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Design and Evaluation of an Interactive Individual Ergonomic Report for Surgeons

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Design and Evaluation of an Interactive Individual Ergonomic Report for Surgeons

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Abstract

Surgeons have been identified as one of the highest risk groups in healthcare to develop work-related musculoskeletal disorders (WMSDs). Especially the neck and shoulders are found to be at high musculoskeletal risk due to surgeons commonly operating in a static and awkward posture for a prolonged time. Raising ergonomic awareness has been found to favour postural improvement among healthcare professionals. This thesis therefore aimed to design and evaluate an individual ergonomic report as means for risk assessment and ergonomic education for surgeons. Hereby, two surgeons and two ergonomists were included in the design process for early user feedback. Thematic analysis was applied to analyse the user feedback and potential improvements were identified and performed. The final individual ergonomic report was evaluated as a material used in an individual educational session (i.e., the intervention group) and compared against the use of an ergonomic guideline (i.e., the control group). Each group consisted of two surgeons. Both questionnaire and semi-structured interview were used to evaluate the session. The results from the questionnaire showed similarly positive ratings on the user experience of both groups, but higher ratings were given on the perceived impact by the intervention group. The interview results also showed more positive responses by the intervention group in terms of the usability. Furthermore, facilitators and barriers for adopting ergonomic principles were collected from the surgeons. Multiple ways to improve surgical ergonomics as perceived by the surgeons were also identified, e.g., the use of ergonomic equipment, and implementation of stretch breaks in the OR. The results show the potential of an individual ergonomic assessment report as ergonomic intervention for surgeons to raise their awareness and knowledge about ergonomic principles which can contribute to decreasing their risk of developing WMSDs as well as improved surgical performance and patient safety. Future studies can regard further ergonomic risk parameters and incorporate practical instructions on ergonomic principles into educational ergonomic intervention.

Keywords

Surgical ergonomics, Risk visualization, Ergonomic awareness, Physical workload, Work-related Musculoskeletal Disorders, Usability evaluation

Sammanfattning

Kirurger har identifierats som en av de högsta riskgrupperna inom hälso- och sjukvården att utveckla arbetsrelaterade belastningsskador. Särskilt nacke och axlar har visat sig ha hög risk för belastningsskador på grund av att kirurger ofta arbetar i en statisk och ogynnsam kroppsställning under en längre tid. Att öka den ergonomiska medvetenheten har visat sig gynna en förbättring av arbetsställning bland vårdpersonal. Denna avhandling syftade därför till att utforma och utvärdera en individuell ergonomisk rapport som ett medel för riskbedömning och ergonomisk utbildning bland kirurger. Två kirurger och två ergonomer deltog i designprocessen och tidig användarfeedback samlades. Tematisk analys användes för att analysera användarfeedback och potentiella förbättringar identifierades och genomfördes. Den slutliga individuella ergonomirapporten utvärderades som ett material som användes i en individuell utbildningssession (dvs interventionsgruppen) och jämfördes med användningen av en broschyr på kirurgergonomi (dvs kontrollgruppen). Varje grupp bestod av två kirurger. Både frågeformulär och semistrukturerad intervju användes för att utvärdera utbildningssessionen. Resultaten från frågeformuläret visade lika positiva användarupplevelse betyg från båda grupperna, men högre betyg gavs på den upplevda effekten av interventionsgruppen. Dessutom identifierades faciliteter och barriärer för att anta ergonomiska principer från kirurgerna. Flera sätt att förbättra kirurgisk ergonomi som uppfattades av kirurgerna identifierades också, till exempel användning av ergonomisk utrustning och implementering av sträcknings pausar i operationssalen. Resultaten visar att individuell ergonomisk bedömningsrapport som ergonomisk intervention för kirurger har potential för att öka medvetenhet och kunskap om ergonomiska principer. Detta kan bidra till att minska kirurgers risk att utveckla arbetsrelaterade belastningsskador samt förbättrad kirurgisk prestanda och patientsäkerhet. Framtida studier kan ta hänsyn till ytterligare ergonomiska riskparametrar och införliva praktiska instruktioner om ergonomiska principer i pedagogisk ergonomisk intervention.

