt, die erklären, wie SOS Stress reduzieren kann. Zudem wird das Konstrukt Kommunikation sowie dessen Funktion im OP erläutert. Anhand von Studien wird gezeigt, dass Lärm und Stress die Kommunikation beeinträchtigen. Andere Ansätze zur Verbesserung der Lärmsituation in diesen Arbeitsumgebungen sind suboptimal, weshalb das SOS durch eine Untersuchung der abgeleiteten Hypothesen bewertet wird, die in den drei Artikeln untersucht werden.

Im ersten Artikel wurde das SOS im OP untersucht. Insgesamt füllten 81 Personen vor und nach jeder der 21 Herzoperationen und 32 robotergestützten radikalen Prostatektomien Fragebögen aus. Die Ergebnisse zeigten einen SOS-Effekt. In der Gruppe, die das System verwendete, waren Stress und Erschöpfung signifikant reduziert.

Im zweiten Artikel wurden die SOS-Effekte in Herzoperationen erforscht. Die Kommunikation von 46 Testsubjekten während 22 Herzoperationen wurde aufgezeichnet, transkribiert, segmentiert und kodiert. Die Ergebnisse zeigen keine Lärmunterschiede zwischen den Bedingungen im Raum. Das Personal, das das System benutzte, sprach weniger, was eine geringere mikrobielle Belastung begünstigen könnte, die für die Häufigkeit von den chirurgischen Postinfektionen (SSI) relevant ist. SSIs kamen in der Experimentalgruppe seltener vor. Daneben war der Anteil der fallrelevanten

Kommunikation (CRC) in der Experimentalgruppe nicht generell höher, sondern nur in der kritischen Phase 4. Das SOS senkte auch den Anteil der fallirrelevanten Kommunikation (CIC) in der letzten Phase der Operation nicht. Das gefundene Kommunikationsmuster kann indes vorteilhafte Effekte auf Leistung und Teamklima haben, welche weiter erforscht werden sollten.

Im dritten Artikel wurden die Effekte des SOS in einem medizinischen Labor analysiert. Die Ergebnisse zeigen, dass SOS den Lärm im Raum nicht senkte, aber für die Mitarbeiter*innen, die das System nutzten, reduzierte. Bei allen subjektiven Messwerten wurde eine Reduktion von Stress durch das SOS beobachtet, nicht dagegen bei dem physiologischen Parameter Cortisol. Die Akzeptanz des Systems wurde von den Teilnehmer*innen überwiegend als hoch eingestuft.

Die Evaluation ergibt, dass das System den Lärm für das Personal reduziert, ohne sich auf den Lärmpegel im Raum auszuwirken. Da die Nutzer*innen der primäre Untersuchungsgegenstand sind, wird vorgeschlagen, dass das SOS ein Instrument zur Lärmreduzierung ist (H1). Weiterhin wurde nachgewiesen, dass SOS Stress reduziert (H2). Positive Effekte wurden bei den subjektiven und nicht bei den physiologischen Messungen beobachtet. Weitere Untersuchungen sind erforderlich, um zu klären, ob ein suboptimaler Messansatz ursächlich dafür war, dass der erwartete kleine Effekt nicht aufgedeckt werden konnte oder ob das SOS keine Auswirkung auf die physiologischen Parameter hat. Die Kommunikation wurde durch das System nicht im Sinne der Hypothese verbessert (H3). Dennoch zeigt das SOS einen Effekt auf die Kommunikation, der weiter untersucht werden sollte. Das SOS führt zu weniger Kommunikation, was einen reduzierenden Effekt auf SSIs haben könnte und es ermöglichte durch seine technischen Eigenschaften eine qualitativ hochwertige Kommunikation. Der gefundene höhere CRC-Anteil in der kritischen Phase und das grundsätzlich konstante Niveau des CIC-Anteils könnten positive Auswirkungen auf Leistung und Teamklima haben. Da die stressreduzierende Wirkung nachgewiesen werden konnte, wurde eine neue Hypothese entwickelt, nach der das SOS Stress durch das aufgefundene Kommunikationsmuster reduzieren könnte. Die Akzeptanz des SOS war in allen Studien hoch (H4). Im Ergebnis kann gesagt werden, dass das SOS ein Instrument zur Lärmreduzierung und zum Kommunikationsmanagement mit stressreduzierenden Effekten und einer hohen Akzeptanz ist.

Single Article Overview

This dissertation is based on three separate articles. The articles have been accepted by or submitted to peer-reviewed scientific journals and are formatted as submitted. In the first article (*Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres*), published on November 22nd, 2021, in the Thoracic and Cardiovascular Surgeon Journal by Thieme, the SOS in the operating theatre is examined concerning exhaustion and stress. In the second article (*Impact of the Headset Tool SOTOS on Communication in Heart Surgeries in a Randomised Field Study*) the SOS during heart surgeries is examined concerning noise and communication. The article is under review by the British Medical Journal Quality & Safety since February 24th, 2023. In the third article (*Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise and Stress of Medical Laboratory Workers*) the SOS in the medical laboratory is examined concerning noise, stress, exhaustion, and user acceptance. The article was accepted on February 27th, 2023, by the Laboratory Medicine Journal by the Oxford University Press and will be published this year.

Chapter 3.1: Article 1.

Lehrke J, Boos M, Cordes A, Leitsmann C, Friedrich M. Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres. Thorac Cardiovasc Surg. 2022 Aug; 70(5): 392-400. doi: 10.1055/s-0041-1741059. Epub 2022 Feb 2. PMID: 35108735.

Chapter 3.2: Article 2.

Lehrke J, Boos M, Lauff S, Friedrich M. Impact of the Headset Tool SOTOS on Communication in Heart Surgeries in a Randomised Field Study. BMJ Quality & Safety. 2023 Feb; under revision.

Chapter 3.3: Article 3.

Lehrke J, Lauff S, Muecher, J, Friedrich M, Boos M. Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise and Stress of Medical Laboratory Workers. Laboratory Medicine. 2023 Feb; accepted.

Stories have been written down in human history since writing has existed. Even before that, our ancestors sat at fireplaces and told each other stories (Kearney, 2002). It has been shown that delving into a story can lead to higher activation in the motor regions of the mid-cingulate cortex, which is called the empathy network (C.-T. Hsu et al., 2014). Stories also activate the dorsomedial prefrontal cortex, which is enabled in social decision making (Tamir et al., 2016), and which increases the capacity to simulate hypothetical scenes. This capacity might help to understand the following research, as researchers set up hypotheses to test them via experiments or field studies. This is why this dissertation will begin with a story. And as all good stories include a hero and a villain, let's begin right there.

Once upon a time there were doctors working intensely for humankind. In the midst of stressful working conditions, late nights and the responsibility for life and death, they were trying to save lives in the operating theatre. The villain in this story is noise. Noise is hard to be aware of. It creeps in unnoticed through machine sounds, beepers or closing doors and sometimes also through the doctors and the staff themselves, who talk about work and life and raise their voices in answer to the loud machinery in the background. It is similarly loud on a highway. Chronically elevated noise levels are hordes of villains who attack the health of the staff and lower their performance through diminished concentration and communication. No real solutions have been found yet, as just closing one's ears makes communication impossible and following behavioural rules like "No talking allowed" makes for a bad atmosphere –and humans tend to forget those rules anyway. But behold, the potential hero is approaching: The Silent Optimisation System (SOS) was developed for the operating theatre to bring order into the chaos, or silence into the noise. This noise reduction and communication management tool uses headphones to reduce the noise through active and passive noise cancelling. Microphones and a communication matrix allow for functional communication. The hero promises much: Less noise, less stress and more functional communication, while being accepted by its users. And not only in the operating theatre but also in the medical laboratory, where the situation is similarly problematic. Will the hero live up to those expectations? How will the villain react? Will the SOS save the day and help the doctors to work healthier and more effective in order to achieve better results for their patients?

As the current discussion about fake news (Pennycook & Rand, 2021) showed, one should not believe everything in a blink of an eye. Check the validity of the source and believe in facts, which are, in the best case, provided by research. This is why the mentioned story will from now on be investigated in a reputable way, namely through three studies, bound together in this dissertation. We, as researchers, will try to investigate if the hero really is a hero or not. How does the SOS work and what are the consequences? This is what is tried to be answered in this dissertation. As the present situation in operating rooms is suboptimal and research is needed to allow change to happen. The following chapter will introduce the situation and give an overview of this dissertation, including the three mentioned studies.

1 Introduction

This dissertation focuses on the evaluation of the *Silent Optimisation System* (SOS) concerning its effects on noise, stress, communication, and user acceptance. In this introduction an overview of the content of this dissertation structured into the following four chapters is offered.

In Chapter 2 the theoretical background for understanding the three articles of this dissertation is offered. Working definitions will be given and the current state of research will be presented. In the beginning a definition of noise is given and the difference between sound and noise will be explained. It is shown that noise is exceeding thresholds in the *operating theatre* (OT) as well as in medical laboratories (Busch-Vishniac et al., 2006; Griffiths et al., 1970; Gultekın et al., 2013; Hasfeldt et al., 2010; J. D. Katz, 2014; Shapiro & Berland, 1972). Noise reduces health and performance of the staff. Next to auditory problems (J. Katz et al., 2015; Wallace et al., 1994; Willett, 1991), studies showed a positive correlation between noise and cardiovascular diseases (Babisch, 2011; J. D. Katz, 2014; Münzel et al., 2018). Also, the performance of the crew can suffer due to noise (Keller et al., 2016; Szalma & Hancock, 2011), which will also be explained in this chapter.

One potential explanation for the adverse effects of noise on health and performance is stress (Bergefurt et al., 2022; Clark & Paunovic, 2018; Gultekın et al., 2013; Waterland et al., 2016). This topic will be introduced in Chapter 2.2. The crucial argument in this chapter comes at the end, where it will be argued that noise is a stressor and that this is one pathway for the mentioned health and performance reduction. Even though it seems self-explanatory that noise is a stressor it was this chapter's goal to use studies and theories to find evidence for this claim. The argument is based on multiple assumptions which are backed up with data from different studies. It will be shown that several studies already work with this argument and in some manuscripts the term *noise induced stress* (Topf & Dillon, 1988; Westman & Walters, 1981) is already given without any explanation, assuming it to be self-explanatory. Studies investigating either noise or stress have been conducted independently from one another and their results show that consequences of noise (Babisch, 2011; J. D. Katz, 2014; Münzel et al., 2014; Munzel et al., 2014) and of stress (Brown et al., 1991; Kivimäki & Kawachi, 2015; Steptoe & Kivimäki, 2013; Taggart et al., 1973) are similar, as both variables lead to diminished cardiovascular health. Also, both constructs react similarly to *control* over the stimulus (Karasek, 1979; Lazarus, 1974) and in both processes the role of *appraisal* is a central element. Appraisal processes decide whether a stimulus is a stressor, or a sound is noise (Lazarus, 1966, 1974; Lazarus & Folkman, 1984; Molnar, 2005). The mentioned arguments are sufficient to work with the conclusion that noise is a stressor. Before making the final argumentation, the chapter offers a definition of stress and explains the physiological and psychological stress mechanisms. The used psychological model is the transactional model of stress (Lazarus, 1966; Lazarus & Folkman, 1984; Lazarus & Launier, 1981), which focuses on the role of appraisal processes. After the presentation of the model, the psychological factors *social support* (Aureli et al., 1999; Gust, 1996; Ruis et al., 1999; Sapolsky, 1997; Smith et al., 1998), *predictability* of the stressor (Abbott et al., 1984; H. Davis & Levine, 1982) and *control* (Houston, 1972; Lundberg & Frankenhaeuser, 1978; Visintainer et al., 1982) will be introduced as they influence whether and how a stimulus is likely to be perceived as a stressor. The role of control is also part of the job-demand-control model, which will be introduced. Stress consequences on health and performance will be thematized afterward such that the relevance of a noise and stress reduction tool becomes obvious.

Noise is also influencing communication, which is why in Chapter 2.3 the concept of communication is introduced. Here it is argued that communication is crucial for team success (Fernandez Castelao et al., 2011; Hunziker et al., 2009, 2010; Mäkinen et al., 2007; Marsch et al., 2004), especially in the OT. Different types of communication in the context of surgery will be explained and studies will be introduced that show that not only noise but also stress has adverse effects on communication (Cheriyan et al., 2016; Hasfeldt et al., 2010; Keller et al., 2016, 2018; Padmakumar et al., 2017; Pfaff, 2012). Since patient safety is depending on teamwork and performance of the working crew (Fernandez Castelao et al., 2015), an investigation of performance markers is relevant. *Surgical site infections* (SSIs) will be briefly introduced as they are one example of such a marker. Evidence suggests that communication may influence the SSIs (Tschan et al., 2015), which is relevant as the SOS claims to be a noise reduction and communication management system. This chapter will finalize the attempt to give the reader an overview of the status-quo and its consequences.

As the current situation in OTs and laboratories is suboptimal with the mentioned noise levels and their consequences, the suggested solutions are being introduced and discussed in Chapter 2.4. Here, the alternative solutions like earplugs, which were suggested by the WHO (Berglund et al., 1999), or behavioural modification systems (Engelmann et al., 2014; Kahn et al., 1998) are introduced and discussed. As none of these are fully convincing, the SOS (Friedrich et al., 2017) will be presented with its technical features and current research results about its evaluation so far.

The SOS is likely to be more effective when the working team accepts the new technology. Which is why in Chapter 2.5 it will be explained how the system is evaluated in terms of acceptance. Next to the *technical acceptance*, which involves questions about the functionality of the system, like the audio quality or comfort, and the *communication effects* of the SLOS, the focus will lie on the validated *technology acceptance model* (TAM) (F. D. Davis, 1985, 1989) which will be explained in detail as it is the foundation of the variable named the *specific SLOS acceptance*. All three variables will be introduced as they together form the *SOS acceptance*, which has been developed gradually throughout the SOS project to assess the acceptance of the system.

As the system could be able to address the issues of concern, namely the noise and stress reduction, while allowing for functional communication, the investigations of those claims are in the centre of this evaluation. The psychological hypotheses will be explained und further developed into sub-hypotheses in Chapter 2.6 and investigated in the three articles (see Chapter 3) where they will be translated into statistical hypotheses, which then will be tested. The effects of the SOS on the dependent variables noise, stress and SOS acceptance are investigated in the OT and the medical laboratory. Only the communicational analysis is focused exclusively on surgery. The scientific question is, if the SOS delivers substantial value to the quality of the work of the staff in terms of noise and stress reduction, while allowing for functional communication and while being accepted by its users. All theoretical arguments are aligned in order to derive the main psychological hypotheses which are:

H1: The SOS reduces noise.

H2: The SOS reduces stress.

H3: The SOS enhances communication in the OT.

H4: The SOS is accepted by the workers.

It is the aim of this dissertation to deliver results for the evaluation of the SOS. In order to allow an overview of the SOS project a framework model has been developed and is displayed in Figure 1. The content of Chapter 2 verifies all relationships presented in the framework, except for those relationships labelled with the hypotheses. Those are not yet sufficiently investigated, and this dissertation will try to close this gap. The mentioned psychological hypotheses are found next to the specific arrow.

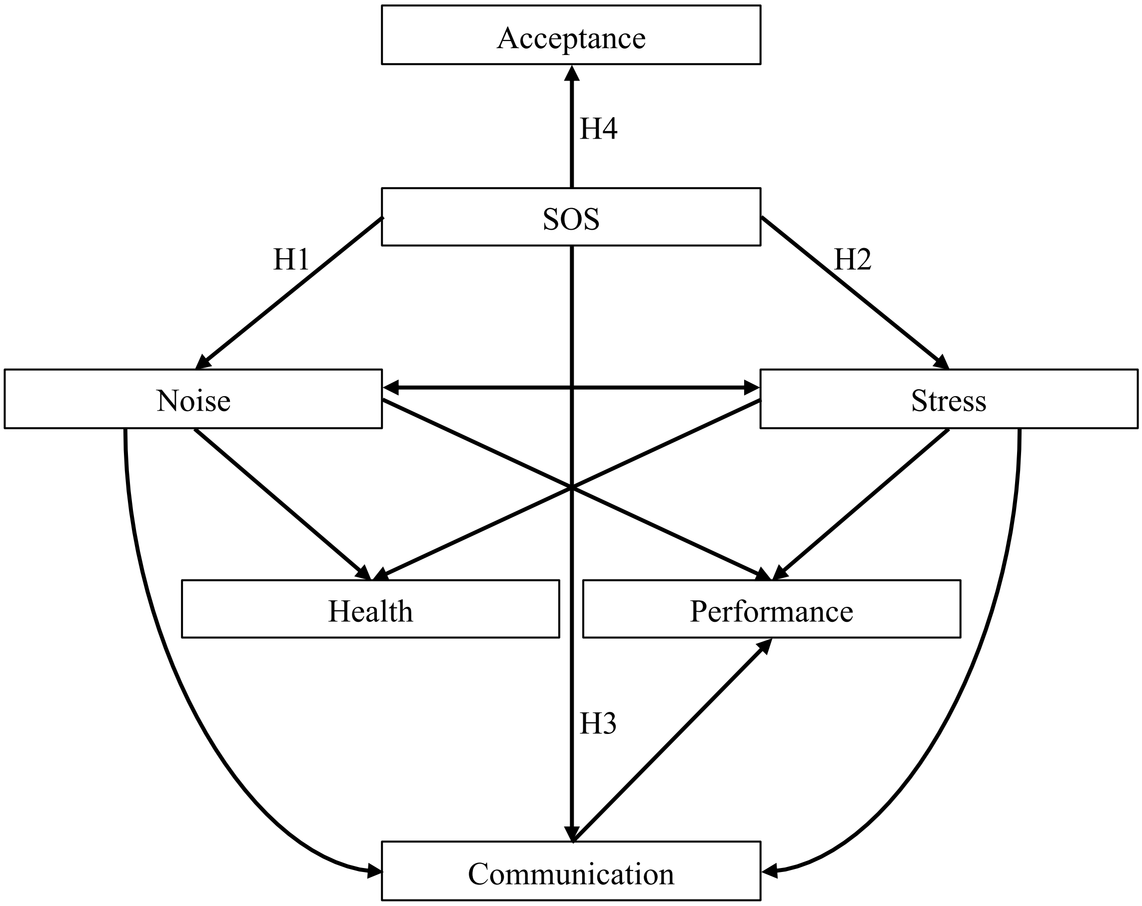

Figure 1. Framework model of the SOS project. All relationships are investigated and verified in the theoretical background (Chapter 2). H = Hypothesis.

In Chapter 3 all published or submitted articles of this dissertation will be found. In Chapter 3.1 the *Silent Operating Theatre Optimisation System* (SOTOS) is evaluated in the OT. In 22 heart surgeries and 32 radical prostatectomies the SOTOS is compared to a control group concerning the measurements of subjective stress and the stress reaction exhaustion, thus focusing on H2. Chapter 3.2 contains the manuscript from the SOTOS-communication project, which investigated the SOTOS in heart surgeries with the focus on noise levels and communication, focusing on H1 and H3. In Chapter 3.3 the SOTOS was modified into the *Silent Laboratory Optimisation System* (SLOS) and evaluated in a medical laboratory. The workers were investigated for 43 working days in their early shift and again an experimental group, with the system, was compared to a control group working in a regular manner without the system. The dependent variables of noise levels were measured objectively in the room and subjectively, stress, including multiple subjective measurements and the physiological measurement of cortisol, and the SOS acceptance were examined. The focus laid on H1, H2 and H4.

In Chapter 4, a summary of the findings of the three articles will be given additionally to other findings concerning the SOS evaluation from previous studies in the SOS project (Friedrich et al., 2017; Leitsmann et al., 2021; Meyer-Lamp et al., 2021). All results will be integrated into the discussion in order to arrive at conclusions about the above-mentioned psychological hypotheses which were explained in more detail in Chapter 2.6. As the results are always dependent on the methodological approach, this approach and the limitations will be discussed alongside the results discussion. The end of Chapter 4 will contain a conclusion and implications for future research.

2 Theoretical Background

This first chapter covers the relevant themes in order to understand the motivation and approach of all three articles. The relevant factors contributing to the problematic situation in the OT and medical laboratory, namely noise and stress, are introduced and explained. As communication in the OT, an influencing factor of performance, team climate and post-infections, can be impaired by noise and stress, this construct is focused on in one subchapter. Potential alternative solutions are presented before the SOS is introduced. In the end the variable called the *SOS acceptance* is explained, followed by the introduction of the research objective and the four psychological hypotheses which are derived from the theoretical background and previous research.

2.1 Noise

This chapter will give an overview of the concept of noise, deliver a definition, and explain noise characteristics. The current situation concerning noise in the OT and the medical laboratory will be introduced. In the end, the consequences of noise on health and performance are presented.

2.1.1 Noise Definition and Characteristics

The human auditory system is stimulated by air pressure waves which are called sounds. A vibrating object, like the vocal cords, leads to the vibration of air molecules and through the air this pressure wave can reach the auditory system of a human, namely the ear and its inner structures. If certain characteristics concerning sound pressure level and frequency are existent a hearing sensation is possible (Pinel & Barnes, 2018). The sound pressure level of such a sound can be measured in decibel (dB) whereas the frequency is usually measured in Hertz (Birbaumer & Schmidt, 2010), which are technical and not psychoacoustical measures. It is not easily possible to infer the perception of loudness from the sound pressure level in dB, as different characteristics, like frequency, play a role. In general, an increase or reduction in dB is associated with an increase or reduction in perceived loudness. Beyond the threshold of 40 dB, when the frequency is stable around 1 kHz, the Stevens's power law describes the perceived loudness and an increase of 10 dB is normally perceived as a doubling in loudness. Below this threshold already smaller changes in dB lead to a perceived doubling in loudness (Birbaumer & Schmidt, 2010). As the frequency of a sound pressure level is also relevant for the hearing perception it is always a complex matter of assessing the perceived loudness of a sound. To simplify the matter, the A-weighted filter is commonly used, which is a filter through which the effects of human hearing are mimicked. The A-weighting represents equal loudness curves with frequencies between 20 and 40 phone and is labelled as dB(A). There is a correlation between this rating and the perception of the frequency range of human speech, which is why this filter plays an important role in noise measurements in occupational and environmental contexts (Meyer-Bisch, 2005; Passchier-Vermeer & Passchier, 2000). Different filters like for example the dB(B), dB(C), or dB(D) exist with different foci. The dB(A) filter is a type of frequency weighting filter used to measure the sound pressure level (SPL) of a sound in decibel according to the human perception.

Studies exploring noise issues at work (Giv et al., 2017; Lutman, 2000) typically measure SPL as a noise level in dB(A), which is why this measurement is also included in this dissertation. However, the perceived loudness alone does not determine whether a human perceives sounds as noise, as also quiet sounds can be perceived as noise (Waye et al., 2002), which can be explained by the subjective appraisal of a sound (Molnar, 2005). Noise is defined as a sound that is loud, unpleasant or frightening or alternatively, noise is information, which is not wanted, and which makes it difficult to perceive the relevant information (Hornby, 1995). Thus, it can be stated that loud sounds are more likely to be perceived as noise (Bundesministerium fuer Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, 2014), but loudness is not a sufficient characteristic, due to the appraisal of the perceiver, which is decisive concerning the question of when a sound is perceived as unpleasant or frightening. This definition shows that noise is a psychological phenomenon rather than a physical one (Molnar, 2005).

Additionally, it must be noted that noise can have different qualities concerning the waveform of the stimulus. The temporal characteristics of a sound wave can be intermittent or continuous (Szalma & Hancock, 2011). Intermittent noise shows changes in intensity over a certain period of time, showing gaps of quieter intervals between louder phases, which are unpredictable. Continuous noise in contrast shows no breaks in intensity, an example being constant noise levels generated by a humming of a machine that is constantly working (Speaks, 2017).

Noise stimuli can be generated by non-living objects or living objects, like humans using speech for communication. A major distractive stimulus category for humans is speech of others. It seems that humans are especially sensitive to this distraction. Speech is monitored by a nearby human to some extent, which was shown by the phenomenon of the cocktail party effect (Cherry, 1953). It was shown that intermittent noise, which is existent in the OT and the medical laboratory, is more disruptive than continuous noise (Szalma & Hancock, 2011). One explanation is that the change in intensity is the reason for that, as it leaves less possibility for behavioural habituation (Loeb, 1986).

Concludingly if a study's goal is to investigate noise and its effects it is recommended to use the dB(A) measurement and additionally a survey asking for the subjective component in order to address the psychological aspect. In the following dissertation it is concluded for practical reasons that higher dB(A) measures at work are measuring higher noise levels. In order to integrate the psychological component a subjective assessment is integrated, additionally to the dB(A) measurement in the room.

2.1.2 Noise Situation in the Operating Room and the Medical Laboratory

Noise recommendations, as for example stated by the World Health Organization (WHO), are regularly exceeded in the OT and the medical laboratory. Noise sources are typically technical devices like beepers, machines, alarm sounds or air conditioning and human actions, closing doors, use of equipment and communication (Arabacı & Önler, 2021; Giv et al., 2017; Hasfeldt et al., 2010; T. Hsu et al., 2012). Guidelines offered by the WHO differ, with one of the highest limits being 55 dB(A) (Berglund et al., 1999; Clark & Paunovic, 2018; de Lima Andrade et al., 2021; Giv et al., 2017; J. D. Katz, 2014). The target contexts of this dissertation are the OT and the medical laboratory. Studies found noise levels above recommendations in both working contexts (Busch-Vishniac et al., 2006; Griffiths et al., 1970; Gultekın et al., 2013; Hasfeldt et al., 2010; J. D. Katz, 2014; Shapiro & Berland, 1972; Szalma & Hancock, 2011). For the human-made noise source, behavioural change interventions can lead to a reduction of noise (Engelmann et al., 2014; Kahn et al., 1998), whereas the machine noise can be reduced by earplug solutions as recommended by the WHO (Berglund et al., 1999), which does not help in working contexts like the OT or medical laboratories as communication between staff is necessary. The elimination of all noise sources seems unrealistic (Arabacı & Önler, 2021), which leaves the staff with limited resources to cope with the noise situation at work.