Nyckelord

Kirurgisk ergonomi, Riskvisualisering, Ergonomisk medvetenhet, Fysisk arbetsbelastning, Arbetsrelaterade belastningsskador, Utvärdering av användbarhet

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List of acronyms and abbreviations

APDF	Amplitude Probability Distribution Function
EMG	Electromyography
EVA	Exposure Variation Analysis
GNP	Gross National Product
HSE	Health and Safety Executive
IMU	Inertia Measurement Unit
KI	Karolinska Institutet
LBP	Lower Back Pain
MSD	Musculoskeletal Disorders
MU	Motor Unit
NPS	Net Promoter Score
OSHA	Occupational Safety and Health Administration
OR	Operating Room
RULA	Rapid Upper Limb Assessment
SULMA	Sustained Low-Level Muscular Activity
UK	United Kingdom
uMARS	User Version of the Mobile Application Rating Scale
UMUX	Usability Metric User Experience
WHO	World Health Organization
WMSD	Work-related Musculoskeletal Disorder

1 Introduction

There is an understanding that one's occupation can harm one's physical health and over-all wellbeing while the problem of developing dysfunctions of the musculoskeletal apparatus has been reaching broad relevance across the world: Already in 1985, the WHO (World Health Organization) has officially stated so called "Work-related Musculoskeletal Disorders" (WMSDs) as a global health issue containing multiple risk factors (1). Although numbers have decreased since the beginning of the century, still 24% of workers in the EU countries regard their occupation as harmful for their health (2). While some effects of WMSDs are obvious, such as the sensation of discomfort and pain which can lead to a decrease of work performance, an increase in the need for sick days and even early pension and disability, other consequences reach a larger scope (3,4): The rising amount of sick leaves and decreasing task performance lead to an overall reduction of productivity which results in not only the company's but also the national or global healthcare system's heightened economic effort for compensation of work performance. In the UK, the HSE (Health and Safety Executive) estimated an overall cost of £ 5.7 billion every year due to musculoskeletal disorders (MSDs) with an average of 17.8 lost working days per worker who reported sick leave (4). In Sweden, an estimated 1% of the GNP (Gross National Product) is used for compensations for disabilities and illness that have been associated with WMSDs (5).

For decades, MSDs have remained one of the most extensive health issues in industrialized regions around the globe (5,6). Surgeons are also affected by MSDs and there is a rising awareness of the scope of this problem (7). In various specialties, surgeons often suffer from musculoskeletal pain on multiple body sites, especially in the neck due to the static forward bending neck positions during operations. Their demanding physical workload has been associated with WMSDs which impacts their overall health condition (6,8,9).

Applying ergonomic methods for WMSDs is regarded as prevention measurement to minimize risk factors that are harming the worker (4). Intervention strategies in surgical ergonomics can be implemented via two different approaches, which are illustrated in Figure 1-1. The first aims at 'fitting the task to the human', which focuses on an ergonomically appropriate adaptation of the work environment and equipment (10). There have been many different studies of re-designing surgical adjunctive equipment to improve musculoskeletal health (11–13). One example is a new design of prismatic loupes. Many surgeons wear vision enhancing loupes and headlamps in the operating room and need to bend their neck forward to get a better view of the surgical field, which together lead to an increased torque in the neck. The prismatic glasses, which can refract the light and reduce the neck flexion, have been found to be advantageous for dentists and hygienists by reducing the strain and risks of developing MSDs in the neck (6-7).

The second ergonomic prevention approach deals with 'fitting the human to the task', which can be achieved through e.g., training the subject's style of working and physical capabilities (16). Studies have shown that the subject's knowledge and awareness of ergonomic practices can influence their occupational behavior, and a higher level of ergonomic awareness can lead to behaviors following ergonomic principles and decrease the risk of developing WMSDs (17,18). Multiple studies have stated ergonomic awareness as an important factor when implementing an ergonomic intervention in various occupations (4,10,19). In addition, intraoperative stretching exercises, so-called microbreaks, have also shown positive effects on reducing surgeons' fatigue and musculoskeletal discomforts after surgery (20,21). One study tested the effectiveness of providing individual risk reports as ergonomic education intervention for surgical residents/students and found positive impacts on their work postures (18). Still, there is a lack of knowledge about providing ergonomic education for surgeons regarding both the risks from awkward postures and prolonged low-level muscle activities, and potential preventive actions which they can take. Furthermore, it is of great interest to know the perceived facilitators and barriers among surgeons for improving ergonomics in the operating room (OR) and the ways to reduce WMSDs risks, in order to make changes and implement new practices in the clinical settings.