2.1.3 Consequences of Noise on Health and Performance

The health consequences due to noise (Babisch, 2011; Burns et al., 2016; Münzel et al., 2014) are reported in multiple studies. In modern times the highest health risks are not due to directly observable wounds but rather through unhealthy habits and conditions like an unhealthy diet, drugs like alcohol or the regular listening to loud music (Taylor, 2018). High noise levels in the medical workplace (Busch-Vishniac et al., 2006; Griffiths et al., 1970; Gultekın et al., 2013; Hasfeldt et al., 2010; J. D. Katz, 2014; Shapiro & Berland, 1972; Szalma & Hancock, 2011) display an example of that statement, as the consequences are not directly visible. Health consequences can be divided into auditory and non-auditory consequences. Auditory problems include hearing loss or impairment (J. Katz et al., 2015; Wallace et al., 1994; Willett, 1991). Non-auditory effects are exhaustion, reduced well-being and higher stress (Bergefurt et al., 2022; Fritsch et al., 2010; Love, 2003; McNeer et al., 2016). Fatigue and burnout among the medical staff are also observed consequences (A. Joseph & Ulrich, 2007), which can lead to higher absenteeism rates (A. Cohen & Ward, 1974). One of the most established connections between noise and negative consequences is the connection between noise and cardiovascular issues like ischaemic heart diseases, myocardial infarction, heart failure, stroke and hypertension (Babisch, 2011; J. D. Katz, 2014; Münzel et al., 2018).

Research also showed that noise reduces performance in general (Keller et al., 2016; Szalma & Hancock, 2011). A meta-analysis showed lower cognitive performance and psychomotor performance (Szalma & Hancock, 2011). In the OT noise can lower surgical performance (Siu et al., 2010) which can reduce patient safety (Keller et al., 2016, 2018). The reduced performance was greater while conducting more difficult tasks (Siu et al., 2010). Intermittent noise seems to be a stronger influence than continuous noise levels (Szalma & Hancock, 2011), as it allows less opportunity for habituation (Loeb, 1986). Evidence suggests that concentration is reduced by high noise levels (Bergefurt et al., 2022), which can explain why performance is reduced in general, especially, when the exposed are stressed, reporting lower well-being (Bergefurt et al., 2022; Fritsch et al., 2010; Love, 2003; McNeer et al., 2016) and higher exhaustion (A. Joseph & Ulrich, 2007). Concentration could be impaired due to noise effects on the working memory. The working memory is the system that is relevant for keeping information in the mind, while performing tasks, such as reasoning (A. Baddeley, 2010). Even though the research concerning the working memory is still in process and controversial debates about details exist, it seems clear that humans can only hold a certain amount of information in their working memory (A. Baddeley, 2010; Cowan, 2012). Noise is another input that needs to be processed by the working memory and increases the mental workload of the given task, binding capacity, which could otherwise be used for the task (A. Baddeley, 2010; Becker et al., 1995; Szalma & Hancock, 2011). Even though the exact underlying mechanisms remain speculative, the adverse effects of noise on concentration are well investigated (Bergefurt et al., 2022; Engelmann et al., 2014; Way et al., 2013).

Another reason for the reduced performance due to noise is likely to be the disturbed communication. Noise at the workplace increases disruptions, masks relevant information, and thus impairs speech intelligibility and speech discrimination (Gawande et al., 2003; Healey et al., 2007; Lewis et al., 1990; Murthy et al., 1995; Stringer et al., 2008; Tsiou et al., 2008). A common reaction in this situation is to raise the voice in order to maximize the probability of being heard correctly, which adds up to even higher noise levels (Healey et al., 2007; Stringer et al., 2008; Tsiou et al., 2008). This situation disturbs communication and thus makes effective team leadership difficult, which has negative effects on performance (Fernandez Castelao et al., 2015). In the OT it was found that different contents of communication, for instance the proportion of crew talk about the case to non-case-related subjects had effects on outcomes like surgical post infections (Tschan et al., 2015), which makes communication even more relevant for successful work outcomes.

Consequences of noise seem detrimental to health and performance of the working crew. One potential explanation for the described consequences, for example on health, could be that noise functions as a stressor (Bergefurt et al., 2022; Clark & Paunovic, 2018; Gultekın et al., 2013;

Waterland et al., 2016), which will be argued in the end of the next chapter (Chapter 2.2.6). As one component of this argumentation is the concept of stress, this topic will be introduced in the following chapter.

2.2 Stress

Stress is a commonly used term and has marked an interdisciplinary field of research (Kaluza, 2011). This chapter will define the construct and introduce the segmentation of stress into stressors and stress reactions (Kaluza, 2011) with a physiological perspective. Afterwards, a psychological approach including the Lazarus Model (Lazarus, 1966; Lazarus & Folkman, 1984) and the job-demand-control model (Abbasi et al., 2019, 2020; Chau et al., 2009; Karasek, 1979), and psychological factors influencing the stress reaction will be explained. Finally, consequences of stress will be discussed, and it is argued that noise is a stressor.

2.2.1 Stress Definition

Modern stress research acknowledges that the construct stress can only be understood through a bio-psycho-social perspective (Kaluza, 2011). In the beginning the biological perspective was focused on the concept that the human body has an ideal state called homeostasis in which for example the temperature, the degree of acidity or the level of oxygen should stay close to an optimal level (Cannon, 1922). The following working definition of stress may be correct for most animals but not entirely for humans, as it is missing the psycho-social part. This definition applies that a stressor is a stimulus which disturbs the homeostatic balance and the stress response is the reaction which tries to re-establish this homeostasis (McMillan, 2008). This construct of homeostasis has been modified through the concept of allostasis, as it seems rather likely that instead of an optimal level for any measure in the body in general there are different optimal levels depending on the current situation in which the body is in (Sterling & Eyer, 1988). For example, the ideal heartbeat differs between the situation of giving a speech and laying in the sauna, so rather than an optimal level there seem to be different ideal levels or windows depending on the given situation. Another critique was that the homeostasis concept worked with the idea that through one local regulatory mechanism the ideal level was reached, whereas the alternative explanation would be that any level could be regulated by several different physiological pathways (McEwen & Lasley, 2002). Additionally, it must be noted that in humans the regulatory mechanisms are not only activated when a set point must be reached after physical changes happened to a human, but sometimes in anticipation of that change. This means that allostatic changes can be observed in humans in anticipation of an event which is potentially leading to a set point change (Sapolsky, 2004). This anticipation process will get relevant later when psychological concepts of stress are introduced.

Stress can be defined as the experience of encountering or anticipating adversity in one's goal related efforts (Carver & Connor-Smith, 2010). This often is a negative emotional experience triggered by stimuli called stressors, which are escorted by specific physiological, cognitive, and behavioural modifications (Taylor, 2018). The stimuli triggering a stress reaction are called stressors and those are categorised differently within various categorization systems (Kaluza, 2011; McGrath, 1976; Sonnentag & Frese, 2013) but noise finds a place within each system, like under the biophysical environmental (McGrath, 1976) or under the physical category (Kaluza, 2011; Sonnentag & Frese, 2013). So basically, stress is including several components, starting with the stimuli who begin this process (stressors), to the reaction itself (stress reaction). First, an introduction into the physiological components of the stress reaction will be given and afterwards the psychological approach will be explained. The psychological approach will show that between the appearance of stimuli (potential stressors) and the stress reaction, an appraisal phase takes place, which is responsible for the decision if a stimulus is rated as a stressor or not. This goes along with the concept of allostasis which includes the idea that the regulatory processes can influence certain physiological measures like the heartbeat in anticipation of certain events (McEwen & Lasley, 2002; Sterling & Eyer, 1988). Therefore, the human stress reaction does not have to start right when a lion is already chasing the human, but also before, in anticipation of such a threat, due to appraisal processes described later in the transactional stress model (Lazarus & Folkman, 1984).

2.2.2 Physiological Stress Pathways

The biological perspective focuses on physiological processes within the human body. The stress reaction is the body's reaction to the current demands via an activation of the sympathetic nervous system (SAM) and an activation of the hypothalamic pituitary adrenal axis (HPA) (Hüther, 2016; Kunz-Ebrecht et al., 2003). The SAM pathway begins with activation in the cerebral cortex, where appraisal processes, which will be explained in the next chapter, may play a role. This in turn activates the hypothalamus and finally leads to sympathetic nervous system activation and the activation of the adrenal glands (Birbaumer & Schmidt, 2010). The relevant part of the adrenal glands here is the adrenal medulla, which then starts the secretion of catecholamines like adrenalin and noradrenalin, leading to physiological stress modifications for example on heart rate, blood pressure and sweating (Taylor, 2018). Within the HPA axis the hypothalamus is activated leading to the secretion of *corticotripin-releasing hormones* (CRH), which in turn stimulates the pituitary gland and leads to the release of *adrenocorticotropic hormones* (ACTH). ACTH within the blood stream will find its way to the adrenal glands, where it will trigger the release of glucocorticoids like cortisol in the adrenal cortex (Kaluza, 2011; Kirschbaum & Hellhammer, 1994; Taylor, 2018).

Both introduced pathways are playing a role in most stressful situations for humans, but it must be noted that the manner of their activation varies, depending on various factors. There has been some criticism towards the fight-flight perspective in so far, that Shelley Taylor, a psychologist from the University of California, argued that this perspective is strongly men-oriented. Taylor and her research team were able to find another reaction to stress called the *tend and befriend* reaction which was found more often in females and is strongly driven by the hormone called oxytocin (Taylor et al., 2000). This reaction leads to behaviour which is associated with taking care of the young and the effort to seek social bonds, instead of fighting or fleeing (Taylor, 2018). Nowadays, it has been shown that the gender differences are not strict, as females also react physiologically and behaviourally in the fight-flight manner, and that males also use the tend and befriend reaction (Geary & Flinn, 2002). However, this shows how complex the matter of stress reactions can be. Additionally, it has been

shown that not all stressors lead to the same stress response. It seems that certain stressors have hormonal signatures which are somewhat similar, whereas others do not (Schommer et al., 2003).
Even though the mentioned physiological pathways are used as a reaction for most stressors the pace and the magnitudes of the physiological reactions vary depending on the stressor and other factors (Sapolsky et al., 2000). This means that the mentioned pathways are the core of the stress reaction but its exact activation in a given transaction between human and environment is specific and highly complex. For this thesis it is relevant to note that the described physiological processes are present reliably when a human is faced with a stimulus, he/she considers a stressor.

2.2.3 Psychological Stress Approaches

Whether one of the mentioned pathways will be activated and begin a stress reaction is substantially dependent on the appraisal of the situation according to the transactional stress model which includes the anticipation of a potential threat. The following psychological models try to explain how this can happen.
One of the most important stress models in psychological research is the transactional stress model (Lazarus, 1974; Lazarus & Folkman, 1984). It is based upon the assumption that a person is in transaction with the environment and its stimuli, which are potential stressors. The model claims that the appraisal of these transactions is relevant for the stress reaction. An example for a transaction could be that a human meets a lion. The mentioned appraisals are cognitive calculations through which an interpretation of the given environmental or internal stimuli are made leading to consequential meaning (Dewe & Cooper, 2008; Lazarus & Folkman, 1984). Within this model a differentiation is made between appraisal forms. Within the primary appraisal a person is concerned with the question whether the transaction is negative for the well-being of the person. Following up, on the example, the human would probably decide that a lion could be dangerous for his/her well-being. If the individual comes to the conclusion that this is the case, the first hurdle is taken, and the secondary appraisal is decisive about the question of whether a stress reaction will be started or not. In the secondary appraisal the person decides if enough resources are available for him/her in order to deal with the problem. If a lion comes into the persons living room the secondary appraisal will

probably be that he/she does not have enough resources to deal with the situation. If the lion would come into the room of a zoo, which is restricted through a wall and a window, the secondary appraisal could be that enough resources are available at the moment. Both appraisal forms can happen consciously and subconsciously and the order is more flexible than thought of in the beginning (Lazarus, 1974; Lazarus & Folkman, 1984). Feedback loops rather than a unidirectional approach are integrated into the model, which shows that the human can reappraise the situation. In the example a huge crack in the window may lead to a reappraisal and start a stress reaction.

This psychological approach opens up a different dimension in terms of stress reactions for humans compared to other animals, as the appraisal mechanisms can deal with questions far in the future. That means that stressors for humans are not only stimuli which disturb their allostasis right now, but a stressor can also be the anticipation of that happening. Humans can see events coming in the future and this in turn can activate the presented physiological stress pathways. Of course this is not exclusively found in humans as the gazelle running from the lion also anticipates a bad outcome if the lion gets to him/her, but the difference is that humans can think about the lion coming far in the future (Sapolsky, 2004; Taylor, 2018).

Before psychologists came into the picture the bioengineers were leading researchers concerning stress and they supported the biomedical perspective. They measured the characteristics of the stimuli with which they confronted test subjects and then measured or predicted the stress reactions. It seemed perfectly sufficient until they realized that a painful stimulus would lead to different stress reactions in one test subject if he/she would get the painful stimulus while crying in her/his mother's arms (Sapolsky, 2004). But the stimulus was the same. Why was the reaction a different one? A controversial debate between the camp of people with the biological perspective and the camp of people who wanted to add the psychological perspective began (Selye, 1975). Nowadays it is widely accepted that psychological factors do play a significant role through appraisal processes (Lazarus, 1974). Also, other psychological factors come into play and are introduced in the next chapter.

2.2.4 Psychological Factors of Stress

Crucial psychological factors are social support, predictability of the stressor and control over the stressor. Social support is empirically shown a protective factor concerning stress in animals and humans (Aureli et al., 1999; Gust, 1996; Ruis et al., 1999; Sapolsky, 1997; Smith et al., 1998). Socially isolated people have exceedingly active sympathetic nervous systems (Smith et al., 1998). Another factor is the predictability of the stressor (Abbott et al., 1984; H. Davis & Levine, 1982; Seligman & Meyer, 1970; Ursin et al., 1978). Rats getting a warning signal before painful stimuli get less ulcers, a common stress reaction, than rats getting the same exact painful stimuli without the warning. Predictability can decrease the stressors intensity. The organisms learn that there are phases of pain and phases of security in which they can relax (Abbott et al., 1984; H. Davis & Levine, 1982). Humans can habituate to chronic stressors. They may still impair the physiological allostasis but as it is happening regularly the predictability is high and a smaller stress reaction likely. This was demonstrated by military personal in their first parachute trainings. The men were highly stressed in the beginning with reduced stress reactions after they habituated to the process (Ursin et al., 1978). The last facet of psychological stress is the concept of control (Houston, 1972; Lundberg & Frankenhaeuser, 1978; Visintainer et al., 1982). Rats given a lever can learn that they can avoid painful stimuli show lower stress reactions than rats who have no lever. If the lever is taken away in the first group, the stress reaction is strong. This experiment was replicated even without a connection between lever and painful stimuli, but the effects were the same (Visintainer et al., 1982), which led to the idea that it is rather the belief of control, than the control itself (Houston, 1972). This was confirmed in human studies which showed that that the feeling of control effects the appraisal. It was shown that the group with the belief of control over loud unpleasant noise-stimuli was less hypertensive (Glass & Singer, 1972). As hypertension is used as a stress maker, this gives a first impression about the relationship of noise and stress, which will be investigated further in Chapter 2.2.6. In another study the subjects were asked not to use the control button if not necessary. In this experiment the participants did not use the button at all, but still showed a lower stress response, longer task persistence and a higher tolerance for the noise induced stress (Glass et al., 1969). This showed that the exercise of control is not exclusively the stress reducing effect, but rather it is the belief or appraisal of control.

That control plays a major role in this process is supported by the job demand-control model (Karasek, 1979). According to the model psychological strain is a result of the trade-off of the demands of a job situation which a worker is in and the degree of control this worker has of the situation. Control is operationalised as decision making freedom or job decision latitude. The workers would show the highest stress reactions when the demands are high and the control is low (Karasek, 1979). Accordingly all measures that lower job demands and heighten control could reduce the likelihood of high strain at work and therefore reduce stress (Karasek, 1979). The model has been adapted by the variable of social support, which has a stress-buffering effect and therefore leads to another adjusting screw in the stress system: More social support is supposed to reduce stress (S. Cohen & Wills, 1985; Karasek et al., 1982; LaRocco et al., 1980).

In summary one can state that noise is an issue in workplaces which can lead to higher stress levels of the exposed workers. Stress is a complex variable with different components. One component is the physiological background in form of a stress reaction which was explained in detail in this chapter. Another component of stress is the psychological part which seems decisive concerning the question which stimuli will become stressors. The next chapter will explain what consequences arise when humans experience stress in the short and long term.

2.2.5 Stress Consequences on Health and Performance

Current research has agreed upon the fact that the biomedical model is overdue and that the bio-psycho-social model has more explanatory value, which includes psychological factors (Lazarus, 1974), like stress appraisal. Human organisms do not react solely to manifest stressors in their environment, but appraisal processes decide which stimulus becomes a stressor and therefore which stimulus starts a stress reaction (Lazarus, 1966; Sapolsky, 2004). These stress reactions have consequences, which are discussed in this chapter. First, stress effects on performance are explained, and afterwards the effects on health will be discussed. It is important to differentiate between short-term stress and long-term or chronic stress.

Short-term stress can enhance performance. The stress reaction, namely the sympathetic nervous system activation, the parasympathetic withdrawal, and stronger activation of the HPA, is the organism's general reaction if it meets demands (Kunz-Ebrecht et al., 2003). Evolutionary speaking this reaction is healthy as it improves the physiological and mental reaction to a stressor and improves surviving chances (Sapolsky, 1996). In the working context, stress can lead to initiative taking, through which workers take actions to earn necessary skills needed for facing the current demands (Fay & Sonnentag, 2002). The narrowing of attention due to stress can activate attentional resources and thus increase the pace with which specific brain processes work (Hancock & Weaver, 2005). One study suggests that some stress hormones can enhance memory and increase performance on cognitive tasks (Cahill et al., 2003). Thus, it can be stated that short-term stress is helpful for performance.

Nevertheless, especially chronic stress and high stress is rather associated with negative effects on performance (Taylor, 2018). If the effect of stress on performance is considered one can differentiate between the stress reaction following different stressors. In on review, different types of stressors were investigated concerning their effects on several components of cognitive performance. It seems that commonalities exist, but also that each stressor type has a unique signature pattern in terms of consequences (Hockey & Hamilton, 1983). Noise for example has been shown to reduce performance (for details see Chapter 2.1.3) in multiple domains (Szalma & Hancock, 2011). Considering stress at work, a meta-analysis with 169 included samples showed a negative correlation between every integrated job performance marker and each stressor included in the analyses (Gilboa et al., 2008). In line with this argumentation evidence suggests that stress can reduce motor performance in humans (Maki & McIlroy, 1996) and rodents (Metz et al., 2001). At the same time, through the mentioned narrowing of attention (Hancock & Weaver, 2005) as a benefit, it is a challenge to focus on other things than the stressor and thus one can miss helpful stimuli, which is rather a cost of the stress reaction. Especially chronic stress can reduce concentration long term (Q. Liu et al., 2020; Pourbagher et al., 2021). In the context of surgery, it was shown that chronic stress negatively affects surgical performance (Wetzel et al., 2011), patient health outcomes (Klein et al., 2011) and patient safety

(Horner et al., 2012). Growing evidence suggests that chronic and high stress can reduce the surgeon's psychomotor-abilities, communication in the team, teamwork in general and decision making (Arora et al., 2009; Berguer et al., 2001; Moorthy et al., 2003; Wetzel et al., 2006). Most of these skills are soft skills and not technical skills, which is relevant, as failure in these areas is associated with adverse outcomes in work (Gawande et al., 2003; Vincent et al., 2004).

Other research showed a more complex link between short-term stress and performance for example in the cognitive performance domain. The effects of stress hormones on cognition would be best described with an inverted-U shape function between the glucocorticoids and cognitive performance like memory functioning (Lupien et al., 2007) .This is consistent to the Yerkes-Dodson law (Broadhurst, 1957), which states that an inverted-U shape describes the relationship between arousal and performance best. This description is a strong simplification, and the function depends on the individual and the task type in which the performance is executed. Nevertheless, it seems that a moderate stress activation is desirable for optimal performance (Broadhurst, 1957; Lupien et al., 2007). As the work in an OT is already perceived as extremely stressful (Balch et al., 2010), it seems favourable to reduce stress in order to allow a moderate instead of a high stress level.

Stress helps to deal with immediate stressors and is therefore not only useful but necessary to handle certain situations in life. Nevertheless, evidence suggesting adverse stress effects on health outcomes exists. One anecdote can explain how the awareness began to grow about the influence of stress. It was after the discovery of the Helicobacter pylori bacterium, which was made responsible for most cases of those ulcers. The physicians were sure that they have found the source of the disease, accordingly to the bio-medical model. They were not completely wrong about that, but they missed the fact that the majority of healthy subjects also showed markers of this bacterium. It was shown that not only antibiotics helped against the issue but also psychological treatments (Maixner et al., 2016). It became clear that stress is the variable, moderating the link between bacterium and disease outbreak. This means that people living in stressful situations and perceiving them as stressful are more likely to develop gastric ulcers, when having the bacterium (Pinel & Barnes, 2018). Nowadays, stress and its effects are investigated, and the results show the following state:

Stress effects on health are diverse and complex. One study showed that short term stress can have positive effects on health through a boost of the immune system (Sapolsky, 2004). On the other hand, acute stress can trigger allergic manifestations, angiokinetic phenomena, like migraines or hypertensive attacks, different types of pain, gastrointestinal symptoms and psychiatric issues like panic attacks or psychotic episodes (Chrousos, 2009). Chronic stress can decrease health through different pathways. There are direct physiological effects like chronic inflammation, health behaviour changes like decreased sleep quantity, health care behaviour changes, like decreased adherence and changes in psychosocial resources, like less social support (Taylor, 2018). Twenty-seven studies were included in a review, which showed that work stressors are positively correlated to an elevated risk of stroke, coronary heart diseases and diabetes (Kivimäki & Kawachi, 2015; Steptoe & Kivimäki, 2013). Multiple studies found a connection between stress and sicknesses like hypertension, cardiovascular disease and stroke (Allen & Patterson, 1995; Folkow, 1982; Rozanski et al., 1988; von Känel et al., 2001). It was also shown that one stress outcome (Stordeur et al., 2001) is exhaustion, which is a result of workplace- stressors (Demerouti et al., 2001). In surgery it was found that stress reduced the health of the surgical crew (Buddeberg-Fischer et al., 2008; Hiemisch et al., 2011).

Stress consequences are complex. They are especially adverse for health and performance when the individual is chronically stressed. Noise at the workplace constitutes a chronic stressor in the investigated contexts, as is regularly existent, which is detrimental to the health of the working crew. It also seems that the workers in medical contexts are already highly stressed (Balch et al., 2010), and as a moderate stress level is desirable for their performance (Broadhurst, 1957), a stress reduction might be beneficial. The next chapter will argue that noise indeed is a stressor, making a noise reduction a desirable endeavour in order to reduce stress and improve performance.

2.2.6 Noise as a Stressor

Not every stressor is noise, but in this chapter, it is argued that every noise stimulus is a stressor due to four arguments. First, different peer-reviewed studies suggest that argumentation implicitly and work with constructs like *noise induced stress*. Second, different studies dealing with noise and with stress report similar consequences of those constructs. Third, both constructs react similarly to the role of control. Fourth, the role of appraisal is similar for both constructs.

Studies working with the construct called noise induced stress examine the role of noise as a stressor and dependent variable affecting different independent variables (Topf & Dillon, 1988; Westman & Walters, 1981). One study showed that coping with noise leads to a disturbance of the homeostasis of the cardiovascular and endocrine system (Prasher, 2009). Another scientific report cited different studies showing noise induced effects on the stress pathways (Hahad et al., 2019). Acute and also chronic noise has effects on the HPA, which was introduced as one stress pathway in Chapter 2.2.2 (Ising & Braun, 2000; Melamed et al., 2004; Miki et al., 1998). In a study in the OT noise led to higher stress reactions subjectively and objectively (Waterland et al., 2016). It can be summarized that within research noise is seen as a stressor.

This goes along with the fact that independent studies dealing with effects of noise or stress report similar consequences derived from both constructs. The focus is mostly on cardiovascular diseases, which are positively associated with noise (Babisch, 2011; J. D. Katz, 2014; Münzel et al., 2014; Munzel et al., 2014) and, also with stress (Brown et al., 1991; Kivimäki & Kawachi, 2015; Steptoe & Kivimäki, 2013; Taggart et al., 1973).

Both constructs react similarly to control. If a person feels in control of an environmental situation or feels that she/he has enough of resources to deal with a stressor, which is equivalent to the feeling of control, a stress reaction is unlikely (Karasek, 1979; Lazarus, 1974). For the effects of control on stress in general see Chapter 2.2.4. Similarly, if a person feels in control of the sound it is unlikely that he/she will perceive this sound as noise (Felscher-Suhr & Schreckenberg, 2000). Also if the test subjects believed to have control over a noise stimulus in a study the adverse effects were reduced (Glass et al., 1969). This notion is intertwined with the appraisal of the situation, which leads to the last argument, which states that the role of appraisal is similar for both constructs. It depends on the appraisal whether a stimulus develops into a stressor (Lazarus, 1966, 1974; Lazarus & Folkman, 1984), similarly to the fact that it is the appraisal of a sound, which determines if it is perceived as noise (Molnar, 2005).

This chapter argued that noise is a stressor. The empirical data foundation seems strong enough to support this claim. In scientific articles the term noise induced stress is already well known. Both constructs lead to the same consequences, mainly cardiovascular diseases. The pathway seems to be that noise leads to stress, which leads to the adverse effects. Both constructs react similarly to control, in so far as more control leads to lower stress reactions in the end and in both processes the appraisal is decisive concerning the question if a stimulus is a stressor and equivalently if a sound is a noise stimulus. It is from now on assumed that noise is a stressor.

2.3 Communication

Besides the claim that the SOS is a noise and stress reduction system, the SOS promises to be a communication management system, by offering a high sound quality and thus clarity of communication between crew members. With help of the communication matrix of the SOS, which will be explained in detail in Chapter 2.4.2, the opportunity of social support is provided to the medical crew. Therefore, it is likely that the SOS does not only influence stress and noise, but also communication. In order to investigate this matter, a definition will be given in the beginning of this chapter. Then the focus is shifted on communication in the OT, as only here data sets from this project were available. Two different types of communication during surgery, *case-relevant communication* (CRC) and *case-irrelevant communication* (CIC), will be introduced. Afterwards it will be shown that noise and stress can lead to dysfunctional communication.

Every human is part of different groups throughout his/her life and therefore makes different experiences within a group context (Negri & Negri, 2010). A group is defined as two or more individuals, who interact with each other and thus are interdependent of another, in so far as their goals and desires are influenced by another (Lewin, 1948). Therefore, the human is a social animal ever since, who uses communication (Keupp, 1995) In the widest sense communication is defined as a process in which information is being transmitted from a transmitter to a receiver (F. Joseph, 1999). It is shown that in modern jobs, like in the OT, communication is crucial for successful work (Fernandez Castelao et al., 2015; Tschan, 1995). The communication process is not unidirectional but dynamic in the sense that the receiver already communicates in the same time the transmitter sends, which can influence the transmission at all times (F. Joseph, 1999). Communication at work includes finding agreements, making offers, negotiations, convincing somebody, conflict management, learning or the acquisition of something new (Bierhoff & Auhagen, 2003).

2.3.1 Communication in the OT

In this chapter the importance of communication for successful team performance will be indicated by current studies. Afterwards, definitions concerning the specific communication during surgery will be given for two main communication types. Both communication types are associated with different advantages and disadvantages, which are explained. SSIs will also be briefly introduced, as they are influenced by communication. The terms group, team and crew are used interchangeably.

In the medical context of an OT studies support the high importance of functional teamwork and cooperation through communication (Tschan et al., 2015). Studies suggest that communication is a central piece of successful teamwork and performance (Fernandez Castelao et al., 2011; Hunziker et al., 2009, 2010; Mäkinen et al., 2007; Marsch et al., 2004), which influences patient outcomes (Fernandez Castelao et al., 2013, 2015; Salas et al., 2008). The same can be said for the medical work of nurses, where communication between team members is pivotal in the successful care of patients (Boynton, 2022; Edmondson, 2018). On the other hand dysfunctional communication through communication failures can be found (Lingard, 2004) and this poor teamwork is connected to technical errors in the procedure (Catchpole et al., 2008). This shows that communication is significantly associated with performance.

It is difficult to operationalize communication as it is a complex construct. One approach is to focus on the content of communication. Communication within surgery can focus on the working environment and thus on the present patient case and is called *case-relevant communication* (CRC) in research (Seelandt et al., 2014; Tschan et al., 2015; Widmer et al., 2018). Another possibility is that the staff communicates about other aspects than the present patient case which is called *case-irrelevant communication* (CIC) (Seelandt et al., 2014; Tschan et al., 2015; Widmer et al., 2018). CIC includes small talk or communication about work in general instead of the specific case. Both communicational types are theoretically mutually exclusive and collectively exhaustive. CRC is associated with rather positive consequences as it improves team performance through the sharing of information within the crew (Mazzocco et al., 2009). This allows the team to evolve a common understanding of the given requirements and assignments (Westli et al., 2010), and through anticipation of developments in surgery, functional team coordination arises (Waller et al., 2004; Weaver et al., 2010). Contrary to CRC, CIC seems to have advantages and disadvantages. The advantage is that a positive environment is promoted by CIC (Nurok et al., 2011; Tschan et al., 2015). The disadvantage might be that CIC can be a distraction from the work related case in surgery (Wheelock et al., 2015). Too much CIC during the end of surgery has been shown to positively correlate with SSIs (Tschan et al., 2015). The WHO defined SSIs as infections which occur at the site of operation in patients (WHO, 2009). Those infections can lead to severe consequences for the patient and increase costs for the hospitals. Airborne contamination from the working staff has been identified as one source for this problem (Markel et al., 2017). Evidence suggests that not only noise levels (Dholakia et al., 2015) but also communicational frequency due to its direct effect on microbial load (Z. Liu et al., 2019; McHugh et al., 2014; Tammelin et al., 2013), and the amount of CIC and CRC (Tschan et al., 2015) can influence the occurrence of SSIs. Possibly noise levels and dysfunctional communication can lead to distraction and reduce the concentration of the workers (Dholakia et al., 2015), at the same time it is possible that private conversations at the end of surgery (Widmer et al., 2018) lengthen the process of closing the wound, which heightens the possibility of a post infection. The exact underlying reasons remain speculative. Certainly, communication is a key variable, which should be optimised to allow for closing in on optimal performance and possibly reducing the chance of SSIs and thus enhancing patient safety.

2.3.2 Noise and Stress Effects on Communication

As we have seen communication is the foundation of all social relationships (Brumm & Slabbekoorn, 2005) and it is crucial for team performance in the working context (Fernandez Castelao et al., 2011; Hunziker et al., 2009, 2010; Mäkinen et al., 2007; Marsch et al., 2004). In this chapter it will be explained how noise impairs communication, through affecting the mental workload and how it can bind capacity from the working memory. Afterwards, it will be shown that studies also found a negative effect of stress on communication. Current research shows that both constructs impair communication.

Communication in loud working environments, like in the OT and the medical laboratory, is constrained constantly by noise, which leads to decreased signal to noise ratios for the receiver and interferes the communicational process (Klump, 1996). Noise seems to disturb the clarity of communication leading to dysfunctional communication (N. Singh & Davar, 2004). A transparent reason for that is that noise disturbs the receiver hearing the information from the communicational channel (Shannon & Weaver, 1949). A significant positive correlation between noise levels in the OT and information loss has been confirmed (Ford, 2015; S. A. Singh & Trikha, 2006). An explanatory mechanism is that noise is detrimental to the *mental workload*. The mental workload is the mental effort that a worker devotes to control or supervise his/her capacity to expand mental effort (Johanssen et al., 1979). More input from the environment leads to greater mental effort which is needed to process, cope with and control the needed information. This is consistent to implications of noise effects on the working memory (A. Baddeley, 2010). As already mentioned in Chapter 2.1.3 humans are only able to hold a specific amount of informational chunks in their working memory (A. Baddeley, 2010; Cowan, 2012). This means that noise adds another input information, which leads to higher mental effort to deal with this potential information. Noise in this sense is a distractor which heightens the mental workload of a task, as mental resources have to be used to deal with the task while shielding from or actively ignoring irrelevant input as noise (Becker et al., 1995; Szalma & Hancock, 2011). One model of the working memory suggests different components in which the information has to be held in order to process it, with one component being the articulatory loop (A. D. Baddeley & Hitch, 1974). In this loop all phonetic information is stored short-term and repeated so that they can be recalled (A. Baddeley et al., 1984). Noise would have a disruptive effect on this intern process, which would disturb the process (Jones, 1993). This noise effect is disadvantageous, as the short-term storage of information during a communicational process and the usage of this information during the planning of a verbal or nonverbal reaction are crucial for communication (Cowan, 1996). Not focusing on the exact underlying mechanisms studies showed that, during surgery noise reduces communication quality, which can reduce patient safety (Cheriyan et al., 2016; Hasfeldt et al., 2010; Keller et al., 2016, 2018; Padmakumar et al., 2017).

Studies also showed that stress seems to have a negative impact on the ability to communicate. One reason is that stress reduces the ability to focus on a wider perspective and perceive objects other than the stressor due to glucocorticoid secretion (McEwen, 2012). The attention becomes narrow and focuses strongly on the stressor (van Steenbergen et al., 2011). This change in perspective can decrease the probability of listening to another person, thus leading to miscommunication (Arnsten, 2009). A second reason is that stress causes humans to be more emotionally reactive (Stawski et al., 2008), which can lead to defensive or aggressive reactions to perceived misunderstandings leading to a higher likelihood of conflict. Chronic stress can also impair cognitive function, including memory, (Het et al., 2005). Those impairment can make functional communication less likely, as those functions are needed in order to retrieve details from memory and make sound judgments. Lastly it was shown that the communicational quality is reduced as stress inhibits the explicitness in communication (Pfaff, 2012). To sum this up, noise and stress do seem to influence communication during surgery negatively.

2.4 Potential Solutions

Until now it was shown that noise is an issue in health care settings. This noise situation goes along with negative consequences concerning the health of the workers, which is also because noise is a stressor and high and chronic stress is associated with adverse effects on health. Communication suffers under the noise levels and stress in those working contexts, which can go along with performance reduction and in the worst case reduces patient safety. This chapter will focus on potential solutions concerning the present noise situation in medical working settings.

2.4.1 Behavioural Change and Earplugs

As Chapter 2.1.2 has demonstrated the noise situation in medical working settings and especially in the OT and medical laboratory are suboptimal. Noise in those contexts is generated by machines like alarm-sounds, air filtrations systems, beepers, heating or specific medical tools and machinery, but they can also be driven by human behaviours like verbal communication, using tools, or closing doors loudly (Arabacı & Önler, 2021; Giv et al., 2017; Hasfeldt et al., 2010; T. Hsu et al., 2012). In order to confront the noise issue different solutions were investigated.

One solution found especially often in industrial settings is the physical closure of the ear in order to reduce the sound entrance, for example via earplugs. The WHO (Berglund et al., 1999) recommended this approach for some working contexts, but this solutions is suboptimal as it also reduces the communication quality. According to the mentioned model of transactional stress (Lazarus, 1974; Lazarus & Folkman, 1984; Lazarus & Launier, 1981), earplugs would certainly change the situation and therefore the primary appraisal as they reduce the perceived noise and additionally offer a resource (secondary appraisal) for coping with noisy situations. But communication is necessary in both contexts and this approach would disturb communication by blocking the receiving end. One could speculate that this would also increase the likelihood of a stress reaction as the work cannot be done properly and no social interactions are possible.

Another approach constitutes the idea of behavioural adaptations. Certain programs teach the modification of behaviour in order to reduce human made noise (Engelmann et al., 2014; Kahn et al., 1998). Studies showed that a significant noise reduction is possible and that also a reduction of surgical complications was observed (Engelmann et al., 2014). A disadvantage of this approach is that exclusively human made noise is approached, technical noise sources are only partially reduced or not changed at all. Another downside is that private conversations were officially forbidden in this study (Engelmann et al., 2014), but private conversations, which are included in CIC, do fulfil a meaningful task as they enhance a positive working climate (Nurok et al., 2011; Tschan et al., 2015). The equilibrium model states that a team should keep an equilibrium between socio-emotional and task-oriented needs to be thriving (Bales, 1953, 1970). As CIC also has distractive effects, a reduction of CIC is sometimes a benefit (see Chapter 3.2 for details), but a complete prohibition would reduce the positive effects to zero and is therefore not desirable. In those behaviour modification programs it was also found that after a couple of months a rise in noise was found, probably due to the lower compliance to the learned rules (Engelmann et al., 2014). All things considered this approach seems beneficial in some terms but does not seem to solve the noise issue fully. Especially the noise sources of technical devices were not addressed properly, leaving the staff with alarm sounds or suction noises without any support.

A systematic review (Ayas et al., 2022) focused on mitigation strategies in the OT setting, and found that most studies focused on noise reduction. Next to the mentioned studies implementing behavioural changes through training and checklists (Engelmann et al., 2014; Jing & Honey, 2016; Morgan et al., 2015) the headphone system called the SOTOS (Friedrich et al., 2017) was mentioned. It seems to be the only measure confronting the noise levels generated by the machines and the existing interaction effects, as the crew has to speak up louder in order to be heard, when the surrounding is noisy (Junqua, 1993). The next chapter will introduce this approach.

2.4.2 SOS: SOTOS & SLOS

In order to confront the noise problem, the noise reduction and information management system called SOTOS was developed for the OT. As the system has been modified and also been adapted and used in a medical laboratory under the name SLOS, this passage will focus on the system in general under the acronym SOS. Differences between the systems are only found in specific technical components and acoustical adjustments, which do not play a decisive role for the psychological evaluation in this dissertation. The SOS consists of headsets and microphones for the users, a digital workstation, and the corresponding software.

The headsets are wireless or wired, in-ear or over-ear and can be adjusted to specific needs (Friedrich et al., 2017). All headset types allow for active and passive noise cancelling. Through isolating the hearing organ physically from external sounds the passive noise cancelling achieves its effect, whereas electro-acoustical means are used for the active sound cancelling (Kuo & Morgan, 1996). A decrease of up to 17 dB can be attributed to the passive noise cancelling option, whereas the active noise cancelling leads to a general decrease of up to 33 dB, which is noticed as a 90% reduction in perceived sound volume. The users are able to listen to music via the headsets, which can be set up through different channels or individual music choices via the digital workstation. The headphones have an integrated ducking mechanism, which reduces the music volume in 0.6 seconds to the lowest perceivable volume, in the moment a crew member speaks to the user of this headset (Friedrich et al., 2017). Through the microphones the headphones with their noise cancelling options, the SOS allows fluid communication without the issue of interrupting one another because of latencies (Friedrich et al., 2017).

On the digital workstation the signal selection can be programmed before or during the working shift. As the system works with radio waves the frequency of the transmitter (microphone) and the receiver (headset) can be set to a specific frequency. This way it is possible to build sub-groups of workers which are working on the same frequency and can then hear each other on this frequency. This matrix of connections can be programmed into system beforehand, but also flexible changes are possible via the digital workstation, which then defines a communication structure connecting the defined subgroups. The communication matrix is based upon the needs of the specific team working together, their task and working context. In urological prostatectomies only a small team of staff works together, and it makes sense to use the all-in mode, through which everybody is working on the same frequency, making everybody audible for everybody. In heart surgeries a communication matrix based on the task is often desirable and in the setting of medical laboratories a more flexible communication matrix is necessary, as the team is normally larger and flexible connections are possible (Friedrich et al., 2017).

Since 2017 the SOTOS has been evaluated in studies at the University-Medical Centre in Goettingen. In all studies of the SOS project a control condition working in a regular manner is compared to an experimental condition, working with the SOS. Through the active and passive noise reduction a noise reduction of up to 33 dB(A) was convertible (Friedrich et al., 2017). This means a relevant reduction, as a 10 dB reduction corresponds to a 50% decrease of the original sound volume (perceived loudness) (Friedrich et al., 2017). The acceptance of the system by its users was stated as good (Friedrich et al., 2017). Another study investigated the noise level in the room, the stress experience, operationalised via the heart rate of the participants, and the acceptance of the system in the context of urological prostatectomies (Leitsmann et al., 2021). A special issue here constitutes the usage of the Da-vinci system, which is used by the primary surgeon. The robotic system is operated by a trained surgeon via a console, which leads him/her being isolated from the team as the console must be faced and which then creates an auditory and visual barrier, which in theory should be overcome better by the SOTOS (Leitsmann et al., 2021; Meyer-Lamp et al., 2021). This barrier makes functional communication more challenging (Kawase et al., 2005; Schiff et al., 2016). The results showed a significant noise reduction in the room, no significant stress differences between control and experimental group and a high subjective acceptance of the system (Leitsmann et al., 2021). It has to be noted that arithmetic means were calculate for the dB(A) measurement, which is not permissible, as the logarithmic scale does not allow that. Rather an energetic mean or the median should have been used. This diminishes the found effect concerning noise in the room. It is important to add here, that the noise entering the workers ears is diminished by the system itself and its active and passive noise cancelling effects (Friedrich et al., 2017). Nevertheless, the noise reduction in the room is of interest because it might have an effect on the patient and on communication volume which is influenced by the surrounding noise level. The heart rates did not react significantly to the SOTOS. This could be because the heart rate alone is not an optimal operationalisation for stress (Leitsmann et al., 2021). As stress is a complex construct a multimodal approach is more valid (Kaluza, 2011) and there are already attempts to use different physiological variables to measure stress (Hosseini et al., 2022). Nevertheless, as the subjective appraisal plays a major role in the stress process (Lazarus & Launier, 1981) an operationalisation of stress via subjective questionnaires and more objective physiological measurements are of interest. Another explanation could be that a higher rate of movement artefacts were found for heart rate (Leitsmann et al., 2021), which could have reduced the validity of the measurement and also made it not feasible to use the more validated operationalisation of heart rate variability (Järvelin-Pasanen et al., 2018). In the end the acceptance of the system was good and 85% felt that the system was supporting them in their work (Leitsmann et al., 2021). The last study evaluating the SOTOS showed that the staff working in urological prostatectomies was significantly less stressed, less exhausted and more active when using the system, but not more concentrated (Meyer-Lamp et al., 2021). The exercising effect for the concentration test was not addressed by this study.

In summary it seems possible that the system reduces noise for its user and possibly that the SOS reduces noise in the room and stress for the working crew. The system has been well accepted so far by the working crews. More research is needed at this point to clarify these effects, which is why the following three articles have been generated. Before the psychological hypotheses are derived the SOS acceptance will be introduced.

2.5 SOS Acceptance

A supporting tool only adds value if it is used by the target audience regularly. Therefore, the evaluation of the acceptance and technical quality of the system was developed across the SOS studies. This concept is from now on called the *SOS Acceptance*. It was of interest whether the medical workers would accept the SOS in their working context. A high acceptance is necessary to implement a technical tool and it is important that the workers are comfortable with the new device (F. Davis, 1993). As this variable was never operationalised before, it was a goal of this dissertation to begin the development of this endeavour. A first approach was the operationalisation in heart surgeries (Friedrich et al., 2017) in which the workers were asked about their acceptance level on a Likert-type scale. Afterwards, in urological prostatectomies (Leitsmann et al., 2021) the workers were asked about their perception of disturbance versus support of the system. These approaches were tolerable as a first measurement and gave an indication of the perceived SOS acceptance but do not meet high quality standards, which is why a more nuanced measurement was desired. This led to the integration of more variables leading to the SOS acceptance as it is today, which was in the end operationalised via three variables. The first is called the *technical acceptance* and asks about the perceived support of the system, the comfort of different aspects and the audio quality. The second variable is named the *specific SLOS acceptance* and includes 12 items. This construct is derived from the modified *Technology Acceptance Model 2* (TAM2)(Venkatesh & Davis, 2000). The third variable is called *communication effects* and uses three items to ask about the perception of the communication with the colleagues. The following passages will explain the development of the specific SLOS acceptance variable, as this approach is based on a validated questionnaire.

The specific SLOS acceptance was built upon the validated technology acceptance model (TAM)(F. D. Davis, 1985, 1989), which in turn is based on the theory of reasoned action (TRA) (Fishbein & Ajzen, 1975). The TRA tries to predict every kind of behaviour under conscious control, whereas the TAM predicts behaviour in the context of technology adaptation. Technology acceptance is defined as the behaviour of a person adopting a new technology. This definition is derived from both theories. The idea to investigate the process of technology acceptance was originally nudged by investors who wanted to predict the usage of new technology before investing in the technology, as technologies which are offered without the adherence of the consumers are expected not to be used much (Lee et al., 2003).

The TAM is an information system theory, which measures how users accept and use certain technology. The goal variable of the theory is the behavioural response of a user called the *actual system use*, which is directly influenced by the *attitude toward using* the system. The attitude toward using the system is an affective response which in turn is directly affected by the *perceived usefulness* and the *perceived ease of use*. The perceived usefulness is the perception to which a user believes that using this system would enhance the actual work. Whereas the perceived ease of use is the perception to what extent a user believes that using this system is not combined to a higher physical or mental effort. The last two described variables are categorised as cognitive responses. The author proposed that the perceived use does not only affect the attitude towards the using but also the variable on the same level, namely the perceived usefulness (F. D. Davis, 1985). The idea is that a system which is perceived as being easy to use will allow its user a higher productivity which would lead automatically to a higher perceived usefulness. Both cognitive response variables are influenced by variables on the last level of the model called *design features*. Those design features are inherent to the specific technological system and examples are button sizes, interfaces, or other features. Those features are appraised by the user on the base of both cognitive response variables (F. D. Davis, 1985). The model is validated and simple. Additionally, it has a high general applicability which led to its regular use (Lee et al., 2003; Ma & Liu, 2004; Schepers & Wetzels, 2007). It was further developed, leading to the design of the TAM2. The most important change was the integration of the variable called the *subjective norm*, a direct predictor of the intention to use and the perceived usefulness (for more detailed information see this evaluation (Jayasingh & Eze, 2010)).

In the last iterative step three different variables are used in the end to investigate the SOS acceptance in the last article (Chapter 3.3). Additionally, to the TAM2 it was of interest how the technology was perceived from a solely technical perspective. This is why items were generated and combined to ask about the technical acceptance concerning the perceived support, the comfort, and the general sound quality. Also, a variable was integrated focusing on the communication effects of the system, asking about the effectivity of communication with the SOS. Those variables can be seen as a basic intervention check and not yet validated items were used. Whereas the specific SLOS acceptance is built on the just explained models (F. D. Davis, 1985, 1989). The classical TAM was integrated into the last article with the additional variable of the subjective norm from the TAM2. The used model has been validated (Lee et al., 2003). The subjective norm was included as the SOS is a device to support teams instead of individuals. This makes the subjective norm a relevant variable and led to the integration of the TAM2 (Venkatesh & Davis, 2000).

The development of the SOS acceptance measurement with all three variables is not final yet, and more research is needed to validate the approach, eventually adjusting, or eliminating certain items after validation studies for this instrument have been done. The developed solutions seem suitable to give an overview concerning the acceptance of the SOS.

2.6 Research Objective and Psychological Hypotheses

So far, the necessary theoretical background was delivered to allow the derivation of the following hypotheses. It was shown that the noise levels are higher than the WHO recommendations. This situation is critical as there are negative consequences on health, performance, and communication, also because noise is a stressor. As no optimal solutions are available, the SOS was developed. This system will be evaluated by this dissertation. The SOS claims to be a noise and stress reduction and communication management tool, which is accepted by its users. The following hypotheses were derived from the theoretical background and are explained in further detail in the subchapters. All psychological hypotheses with their sub-hypotheses are displayed in Table 1.

Table 1

Psychological Hypotheses (H)

Number	Hypothesis
H1	SOS reduces noise
	H1.1 noise = sound pressure level (dB) in the room
	H1.2 noise = subjective perception
H2	SOS reduces stress for the working crew
	H2.1 stress = subjective perception
	H2.2 stress= stress reaction = exhaustion
	H2.3 stress = physiological measurement
H3	SOS enhances communication in the surgical team
	H3.1 SOS reduces the total communicational utterances
	H3.2 SOS heightens the CRC proportion across all phases
	H3.3 SOS reduces the CIC proportion in the last phase of surgery
	H3.4 SOS enables technical high-quality communication
H4	SOS is well accepted by the working staff

Note. dB = decibel.

2.6.1 H1: SOS reduces noise

The first question was whether the SOS reduces noise as implicated by the technical study from 2017 (Friedrich et al., 2017). The focus lies on the noise reduction for its user and not on the noise level in the room, even though a study found a noise reduction in the room (Leitsmann et al., 2021). A replication of this noise reduction in the room will be tried in the OT and in the medical laboratory (H1.1). The motivation for that investigation was to find out whether the noise levels are exceeding the critical threshold of 55 dB(A), mentioned by the WHO[4–6]. If so, it can be claimed that the noise levels in those working conditions are too high and severe consequences can follow. It was of further interest whether the system would reduce noise in the room, as this would implicate that human made noise is a relevant issue in those working contexts. This would strengthen the idea to work on behavioural interventions (Engelmann et al., 2014; Kahn et al., 1998) as the impact would be incremental. The most important matter in this question is whether the SOS reduces noise for the users like an in-ear measurement has shown (Friedrich et al., 2017). As was already argued in Chapter 2.1.1 noise has a psychological component, which is why a subjective questionnaire was integrated, through which the subjective noise perception is measured (H1.2). A significantly lower noise perception in the experimental group would support the idea that the SOS is a noise reduction tool.

2.6.2 H2: SOS reduces stress

Another investigation of this dissertation is the question if the SOS is able to add a benefit to the work of medical crews in terms of stress reduction. This hypothesis is derived from different arguments. If the SOS reduces noise for the users and noise indeed is a stressor (as argued in Chapter 2.2.6), then a noise reduction should lead to a stress reduction, according to the transactional stress model (Lazarus, 1974) and the job-demand-control model (Karasek, 1979). The argumentation is that the SOS would change the transaction between the worker and their environment, as less noise is present. This way the primary appraisal would not be negative for the well-being and a stress reaction would not be triggered. Even on the secondary appraisal a beneficial change is likely as the SOS represents a resource which can be relied upon when the primary appraisal would consider the noise situation as potentially harmful. This would enhance the feeling of control, which was shown to be a stress reducing factor (Houston, 1972; Lundberg & Frankenhaeuser, 1978; Visintainer et al., 1982). This factor is also one critical variable in the job demand control model, which stated that more control is leading to a lower likelihood of job strain. Consistent to the model, reducing noise, which functions as a demand (Abbasi et al., 2019, 2020; Chau et al., 2009), and heightening control through the possibility of using the SOS would diminish stress (Karasek, 1979). Furthermore, the possibility to connect to other co-workers offers the possibility of social support, which is said to have stress buffering effects (S. Cohen & Wills, 1985; Karasek et al., 1982; LaRocco et al., 1980). Also, outside the job-demand-control model the factor of social support has been shown to reduce stress effects (Aureli et al., 1999; Gust, 1996; Ruis et al., 1999; Sapolsky, 1997; Smith et al., 1998). If demand is high and control is low, the highest possible stress reaction is predicted by the model (Karasek, 1979), which is why the SOS offering more control should reduce stress. At last, also the factor of predictability should support the hypothesis that the SOS reduces noise, as the noise in the medical settings is unpredictable and this unpredictability is reduced by the system. It was shown that intermittent noise, which is present in the investigated context, is more disruptive (see Chapter 2.1.1) and it should also be more stressful as it is more unpredictable. The SOS delivers more predictability as it reduces noise constantly and offers the music option (Friedrich et al., 2017) which is operated by the user him/herself and offers high predictability concerning the question what sound stimuli reach the hearing organ. This higher predictability in turn should reduce stress (Abbott et al., 1984; H. Davis & Levine, 1982; Seligman & Meyer, 1970; Ursin et al., 1978). All the named reasons would support the hypothesis, that the SOS reduces stress for the working crew in terms of subjective perception (H2.1), the perceived exhaustion as a stress reaction (H2.2) and physiological reactions (H2.3).