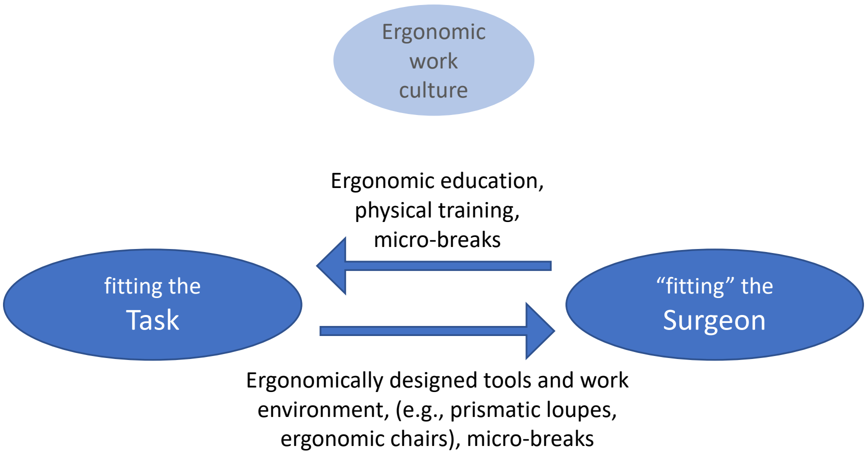

Figure 1-1 **Visualization of two approaches for intervention strategies in surgical ergonomics. Based on (16,22–24)**

Aims and practical implications

This degree project focuses on the design and evaluation of an interactive individual ergonomic risk report that is based on objective measurements of surgeons' workload in the OR. The interactive report was to be developed involving both end users and professional ergonomists and evaluated as part of an individual ergonomic educational session. Another aim was to identify the perceived facilitators and barriers as well as the ways to improve surgical ergonomics in the future as insights from surgeons.

This ergonomic intervention can contribute to better surgeons' wellbeing, career longevity, as well as improved surgical performance and patient safety. The project can furthermore support the evaluation and potential adoption of new types of ergonomic adjunctive equipment for decreasing the physical strain on the surgeons, and therefore preventing possible musculoskeletal injuries.

2 Methodologies

This degree project was part of a larger research project that examined the potential of new prismatic loupes on decreasing the physical strain and musculoskeletal discomforts of surgeons, the impacts on surgical performance, as well as the usability, compared to the non-prismatic loupes. The underlying methodologies of this project are sectioned into the information of the participants and the process of designing and evaluating the individual ergonomic assessment report.

2.1 Participants

Two groups of subjects took part in the study: The participants for giving user feedback on the demo version of the individual ergonomic assessment report and those who participated in the final ergonomic education session and evaluation. The first group consisted of two surgeons (one male, one female; median age of 55) who work at the Karolinska University Hospital in Stockholm and two ergonomists (both female; median age of 42,5) from the Center for Occupational and Environmental Medicine, Region Stockholm). The surgeons are both specialized in endocrine surgery. The second group was made up of four surgeons (four male; median age of 56) from the Karolinska University Hospital in Stockholm. These surgeons' specialties include ear, nose, and throat surgery (two surgeons) and endocrine surgery (two surgeons). One surgeon participated in both groups due to a limited number of available subjects. The inclusion criteria for all surgeons for participating in the measurements in the OR were: being comfortable to wear the new prismatic loupes in surgery; and being able to alternate for each surgical case between their own conventional loupes and the new prismatic loupes.

2.2 Design and evaluation process of individual ergonomic assessment report

The creation of a report from the results of the technical measurements of surgeon workload for each participant was conducted with the analytics software Tableau (Seattle, USA) for visualizing the data and providing possible interaction with the subjects. The making of the individual ergonomic assessment report was leaned on aspects of the approaches of participatory design and joint application design (1). This method uses active incorporation of the users iteratively during the different stages of the design process. Creating interaction between the designer of the report and its subjects (users) improves the quality of the results in aspects of creativity and comprehensibility. Since the ergonomic assessment report was used as an intervention for raising ergonomic awareness and to lay the foundation for improving the surgeons' ergonomic behavior and reducing risks of developing WMSDs, a collaborative design approach was chosen for optimized knowledge transfer. The design and evaluation process were therefore conducted in the following steps, which can be seen in Figure 2-1 and are described in detail in the following subsections.

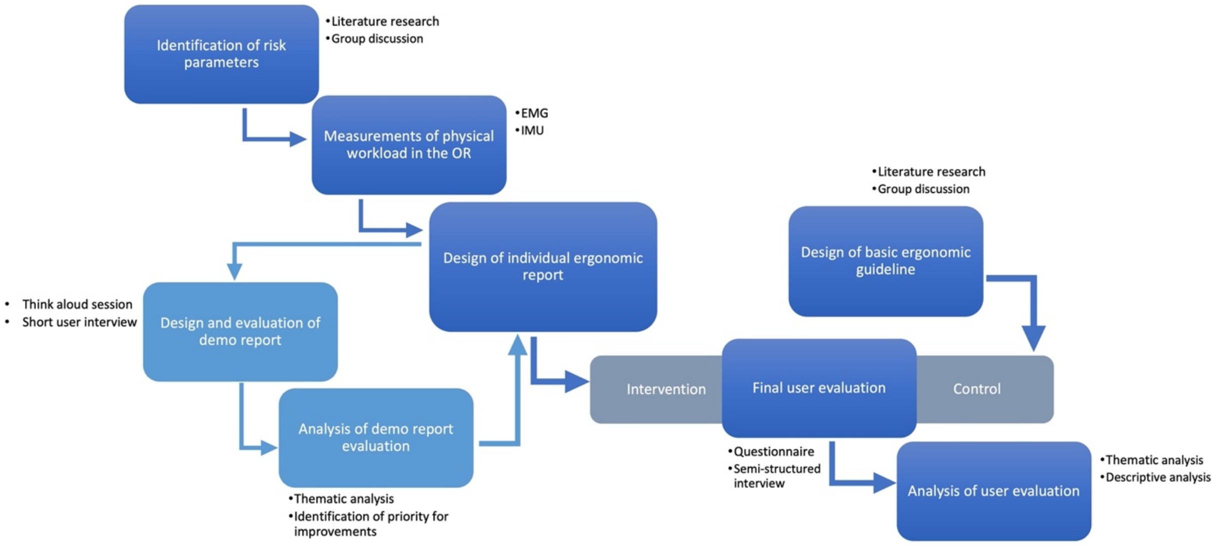

Figure 2-1 **Design and evaluation process of individual ergonomic assessment report**

Design of demo report

The purpose of this demo report was to acquire feedback from end users and experts early in the design process, which is further described in 2.2Usability evaluation of demo report. The report was designed using Tableau Desktop 2021.4 (Seattle, WA, USA), based on the technical measurements of surgeon workload using the IMU and EMG sensors from a pilot measurement in the OR. The possible interaction with the presented data is one of the advantages of Tableau. Since research in digital instruction has shown that interactivity with the content can increase the perceived learning outcome significantly, the report was designed with interaction elements (27). This was realized by integrating action buttons into the digital report, where the surgeon can choose between the muscle group of interest, the body part as well as the surgical case of choice. The demo report was designed as a Tableau Story, which is a series of sheets of data visualizations, that the user can click through. The design choices of the individual ergonomic report were taken considering comprehensibility, intuitiveness, and interactivity to increase the learning outcome when providing the report to each surgeon as an ergonomic education session. Part of the designing stage in Tableau was the prior identification of ergonomic risk criteria and other implementation choices such as the presentation mode and applied color schemes.

Definition of ergonomic risk criteria

The first step for designing the report was to define the ergonomic risk criteria to be included. This was done by group discussion and literature research. For the measurement data from the IMU sensors, the risk criteria were based on the validated observational method of RULA which provides four different risk scores for postural behavior (28). These scores grade the risk of the different body parts in relation to the postural angle. The RULA is originally used to evaluate risk levels based on observations and has been adopted in previous studies assessing surgeons workload using measurement data (29). In this project, the more accurate angle values from the IMU sensors are used instead. Adaptions to the original RULA angle cutoffs were made taking into consideration of possible motion artifacts from the IMU measurement. Therefore, a wider range of the flexion angle (-10° to 10°) of the neck and trunk was used to define risk score 1. The modified angle thresholds can be viewed in Table 2-1.

Table 2-1 **Modified RULA angle thresholds for risk evaluation of postural angles. (28)**

Risk score	Neck	Trunk	Upper arms
1	> -10° & <= 10°	> -10° & <= 10°	<= 20°
2	> 10° & <= 20°	> 10° & <= 20°	> 20° & <= 45°
3	> 20° & <= 60°	> 20° & <= 60°	> 45° & <= 90°
4	> 60° or <= -10°	> 60° or <= -10°	> 90°

For the data from the EMG sensors, the thresholds as suggested by Jonsson (30) for the trapezius were used as values in %MVC in relation to the 10th, 50th and 90th percentile. According to Jonsson, there were two limits for each EMG parameter, i.e., static load (the 10th percentile), mean (the 50th percentile) and peak load (the 90th percentile). The risk criteria can be seen in Table 2-2.