2.6.3 H3: SOS enhances communication

As the SOS is not only a noise reduction tool, but claims to be a communication management system, it was of interest to investigate this topic. This led to the broad hypothesis, that the system would enhance the communication in the working context. The communication was only recorded during surgeries, which is why the hypotheses 3.1–3.3 refer only to the OT. Chapter 2.3 introduced the topic of communication and described the difference between CRC and CIC and its potential effects on SSIs. There are studies (Seelandt et al., 2014; Tschan et al., 2015) implicating certain advantageous configurations of communication types, like a generally higher amount of CRC and a lower amount of CIC in the end of surgery, concerning the SSI outcomes of the patients. It was hypothesised that the SOS would change the communication in this direction, as it would set free more mental resources (Moray, 1979), which in turn should lead to more functional communication, like more CRC and less CIC (for details see Chapter 3.3). Additionally, it was assumed that the SOS would lead to a lower frequency of communication as it could reduce the number of misunderstandings and present a lower need of clarification due to the higher clarity provided by the system (Friedrich et al., 2017) .This could mean less microbial load in the air, which in turn could lead to less post-infections (Z. Liu et al., 2019). In the end the SOS was suspected to reduce the total amount of communication (H3.1), while at the same time allowing for a higher CRC proportion in general (H3.2) and a lower CIC proportion at the end (H3.3). For more details see Chapter 3.2. The last sub-hypothesis focuses on the technical realisation of the SOS. Studies suggested that the SOS allows a comfortable, stable, and clear communication (Friedrich et al., 2017). Therefore, it was also hypothesised that the SOS enables technical high-quality communication (H3.4). This is investigated only in terms of technical realisation and its perception by the users.

2.6.4 H4: SOS is well accepted

The last hypothesis deals with the topic of the SOS acceptance. This topic is important, as a low acceptance might bias the results concerning the other hypotheses. It will be investigated whether the system works as it technically is supposed to. The perceived support by the system, the audio quality and the comfort are investigated. As the device claims to be a communication management system, it was also of interest if the system allowed the users to be technically reachable through the device and whether the technical features allowed the users to be heard and informed at all times. Another goal of this investigation was to find out whether the system was perceived as useful, how easy it was to use, what the subjective norm implicated and if the intention to use it was high. The last questions were based on the validated TAM2 (F. D. Davis, 1985, 1989), which was explained in Chapter 2.5. This hypothesis is investigated descriptively as no data concerning the SOS were collected previously in this manner. Follow-up studies could use the collected data to allow comparisons.

3 Articles: Evaluation of the SOS

3.1 Article 1: SOTOS Effects on Stress in the Operating Room

Lehrke J, Boos M, Cordes A, Leitsmann C, Friedrich M. Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres. Thorac Cardiovasc Surg. 2022 Aug; 70(5): 392-400. doi: 10.1055/s-0041-1741059. Epub 2022 Feb 2. PMID: 35108735.

Thoracic and Cardiovascular Surgeon– Original Research (Article)

Title	Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres
Study Type	Quasi-experimental field study
Order of Authors	Jan Lehrke, Margarete Boos, Andreas Cordes, Conrad Leitsmann, Martin Friedrich

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Keywords SOTOS, noise reduction, technology, operating room, operating theatre, surgery, surgical staff, stress, exhaustion, communication

Abstract

Background

Noise in operating theatres (OT) exceeds safety standards with detrimental effects on 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 minimised by the SOTOS, a noise reductive headset solution.

Methods

This study evaluates the effects of the SOTOS on the stress perceived by OT crew members, operationalised 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 the SOTOS and 27 without. The SOTOS-effect is defined as more beneficial stress course from before to after the surgery compared to the control group.

Findings

Eighty-one OT workers were investigated. The linear multilevel models revealed significant interactions between treatment and time of measurement on stress level ($F[1, 406.66] = 3.62$, $p = .029$) and exhaustion ($F[1, 397.62] = 13.12$, $p = .00017$). Nevertheless, there was neither a significant main effect of surgery type on stress level ($F[1, 82.69] = 1.00$, $p = .32$) nor on exhaustion ($F[1, 80.61] = 0.58$, $p = .45$). Additionally, no significant three-way interaction including surgery type, neither for stress level ($F[1, 406.66] = 0.32$, $p = .29$) nor exhaustion ($F[1, 397.62] = 0.03$, $p = .43$) was found.

Interpretation

A 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.

Introduction

Operating theatre (OT) crews face various stressors, such as time pressure, distractions or physical demands.[1] While most stressors are an 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 (WHO), 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, 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 behavioural 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) are 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 Theatre 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 hypothesised that the SOTOS positively modulates the development of stress from before to after surgery compared to 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, wherefore 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 randomised 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 minimise 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 operationalised 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, post), and surgery type (heart surgery vs. radical prostatectomy), leading to a 2x2x2 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) 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 minimise 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 a.m. in prostatectomies and around 9.00 a.m. 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 p.m., heart surgeries at around 12.50 p.m. The post-testing was conducted immediately afterwards.

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 cancelling. 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 allows 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 set-up which physically resembled the SOTOS set-up, 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. In order 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 while 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 subscale exhaustion ask for the present perception of six adjectives linked to exhaustion. Answers were given on a five-point Likert scale.

Statistical Analysis

Data was analysed with the software SPSS (IBM Corp., Armonk, New York, United States) and R (version 4.0.3). For the age variable, arithmetic means (*M*) and standard deviations (*SD*) are presented and compared for the control and treatment condition. For the categorical variables gender and role, frequency distributions were analysed. 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 are investigated with the linear multilevel approach and presented via ANOVA-tables. P-values in the text are halved for the directed hypotheses H1 and H3, allowing for one-tailed testing.

For all statistical tests, an alpha level of .05 was set as a default (α = .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 analysed 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 means and standard deviations.

Table 1

Means and standard deviations of each dependent variable

DV	total (N = 262)		exp. ($n_{\text{exp.}}$ = 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

Note. N/*n* refers to cases, not individuals. Exp. = experimental. DV = dependent variable.
M_k = adjusted mean by multilevel modeling.

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.

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	·011*
Treatment	2·09	2·09	1	45·77	3·31	·075
Surgery type	0·63	0·63	1	82·69	1·00	·32
Time*Treatment	2·29	2·29	1	406·66	3·62	·058
Time*Surgery type	4·91	4·91	1	406·66	7·78	·0055*
Treatment*Surgery type	0·18	0·18	1	45·77	0·29	·60
Time*Treatment*Surgery type	0·20	0·20	1	406·66	0·32	·57

Note. Multilevel model for stress level. SS = sum of squares. MS = mean square.
Df = degrees of freedom. Num = numerator, den = denominator. Time = time of measurement.
$^{*}p \leq .05$, two-tailed.

There was a significant interaction between time of measurement and treatment on stress level, $F(1, 406.66) = 3.62$, $p = .029$. Figure 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 to the control condition.

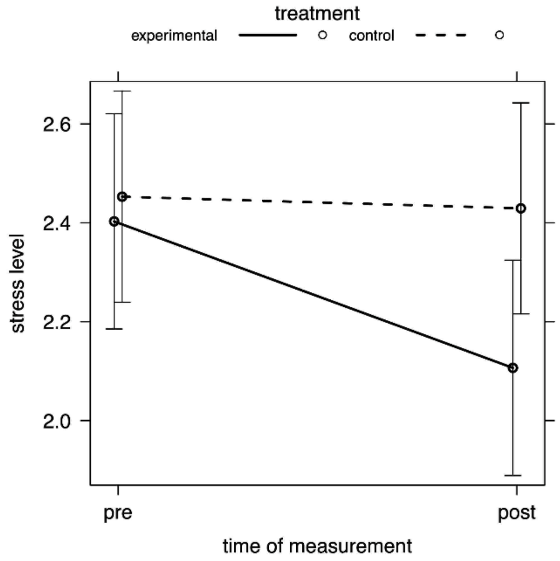

Figure 1. Time of measurement*treatment effect plot for stress level. Means before and after surgery displayed for the experimental and control condition. $N = 262$. Error bars represent 95% confidence intervals.

No significant main effect of surgery type on stress level was found, $F(1, 82.69) = 1.00$, $p = .32$. 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, $F(1, 406.66) = 0.32$, $p = .29$. Figure 2 presents the results as a graph. In conclusion, the effect of treatment on stress level is not significantly different in prostatectomies compared to heart surgeries. The interaction between time of measurement and treatment does not differ between the surgery types.

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	·00015*
Treatment	2·15	2·15	1	45·37	5·66	·022*
Surgery type	0·22	0·22	1	80·61	0·58	·45
Time*Treatment	4·98	4·98	1	397·62	13·12	·00033*
Time*Surgery type	1·39	1·39	1	397·62	3·65	·057
Treatment*Surgery type	0·01	0·01	1	45·37	0·02	·88
Time*Treatment*Surgery type	0·01	0·01	1	397·62	0·03	·87

Note. Multilevel model for exhaustion. SS = sum of squares. MS = mean square.
Df = degrees of freedom. Num = numerator, den = denominator. Time = time of measurement.
$*p \leq .05$, two-tailed.

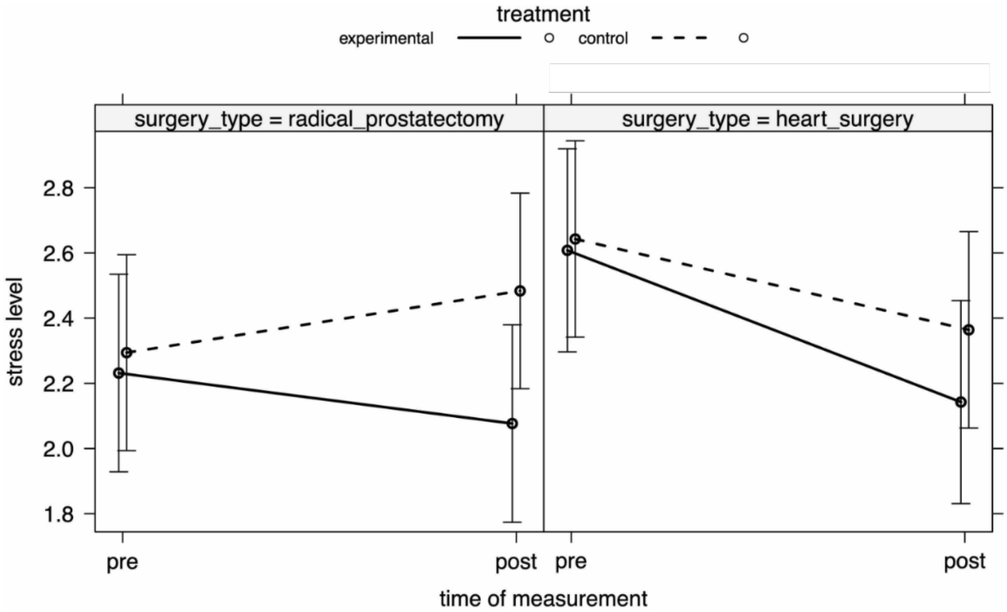

Figure 2. Time of measurement*treatment*surgery type effect plot for stress level. Means before and after surgery displayed for treatment conditions. Left plot = radical prostatectomy. Right plot = heart surgery. $N = 262$. Error bars represent 95% confidence intervals.

There was a significant interaction between time of measurement and treatment on exhaustion, $F(1, 397.62) = 13.12$, $p = .00017$. Figure 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.

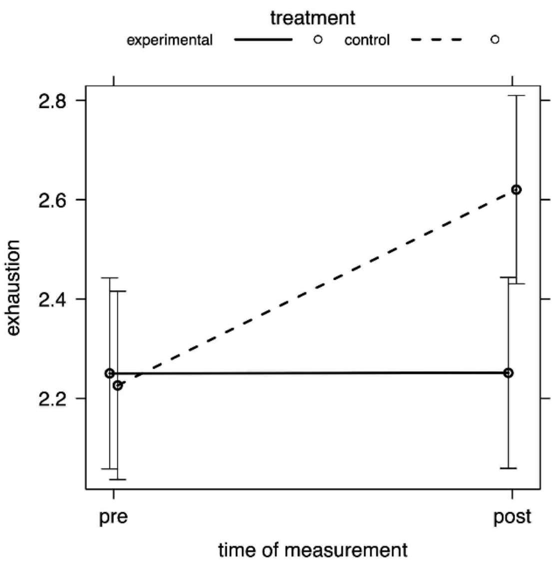

Figure 3. Time of measurement*treatment effect plot for exhaustion. Means before and after surgery displayed for the experimental and control condition. $N = 262$. Error bars represent 95% confidence intervals.

No significant main effect of surgery type on exhaustion was found, $F(1, 80.61) = 0.58$, $p = .45$. The exhaustion mean of radical prostatectomies does not differ significantly from heart surgeries.

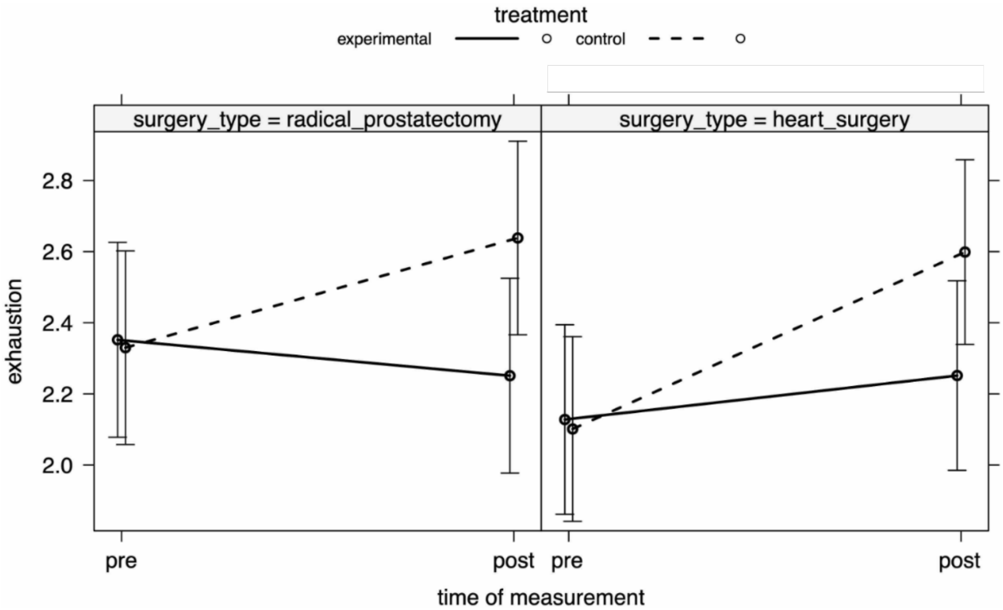

Figure 4. Time of measurement*treatment*surgery type effect plot for exhaustion. Means before and after surgery displayed for treatment conditions. Left plot = radical prostatectomy. Right plot = heart surgery. N = 262. Error bars represent 95% confidence intervals.

There was no significant interaction between time of measurement, treatment, and surgery type on exhaustion, $F(1, 397.62) = 0.03$, $p = .43$. Figure 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 to the control condition. The stress level of the groups differs in so far as the control group displayed a stable 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 minimised. 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 informational 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 a 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 graver 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 data set 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 to the control group and exhaustion increased exclusively in the control group, whereas in the experimental group a stable course was found. That means, after surgery the experimental group was less stressed. These findings indicate that the SOTOS changes the primary and secondary appraisal 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 surgery 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 potential health and communication benefits of the SOTOS.

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Contributors

JL contributed to the statistical analyses, the interpretation of the findings, and writing of the manuscript. MB contributed to the overall design and conduct of the study, management processes, and writing of the manuscript. AC contributed to the statistical analyses and writing of the manuscript.

CL contributed to the management processes, implementation of the treatment in radical prostatectomies, and writing of the manuscript. MF 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. Manuela Pagel (MP), Lisa Schugmann (LS), Imke Meyer-Lamp (IL), Giorgi Bubuteishvili (GB) contributed to the data collection and implementation of the treatment.

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Competing interests

MF invented and technically developed the SOTOS. The system is patented by the University Medical Center Goettingen (DE102015205463, PCT/EP2016/056659, EP20213914). JL, MB, AC & CL declare no competing interests.

Patient consent for publication

Not required.

Ethics approval

Ethics approval (ID1: DOK_204_2015, ID2:12/12/14) for this research was granted by the Ethics Commission of the University Medical Center Goettingen (UMG), Germany (ethik@med.uni-goettingen.de).

Provenance and peer review

Not commissioned; externally peer reviewed.

Data availability statement

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

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3.2 Article 2: SOTOS Effects on Noise and Communication in the Operating Room

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Study Type	Randomised field study
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Abstract

This field study investigates how the Silent Operating Theatre Optimisation System (SOTOS), a technical noise reduction and communication system, influences communication during surgery. In 22 heart surgeries (11 with SOTOS = experimental; 11 without = control) communication of 46 crew members was recorded, transcribed, segmented and coded for the last two of five surgical phases. All 47 387 segments were coded as case-relevant or case-irrelevant communication (CRC, CIC). Communication was analysed via multilevel models. The SOTOS led to less communication compared to regular operations ($F(1, 21.39) = 11.33$, $p = 0.003$). Concerning CRC, no difference was found between treatment conditions across both phases ($F(1, 21.69) = 1.40$, $p = 0.249$), but a post-hoc test revealed a significantly higher CRC mean for the experimental group in phase 4 ($F(1, 20.92) = 4.47$, $p = 0.047$). No difference in CIC in phase 5 between the treatment conditions was found ($F(1, 20.30) = 0.6$, $p = 0.446$). Crew members communicated less with the SOTOS, which might reduce the microbial load. More CRC in critical phase 4 and a constant CIC-level overall were found in the SOTOS group, potentially enhancing information sharing and team climate, while reducing distractive effects.

Keywords SOTOS, general surgery, noise reduction, technology, operating theatre, heart surgery, surgical staff, noise, case relevant communication, case irrelevant communication

Introduction

Current literature states that noise levels in operating theatres (OT) regularly exceed noise-safety standards[1]. It is empirically confirmed that noise leads to lower performance in general[2], which can negatively impact patient safety[3], and results in health problems among the OT-workers[4]. Common hearing protection devices lower noise, but also filter out the necessary communication. As a remedy for this problem, the Silent Operating Theatre Optimisation System (SOTOS) has been developed. This tool allows communication via headsets and microphones[5]. Noise is filtered out and listening to music is possible. A matrix of bi- and multilateral connections in this technology allows a predefined communication structure for subgroups. In this study, a control condition without the system is compared to an experimental condition with the SOTOS, for the last two of five surgical phases across 22 heart surgeries.

Communication in the OT is a core component of teamwork, which is crucial for successful patient care[6]. Poor teamwork is linked to a higher error rate[7]. Communicational topics during surgery can form part of the professional context, focusing on the present case, thus called case-relevant communication (CRC), or be concerned with other aspects than the current case, including small talk or professional exchange about work in general, and is therefore called case-irrelevant communication (CIC). CRC is essential for task-oriented teamwork and seems to enhance team performance, because it enables information sharing within the team[8] and thus enables the OT crew to develop a common understanding of the given task[9]. This way the crew members are able to anticipate developments in the OT or problems in the procedure and can coordinate their actions adequately, which leads to functional crew coordination[10,11]. CIC on one hand may support a positive working environment[12,13]. This argument would be in line with the equilibrium model, which claims that a group must keep a balance between task-oriented and socio-emotional needs, in order to be successful[14]. Socio-emotional reactions include sharing private anecdotes and jokes. Those positive socio-emotional reactions reduce tension within the group[14]. On the other hand, CIC might cause a distraction for the OT crew and may lead to reduced performance[15]. Meaningful noise, like CIC, is more difficult to ignore than machine sounds[16], thus it is more probable to deteriorate concentration and coordination[15]. Dysfunctional communication, like too much CIC in specific phases raises the probability of surgical site infections (SSIs)[13].

SSIs are associated with higher rates of mortality and morbidity[17]. Even though the reduction of those infections has been a goal, a high incidence persists[18]. Communication behaviour can influence the SSI probability through two pathways. First, the frequency of communication is positively associated with the microbial load, due to the effects of speaking and breathing on the permeability of the surgical mask[19]. Hence, less communication could lead to a reduced likelihood of infections[20], as a lower load of microorganisms from the upper respiratory tract of the OT crew members would spread. Second, the content of communication might induce higher incidences of SSIs. More CRC in general was associated with a decreased incidence of organ/space SSIs and more CIC during the wound closure phase (last phase) of surgery was associated with more incisional SSIs[13].

First, we hypothesised that the usage of the SOTOS leads to less communicative utterances (H1). Arguments for that are, that less noise was found in the SOTOS condition in prostatectomies[21] and as the OT tools and machines were not affected by the SOTOS, quieter or less communication could account for that finding. Additionally, the SOTOS reduces perceived noise for the users[5], due to the microphone system, and can thereby improve the clarity of communication, and reduce unnecessary discussions and repetitive questions by the staff.

Previous research showed that smoothing task execution and using tools that enhance the work environment increases team performance[22]. The SOTOS was specifically developed for the OT[5] in order to function not only as a means to channel communication between the crew members but also as a tool to improve the work environment. Every word said passes through the communication system and is heard by specifically chosen receivers in an official working channel[5]. This professional communication setting could lead to a promotion of CRC and its positive effects on crew coordination[10,11]. Therefore, it was assumed that OT crews with SOTOS produce more CRC in both analysed surgical phases compared to OT crews within the control condition (H2).

CIC is more probable during routine tasks[13], such as in the wound closure phase, which is the last phase of surgery. This might be caused by the higher exhaustion level of the crew members at the end of surgery[23] and the lower task requirements in the last phase. Since it was shown that less CIC in the last phase reduces the SSI-risk[13], this phase (*phase 5*) was one focus of the investigation. Research has shown that the exhaustion and stress levels of the OT crews working with the SOTOS are lower compared to crews working without the system[23] and it has been empirically confirmed that less stressed and less exhausted workers are not as easily distracted[24], which should lead to less CIC. Furthermore, small talk, which is included in CIC, has a function as a stress reliever[14]. As in the SOTOS condition, the staff is less stressed[23] less CIC would be necessary. As some crew members want to listen to music without interruptions it is likely that information perceived as unnecessary is held back to reduce the extent of interruptions for the workflow[25]. This aspect seems to be particularly relevant in the last phase, as private conversations happen mostly in routine phases[26]. This line of argument led to the assumption that OT crews in the experimental condition produce less CIC in phase 5 of surgery compared to OT crews in the control condition (H3).

Methods

The study comprised 22 heart surgeries between April 2015 and March 2016. Only coronary bypass grafting and valve replacements using conventional extracorporeal circulation were included. Exclusion criteria were emergency interventions, age under 18 years and patient refusal. Eleven surgeries were conducted with the SOTOS (experimental condition) and 11 without it (control condition). For the given sample, a task-based communication matrix was implemented into the SOTOS[5], which allowed to connect members of certain subgroups with each other. The control group worked with a neck-worn microphone set-up. Each day of the investigation the OT crew was randomly assigned to the control or experimental condition. All examined surgeries were the first of the day.

Each of the operations can be divided into five phases. Phase 4 takes place from the time the aorta is reopened until the time the cardiopulmonary support is finished. Here the heart must pump again by itself without machine support and readjust to its protracted metabolic disturbance. During this period, the patient is still in a vulnerable state and the members of the surgical team are under pressure, as a mistake can have a strong impact on the success of the operation. Phase 5 is the last phase, which starts with the disconnection of the heart-lung machine and ends with the placement of the last skin suture. Part of the study were exclusively the last two phases, since one critical phase (*phase 4*) and one routine phase (*phase 5*) had to be compared and since the investigation of CIC in the last phase was of interest.

The OT crew was composed of members with the following roles: primary surgeon, assisting surgeon, scrub nurse, circulating nurse, anesthesiologist, perfusionist. As six crew members were present in each of the 22 surgeries, this added up to 132 audio recordings on a separate audio channel for each crew member. Before analysis, seven of these recordings were excluded due to technical (microphone defect) or organizational (crew member left surgery early) reasons. All participants signed a declaration of consent for their participation.

The surgeries were performed at the University Medical Centre Goettingen (Germany) within the Department for Cardiovascular and Thoracic Surgery. All the operations took place in the same operating theatre specially equipped for heart operations with a wall-driven lamina airflow system. The ethics committee of the UMG approved on January the 8^{th} in 2015 (no. 12/12/14). Concerning the patients, procedures like hair clipping before surgery, skin disinfection with povidone–iodine-based solution and administration of a single dose of a broad-spectrum antibiotic were part of the preoperative preparation. Additionally, clinically abnormal wound combined with systemic inflammatory parameters such as leukocytosis and CRP combined with antibiotic therapy prolonged beyond routine, was classified as an SSI by a physician. Hygienic standards were met, as hygienic examinations of swabs of the system were performed in each surgery by the Hygiene Institute of the hospital. The system was disinfected after each shift and again before use. Employees of the Hygiene Institute were present at the beginning and end of every surgery and took swabs from the system (microphone and headband), which were smeared on agar plates. The Hygiene Institute allowed the usage of the SOTOS based on these results.

Measurement of communication behaviour

The audio recordings of all communications during the last two phases of the heart surgeries were transcribed, syntactically segmented into coding units, and coded between June and August 2020 by trained psychologists. The MAGIX Samplitude Music Studio 2017 software (Magix Software GmbH, Berlin, Germany) was used to listen to the communication and the transcripts were written in Excel 2010 (Microsoft US, 2018). For the segmentation of the communication flow into coding units, an objective system based on syntactic criteria[27] was used. The interrater reliability for the segmentation of the five segmenters measured by a normalised Levenshtein-distance with a mean of 0.065 is excellent[27].