Table 2-2 **Risk criteria for different load patterns according to Jonsson stated in %MVC. (30)**

Risk criteria	Static load	Median load	Peak load
No risk	> 0 & <= 2	> 0 & <= 10	> 0 & <= 50
Should not exceed	> 2 & <= 5	> 10 & <= 14	> 50 & <= 70
Must not exceed	> 5	> 14	> 70

In addition, there is a cumulative risk for staying in low static muscular activity for prolonged time (see Appendix A.1.4) which were a common risk factor for surgeons. Therefore, another criterium was added to show and highlight this potential risk. Østensvik and his colleagues (31) defined SULMA (sustained low-level muscle activity) as uninterrupted muscular activity of over 0.5 % of the maximum EMG value for above 1.6 seconds. They proposed the threshold of 8 minutes of SULMA should not be exceeded due to a risk increase of developing pain in the neck and shoulders. These SULMA periods have been linked to an increased appearance of MSDs (32).

Usability evaluation of demo report

In the next step, the demo report's usability was evaluated with the 'think aloud' method combined with a short user interview. The demo report was thereby presented to a representative group of two surgeons and two ergonomists during individual in-person sessions which lasted about 20 to 30 minutes each. To achieve interactivity, the presentation of the report was therefore presented digitally via an iPad (Apple Inc, USA). The 'think aloud' method was applied to collect the participant's experiences by communicating their thoughts while interacting with the report (33,34). An oral informed consent was obtained from the participants to audio record the session. For collecting feedback from observations of the subjects' interaction with the report, the interviewer also took notes. The report interaction was followed by a short user interview, which included questions about redundant or missing information, possible areas of improvement and a question on preferred electronic devices for report presentation. The interview guideline can be found in the B.1 Appendix.

Analysis of demo report evaluation

The gathered user feedback from the recordings and notes from the 'think aloud' sessions were collected in an Excel sheet arranged for each segment (Tableau Story sheet). Thematic analysis was used to analyze the data and identify potential improvements of the demo report. It is commonly used for analyses of qualitative data and has been applied in studies on usability of digital applications before (33,35). Furthermore, the key themes were identified in a semantic way, focusing on their explicit meaning on the surface. This method includes the stage of collecting the data in a descriptive way and the interpretation of relevance of the thematic clusters.

Measurement of physical workload in the operating room

To measure the physical workload, quantitative data of muscle activity was obtained by using EMG as well as postural data from IMU sensors. Each participating surgeon was followed during a full working day. Figure 2-2 shows two surgeons during the data collection in the operating room (OR). At least two similar surgical cases needed to be performed and switched in between the conventional and the new prismatic loupes.

Figure 2-2 Technic measurement of surgeon physical workload in the OR with IMU and EMG

Measuring muscular activity with electromyography

Bipolar gel electrodes (Ag/AgCl electrodes, N-00-S/25, Ambu A/S, Copenhagen, Denmark) were put on the skin according to the European recommendation for surface EMG placement (36), as displayed in Figure 2-3. The EMGs were thereby placed bilaterally on the following six muscle pairs:

- Left and right neck extensor (placement at C3/4 level)
- Left and right upper trapezius (placement on 2 cm lateral of the middle distance between C7 and the lateral rear edge of the acromion on the shoulder blade)
- Left and right lumbar erector spinae (placement at two finger width distance or approximately 3 cm lateral to L1)

In addition to the electrodes on the muscles, a location on the spine close to C7 was chosen to place two more electrodes that were connected to two ground cables. Each pair of electrodes was placed with 2cm distance between their centers. The skin was wiped with an alcohol patch before the electrodes were attached to enhance the conductance. After attaching the electrodes, they were connected with cables (which have been secured with adhesive tape) to two data loggers (Mobi8, from TMSi, Oldenzaal, The Netherlands).

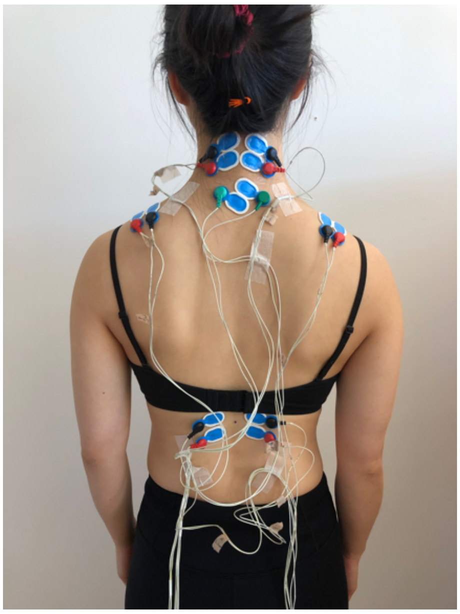

Figure 2-3 Placement of electrodes for EMG measurements

To obtain a reference value for data analysis in form of percentage of the maximum voluntary contraction (% MVC) or reference contraction, each subject was asked to perform a set of movements to generate maximum contraction of the measured muscle groups. The following exercises were performed three times and are shown in Figure 2-4.

- In a sitting position: Two seconds of shoulder elevations in abduction of the upper arms in approximately 45°, the study personnel are pressing against the arms to achieve maximum contraction
- In a sitting position, looking forward: Two seconds of pressing the head into the surgeon's own folded hands behind the head
- In a prone position with support of the legs and pelvis: Five seconds of lifting the upper body with arms crossed in front of the chest, holding in an isometric horizontal position

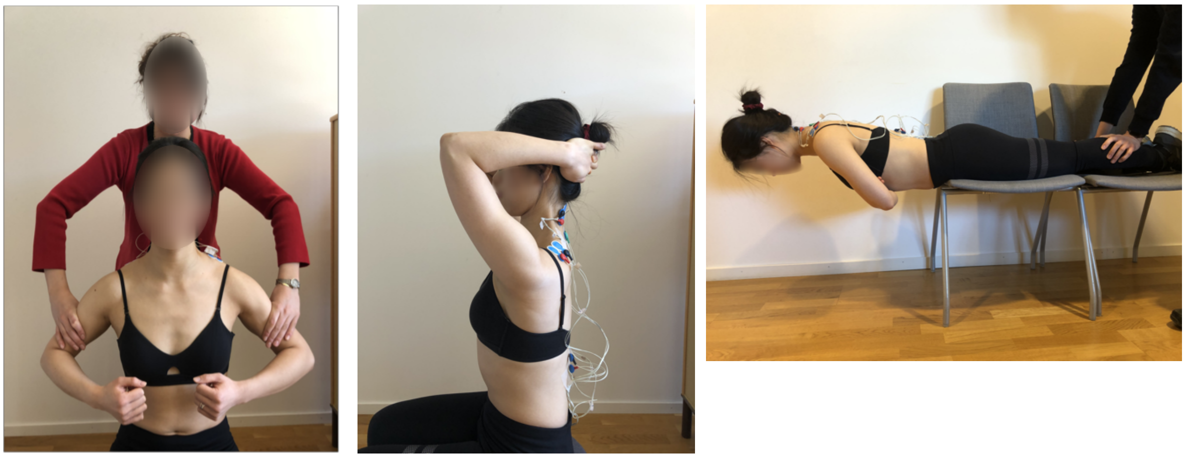

Figure 2-4 **Movements of maximum voluntary contraction for EMG calibration (left: calibration of trapezius, middle: calibration of neck extensors, right: calibration of lumbar erector spinae)**

Measuring posture with inertial measurement units

For obtaining the postural data, four IMU sensors (AX6, Axivity Ltd., Newcastle, UK) were mounted on the surgeon on the upper arms (at the distal end of the deltoideus muscle), trunk (placed on the sternum) and back of the head. They were stuck to the skin with double-sided adhesive tape and secured with medical tape to prevent movements of the sensors. The IMUs measure the angles and angular velocity of the different body segments. The data was sampled at 25 Hz and the recording time was set using the program Open Movement (Newcastle, UK).

After the mounting, the following movements for calibration of the sensors were performed:

- Jumping for five times with the arms down on each side of the leg
- Standing upright and looking straight ahead at eye level with both arms hanging (I-pose), followed by three quick forward bows of the upper body
- Sitting and leaning to the right side with a 2kg dumbbell in the right arm for five seconds, followed by three quick right upper arm lifts
- Sitting and leaning to the left side with a 2kg dumbbell in the left arm for five seconds, followed by three quick left upper arm lifts
- Standing holding both arms in an abducted position of approximately 90° horizontally with the palms faced down for 10 seconds (T-pose)

The calibration of both the EMG and IMU sensors were timed with a digital master clock for processing of the data to identify the reference values. Furthermore, the starting and ending time of each surgical case was collected for the further data analysis and to identify the duration of the surgery.

Data processing of EMG and IMU Data

The data from the EMGs were obtained at 1024 Hz for each channel and saved onto an SD-card by the data loggers with an AD convertor. After preprocessing and down sampling to 1Hz, which was done with an Excel Macro code from another researcher in the project group, the data were structured into an Excel file containing processed data of all muscle groups for each subject to be used by the Tableau software. After an initial data screening, it was decided to not include the EMG measurements from the lumbar erector spinae in the report due to lower relevance for risk indication and lack of relevant risk criteria.