The segments were coded based on a valid and previously tested observational system[26,28]. Each segment was assigned to one of the three categories: CRC, CIC, rest. The *case* was defined as the present patient case, including all information about the present medical procedure and the present patient. CRC included comments, questions, and requests about the case. CIC comprised communication about other tasks or patients, about work and medicine in general, about the study design, but also acquaintance talk, gossip, and private conversations. The rest category was used when the decision between CRC and CIC was unclear. To examine the interobserver agreement of the seven coders, 359 randomly selected segments before the official coding and 400 random segments halfway through the coding were coded and examined for interrater reliability. The Fleiss' kappa coefficient was 0.59 for the first sample and the 0.63 for the second sample, which is considered moderate and then substantial agreement.

Statistical analysis

Statistical analysis and graphical representation were performed using the packages *stats*, *dplyr*, *car*, *lme4*, *ggplot2* and *ggtext* in R version 4.0.3. The age of the participants is reported as an arithmetic mean (*M*) with standard deviation (*SD*) and gender is reported as a frequency distribution. Noise exposure was calculated separately for the surgical phases as energetic means of dB(A) measurements. Due to technical problems during the dB(A) measurement, six surgeries (three experimental, three control) had to be excluded, but only for the noise analysis.

Test subjects participated according to their shift schedule rendering this study a randomised quasi-experimental field study. The members of each crew were not identical across surgeries. Consequently, participants could be members in several crews, based on their work schedules. This resulted in a complex pattern of dependencies between the observations. By design, the assessed communication variables were nested within the participants and participants were further nested within surgeries, as one participant was part of different surgeries. This resulted in an incomplete crossing of participants between surgeries and, hence, between treatment conditions. From the audio files, the role of a speaker can be identified because each role was recorded on a separate audio track. That is why the described dependencies were addressed by using linear multilevel models with crossed random intercepts for the role of the participants and surgeries for the analysis of communication data (H1 – H3). Fixed effect factors can be treatment (experimental, control) and surgical phase (phase 4, phase 5). The variable communicative utterances (H1) was operationalised as the total number of segments, spoken by a specific role in a specific phase of a specific surgery, relative to the duration of the specific phase in minutes. CRC (H2) was operationalised as the proportion of CRC segments spoken by a specific role in a specific phase of a specific surgery relative to the total sum of communication segments spoken by a specific role in a specific phase of a specific surgery. CIC (H3) was operationalised as the proportion of CIC segments spoken by a specific role in phase 5 of a specific surgery relative to the total sum of communication segments spoken by a specific role in phase 5 of a specific surgery. None of the test assumptions were violated for these linear multilevel models (H2, H3). For all statistical tests, an α-level of 0.05 was set as a default. All tests were calculated two-tailed.

Results

Data from 22 heart surgeries was included in the analysis. A total of 46 subjects participated in the study. The mean age of the participants was $M = 39.91$ years ($SD = 9.99$). Twenty-four participants were male (52%) and 22 participants were female (48%). Five cases of SSIs were reported in the control group, whereas one case was found in the experimental group. Regarding noise exposure, the median dB(A) level across both analysed surgical phases was $Mdn = 70.34$ dB(A) for the control group and $Mdn = 69.45$ dB(A) for the experimental group. The difference in noise exposure between the treatment conditions was statistically not significant, according to the Wilcoxon-Mann-Whitney-Test ($W = 155$, $p = 0.322$).

In the analysis of the communicative utterances (H1), treatment and surgical phase were included as fixed effects, whereas role and surgery were integrated as random effects. There was a significant main effect of treatment on the communicative utterances ($F(1, 21.39) = 11.33$, $p = 0.003$). On average, the participants in the control group uttered $M = 4.54$ segments per minute, while the participants in the experimental group spoke $M = 3.57$ segments per minute. There was no significant main effect of the surgical phase on the communicative utterances ($F(1, 232.60) = 3.03$, $p = 0.083$; phase 4: $M = 4.28$, phase 5: $M = 3.81$). No significant interaction effect between treatment and surgical phase on the communicative utterances could be found either ($F(1, 232.70) = 1.14$, $p = 0.288$). The results are displayed in Table 1 and graphically represented in Figure 1.

Table 1 Communicative utterances: Analysis of Variance Table with Satterthwaite's Method

Fixed effects	SS	MS	Df_{num}	Df_{den}	*F*	*P*
Treatment	51.64	51.64	1	21.39	11.33	0.003
Phase	13.81	13.81	1	232.70	3.03	0.083
Treatment*Phase	5.18	5.18	1	232.70	1.14	0.288

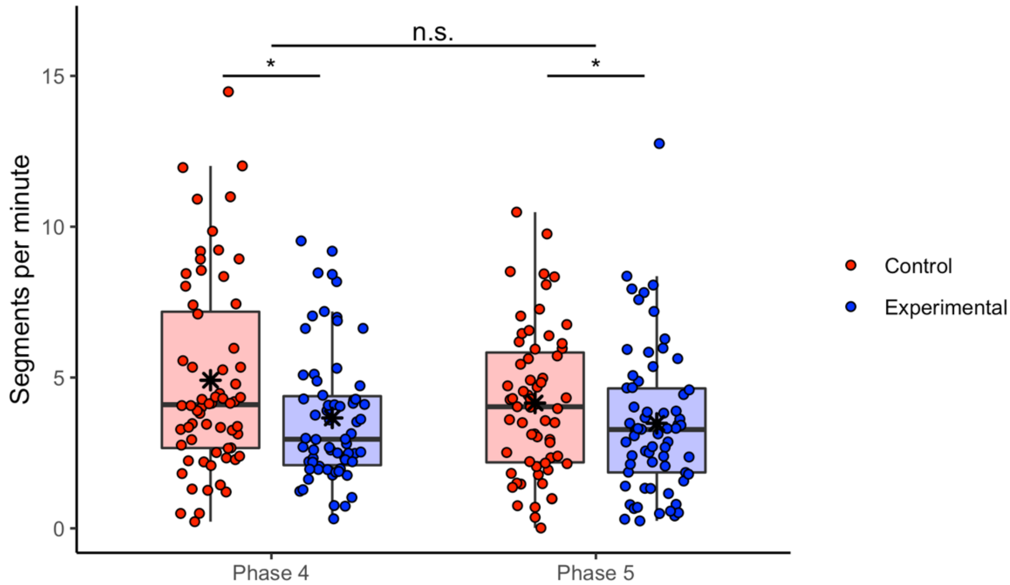

Fig. 1. Box-plots of the communicative utterances as segments spoken per minute during the fourth and fifth surgical phase in the treatment conditions. Lower and upper box boundaries 25th and 75th percentiles, respectively, line inside box median, asterisk inside box arithmetic mean, lower and upper error lines 10th and 90th percentiles, respectively, filled circles segments spoken per minute by a specific role.

In the analysis of CRC (H2), treatment and surgical phase were included as fixed effects, whereas role and surgery were integrated as random effects. No significant main effect of treatment on CRC was found (F (1, 21.69) = 1.40, p = 0.249), indicating that treatment conditions did not differ (experimental condition: M = 73.3%, control condition: M = 70.2%). There was a significant main effect of the surgical phase on CRC (F(1, 232.09) = 7.43, p = 0.007; phase 4: M = 69.5%, phase 5: M = 74.1%). There was a significant interaction effect between surgical phase and treatment on CRC (F(1, 128.38) = 9.12, p = 0.001), limiting the interpretation of these main effects. The results are displayed in Table 2 and graphically represented in Figure 2.

Table 2 CRC: Analysis of Variance Table with Satterthwaite's Method

Fixed effects	SS	MS	Df_{num}	Df_{den}	F	P
Treatment	0.03	0.03	1	21.69	1.40	0.249
Phase	0.14	0.14	1	232.09	7.43	0.007
Treatment*Phase	0.17	0.17	1	232.09	9.12	0.003

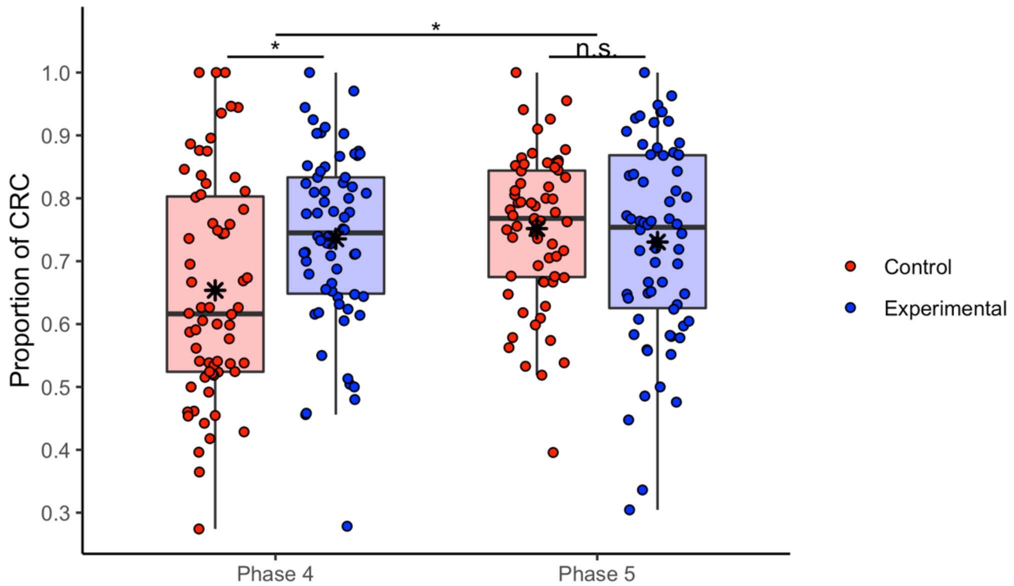

Fig. 2. Box-plots of CRC during the fourth and fifth surgical phase in the treatment conditions. Lower and upper box boundaries 25th and 75th percentiles, respectively, line inside box median, asterisk inside box arithmetic mean, lower and upper error lines 10th and 90th percentiles, respectively, filled circles proportion of CRC in a specific role.

Due to this interaction effect, the differences between the conditions were analysed separately for each surgical phase post hoc. On average CRC in the fourth surgical phase was significantly higher in the experimental group (M = 73.6%) than in the control group (M = 65.6%) (F(1, 20.92) = 4.47, p = 0.047). The results are displayed in Table 3. In the fifth surgical phase, no significant difference was found between the conditions (F(1, 22.24) = 0.45, p = 0.507; experimental condition: M = 73.3%, control condition: M = 70.2%). The results are displayed in Table 4.

Table 3 CRC, Phase 4: Analysis of Variance Table with Satterthwaite's Method

Fixed effects	**SS**	**MS**	**Df_{num}**	**Df_{den}**	***F***	***P***
Treatment	0.08	0.08	1	20.92	4.47	0.047

Table 4 CRC, Phase 5: Analysis of Variance Table with Satterthwaite's Method

Fixed effects	**SS**	**MS**	**Df_{num}**	**Df_{den}**	***F***	***P***
Treatment	0.01	0.01	1	22.24	0.46	0.507

In the analysis of CIC in the fifth surgical phase (H3), treatment was included as a fixed effect, whereas role and surgery were integrated as random effects. No significant main effect of treatment on CIC was found $F(1, 20.30) = 0.60$, $p = 0.446$, indicating that treatment conditions did not differ in the fifth surgical phase (experimental condition: $M = 26.2\%$, control condition: $M = 23.7\%$). Since the proportion of communication that was assigned to the residual category is negligible, this finding is inversely related to the post hoc analysis of CRC in Phase 5. The results are displayed in Table 5 and graphically represented in Figure 3.

Table 5 CIC, Phase 5: Analysis of Variance Table with Satterthwaite's Method

Fixed effects	**SS**	**MS**	**Df_{num}**	**Df_{den}**	***F***	***P***
Treatment	0.01	0.01	1	20.30	0.60	0.446

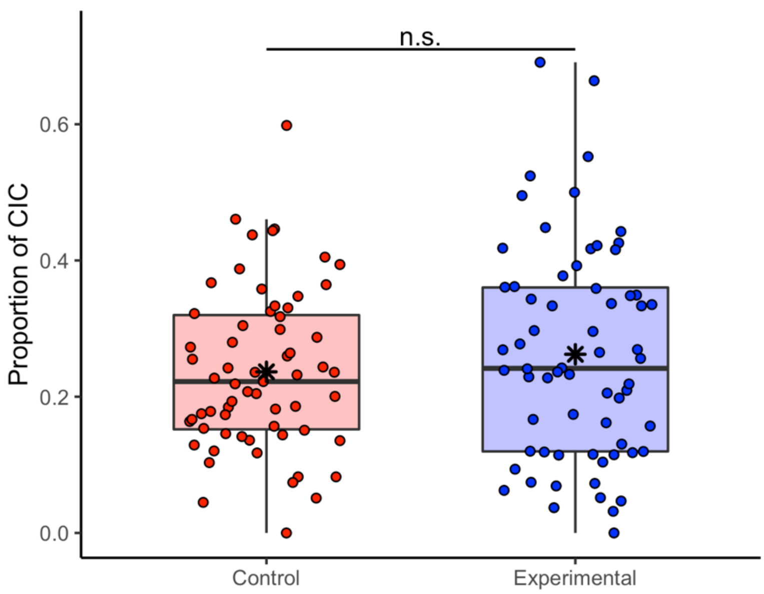

Fig. 3. Box-plots of CIC during the fifth surgical phase in the treatment conditions. Lower and upper box boundaries 25th and 75th percentiles, respectively, line inside box median, asterisk inside box arithmetic mean, lower and upper error lines 10th and 90th percentiles, respectively, filled circles proportion of CIC in a specific role.

Discussion

In this field study, the OT crew communicated significantly less when using the SOTOS. The advantageous conditions concerning SSI-risk reduction, found by Tschan et al.[13], namely more CRC in general, which is equivalent to more CRC in both analysed surgical phases, and less CIC in the closing phase, which is phase 5 in this setting, do not seem to be generated by the SOTOS. Nevertheless, a closer look at the results reveals a potentially beneficial pattern concerning CRC and CIC: The experimental group showed a higher CRC-level in the critical phase 4 which equates to a constantly high level of CRC (circa 73%) over both phases, hence a low level of CIC (circa 27%) over both phases. SSIs occurred less within the experimental group, although the small sample size forbids far-fetched interpretations.

As significantly less segments were spoken with the SOTOS (H1), the first pathway should be researched more closely. However less communication is not generally a positive factor for performance and SSI reduction. As communication is seen as a crucial factor for successful teamwork it is recommended to allow CRC for functional communication, which is necessary to allow for a shared mental model of the team[8,9]. Even though less communication might lead to a lower microbial load and therefore to a lower SSI-risk, it might also lead to a lower exchange of relevant information. Thus, some relevant information might not find its way to the right addressee who might need this information to update his/her mental model and understanding of the task[9]. The crew members might not want to interrupt the music and workflow[25] of their co-workers or do not want to always be heard by all colleagues in their communication channels and hence hold back information perceived as unnecessary. This way, implicit team coordination might arise, which can lead to suboptimal solutions especially in unexpected and complex situations[29], even though the chosen heart surgeries were standard procedures with a limited risk of complications. On the other hand information overload can impair performance of teams working in stressful contexts[30], which would be supportive of less communication being beneficial, as long as all relevant information is shared. Relevant information for the case is per se CRC. Therefore, the reduction of communication should be beneficial in particular if it relates mainly to CIC and not CRC.

A possible explanation for the fact that we did find an SSI reduction but did not find the specific patterns discovered by Tschan and colleagues[13], could be the different method for the segmentation of the communication flow: In their semantic approach, a segment was defined as one or several verbal statements related to the same theme. The advantage of this method is the practical usability and its time-saving advantages, but it has the disadvantage of a lower objectivity as observers might have different opinions about the thematic structure of the conversation. This subjective component is ruled out in the syntactical approach, as here objective rules decide when a segment starts and when it ends.

It is possible that the SSI reduction was a coincidence due to the small sample size. Nevertheless, if taken into account that CRC is particularly important during complicated phases of the surgery[8,13] a closer look at the proportion of CRC during the critical phase 4 may help to investigate the process more clearly: In the experimental group, a substantially higher CRC-mean in phase 4 was found compared to the control group, which would be an indicator for more information sharing in this phase and is associated with lower mortality rates and fewer complications[8]. Additionally, as CRC and CIC are almost mathematical complements (see the results section), the observed constantly high level of CRC in the experimental group can also be interpreted as a constantly low level of CIC. This low level might still be high enough to enable the positive effects of CIC, namely the improved team climate[12,13] and its function as a stress reliever[14], but still low enough to optimise its distractive effects[15]. It is possible that the found level of CIC in the experimental group is close to an optimal balance of CRC and CIC according to the equilibrium model[14]. This would be a plausible explanation of the previously found stress reducing effect of the SOTOS[23].

Since a double-blind optimization was not feasible because crew members were in both conditions and knew about the perceivable noise cancelling effects the internal validity is suboptimal. On the other hand, a strength of this study is the high external validity, as the study was conducted under regular working conditions in a clinic. While the sample size is appropriately high for the analysis of communication behaviour, a weakness is the low sample size concerning the investigation of the SSIs with 22 surgeries, which is why only descriptive results are mentioned.

Conclusion

In summary, less communication compared to surgeries without the SOTOS was observed, which is ambiguous in its effects. On the one hand this lowers the microbial load and on the other hand a low amount of communication can be dangerous if relevant information is suppressed. Fortunately, the SOTOS does not seem to produce this negative facet of communication reduction because in the critical phase 4 CRC was significantly higher in the experimental group and in phase 5 it was similar to the control group. From this it can be concluded that the SOTOS allows for a constant flow of CIC from phase 4 to phase 5 on a level which permits the positive effects of CIC, namely an enhanced team climate, and restricts its negative effects like distraction. The distractive effects of CIC are discussed as potential reasons for higher SSI occurrence in previous research[13]. Since less SSIs occurred under the SOTOS condition, this can be interpreted as an indication that the described effects of the SOTOS on communication result in a higher team performance in the OT. An alternative or supplementary explanation would be the lower frequency of communication. Given that the effect of the SOTOS on SSI occurrence was derived from a relatively small sample size further research concerning this specific question is needed.

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Declaration of Interest Statement

MF invented and technically developed the SOTOS. The system is patented by the University Medical Center Goettingen (DE102015205463, PCT/EP2016/056659, EP20213914). JL, MB, & SL report no declaration of interest. The authors alone are responsible for the content and the writing of this paper.

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3.3 Article 3: SLOS Effects on Noise, Stress and Acceptance in the Medical Laboratory

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Laboratory Medicine – Original Article

Title Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise and Stress of Medical Laboratory Workers

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Conflict of Interest MF invented and technically developed the SLOS. The system is patented by the University Medical Center Goettingen (EP20213914.3). JL, JM, SL & MB declare no competing interests.

Abstract

Background

Study to investigate effects of the technical noise reduction and communication management system (SLOS) on noise load and stress among medical laboratory workers.

Method

Quasi-experimental field study (20 days with SLOS = experimental; 20 without = control) in a within-subjects design. Survey data from 13 workers was collected pre- and post-shift. Additionally, a survey was conducted after the control and experimental condition, respectively. Noise was measured in dB(A) and as a subjective assessment. Stress was operationalised via a stress composite score (STAI and Perkhofer Stress Scale), the Perceived Stress Scale (PSS), an exhaustion score (LPS), and salivary cortisol in µg/L.

Results

SLOS-users perceived significantly less noise ($V = 76.5$, $p = 0.003$). Multilevel models revealed a stress reduction with the SLOS on the composite score, compared to a stress increase in the control condition ($F(1, 506.99) = 6.00$, $p = 0.01$). A lower PSS-score ($F(1,13) = 4.67$, $p = 0.05$) and a lower exhaustion level ($F(1, 508.72) = 9.057$, $p = .003$) in the experimental condition were found, whereas no differences in cortisol ($F(1,812.58.6) = 0.093$, $p = 0.761$) were revealed.

Conclusion

The workers showed reduced noise perception and stress across all criteria, except cortisol, when using SLOS.

Introduction

Noise load is a problem in many workplaces and an important health issue[1–3] for the workers exposed to noise, exceeding thresholds set by ergonomic standards of the World Health Organization (WHO). The WHO recommendations vary depending on specific target contexts, with the highest threshold being 55 dB(A)[4–6]. The health sector itself is a sensitive work domain as noise, potentially impairing performance[7,8], is critical, not only for the workers but also for patients. Noise levels are not only exceeding recommendations in work places like operating theatres[1,7,9], but also in medical laboratories, the target context of this paper, where lab devices alone produce between 66 and 80 dB(A)[10,11].

Performance in general[7,8], productivity and concentration are diminished by increased noise[12]. Noise leads to higher exhaustion, lower well-being and more stress[12]. Additionally, a positive correlation between exposure to noise and cardiovascular diseases was found[1–3]. This is likely to occur because noise is a stressor [4,11–14]. According to the transactional stress model a person perceives stress when two appraisals are made: First, the person appraises the situation to be potentially harmful to the well-being (primary appraisal) and second, the person does not think that she/he has enough resources to deal with the situation or solve the problem (secondary appraisal)[15]. Earplug solutions, as suggested by the WHO[6] do not solve the problem optimally. They would indeed change the situation-person transaction in so far as they reduce the perceived noise and thus offer a resource in the secondary appraisal. But in most workplaces workers still need to communicate, which is prohibited by earplugs. The Silent Operating Theatre Optimisation System (SOTOS), which functions as a noise reduction and communication management tool[16], promises a solution for this suboptimal situation. Initially, it was developed for the operating theatre (OT). Systematic evaluation rendered mostly positive effects on noise perception, stress, exhaustion and technical acceptance of the system[13,16–18]. For this study the SOTOS was adapted to the necessities of the medical laboratory and is now referred to as SLOS. The headphone system allows communication between the workers and reduces environmental noise, while allowing the option to listening to music and to communicate via microphones. A strength of the system is the communicational matrix, which – depending on the structure of the tasks and subtasks – allows to connect certain workers or groups of workers with each other[16].

This field study evaluates the effects of SLOS on noise, stress and its acceptance and comfort in a medical laboratory by comparing the laboratory workers during the experimental condition with the SLOS and the control condition without the system over a total of 40 workdays. It was of interest, whether the system would reduce noise at the work place objectively in the room, as was found in Ots[18], and subjectively for the laboratory workers, as a technical study on SOTOS suggests[16]. Therefore, a replication of these findings was one goal of this study (H1).

According to the transactional stress model[15], the system could positively impact workers' primary stress appraisal by changing the situation through the noise reduction, while allowing communication. The system is offering an additional resource for the secondary appraisal, i.e., workers now having an option to deal with the noise issue. This is why a stronger stress reduction was expected during the experimental condition compared to the control condition based on the transactional stress model[15]. These assumptions are supported by the job demand-control model[19], which postulates that psychological strain results from the joint effects of the demands of a work situation (stressors) and the range of decision-making freedom (control or job decision latitude). Workers experience high job strain when job demands are high and job decision latitude is low[19]. Higher noise is associated with higher job demands[20–22]. Accordingly, working with the SLOS reduces the job demands directly, while also granting laboratory workers higher job decision latitude as they are now able to control noise by wearing the SLOS and to control communication by implementing their own choices in the communication matrix. Both, lower job demands, and higher job decision latitude reduce the likelihood of high job strain[19]. Additionally, the stress buffering effects of work-related social support on work-related stress are empirically confirmed[23–25]. Due to the greater communicative range offered by the communication matrix, more work-related social support can be received from work colleagues, the physical distance can be overcome, which creates more communicational opportunities for social support. Derived from both theories the second goal of this study was to replicate the findings from the OT, in which the system reduced stress[13,17], but this time in the context of a medical laboratory (H2).

Additionally, an evaluation of the system concerning its acceptance and comfort was of interest. In order to implement the SLOS in a workplace it is necessary that the workers feel comfortable with the technical device and accept it as a useful tool. Besides the investigation of the effects of the SLOS on noise and stress outcomes, it was therefore also a goal to research the subjective acceptance of the system called the *Technical System Evaluation*. For this purpose, the test subjects were asked about the perceived comfort and acceptance of the SLOS. Additionally, it was of interest whether the system would enable communication in technical terms and if the users would perceive it as non-obstructive, and always usable in order to stay informed about the work of the other co-workers, when needed. More details can be found in the specific methods section.

Materials and Methods

Study Design and Participants

To evaluate the effects of the SLOS in a laboratory environment, a field study with an experimental and a control condition was conducted. The study took place in the immediate analysis section (Sofortanalytik = SANA) of a large-scale medical laboratory in Goettingen, Germany during the early shift of regular workdays, weekends excluded.

The test subjects were all 13 lab assistants of the SANA. On each weekday a maximum of seven individuals were working in the early shift and therefore integrated into the study. Each worker fulfilled the tasks of a certain role (see Figure 1). In general, some workstations need to be operated dependently of one another, whereas others are independent. The laboratory management claimed that communication takes place irregularly between all roles, which was confirmed by randomly conducted observations.

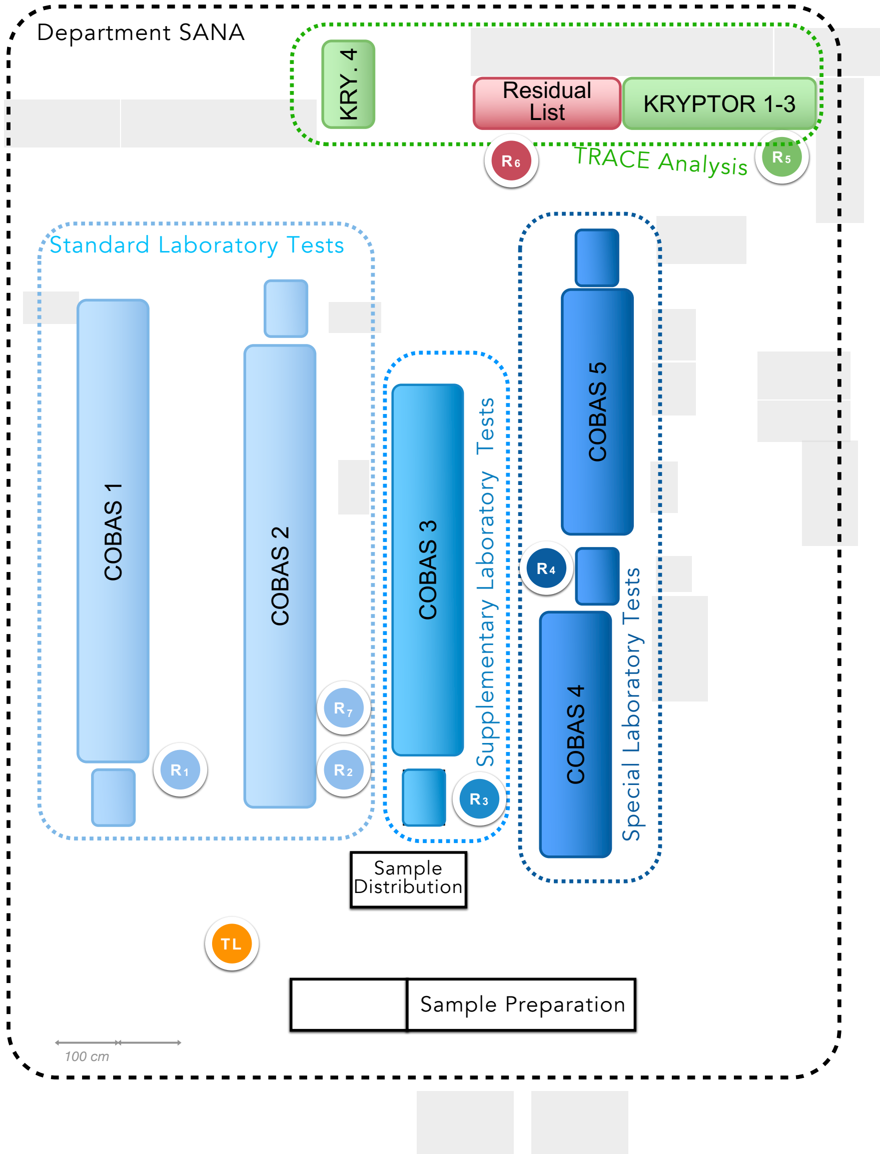

Fig.1 Workplace of the immediate analysis section (SANA) of the medical laboratory. R1-7: Role 1 – Role 7. TL = Team leader.

The main function of the stations COBAS 1 to 5 and KRYPTOR is the clinical, chemical and immunological analysis of samples sent in by local clinics. These stations differ in their specific clinical, chemical and immunological analysis approaches or the test assignments. The Residual List deals with more complex material than the aforementioned roles and offers a manual validation of results. Because of the fixed shift plan, the randomised assignment of test subjects to treatment conditions was practically unfeasible. The lab crew worked together in their regular composition. All participants signed a declaration of consent for their participation and allowed the anonymous usage of data for research. The ethics committee of the Georg-Elias-Mueller Institute of Psychology in Goettingen approved the study (no. 295) on January 1, 2022.

The dependent variables of this study are noise and stress. The latent variable noise is operationalised by the objective measurement of dB(A) in the laboratory and the subjectively perceived noise. The latent variable stress is operationalised by three subjective stress level variables, cortisol level and a subjective exhaustion measurement as a stress outcome. More details can be found in the specific methods chapter. The independent variables (IV) are *treatment* (experimental, control), *time of measurement* (pre-shift, post-shift) and *sample number* of the cortisol sample (1,2,3).

Procedures

The data collection for the control condition was conducted between January 10 and February 4, 2022. The experimental condition started on February 7 and lasted until March 4, 2022, during which the test subjects worked with the SLOS.

Dependent variables were measured via paper-and-pencil questionnaires which included items for all psychological and demographic variables. The Monthly Questionnaire (MQ) was conducted after the control and after the experimental condition. The Daily Questionnaire (DQ) was given daily before and after each shift. To minimise measurement biases, all surveys were conducted right before starting or right after finishing the days' shift. The time of the pre- and post-measurements depended on the arrival and departure of the workers, usually between 6.15 AM and 8.30. AM, and 2.30 PM and 4.00 PM. A decibel meter was used to measure the noise level between 9.30 AM and 2.00 PM in the laboratory. In both study conditions, test subjects were asked to provide saliva samples to create a daily profile of their cortisol-levels. Due to technical problems like battery issues of the SLOS on February 8, 11 and 17, these days were excluded, as not all team members of the lab crew worked the whole shift with the system on these days. The excluded data was replaced by three additional buffer days on March 7, 8 and 9, 2022. In the end, each condition lasted four weeks with five survey days per week, leading to 20 survey days per condition.

Noise Measurement

Noise in the laboratory room was operationalised by the sound pressure level that was measured by a VOLTCRAFT SL-451 (Conrad Electronic SE, Hirschau, Germany) once per second as an A-weighted sound pressure level, namely dB(A). The VOLTCRAFT was used when available, which led to 28 measurement days, of which half were conducted in the control condition and half in the experimental condition. As no special noise events were mentioned in the daily protocols of the test coordinators and as the availability of the VOLTCRAFT was random, it was assumed that a representative sample was collected for the noise measurement. The data of each daily measurement was saved by the software Voltsoft Pro (Conrad Electronic SE, Hirschau, Germany). The subjective perception of noise was measured via two items in the second MQ ("Did you perceive the noise level in general (without the SLOS) in the laboratory as loud and/or disturbing?"; "Did you perceive the noise level in general (with the SLOS) as loud and/or disturbing?").

Stress Measurement

Daily subjective stress levels were measured using the German short version of the State-Trait-Anxiety-Inventory (STAI) for state-anxiety[26] and the Perkhofer Stress Scale[27]. The subjective stress level relating to the experienced stress over the last four weeks were measured with the German version of the Perceived Stress Scale 10 (PSS-10)[28]. Cortisol samples were analysed to assess physiological stress. The stress outcome exhaustion was operationalised by the exhaustion subscale of the Leipziger Mood Questionnaire in German (LPS)[29].

The STAI includes eight items. The items ask for agreement concerning statements about the present stress perception. Answers were given on an eight-point Likert-type scale (1 = not at all, 8 = completely)[26]. The Perkhofer Stress Scale is a combined single-item-questionnaire of visual analogous scales and face-rating scales. It can be assumed that both measurements assess the same construct as their convergent validity was reported, with the variables correlating significantly (r = .67)[27]. This was the reason for calculating a composite stress score.

The PSS-10[28] measures the subjective stress level during the last four weeks, which matches with the length of the treatment conditions. The PSS-10 consists of ten items including questions about the frequency of subjectively stressful experiences during the last four weeks. Answers were given on a five-point Likert-type scale (1 = never, 5 = very often).

Cortisol saliva samples were taken right after waking (sample 1), half an hour after waking (sample 2) and before the post questionnaire (sample 3) with the test sample kit Elecsys Cortisol II. All samples were collected and protocolled by the test administers, resulting in three cortisol samples per subject per day measured in µg/L. Saliva cortisol is an established biomarker for stress in human beings[30–32]. In contrast to serum cortisol, the measurement of saliva cortisol is noninvasive[33], which makes it more practical for studies. Additionally, possible biasing effects of stress about the venipuncture used for serum cortisol can be controlled[33,34] for.

Exhaustion at work is an immediate result of workplace stressors[35] and therefore represents a stress outcome[36], which was the reason to add exhaustion as a further stress-related measure in order to expand the multimodal approach. The subscale exhaustion of the LPS[29] is a questionnaire of six items asking for the extent to which adjectives associated with exhaustion, like being tired or worn out, are applicable to a subject's present perception on a five-point Likert-type scale (1 = not at all, 5 = very much).

Technical System Evaluation

Concerning the Technical System Evaluation three variables were integrated into the MQ2 (all items can be found in the tables 2-4). The first variable is the technical acceptance of the SLOS in general and consists of four self-developed items asking about the perceived support of the system, the comfort of the headphones and the microphone, and the overall audio quality. The second variable is the specific SLOS acceptance and consists of 12 items. This construct was derived from the extended Technology Acceptance Model (TAM2)[37] with the target technology being the SLOS. The TAM2 integrates four facets named *intention to use*, *perceived usefulness*, *perceived ease of use* and the *subjective norm*. The third variable is concerned with the perceived effects of the SLOS on communication via three self-developed items. As this is not a study concerned with communicational analyses it was only of interest whether the system would technically allow for clear communication.

Statistical Analysis

Statistical analysis and graphical representation of the data were performed using R version 4.0.3[38]. Descriptive statistics of demographic characteristics and Technical System Evaluation of acceptance and comfort are reported according to their respective levels of measurement as means with standard deviations, or as absolute and relative frequencies. Noise exposure levels dB(A) are reported as energetic means with standard deviations for the experimental and control condition. Analysis of the difference in noise exposure dB(A) between treatment conditions was performed using a Wilcoxon signed-rank test. To avoid overpowering the test due to the high number of data points of decibel measurements (each survey day one per second from 9.30 AM to 2.00 PM), the energetic means of survey days were compared. The analysis of the difference in subjective perception of noise between treatment conditions was also performed using a Wilcoxon signed-rank test. The effect size of these tests is reported as *r*.

The analysis of the effect of the SLOS on stress was conducted using multiple linear mixed models, with subject ID included as a random effect. In the analyses of the effects of SLOS on the stress composite score and exhaustion, time of measurement and treatment were included as fixed effects. Since a high correlation was present between the STAI and the Perkhofer Stress Scale ($r = .67$)[27], a composite score was calculated with equal weighting of the two scales to test the influence of the system on the state stress. Since for the analysis of the SLOS on the PSS only one data point per participant was available for each treatment condition, only treatment was included as a fixed effect in this model. For the analysis of the effect of SLOS on the concentration of salivary cortisol, the sample number was included as a fixed effect in addition to treatment. The effect sizes of the models are reported as conditional R^2 and the effect sizes of the individual predictors are reported as partial Eta^2. In addition to model parameters, the simple effects are reported for the models investigating the stress composite score and exhaustion. For all statistical tests, $p < .05$ was considered significant. All tests were two-sided.

Results

In total, 13 individuals participated over 40 workdays. The average age of the participants was 36.6 years (SD = 8.12). 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. In addition to the shift plan, holiday periods, sick days and COVID-19 quarantines were further reasons for an unequal frequency of participation per person.

Four participants were male (31%) and nine were female (69%). Concerning all dependent variables, Table 1 gives an overview with means and standard deviations.

Table 1. Means and Standard Deviations of each Dependent Variable

DV	Control		Experimental	
	M	***SD***	***M***	***SD***
Noise in dB(A)	67.40	1.57	69.7	2.92
Subjective Noise	5.08	1.50	1.92	1.12
Composite Stress Score Pre	16.20	5.66	17.70	5.49
Composite Stress Score Post	17.40	5.69	17.00	6.06
Perceived Stress Score	28.40	6.33	25.20	5.74
Cortisol Sample 1 in µg/L	4.27	2.36	4.09	2.35
Cortisol Sample 2 in µg/L	6.70	3.19	6.48	3.07
Cortisol Sample 3 in µg/L	1.32	0.58	1.44	0.80
Exhaustion Pre	2.32	0.94	2.23	0.88
Exhaustion Post	2.57	1.01	2.32	0.95

DV = dependent variable. dB (A)= decibel, a-weighted.

Concerning the Technical System Evaluation, three variables, namely *SLOS Technical Acceptance*, *SLOS Acceptance* (based on the TAM2[37]), and *SLOS Communication*, were investigated descriptively. Results are displayed in table form: Table 2 offers the results for the technical acceptance of the SLOS (M = 4.38, SD = 0.64). Table 3 includes the results for the SLOS acceptance according to the TAM2[37] (M = 4.06, SD = 0.75) with the four facets *intention to use* (M = 4.42, SD = 1.04), *perceived usefulness* (M = 3.96, SD = 1.12), *perceived ease of use* (M = 4.12, SD = 0.91) and the *subjective norm* (M = 3.81, SD = 0.93). Table 4 displays the results for the technical effects on communication (M = 5.10, SD = 0.75).

Table 2. Descriptive Statistics of SLOS Technical Acceptance.

Item	*M*	*SD*
„In general, work with the SLOS was …“	4.85	0.90
„Until the end of the workday, the earphones were …“	4.23	0.73
„If you wore a neckband microphone, this was…“	3.31	1.32
„The overall audio quality was…“	5.15	0.69

Answers were provided on a Likert-type scale: Item 1: 1 = extremely disturbed, 2 = pretty disturbed, 3 = little disturbed, 4 = little supported, 5 = pretty supported, 6 = extremely supported. Item 2 & Item 3: 1 = extremely uncomfortable, 2 = pretty uncomfortable, 3 = little uncomfortable, 4 = little comfortable, 5 = pretty comfortable, 6 = extremely comfortable. Item 4: 1 = extremely bad, 2 = pretty bad, 3 = reasonably bad, 4 = reasonably good, 5 = pretty good, 6 = extremely good.

Table 3. Descriptive Statistics of SLOS Acceptance

Item	*M*	*SD*
„Assuming I have access to the SLOS, I intend to use it.“	4.38	1.04
„Given that I have access to SLOS, I predict that I would use it.“	4.46	1.05
„Using the SLOS improves my performance in my job.“	3.92	1.26
„Using the SLOS enhances my effectiveness in my job.“	3.77	1.30
„I find the SLOS to be useful in my job.“	4.23	1.17
„Using SLOS increases my effectiveness at work.”	3.92	1.12
“My interaction with the SLOS is clear and understandable.”	4.38	0.87
„Interacting with the SLOS does not require a lot of my mental effort.“	4.31	1.11
„I find the SLOS to be easy to use.“	3.85	1.07
„I find it easy to get the system to do what I want it to do.“	3.92	0.86
„People who are important to me think I should use the SLOS.“	3.92	0.95
„People who influence my behaviour think I should use the SLOS.“	3.69	1.03

Answers were provided on a Likert-type scale: 1 = not at all, 2 = little true, 3 = partially true, 4 = pretty much true, 5 = absolutely true.

Table 4. Descriptive Statistics of SLOS Communication

Item	*M*	*SD*
„I could communicate unhindered with my colleagues via SLOS.“	4.85	0.90
„Communication with the SANA-crew was possibly at all times.“	5.15	1.21
„I was always sufficiently informed about what my colleagues were doing.“	5.31	0.86

Answers were provided on a Likert-type scale: 1: Does not apply at all – 6: Does apply fully.

In the analysis of objective noise in the lab and subjective noise, treatment was included as a fixed effect. The Wilcoxon signed-rank test (N = 28) showed no difference in dB(A) between the experimental condition with an energetic mean of 69.70 dB(A) (SD = 2.92) and the control condition with 67.40 dB(A) (SD = 1.57), $V = 37$, $p = 0.358$, $r = 0.11$. However, there was a significant association between the treatment condition and whether the laboratory workers would perceive the noise as loud and annoying, $V = 76.5$, $p = 0.003$, $r = 0.75$. Test subjects in the control condition scored higher ($M = 5.08$, $SD = 1.50$) than workers during the experimental condition ($M = 1.92$, $SD = 1.12$).

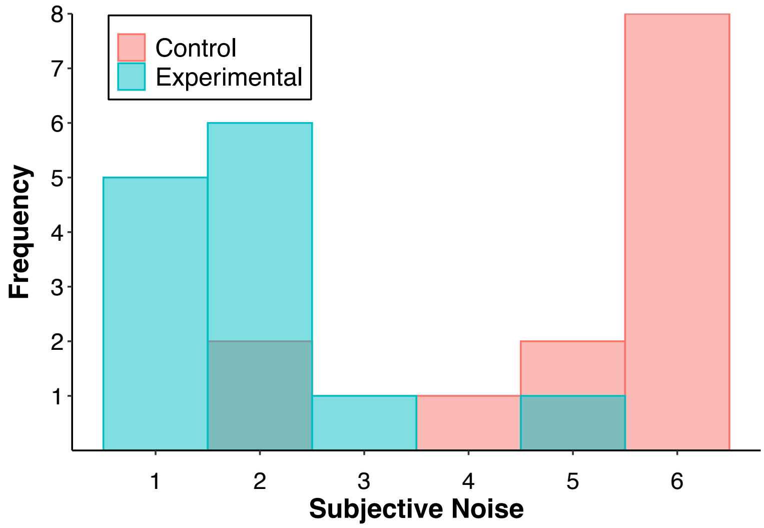

Fig. 2. Bar chart of subjective noise perception ratings for the experimental and control condition.

A significant correlation between the STAI and the Perkhofer Stress Scale was found, $r = .49$, 95% CI [0.43, 0.56], $p < .001$. In the analysis of the composite stress score, treatment and time of measurement were included as fixed effects, whereas the subject ID was integrated as a random effect (*conditional* $R^2 = .334$). There was no significant main effect of treatment on the stress composite score, $F(1, 510.93) = 0.17$, $p = .679$, *partial* $\eta^2 < .001$, and also no significant main effect of time of measurement, $F(1, 506.99) = 0.29$, $p = .590$, *partial* $\eta^2 < .001$. However, there was a significant interaction between treatment and time of measurement on the composite score, $F(1, 506.99) = 6.00$, $p = .015$, *partial* $\eta^2 = .01$. The experimental condition started with a higher mean ($M = 17.70$, SD = 5.49) than the control condition ($M = 16.20$, $SD = 5.66$) before the shift. This difference was significant ($t(509.11) = 2.00$, $p = .046$). The experimental condition showed a decrease in stress, leading to a lower mean ($M = 17.00$, $SD = 6.06$) compared to the control condition ($M = 17.40$, SD = 5.69), after the shift. This difference was not significant ($t(509.11) = 1.40$, $p = .161$). The course from pre to post was significantly different between the treatment conditions. The results are graphically represented in Figure 3.

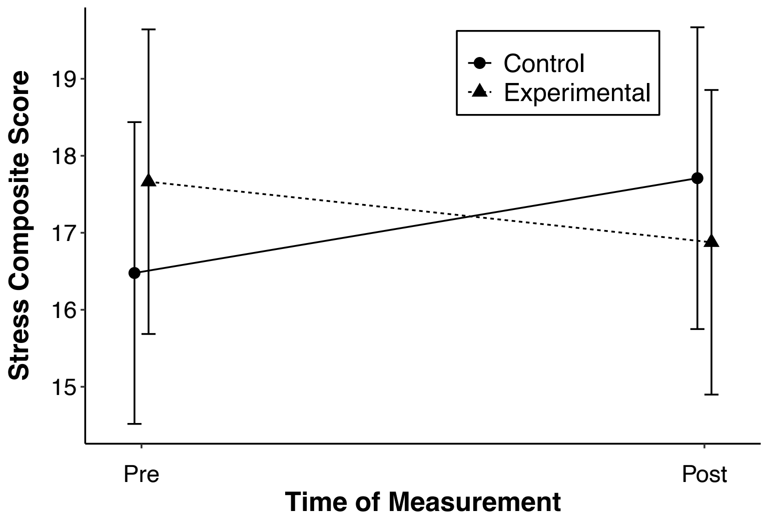

Fig. 3. Time of measurement*treatment effect plot for the composite stress score. Means before and after shift for the experimental and control condition. Error bars represent 95% confidence intervals.

In the analysis of the perceived stress scale, treatment was included as a fixed effect, whereas the subject ID was integrated as a random effect (*conditional* R^2 = .609). There was a significant main effect of treatment, $F(1, 13) = 4.67$, $p = .050$, *partial* $\eta^2 = .26$. The mean of the control condition (M = 28.4, SD = 6.22) was significantly higher than during the experimental condition (M = 25.2, SD = 5.74).

In the analysis of the cortisol level, treatment and sample number were included as fixed effects, whereas the subject ID was integrated as a random effect (*conditional* R^2 = .596). There was no significant main effect of treatment on the cortisol level, $F(1,812.58) = 0.09$, $p = .761$, *partial* $\eta^2 < .001$, but a significant main effect of the sample number, $F(2, 806.35) = 480.58$, $p < .001$, *partial* $\eta^2 = .54$. There was no significant interaction between treatment and sample number on the cortisol level, $F(2, 806.35) = 0.61$, $p = .543$, *partial* $\eta^2 < .001$. In both conditions, a similar level was measured for the first sample (experimental: M = 4.09, SD = 2.35; control: M = 4.27, SD = 2.36), followed by a peak at the second sample (experimental: M = 6.48, SD = 3.07; control: M = 6.70, SD = 3.19) and a decrease leading to a lower cortisol level in sample 3 (experimental: M = 1.44, SD = 0.80; control: M = 1.32, SD = 0.58) compared to the first sample. The results are graphically represented in Figure 4.

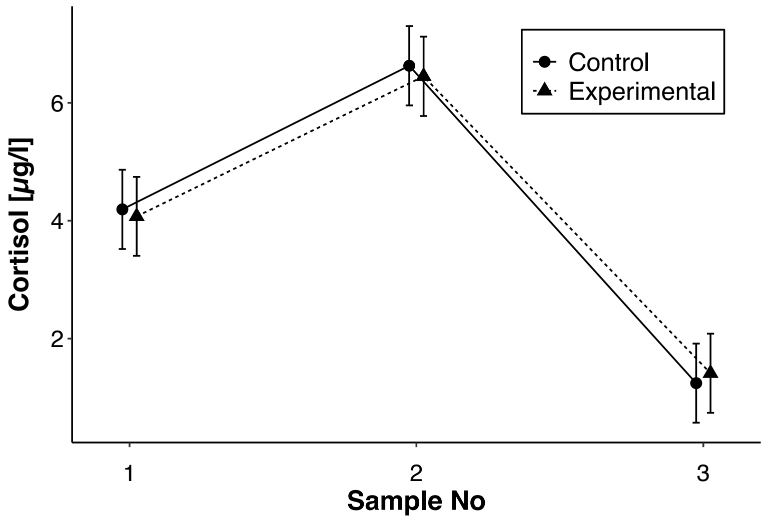

Fig. 4. Sample number*treatment effect plot for the cortisol level in µg/l. Means for each sample number (after waking up, half an hour after waking up, and before the post questionnaire) for the experimental and control condition. Error bars represent 95% confidence intervals.

In the analysis of exhaustion, treatment and time of measurement were included as fixed effects, whereas the subject ID was integrated as a random effect (*conditional* R^2 = .309). There was a significant main effect of treatment on exhaustion, $F(1, 508.72) = 9.06$, $p = .003$, *partial* $\eta^2 = .01$, and also a significant main effect of time of measurement, $F(1, 504.23) = 6.40$, $p = .012$, *partial* $\eta^2 =$ .02. However, there was no significant interaction between treatment and time of measurement on exhaustion, $F(1, 504.23) = 1.59$, $p = .208$, *partial* $\eta^2 = .003$. A similar exhaustion mean was found in both conditions, in which the control condition ($M = 2.32$, $SD = 0.94$) was reporting a slightly higher mean in the pre-measurement, than during the experimental condition ($M = 2.23$, $SD = 0.88$). This difference was not significant ($t(506.64) = 1.29$, $p = .197$). Both conditions showed a rise from the pre- to the post-measurement leading to significantly higher mean for both conditions after the shift than before. The rise of the control condition was stronger, leading to a higher exhaustion mean in the control condition ($M = 2.57$, $SD = 1.01$) compared to the experimental condition ($M = 2.32$, $SD =$ 0.95), at the post-measurement. This difference was significant ($t(506.69) = 3.03$, $p = .003$). Less exhaustion was found in the experimental condition compared to the control condition in general. The results are graphically represented in Figure 5.

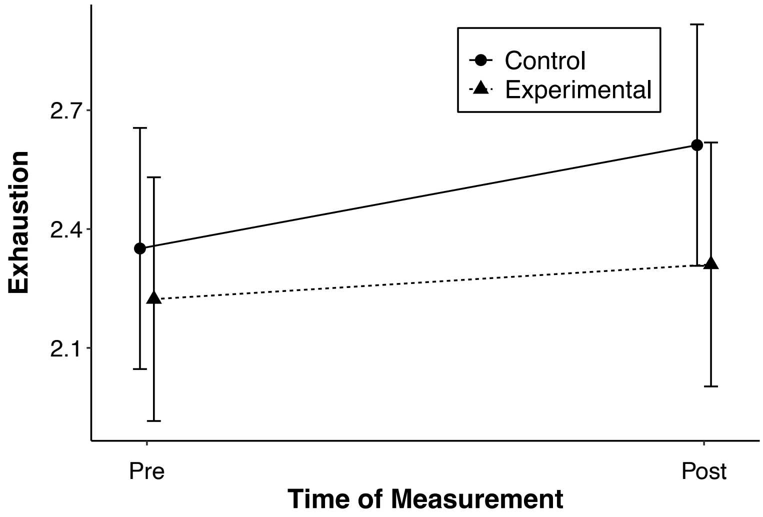

Fig. 5. Time of measurement*treatment effect plot for exhaustion. Means before and after shift for the experimental and control condition. Error bars represent 95% confidence intervals.

Discussion

Besides the investigation of the SLOS-effects on noise and stress, it was a goal to evaluate the SLOS concerning its acceptance among the staff, as a low acceptance could change the interpretation of the findings. The three constructs (*SLOS Technical Acceptance*, *SLOS Acceptance, SLOS Communication*) that were built to investigate this topic termed Technical System Evaluation, show means that are all above the center of the scale, that is 4.38 (center at 3.5) concerning technical acceptance, 4.03 (center at 3.0) for the SLOS acceptance based on the TAM2[37] and 5.10 (center at 3.5) for SLOS acceptance concerning communication. These results show that the system is well accepted by its users. Furthermore, the users wanted to continue working with the SLOS once they have learned about its features. The score of the corresponding facet of SLOS acceptance – intention to use – is 4.42 (center at 3.0) and therefore near the maximum of 5. Solely the comfort of the neckband microphone is not consistent with the consistently positive acceptance scores, as the test subjects judged its comfort with a rating just under the center of the scale of 3.5, which is between a little uncomfortable and a little comfortable. Possibly the separate microphone set-up should be reconsidered concerning the future use, as the user were not strongly convinced. In general, the results for the acceptance and comfort suggest that the SLOS is integrated well into the working day and is not perceived as disturbing or awkward but as a useful support.