The data from the IMUs are extracted and after pre-processing with the program 'OpenMovement' by another researcher, the data were down sampled from 25Hz to 1Hz and arranged into Excel files containing all body parts aligned to the time using MATLAB R2020b (Mathworks, Massachusetts). To visualize the IMU data over time they were imported as continuous average values using the AVG function in Tableau.

Design of improved ergonomic report and general ergonomic guideline

After the demo report evaluation, the ergonomic risk report was improved and finalized. An individual report was generated for each surgeon based on the technical measurement in the OR.

In order to evaluate the individual report as means for ergonomic education, an individual session was planned for the participants. The intervention group was provided with their own individual ergonomic report. The control group was provided with a traditional education material, i.e., a basic ergonomics guideline in a two-page document. This ergonomic guideline was designed based on common principles of surgical ergonomics and focuses mainly on the upper body (8,37). The designed guideline's structure and content are shown and explained more in detail in the result section 3.3.

Evaluation of the ergonomic report in an educational session

An intervention group that consists of two surgeons was presented with their individual interactive ergonomic assessment report and a control group consisting of two surgeons was provided with the basic ergonomic guideline. The ergonomic education sessions were evaluated with a combination of survey and semi-structured interview.

User evaluation survey

The first part of the final user evaluation of the ergonomic education session was conducted with a self-designed questionnaire including usability and perceived impact (see B.2 Appendix). The five questions on usability were based on the validated UMUX-LITE, a short version of the validated Usability Metric for User Experience (38), the uMARS (User Version of the Mobile Application Rating Scale) (39) and NPS (Net Promoter Score) (40). The NPS is commonly utilized to measure the applicants' loyalty by stating a likelihood-to-recommend question in the standardized form *"How likely is it that you would recommend our company to a friend or colleague?"* (40) with a scale ranging from 0 (not likely at all) to 10 (very likely). To fit the context of the study and inspired by the subjective subscale of the uMARS, the question was adapted to *"How likely is it that you would recommend this type of ergonomic education session to people who might benefit from it?"* (39). The six survey questions on perceived impact were also adapted from the (uMARS), which has been validated and found to be a reliable method to evaluate the quality of mobile applications within the health sector (39). In accordance to the uMARS, a standard five item Likert scale ranging from 'strongly disagree' to 'strongly agree' was used in the questionnaire for evaluating the degree of opinion and due to its advantageous characteristic of uncomplicated interpretation (39,41).

Semi-structured interview

The second part of the user evaluation of the ergonomic education session consisted of a semi-structured interview that contained multiple open questions on user experience and ergonomic awareness. The full interview guide is attached in B.3 Appendix. The first part was designed with an opening usability question, followed by two items that aimed at receiving feedback about possible missing information and suggestions for improvement. The six interview questions about ergonomic awareness contained questions about the current state of knowledge and awareness of ergonomics and the surgeons' adoption of ergonomic principles (based on (42)). The following questions were about the perceived learning outcome and impact of the educational session on the surgeons' way of working and initiatives for further improvements in surgical ergonomics and were based on (43). After having been given the consent of the participant, the interview was recorded with an iPod (Apple Inc, USA). The style of semi-structured interview was chosen for creating a natural conversation with the surgeons and being able to ask follow-up questions to get more detailed insights.

Analysis of the final evaluation

The measurements of ergonomic awareness and perceived impact via the questionnaires of the intervention and control group were analyzed with descriptive statistics. This choice was based on the nature of the data which is distributed on a Likert scale and the small number of participants. The recordings from the semi-structured interviews were automatically transcribed using the Descript software (San Francisco, CA, USA) and the transcription was proofread. The interviews were then evaluated with semantic thematic analysis through the steps of (i) familiarization with the transcript, (ii) extraction of open codes, (iii) review of codes with another research team member (iv) establishment of themes as categorical groups of codes (see 0).

3 Results

This chapter presents the results of the study. First, the outcomes of the evaluation of the demo version of the ergonomic report are described. Second, the final ergonomic report, which was used for the intervention group, are presented. Then, the basic ergonomic guideline, which was used for the control group, are described. Last but not least, the analysis outcomes of the questionnaires and interviews of the educational session are presented.