The replication of the noise reduction effect in the working area[18] failed, as there was no difference between the conditions concerning the dB(A) measurement in the laboratory. The SLOS does not change the noise in the room. Nevertheless, in both conditions the dB(A) levels were exceeding the mentioned WHO recommendations[4–6] confirming the noise issue in the context of medical laboratories. This implies that helpful solutions are needed, as consequences of noise are detrimental on performance[7,8,12] and health[1–3] of the medical laboratory staff. However, the SLOS does reduce noise for the user objectively via its technical headphone proprieties like the active and passive noise canceling effects[16]. This means that even though the noise level in the room is objectively not changed by the SLOS, it is changed for the SLOS-user[16]. This objective noise reduction is confirmed by the subjective noise perception results of this field study. The effect size of $r = 0.75$ displays a large effect, which shows that SLOS causes an appreciable improvement of working conditions for the laboratory crew. The result indicates that the noise level in the medical laboratory is primarily generated through machine and environmental sounds. As the consequences of noise are mostly relevant to the humans working in this context, the H1 can be accepted as the SLOS lowered noise perception for the users. Equally to the SOTOS, the SLOS is confirmed as a tool to reduce noise for the users, which they also subjectively perceive.

Since the laboratory crew is exposed to notable noise, it seems in line with the illustrated stress theories[15,19] that the measured stress level should be beneficially moderated by the SLOS. For the stress analysis, subjective and objective measures were considered. Regarding the subjective measures, the claimed correlation between the STAI and the Perkhofer Stress Scale[27] was confirmed in this study, which substantiated the decision to integrate both measures into one composite score. A stress-reducing effect of the SLOS is consistently suggested by the results of the analysis of all subjective measurements, whereas this is not supported by the analysis of the objective stress criterion cortisol. The relationship between salivary cortisol and self-reported stress remains unclear. A meta-analysis showed inconsistent findings on the relationship between salivary cortisol and self-reported stress[39]. Consistent with our results, two studies found no significant correlation between salivary cortisol and perceived stress in a healthy population at work[40,41]. It seems that unexpected work-related stressors trigger a significant salivary cortisol response, whereas, work-related stressors to which workers are accustomed are not associated with evoking a salivary cortisol response, possibly because of habituation processes[40]. Remarkably, no significant cross-sectional and longitudinal relations between salivary cortisol and perceived stress measured via the PSS have been found[42]. Also associations of salivary cortisol and self-reported stress via STAI are not always found[43]. In addition, salivary cortisol levels are influenced by light exposure. Greater exposure to daylight results in a higher morning-cortisol peak[44]. The salivary cortisol samples of the control condition were mainly collected in January. The data collection of the experimental condition ran until March with greater daylight exposure in the morning. This could bias potential SLOS effects on the salivary cortisol levels of medical laboratory workers. As psychosocial stress is only one potential trigger for cortisol release[45], a different variable, like heart-rate variability[14], may have served as a more valid stress marker. An alternative explanation for the results could be that the cortisol analysis is a valid representation of stress and that the subjective measurements are biased or confounded for example by social desirability or acquiescence. However, a strength of this field study might be the fact that multiple stress measurements were integrated. As all subjective measurements lead to matching implications it seems likely that the multiple subjective measures have a higher informative value than the debatable variable cortisol level.

Due to the assumed supremacy of the subjective indicators, it is concluded that the system provides a benefit for the medical laboratory crew. A reduction in the stress composite score over the course of the shift was found when using the SLOS, compared to an increase for the control condition, which underlines the positive impact of the system regarding the stress composite score. As the significant interaction is disordinal, the main effects are not to be interpreted. In contrast to expectations, a significant difference was found at the pre-measurement, in which a higher stress composite mean was found in the experimental condition, whereas at the post-measurement no difference was found between treatment conditions. One possible explanation for the higher pre-level in the experimental condition could be that the staff’s unfamiliarity with the system triggers a stress response. It was shown that unknown technologies can lead to an activation of the sympathetic stress response[46].

However, results of both experimental and field research display that new technology is not necessarily a stress source[47].

An alternative explanation for the difference before the shift, may be found through a methodical reflection of the field study setting. Due to practical reasons, the first four weeks of the field study were conducted without the system, followed by a four-week period with the SLOS. This set-up comes with the disadvantage that global changes in the environment can systematically influence the stress outcome, as for instance political changes or intensification of global conflicts can affect the everyday life of large parts of the population. Individual stressors were supposed to be balanced out throughout the study, but global events in the last four weeks could account for the observed higher stress levels. Ultimately these explanations remain speculative. Because there is no definitive answer to this question the focus of this study was laid on the development of the level of the composite stress score from pre to post measurements, which was found to be positively modified by SLOS as the significant interaction, leading to a stress reduction in the experimental condition compared to a stress raise in the control condition.

In terms of the PSS this effect seems to be confirmed, as the mean in the experimental condition is significantly lower than the mean in the control condition. The stress-relieving effect of the SLOS does not only seem to be relevant on a daily basis, as the analysis of the stress composite score showed, but also on a monthly scale, for which the PSS was integrated into the study. The effect size of the construct representing the daily stress, namely the stress composite score, is small, whereas a large effect was found for the long-term stress measurement of the PSS. Possibly the stress-reducing effect accumulates over the daily measurements leading to a larger effect for the PSS.

Concerning the stress outcome variable[36] exhaustion, it was shown that the staff was significantly more exhausted after work than before, even though the observed effects were rather small. While both conditions started from a similar level at the pre-measurement, the workers in the control condition were significantly more exhausted after the shift than the test subjects working with the SLOS. Additionally, the significant main effect shows that the SLOS causes a lower exhaustion level for the workers in general and not only after work.

As all subjective stress measures conform to the hypothesis, the conclusion can be drawn, that the system is a tool which enhances the daily working comfort in terms of stress reduction for the medical laboratory staff. The measure of the perceived noise also supports this verdict about the SLOS as a helpful working tool. Since the multi measurement approach of this study leads to consistent findings it can be strongly presumed that the results are valid. Here, the SLOS was firstly evaluated in the context of a medical laboratory, which means that more field studies in other laboratories and other noise-polluted work settings would deepen the understanding of the working mechanisms. As for this study it was shown that the noise levels in the medical laboratory are higher than given standards by the WHO. The SLOS did not reduce the noise levels in the room, but as its technical properties reduce noise for the user via active and passive noise canceling[16] it could be shown that the subjective noise reduction was successful. Concerning stress, all measures but cortisol reacted beneficially to the system, which leads to the conclusion that the SLOS is a noise and stress reducing tool.

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4 General Discussion

In the following chapter all articles from the SOS project, with the main focus on the three articles included in this dissertation, are reviewed. These results are combined with relevant studies and theories in order to make a decision concerning the four psychological hypotheses. When necessary, the results will be weighted, based on methodological reasons and relevance, to allow a decision. As the results discussion is partially dependent on methodological aspects, the discussion of methods is integrated into this chapter, instead of creating a separate chapter. The following chapter is structured along the four hypotheses that were formulated and theoretically founded in the theoretical background chapter. Results that concern variables which are not part of one of the four hypotheses are also integrated into the subchapters, as there is a connection to one of the hypotheses. The last subchapter includes the conclusion of the SOS project.

4.1 H1: SOS Reduces Noise

The SOS claims to be a noise reduction tool. The data supports this claim partially. It is important to differentiate between the noise reduction effect in the given room and the effect on the workers using the system. This differentiation is relevant because the noise in the room is based on a measurement of the sound pressure level and does not contain any subjective aspects about the noise perception of the workers. To include this subjective aspect into the measurement, the crew members were asked about their specific noise perception. This is especially relevant, as noise has a psychological component (for details see Chapter 2.1.1). First, the results concerning the noise in the room are discussed, followed by the results concerning the noise perception. In the end a decision about the H1 is made in Chapter 4.1.3.

4.1.1 H1.1: SOS Reduces Noise in the Room

The noise reduction effect was indicated by the observations that the surgical team developed a greater sense for quieter work and adjusted their behaviour towards quieter movements and actions, like carefully opening packages (Friedrich et al., 2017). Those observations were not systematically observed and coded, but rather implied by observations without a valid coding scheme. The implied effect was supported by a study done in the urological department, in which a 3.6 dB lower mean was found in the group using the SOS compared to the control group (Leitsmann et al., 2021). A critical issue here is that the calculation of the arithmetic mean is not feasible for dB measurements, because the sound pressure level is measured on a logarithmic scale. Therefore, those results have to be interpreted carefully. Both articles included in this dissertation did not find a reduction of this sound pressure level in the room, neither for the OT (Chapter 3.2) nor for the medical laboratory (Chapter 3.3). In both of these articles the energetic mean or the median was calculated in order to allow a comparison between treatment conditions, which is a valid way to conduct such a comparison. Therefore, two studies using a correct statistical methodology (Chapter 3.2 and Chapter 3.3) did not show the effect, one study (Leitsmann et al., 2021) found the effect with a suboptimal methodological approach and one study (Friedrich et al., 2017) indicated the effect. It can be concluded that the data site is not strong enough to accept the hypothesis that the SOS reduces noise in the room. Thus, H1.1 was rejected. However, the measurements in the room revealed that the noise situation in both settings is critical, as all studies showed noise levels above the WHO recommendations (Berglund et al., 1999; Clark & Paunovic, 2018; de Lima Andrade et al., 2021; Giv et al., 2017; J. D. Katz, 2014). For the issue of noise reduction, the more pressing matter is the situation for the workers in the investigated rooms. This includes the realized noise reduction in dB(A) (Friedrich et al., 2017) through the headphones and also the subjective noise perception.

4.1.2 H1.2: SOS Reduces the Subjective Noise Perception

Even though the noise reduction was not successful concerning the measurement in the room, it is still possible that the noise reduction was successful for the staff using the system, which would reveal itself in the subjective perception of the workers. The data support this claim. In the technical paper, concrete measurements were conducted, showing a noise reduction from the SOS of up to 33 dB for the user measured inside on-ear headphones (Friedrich et al., 2017). Additionally, the study investigating the SOS effects in a medical laboratory (Chapter 3.3) found a significant effect on the subjective noise perception of the workers, which was large ($r = 0.75$). Thus, H1.2 was accepted.

4.1.3 Findings and Conclusion

The given results show that noise in those working places is mostly generated by machine sounds, as they were not influenced by the SOS and no noise difference was found in the room. Some investigations led to small noise reductions in the room (Engelmann et al., 2014; Kahn et al., 1998; Leitsmann et al., 2021) showing that human communication can add a relevant part to the decibel level, which is not surprising as humans raise their voice in order to be understood in noisy environments (Silverman, 2006). Both investigations, the technical paper (Friedrich et al., 2017) and the study in the medical laboratory (Chapter 3.3), lead to the same conclusion, namely, a noise reduction for the user due to the SOS. With that in mind and considering that the workers are the primary target of the investigation it is plausible to give the accepted H1.2 a greater weight over the rejected H1.1. The SOS reduces noise for the workers in both medical contexts. As the subjective noise perception is affected by the system, it seems plausible that this would enhance the primary appraisal of the users concerning stress. This will be investigated in the next chapter.

Since the evaluation of noise differences by a comparison of arithmetic means via a t-test comes with some problems, the impact of which is not completely obvious (Leitsmann et al., 2021), the method to discover noise differences was changed to a more conservative approach during the project. The power of this approach is smaller because the arithmetic mean was replaced by the median in Chapter 3.2 and the energetic mean in Chapter 3.3 and a non-parametric test was used. The lower test power may be an explanation for why no differences were revealed in later studies of the SOS project between experimental and control group for the dB(A) comparison measured in the room. Besides the possibility that the effects of the SOS on physical sound pressure are too small to be detected in samples with limited sizes, approaches that take the psychological aspects into account seem preferable. As explained in Chapter 2.1.1 the question of whether a person perceives a sound as noise can be independent from the physical dB(A) measurement (Waye et al., 2002), as the definition of noise includes a psychological component that may vary between individuals (Hornby, 1995; Molnar, 2005). The relevance of the subjective component led to the integration of the subjective measurement in addition to the physical dB(A) measurement. In future research considering the evaluation of technical tools on noise, the methodological advances that were made during the SOS project could be helpful. It is recommended to include three different measures for a proper assessment of the effects of technical devices on noise: The first being the dB(A) measurement in the room of implementation (Leitsmann et al., 2021), the second being the dB(A) measurement inside the ear (Friedrich et al., 2017), and the third being the subjective perception of the user (see Chapter 3.3). Analyses of differences in dB(A) measurements should be done without parametric tests. Considering these developments, this dissertation can provide some help in this complex interplay between physics, statistics, and psychology.

4.2 H2: SOS Reduces Stress

Employment in a hospital and working in an OT is a stressful occupation (Balch et al., 2010), as the workers are regularly exposed to multiple stressors like bleeding of the patient, distractions like noise, time pressure management and equipment problems (Arora, Sevdalis, et al., 2010). This high stressor exposure raises the probability of adverse health effects on the workers (see Chapter 2.2.5) and too much stress is reducing performance (Arora, Tierney, et al., 2010), according to the Yerkes-Dodson law (Broadhurst, 1957). As work in the OT is already highly stressful (Balch et al., 2010), a stress reduction via the SOS would constitute a beneficial modification, as it could lead to a transition from a high to a moderate stress level, which is supposed to be optimal for performance (Broadhurst, 1957). Therefore, it is of interest to find stress reducing options for the workers.

Chapter 2.2.6 showed evidence to believe that noise is a stressor. If that is to be believed, a noise reduction is supposed to lead to a stress reduction for the workers. This was investigated in two studies throughout the SOS project (Leitsmann et al., 2021; Meyer-Lamp et al., 2021) and in two studies of this dissertation (Chapter 3.1 and Chapter 3.3). The bio-psycho-social model (Chapter 2.2) is currently the state-of-the-art perspective for human health. This model claims that psychological factors play a role even though the stress reaction is also physiological. It was one aim of this dissertation to investigate both facets of the stress construct and therefore, subjective measurements were used next to physiological measurements. This is a strength of this dissertation and the SOS-project, as a combination of subjective and objective intraoperative stress assessments is rare (Rieger et al., 2014).

4.2.1 H2.1 & H2.2: SOS Reduces Subjective Stress & Exhaustion Perception

As expected, the SOS is not only a noise reduction tool, but also a stress reduction system, as far as the subjective measurements are considered (H2.1). One study found a stress and exhaustion reduction for SOS-users in urological prostatectomies (Meyer-Lamp et al., 2021). This was confirmed by a study of this dissertation comparing urological surgeries to heart surgeries in their SOS-effects, showing a similar picture with a significant stress and exhaustion reduction in the experimental group compared to the control group with no differences between the surgery types (Chapter 3.1). For the study in the medical laboratory (Chapter 3.3) the stress measurement was further developed, as here more stress parameters were integrated leading to a higher validity of stress assessment. The PSS (Schneider et al., 2020), the STAI (Grimm, 2009), the Perkhofer Stress Scale (Buchberger et al., 2019) and the exhaustion subscale from the Leipzig Mood Questionnaire (Hinz et al., 2002) were used to investigate the subjective assessment of stress. The results of the comparative study in the surgical context (Chapter 3.1) were supported by the stress and exhaustion reduction in the medical laboratory (Chapter 3.2).

Across studies, the effect of the SOS appeared primarily as an interaction between the post-pre measurement difference and the treatment condition. This pattern appeared in three (measurement of stress level in the OT, measurement of exhaustion in the OT, measurement of stress composite score in the medical laboratory) out of four statistical test situations. The only exception was the measurement of exhaustion in the medical laboratory (Chapter 3.3). In this setting, the described interaction was graphically visible but not statistically significant. Here, the main effect of treatment is supporting the hypothesis that a SOS effect exists. The replication of the described pattern across the studies is a strong reference for the existence of a SOS effect. The results concerning those subjective measures of stress and exhaustion lead to the acceptance of H2.1 and H2.2. The SOS reduces subjective stress for the users. Additionally, it was shown that the STAI and the Perkhofer

Stress Scale are significantly correlated. This dissertation has therefore supported the validation of the newer Perkhofer Stress Scale confirming its convergent validity (Buchberger et al., 2019).

According to the bio-psycho-social perspective (see Chapter 2.2.1) and the transactional stress model (Lazarus, 1966, 1974; Lazarus & Launier, 1981) the subjective appraisal as a psychological factor is decisive for whether a stress reaction will follow on a biological level. Therefore, it was expected that the physiological measurements will react similarly to the SOS, showing a physiological stress reduction.

4.2.2 H2.3: SOS Reduces Physiological Stress

The investigation of physiological variables concerning the stress reaction is connected to additional practical and financial investments. Therefore, it was not always possible to implement those measurements. Nevertheless, two studies were able to integrate physiological measurements into their study with heart rate measurements of OT-workers during surgeries in urological prostatectomies (Leitsmann et al., 2021) and with the elicitation of cortisol levels of medical laboratory workers (Chapter 3.3). In both cases, no difference was found between the experimental and the control group. This can mean that the SOS did not lead to a reduced physiological stress reaction for the workers using the system. That would raise the question of why the system led to a subjective stress reduction but not to a physiological one, as the subjective appraisal should precede the physiological stress reaction (see Chapter 2.2.3). As eight different measurements of subjective constructs were used compared to two physiological measures, it would be logically sound to weigh the subjective measures more, in order to derive to a decision concerning H2. This idea is supported by a closer examination of the two physiological measurements used.

In the first approach (Leitsmann et al., 2021), the heart rate was used as an indicator for stress and no difference between the treatment conditions was found, with the exception that the circulating nurse group showed a significant reduction in maximal heart rates when using the system. The authors explain in the discussion section that heart rate alone is not a perfectly valid operationalisation of stress. Also, a high rate of movement artefacts was found, which can have led to biases in the results (Leitsmann et al., 2021). This was also the reason why heart rate variability, as a more valid stress measurement (Järvelin-Pasanen et al., 2018), could not be used (Leitsmann et al., 2021). When heart rate is used exclusively, physical activity and mental stress are indistinguishable, making it difficult to derive implications (Pagani et al., 1989; Payne & Rick, 1986). A systematic review focusing on heart rate variability showed that no consistent measurement for this approach of a stress measurement is being used right now either (Järvelin-Pasanen et al., 2018). This highlights the complexity of the construct stress and how difficult it seems to correctly measure the physiological component via heart rate or heart rate variability. As heart rate variability is superior to the heart rate measurement (Järvelin-Pasanen et al., 2018), future research should try to evaluate the SOS with this measure, additionally to others.

Next to heart rate, the last article of this dissertation included salivary cortisol as a measurement of stress. It is a non-intrusive marker of stress and is supposed to increase with psychological stress (Stroud et al., 2002) and also with stress in surgery (Jezova et al., 1992). No significant stress reduction was found in the medical laboratory as no significant difference was found between the experimental and control group. However, studies have also shown that salivary cortisol levels do not always correlate significantly with the subjective stress assessment, leading to an uncertain conclusion about the relationship between cortisol markers and subjective stress markers (Gonzalez-Cabrera et al., 2012; Hjortskov et al., 2004; Karlson, Björn et al., 2012; Mikkelsen et al., 2017; Sjörs et al., 2014). Cortisol is secreted in the last iterative step of the HPA activation (see Chapter 2.2.2). The complexity of variables influencing the HPA activation is enormous and as factors other than stress may elicit such a cortisol secretion (Ellison, 2017), it is not a perfectly valid approach to rely exclusively on cortisol. Another approach was suggested in a study, which states that ACTH, total cortisol in blood and salivary cortisol measures should be used for a more valid approach (Hellhammer et al., 2009). This way the complex mechanisms can be better understood and observed. A disadvantage of this approach is the high practical investment and taking blood samples can in turn be stressful for the test subjects because of the venepuncture (Bozovic et al., 2013; Pollard, 1995), whereas the saliva cortisol approach is practical and non-invasive (Pollard, 1995) and therefore favourable for certain study designs like ambulatory assessments or other field studies (Jessop &

Turner-Cobb, 2008). Another problem is that unexpected stressors at work seem to trigger a relevant salivary cortisol reaction, but expected or typical work stressors do not always trigger this reaction, potentially due to habituation processes (Karlson, Björn et al., 2012), which may explain the null finding in the medical laboratory study, as noise is constantly present (see Chapter 3.3). This is also supported by the fact that psychosocial stressors are more relevant for the stress response. It was shown in the literature that those stressors which are perceived as a social-evaluative threat, induced the strongest physiological stress reaction in terms of HPA activation if they are new, not controllable or ambivalent (Dickerson & Kemeny, 2004). In contrast to that, studies showed that cortisol responses are rarely reactive to passive physical laboratory stressors like cold temperatures (Schwabe et al., 2008; Smeets et al., 2012). If this finding can be transferred to noise it is possible that the cortisol measures did not react to the reduction of the chronic noise stressor.

Another biasing factor is the light exposure which constitutes a problem concerning the study in medical laboratories, as in this within-subjects design the experimental condition followed four weeks after the control condition, leading them to work in the experimental condition with more sun light exposure during the day. This may bias the results as higher exposure to daylight is associated with higher morning cortisol levels (Scheer & Buijs, 1999).

In the end it seems that as stress is only one trigger for cortisol secretion this measure alone is not optimal (Ellison, 2017). A review focusing on cortisol measures for stress states that across studies, anomalies, inconsistencies and even contradictions exist, which leads to confusion about the salivary cortisol measurement (Jessop & Turner-Cobb, 2008). As both physiological measurements in the SOS project did not show a significant difference concerning the comparison between the experimental and the control group, H2.3 was rejected.

4.2.3 Findings & Conclusion

The expected SOS effect is likely to be small, as the work of the surgical and medical laboratory crew is connected to various stressors (Arora, Sevdalis, et al., 2010), from which the noise stressor is reduced through the system. As will be argued in the discussion concerning the communication enhancement (see Chapter 4.3) another stress relieving factor might be the effect of the SOS on communication, which is a newly developed hypothesis, which has not been tested yet and were further research is needed. It is likely that those potential effects might reduce the stress reaction for the workers, which are still likely to be stressed as other stressors are not addressed by the system. That is why a rather small effect is expected. This is supported by the finding that chronic stressors, like noise in the working place, lead to smaller stress reactions due to habituation processes and a higher predictability (for details see Chapter 2.2.4). It is possible that this small effect of the SOS on physiological stress was not revealed because of suboptimal physiological measurement, whereas the subjective stress response was affected and found due to a valid subjective measurement.

As uniformity concerning stress measurement is lacking (Arora, Sevdalis, et al., 2010), a study group developed the *Imperial Stress Assessment Tool* (ISAT). The authors included subjective measures like the STAI and two physiological measurements with heart rate and salivary cortisol (Arora, Tierney, et al., 2010). Across all studies the work in the SOS project has been consistent with the proposed ISAT-approach, as heart rate (Leitsmann et al., 2021), salivary cortisol and the STAI (Chapter 3.3) were included in the investigations. However, the suggested measures were not integrated into one study, but across different studies. Also, the authors claim that for team measurements their approach is not appropriate and here the integration of subjective measures like the STAI is recommended (Arora, Tierney, et al., 2010). It is a strength of the SOS project to have eight different subjective stress measurements including the recommended STAI. More physiological investigations would have been optimal, but practical constraints made this realisation unrealistic in the context of field studies. Most studies investigating the matter have been done under artificial conditions in skills labs instead of real surgeries or medical laboratories (Arora, Tierney, et al., 2010), which shows how important it is to close this gap and conduct studies in real working situations. Therefore, the SOS project focused on field studies accepting the disadvantage of lower internal validities across studies but benefits from a higher external validity.

A systematic review from 2022 found that around half of their investigated studies ($N = 104$) showed direct associations between every day acute stress exposure and physiological stress reactions, including cortisol levels and heart rate (Weber et al., 2022). The authors mention that this is to be interpreted carefully as the other half of the studies reported null findings regarding this association (Weber et al., 2022). The connection between subjective stress measures and objective physiological measures seems to need more research to make a compelling statement about their relationship. As a rather small effect of the SOS on stress was expected, it may be that the physiological measures were not sensitive enough to uncover this effect. In any case, H2.1 and H2.2 are accepted, whereas H2.3 is rejected based on the current data analysis. Concerning stress, the accepted H2.1 and H2.2 are to be weighed stronger than the rejected H2.3, as the subjective measurements in this project are more valid. However, as both recommended physiological approaches (Arora, Tierney, et al., 2010), heart rate and cortisol concentration, were included, the option that no physiological effect exists has to be considered. Due to the mentioned weighting, H2 is accepted with reservation. The SOS does reduce subjective stress for the workers in the OT and the medical laboratory, but the current data does not allow to say that about the physiological stress reaction. More research is needed to explore the SOS effect on the physiological stress pathways.

4.3 H3: SOS Enhances Communication

The SOS does not only claim to be a noise and stress reduction tool, but also a communication management system. In the following discussion the focus of the investigation of H3.1 – H3.3 will lie on the given communication data from the 22 heart surgeries (Chapter 3.2), whereas H3.4 and H3 are investigated across all studies. Within the 22 heart surgeries (Chapter 3.2) the two last phases of five were investigated, as it was relevant to analyse a critical phase (phase 4) and the last phase of surgery with routine work (phase 5). This was important because an effect of CIC and CRC occurrence in those phases was found to be connected to a SSI reduction (Tschan et al., 2015).

It was of interest, whether the SOS would enhance the communication in the investigated surgical team. As communication is a complex construct it was a challenge to find markers for an enhancement of communication. The decision concerning the markers used in the first three hypotheses, namely less communicative utterances (H3.1), more CRC in general (H3.2) and less CIC in the last phase (H3.3), were derived from previously published studies (Seelandt et al., 2014; Tschan et al., 2015; Widmer et al., 2018) and were also created because evidence suggests that they are relevant for the reduction of SSIs, which are used as a performance marker. This performance parameter in the OT seems to be influenced by the mentioned communication frequency and patterns (Asadi et al., 2019; Seelandt et al., 2014; Tschan et al., 2015; Widmer et al., 2018). Additionally, the communication effects of the system were investigated with questions in the SOS acceptance domain in the medical laboratory, asking whether the system allowed the promised high-quality communication via its technical properties (H3.4). The study investigating heart surgeries (Chapter 3.2) adds substantial value to this communicational research question, as the management of the medical laboratory did not allow to record the communication of their workers.

4.3.1 H3.1: SOS Reduces Communicational Utterances

The results show that the workers spoke less when using the system (H3.1). As the amount of communicational utterances is positively correlated to the microbial load in the room (Z. Liu et al., 2019; McHugh et al., 2014; Tammelin et al., 2013), a reduction might be beneficial, as a lower microbial load reduces the probability of SSIs (Chauveaux, 2015; Z. Liu et al., 2019; McHugh et al., 2014; Tammelin et al., 2013). On the other hand, it is important that all relevant information are communicated between the team members so that every worker can update their mental model of the given situation (Westli et al., 2010). This kind of communication would be classified as CRC since the relevant information would concern the given case (Widmer et al., 2018). Therefore, not all communication should be reduced. The system might represent an issue here, in so far as studies suggest that humans do not want to interrupt others in their workflow and routines (Harr & Kaptelinin, 2012). As the SOS ducking mechanism quiets down the music of the receiver, it might be the case that sometimes information is not shared in order to not disturb the other in his/her music perception. A potential consequence could be implicit team coordination which is associated with suboptimal solutions in unexpected and complex situations (Riethmüller et al., 2012) as in surgery. On the contrary, too much information sharing and an increase in communication might lead to information overload and decreased performance (Johnston & Briggs, 1968). Therefore, it seems of interest to reduce the communication but allow for the relevant information sharing in terms of CRC, leading to the idea to reduce only CIC. It will be shown that a CIC reduction in general is also not always beneficial, as CIC has positive functions in the OT beside its distractive negative consequences (Wheelock et al., 2015), but that a reduction to a low level might be an optimal trade-off.

4.3.2 H3.2 & H3.3: CRC-CIC Patterns

In the investigated heart surgeries, the SOS did not lead to a higher CRC proportion in general (H3.2), but a significantly higher proportion of CRC was found in the critical phase four. At the same time the system did not eliminate the CIC proportion but reduced it, leading to a constant low level of CIC, with around 27% of CIC during all investigated phases, but not with less CIC in phase five (H3.3) in the experimental group compared to the control group. These findings show that the SOS did not lead to the empirically found beneficial patterns, which showed that more CRC in general and less CIC in the last phase are less likely to lead to SSIs (Tschan et al., 2015). Nevertheless, the communicational effects of the system might still be beneficial. Studies suggest that CRC is of heightened relevance in complicated phases of surgery (Mazzocco et al., 2009; Tschan et al., 2015) like the investigated phase four in which a significantly higher CRC proportion was found, when the SOS was used. That makes sense, as the team needs a shared understanding of the task and its requirements when critical decisions have to be made (Westli et al., 2010). Furthermore, the constant level of CIC might be beneficial since the positive effects of CIC on team climate (Nurok et al., 2011; Tschan et al., 2015) and stress relief (Bales, 1970) are discussed. It is important not to eliminate the CIC proportion because of its positive effects, even though a reduction might be favourable, as CIC is also a distraction at work (Wheelock et al., 2015). That is why the SOS seems to have a more beneficial effect than behavioural modification programs with rules suggesting to eliminate small talk completely (Engelmann et al., 2014).

The found stress reduction of the SOS discussed in Chapter 4.2, might also be driven by an optimal balance between CRC and CIC as stated by the equilibrium model (Bales, 1953), which proposes an equilibrium between socio-emotional interactions like CIC and task-oriented interactions like CRC for optimal performance of the team. More research is needed to find out if this allocation of CIC and CRC to socio-emotional and task-oriented interactions is valid. If that were true, the SOS would rightly be considered a communication management system with benefits. Chapter 4.2 showed that the SOS allows for a stress reduction. It remains speculative if the SOS reduces stress only due to the reasons discussed in the previous chapter, but maybe also because of its effects on communication. This led to the development of a new hypothesis, stating that the SOS might lead to a favourable balance of communication, which reduces stress according to the equilibrium model (Bales, 1953). This hypothesis has emerged from the results of the communication study (Chapter 3.2) and has yet to be investigated: Does the SOS lead to a constant communicational pattern which reduces stress?

4.3.3 H3.3: SOS Enables Technical High-Quality Communication

In order to derive to a conclusion concerning H3.4, information from a technical paper (Friedrich et al., 2017) and the study in the medical laboratory (Chapter 3.3) are discussed. It was shown that the clarity of communication was enhanced by the system, which is more essential for efficient communication than the sound loudness itself (Friedrich et al., 2017). Also, studies suggest that the speech quality is reduced by the surgical masks as they do not allow to see the mimic of the communication partner (Mendel et al., 2008) making clear communication more important in this specific setting and the SOS ideal to close this gap. The surgeons appreciated the speech transmission quality and communication comfort and a more relaxed tone was observed, possibly resulting from the limited need to raise the voice due to noise (Friedrich et al., 2017). Findings from the analysis of the SOS acceptance, which will be further discussed in the next chapter, support the notion that the SOS enhanced communication, as the overall audio quality of the system was perceived between the categories of *pretty good* and *extremely good* by the users. Also, the workers answered with high scores, 4.9, 5.2, 5.3 out of 6, to the questions if they could communicate in an unhindered way, communicate at all times and if they were sufficiently informed about the work of their colleagues via the system.

4.3.4 Findings & Conclusion

Finally, the three studies, with the technical study (Friedrich et al., 2017), the focus on communication in the OT (Chapter 3.2) and the study in the medical laboratories with questions about communicational quality of the system (communication effects), are used to answer the question whether the SOS enhances the communication. As significantly less communicative utterances were found in the OT, and the perception of quieter and more relaxed communication was mentioned (Friedrich et al., 2017), H3.1 can be accepted. The SOS reduces the communicative utterances. It has to be kept in mind, that a reduction of communication is not beneficial when the CRC proportion is reduced. The CRC proportion was investigated by H3.2, which is rejected as the SOS did not lead to a higher CRC proportion in total. It was revealed that no difference was found when both phases were investigated together. However, the follow up analysis showed a significantly higher CRC proportion in the critical phase four, in which a higher CRC proportion is rather beneficial (Mazzocco et al., 2009; Tschan et al., 2015). At the same time H3.3 is rejected as well, as the SOS did not lead to a lower CIC proportion in the last phase of surgery. Again, a closer look at the results reveals an interesting finding, as the CIC proportion is being kept constant between the surgery phases in the experimental condition. It seems that the SOS reduces the communication, raising the CRC proportion when it is beneficial in the critical phase and allowing a constant low level of CIC during surgery, with potential positive effects on team climate (Nurok et al., 2011; Tschan et al., 2015) and stress relief (Bales, 1970) while keeping its negative distractive effects (Wheelock et al., 2015) low. The SOS acceptance in the medical laboratory included a section about technical aspects of the communicational quality. All answers implied a very good quality of communication allowed by the system, leading to the decision to accept H3.4. The SOS enables technical high-quality communication.

So even though the postulated beneficial pattern with high CRC in general and low CIC in the last phase (Tschan et al., 2015) was not found, the SOS seems to enhance the communication. It is clear that the SOS affects communication. With less communicative utterances it could have a potential reducing effect on SSIs. The descriptive view on the data shows a reduced SSI occurrence in the experimental condition with five to one, compared to the control condition. Additionally, the SOS may enhance the communication via the mentioned pattern of high CRC proportion when it matters and a constant level of CIC, leading to a higher performance in critical situations while not reducing the team climate and allowing for a potential stress reducing effect. The stress reducing effect via communication constitutes a newly developed hypothesis, which needs more research. Two of the four hypotheses had to be rejected. This can only result in a rejection of H3. However, the found effects of the SOS are convincing. Therefore, the operationalisation of H3 should be questioned and potentially modified in further research. The SOS affects the communication, but does not enhance it in the hypothesised manner.

4.4 H4: SOS is Well Accepted

Next to the SOS effects on the dependent variables noise, stress and communication, it was of interest to investigate the SOS acceptance, as user acceptance is relevant for the successful integration and development of any new technology (Taherdoost, 2018), like the SOS. In order to do that an operationalisation was conceptualized and developed over the course of the SOS project. In the end, the technical acceptance, the specific SOS acceptance and the communication effects were used to investigate the matter in medical laboratories, where all mentioned variables were measured (see Chapter 3.3). In the beginning, self-made items asking about the acceptance and support were implemented (Friedrich et al., 2017; Leitsmann et al., 2021) which gave a first impression of the acceptance. Both approaches in heart surgeries and radical prostatectomies showed positive results.

In heart surgeries 95% of the surgeons and perfusionists reported very good acceptance scores and 5% reported it to be well accepted. In the subpopulation of the nurses 43% accepted the SOS very well and 57% accepted the system well. Within the anaesthetists 62% accepted the system very well and 29% accepted it well, leaving 9% rating it as fairly accepted. Therefore, it can be stated that the subjective acceptance of the SOS is high in heart surgeries (Friedrich et al., 2017).

In urological prostatectomies the whole team was asked about whether the system was a supportive or disturbing tool in one item with two opposite poles (extremely supporting, pretty supporting, little supporting, little disturbing, pretty disturbing, extremely disturbing). One participant (1%) felt extremely disturbed by the system, three felt pretty disturbed (4%), seven felt little disturbed (10%), four felt little supported (6%), forty felt pretty supported (56%) and sixteen felt extremely supported (23%). Only surgeons were asked the question if they would like to use the SOS the whole time. One surgeon (9%) answered that this was pretty applicable, and fifteen surgeons (93%) answered that this was extremely applicable. It was concluded that the SOS was highly accepted by the surgical team (Leitsmann et al., 2021) in the urological department.

Both results indicate a good acceptance of the system through their approach. Instead of only relying on unvalidated items, it was the demand of the SOS project to develop a more valid measurement. Therefore, the question used in prostatectomies was integrated into the technical acceptance variable, additionally to the items asking about the comfort of the earphones, and the microphone, and asking about the audio quality in general. Additionally, the specific SLOS acceptance, which was based on the valid and widely used TAM and the TAM2 (Venkatesh & Davis, 2000), was integrated. In the end, the already mentioned communication effects were used, which were mentioned in the discussion about the SOS effects on communication (see Chapter 4.3). In the investigation of the SOS acceptance in the medical laboratory the results show a high acceptance of the system, with all but one answer above the specific item centre. This anomalous item has to be mentioned, as the comfort of the microphone was below the item centre of 3.5, meaning that the users average answer was found between a little uncomfortable and little comfortable.

The idea to use a separate microphone additionally to the headphone, which are both connected with a wire to a body pack, is based upon the radio wave usage. The integration of a microphone within the headset and a connection via Bluetooth was not feasible in the time of the SOS development due to lag spikes. The delay between the spoken word and its perception by the addressee can impair communication. Nevertheless, newer technology like the model by Sennheiser RS 120-W allows a Bluetooth connection between headphones without such a delay (Wedekind, 2022). This way the radio wave approach could be discarded and allow a connection between users with digital rooms similar to the systems used for online meetings (Gunawan et al., 2021). This could give more flexibility to the team and/or the team leader while being user friendly and intuitive. The flexible approach was used in the study in medical laboratories, where always two workers were by default on the same frequency, which means that if they wanted to talk somebody else, they had to make themselves hearable on the other frequency and make the other person hearable on their frequency, which in turn always also affected the partner on the same frequency. Technical adjustments like the mentioned ones could improve the handling of the system and contribute to an improvement of the perceived comfortability, which was for example measured with the mentioned item above. The described approach constitutes a new hypothesis, which states that the Bluetooth approach with online rooms seems more user friendly, but there is no data to investigate this hypothesis yet. Further research is suggested to investigate the matter.

As to the development of the SOS acceptance it has to be said, that the foundation on the TAM (F. D. Davis, 1985, 1989) for the specific SLOS acceptance is an approach with a high validity. The other two variables were self-generated and should be psychometrically tested to allow a conclusion about their validity. Such a test validation is connected to a higher practical investment which was out of the scope of this dissertation. A weakness of this quantitative approach is that no direct practical implications can be derived from the questionnaire. It functions like an alarm signal, showing the researchers areas of issue, which need to be followed up on, potentially via qualitative approaches like interviews or observations. An example is the result concerning the comfort of the microphone. It is not clear what exactly the issue is with this part of the SOS and only further analyses can shed light onto the potential issue. Another weakness is that not all relevant variables were integrated into the measurement due to the limited time for questionnaires in field studies at work. Factors like the cognitive style of the workers, their personality traits or the availability of trainings or technical support are some other variables, which are not included, but have a potential effect (Dillon & Morris, 1996). A compromise was made in the SOS acceptance measuring, meaning that a measurement had to be developed while being constraint by the practical aspects of field studies and the SOS project. Nevertheless, the approach was refined over the course of the SOS project leading to a better measurement at the end of the project.

In general, the results for the SOS acceptance in heart surgeries (Friedrich et al., 2017), in radical prostatectomies (Leitsmann et al., 2021) and in the medical laboratory (see Chapter 3.3) show that the system was integrated well into the working day with a generally high acceptance of the users leading to the acceptance of H4.

4.5 General Conclusion

The three articles add knowledge to the pool of results by the previous SOS studies. The exact relationship of the SOS and performance remains speculative. One performance marker was the occurrence of SSIs, which was reduced in the experimental group. However, as statistical assumptions for tests were violated, also due to the reduced sample size, no statistical tests were permissible. The change in the SSI rate is interesting to take notice of and investigations of this relationship of the SOS, communication pattern and SSIs should be done in the future. Similar to this, the effect of the SOS on concentration remains unclear. It was shown that noise, stress, and dysfunctional communication can reduce concentration (see Chapter 2). One study investigated this effect and did not find a significant concentration enhancement in the experimental group (Meyer-Lamp et al., 2021). However, this study did not consider the learning effect of the test subjects and additionally the concentration test was not done in the noisy environment of work, but in a quiet room. In the study within the medical laboratory (Chapter 3.3) a concentration test was also included but an analysis was discarded, as the practical constraints allowed only a within-subjects design with four weeks of control condition before four weeks of the experimental condition. Therefore, no valid interpretation of the test results can be made, as this approach makes it impossible to differentiate between the learning effect and a potential SOS effect. In the end, no conclusion can be made concerning effects of the SOS on concentration and more research is required to close this gap and investigate the connection to performance markers.

Concerning the investigation of the hypotheses a knowledge gain was provided. The SOS does reduce noise for the medical crew through its active and passive noise reduction and leads to a lower perceived noise level, as well. However, the noise level in the room is not changed by the system. Nevertheless, the noise levels were exceeding the WHO threshold, which suggests adverse consequences when no measures are taken. The goal of reducing the noise for its users was achieved and it can be stated that the SOS is a noise reduction tool. The interactional stress model suggests that a noise reduction would change the transaction between the user and the environment. This could lead to a stress reduction, which is consistent with other mentioned psychological models and factors.

It can be stated that all eight subjective stress measurements showed a stress reduction and that the two physiological measurements did not. Therefore, it was concluded that the SOS reduced stress for the crew. It remains speculative whether the expected small effect was not found due to suboptimal physiological measurement approaches or whether the SOS has no influence on those measures and why. A subsidiary result in this section was the significant correlation between the Perkhofer Stress Scale and the STAI, which supports the test validation of the Perkhofer Stress Scale. The communication was not enhanced in the hypothesised way, as the potentially beneficial pattern of higher CRC in general and lower CIC in the last phase was not produced by the system. However, the system led to a reduction of communication utterances and allowed for the claimed technical high-quality communication through its features. The reduced communication may decrease the microbial load in the room and potentially have a reducing effect on SSI, which was found in the sample but not tested. Also, another hypothesis was developed, as the stress reducing effect of the system was shown, and the newly found communication pattern, with more CRC in the critical phase and constant low level of CIC, may reduce stress according to the equilibrium model. More research with larger samples is needed to investigate the connection between less communication and SSIs and to secure the new stress-communication hypothesis, as patient safety might profit. The SOS was accepted throughout all investigations, with only the comfort of the microphone being suboptimal. In conclusion, it can be stated that the SOS is a noise reduction tool and communication management system, which reduces stress and is well accepted by medical crews.

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Curriculum Vitae

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Education

04/2020 – to date **Georg-August-University School of Science (GAUSS)**
Ph.D. Program
Keywords: Industrial Psychology, Field Research, Communication, Stress
Final Title: Dr.rer.nat.

10/2019 – to date **WSPP at the Georg-August-University Goettingen**
Training in Psychological Psychotherapy
Behavioural & Cognition Therapy including third wave approaches
Final Title: Psychological Psychotherapist with German Approbation

10/2017 – 10/2019 **Julius-Maximilians-University, Würzburg**
M.Sc. Psychology (German Grade: 1.0; GPA estimate: 4.0; with honors)
Thesis: Evaluation of the Noise Reduction Intervention SOTOS on Stress and Performance of Staff in Operating Rooms.

08/2018 – 05/2019 **University of Texas, Austin (USA)**
Psychology Major (GPA: 4.0)
Tuition-Waiver scholarship

10/2014 – 09/2017 **Georg-August-University Goettingen**
B.Sc. Psychology (German Grade: 1.2; GPA estimate: 3.7; with honors)
Thesis: Validation of a Database Test Battery for Team-Building Optimization Processes.

10/2010 – 09/2014 **Georg-August-University Goettingen**
B.A. English & Athletics (German Grade: 1.8; GPA estimate: 3.3)
Thesis: To the Interrelation of Food Behaviour and Effects of Resistance Training in Leisure Sport.

2002 – 2009 **High School: Gymnasium Goetheschule, Einbeck, A-Levels**
2006 – 2007 **Coppell Highschool, Dallas, TX (USA)**
2000 – 2002 **Sohnreyschule, Einbeck**
1997 – 2000 **Primary School No.1, Poznań (PL) & German Distance Learning School**
1996 – 1997 **Pestalozzischule Primary School, Einbeck**

Research & Project Experience

04/2020 – to date **Research Associate at the Georg-Elias-Müller Institute of Psychology in the Department of Social Psychology & Communication**
Doctoral research associate. Tasks include teaching (see separate section), administrative activities, and research. Research: Coordination of interdisciplinary project team, theoretical work and study design, technical assistance and preparation in data collection and management, data analysis (quantitative), preparation, editing, and submission of publications (articles, conference talks, etc.). Administrative activities: Project acquisition, coordination of student groups and counseling of students, exam management support.

05/2019 – 10/2019 **Alcohol Project at the Julius-Maximilians-University, Würzburg**
Seminar Project: Theoretical work and study design, data collection and management, data analysis (quantitative). Coordination between different subgroups of the project. Manuscript writing.

01/2017 – 05/2017 **Project at Malamut Team Catalyst GmbH**
Tasks included administrative activities, and research. Acquisition of different national and international firms for team analysis and team development. Theoretical work and study design, data collection and management, data analysis (quantitative).

Teaching Experience

04/2020 – to date **Teaching of a Seminar for Master Students (6C), University Goettingen**
Teamwork and Leadership in Organizations **(M.Psy.602)**
Fundamentals and processes of teamwork and leadership in economic contexts will be taught. Students use theoretical models to derive intervention methods. Organizational psychological diagnosis and intervention methods will be compared and used in practical projects.

04/2020 – 11/2022 **Teaching of three Seminars for Master Students (6C), University Goettingen**
Communication and Coordination of Teams **(M.Psy.601)**
Students developed own research projects in groups on questions concerning communication and coordination of teams in organizations and prepared and implemented interventiona within the firm or organization. Research-oriented teaching with practical projects. Teaching presentation skills in pitch and final presentations. Manuscript correction.

04/2020 – to date **Student Supervision of Bachelor and Master Students**
Supervision of five Bachelor and five Master theses
Supervision of multiple internships & individual students

Publications

07/2022	**Article 1: Published in Thoracic and Cardiovascular Surgeon Journal by Thieme** Lehrke J, Boos M, Cordes A, Leitsmann C, Friedrich M. Effects of a Technical Solution on Stress of Surgical Staff in Operating Theatres. Thorac Cardiovasc Surg. 2022 Aug; 70(5): 392-400. doi: 10.1055/s-0041-1741059. Epub 2022 Feb 2. PMID: 35108735.
02/2023	**Article 2: In Revision at the British Medical Journal of Quality & Safety** Lehrke J, Boos M, Lauff S, Friedrich M. Impact of the Headset Tool SOTOS on Communication in Heart Surgeries in a Randomised Field Study. BMJ Quality & Safety. 2023 Feb; under revision.
02/2023	**Article 3: Accepted by Laboratory Medicine Journal of the Oxford University Press** Lehrke J, Lauff S, Muecher, J, Friedrich M, Boos M. Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise and Stress of Medical Laboratory Workers. Laboratory Medicine. 2023 Feb; accepted.

Conference Talks

07/2022	Mücher, J., Lehrke, J., Friedrich, M., Lauff, S. & Boos, M. (2022). Silent Laboratory Optimisation System: Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise and Stress of Medical Laboratory Workers. Presented at the 15th Int. Workshop on Behavioural Science Applied to Surgery, Kopenhagen, Denmark.
07/2022	Lehrke, J., Friedrich, M., Lauff, S. & Boos, M. (2022). Silent Laboratory Optimisation System: Effects of the Noise Reduction and Communication Management Headset System SLOS on Noise, Stress and Concentration of Medical Laboratory Workers. Presented at the SODOC Wuerzburg, Germany.
07/2022	Lehrke, J., Friedrich, M., Lauff, S. & Boos, M. (2022). Silent Laboratory Optimisation System (SLOS) Effects on Stress & Concentration in a Medical Laboratory. SODOC Würzburg. (). Wuerzburg: Fachgruppe Sozialpsychologie der Deutschen Gesellschaft für Psychologie (DGPs).
07/2022	Friedrich, M., Lehrke, J. & Boos, M. (2021). Silent Operating Theatre Optimisation System SOTOS – A new noise reduction and information management system Effects on stress, concentration, well-being and communication of OT crews. 50. Jahrestagung der Herzmedizin. Virtuelle Tagung.
07/2022	Friedrich, M., Lehrke, J., Boos, M., Kutschka, I. & Elger, F. (2021). SOTOS – Ein neues Lärmminderungs- und Informationsmanagementsystem – Auswirkungen auf Stress, Konzentration, Wohlbefinden und Kommunikation des OP-Personals. Vortrag auf der 37. Jahrestagung der Deutschen Gesellschaft für Gefäßchirugie und Gefäßmedizin. Virtuelle Tagung.
07/2022	Boos, M., Hollstein, K., Lehrke, J. & Friedrich, M. (2019). Silent Operation Theatre Optimisation Systems (SOTOS ®) - Effects of a noise reduction system on stress, concentration, well-being and communication of OR crews. Presented at the 13th Int. Workshop on Behavioural Science Applied to Surgery, Amsterdam, Netherlands.

Work Experiences Outside of Academia

10/2021 – to date	**Therapie- & Beratungszentrum at the Georg-August-University Goettingen** Psychotherapist in Training Psychotherapy sessions weekly
01/2020 – 11/2021	**Psychiatric Hospital: Asklepios Goettingen** Clincal Psychologist in Gerontopsychiatry • Diagnosis and treatment of patients • Individual and group therapy • Cooperation in a multiprofessional team (physiscians, psychologists, social workers)
01/2016 – 06/2019	**Exhibition Company: ZEBRA Expo Experts, Poznań (PL)** Internship (Feb.-Mai 2018) & Consultant Activity: Project Management • Marketing and sales in the German market segment (Business Psychology)
03/2014 – 05/2018	**Volkswagen AG** Student Assistant: Various Assignments • Press Support (Wolfsburg, Hannover) • C-Level Support (Paris, Geneva, Frankfurt, Wolfsburg, Hannover)

Extracurricular Activities

08/2018 – 05/2019	**Voluntary Classes at the University of Texas, Austin (USA)** Classes: Abnormal Psychology; Philosophy; Human Sexuality; Behavioural Economics
09/2014 – to date	**Meditation Retreats** Benediktushof, Holzkirchen: Zen-Classes (W. Jäger, A. Poraj, R. Stiegler) Austin, Texas: Mindfulness, Compassion, and the Self (Prof. K. Neff) Online Classes: Mindfulness (J. Kornfield, Thích Nhất Hạnh)
08/2018 – 04/2019	**Volunteer Work for the College Soccer-Team, Austin (USA)** Sports Psychology, Mentoring
10/2015 – 04/2016	**Scientific Project: Scientific Teaching and Learning** Effects of Meditation of Decision Making
07/2009 – 05/2013	**Contract Player for Soccer Teams: Oberliga & Landesliga** Teams: BV Cloppenburg, SVG Goettingen, Goettingen 05, FC Grone

Skills and Achievements

Languages:	**German** (Native)**, English** (Fluent)**, Polish** (Native), Spanish (Low Basic)
EDP Skills:	**Microsoft Office** (Word, Excel, PowerPoint)**, R, SPSS**
Scholarships:	**Deutschlandstipendium Universität Goettingen (2017/2018)** Support program for high-achieving students from federal and private sponsors **Stipendium des Bayerischen Staatsministeriums für Bildung und Kultus, Wissenschaft und Kunst (2018/2019)** Program to support the internationalization of universities 2018/2019
Interests:	**Meditation, Literature, Athletics (Soccer, Surfing, Tennis), Writing**

Jan Lehrke, Goettingen, March 2023