3.1 User evaluation of demo report

The representative group for evaluating the demo version of the report consisted of two surgeons and two ergonomists. The opinions differed between the two groups on several aspects. The general comprehensibility of the report, e.g., the explanation of the SULMA threshold, was considered understandable for surgeon participants, but not the ergonomist participants. The presented amount of information, e.g., the information on muscle activity, was considered too much by the ergonomist participants, but not the surgeon participants. The suggestions for improvement stated by the surgeons were prioritized since they represent the possible users of the final version of the individual report. Nine main themes were identified from the thematic analysis of the 'think aloud' sessions for the user evaluation of the demo report. The number of comments of each theme was counted and expressed in percentage, including general comprehensibility (21%), interaction (17%), data clarification (15%) and further information (15%), followed by presentation device (10%), design choices (6%), overall impression (6%), information amount (6%) and conclusion sheet (4%). The following table (Table 3-1) shows the main statements for the identified themes from the group of surgeons, ergonomists, or both. The grey boxes contain those statements from the ergonomist group that were not considered for further revisioning of the individual report because they were contradictory to the surgeons' opinion. The underlined statements show those comments on which the improvements for the final ergonomic report were taken actions on.

Table 3-1 **Main themes and statements from the user evaluation of the demo report with two surgeons and two ergonomists. The statements are separated in columns, depending on if they were stated by only one group or both groups, from left to right: the surgeons, the ergonomists, and both groups. Items in grey were chosen to not be implemented, due to the differing opinions between groups. Underlined items were turned into improvements for the final ergonomic report.**

Theme	Surgeons	Ergonomists	Both groups
Data clarification	<u>Median and peak load needs to be explained</u>		<u>Pie charts need to be explained</u>
	<u>Jonsson threshold needs to be explained (0&1)</u>		<u>Risk scores need to be explained</u>
			<u>Definition of body parts and muscle groups need to be explained</u>
Further information	<u>Reference of risk threshold (Jonsson) should be added</u>	Further information about working behavior in different load levels should be added	<u>Duration of surgery should be added</u>
		Further information on SULMA (when risk) should be added	<u>Type of surgery should be added</u>

General comprehensibility	Posture over time is nicely shown	Report is too complicated to understand for surgeons	Report is clearly described
	Colors are understandable and clear		SULMA explanation is understandable
Design choices	Coloring of the SULMA periods make sense	Pictures, graphs and colors are good rather than text only	
		Increase headings for phone version	
		Text alignment of second box to the left	
Information amount	Good that not too many parameters	Muscle activity sheet has a lot of information	
	Report is short, that is good	Muscle activity over time sheet has a lot of information	
Interaction	Report is intuitive and easy to interact with	Little time spent on introduction	Interaction feels good
	Interaction possibility not obvious		
	Switching between sheets / going back can lead to exit of report		
Conclusion			Summary or conclusion sheet demanded
Presentation device		No difference between iPad and computer	iPad is best option
			Phone too small
Overall impression	Exited to see final version and own results	Looks professional	Well done

3.2 Final ergonomic report

After the incorporations of the improvements that were identified from the user evaluation of the demo report, the ergonomic report was finalized. The revised version contained six different sheets that presented an introduction sheet, two sheets about the risk assessment results on surgeon's postural load, two sheets about the assessed muscular activity and related risks, and a conclusion sheet with take-home messages.

The introductory sheet (as shown in Figure 3-1 a), contains information about the structure and content of the ergonomic report, explains how to interact with it and gives a brief background about the prevalence of musculoskeletal disorders among surgeons.

The second sheet (Figure 3-1 b) gives an overview of the average percentage of time that has been spent in the different groups of color-coded ergonomic risk level (low, moderate, high and very high, as described in 2.2) with pie charts. It displays thereby the postural data of the surgeon's head, arms, and trunk from the IMUs. The selected surgical cases in this example figure show the comparison between one surgery in which the new prismatic loupes were used and another surgery with conventional loupes. The duration as well as the type of the surgeries are placed in an information box additionally.

The third sheet (Figure 3-3 a) demonstrates the postural angles over time as comparison between the selected surgeries. The line graphs are thereby colored according to the same risk severity levels as in the previous sheet and the same information box containing the duration and type of surgeries is shown as before. The y-axis shows the postural angles as 1-s average degrees. The timeline on the x-axis represents the course of the surgery in datetime format. This sheet furthermore provides the first opportunity of interacting with the report by selecting a body part of interest, after which the graphs adjust accordingly.

The fourth sheet (Figure 3-3 b) displays the 1-s averages of the surgeon's muscular activity from the EMG data as percentage of the maximum voluntary muscle contraction (%MVC). The selected surgeries with prismatic and non-prismatic loupes are thereby compared as bar charts in in three different levels of muscular load (the static, median and peak load). Each load level furthermore shows two colored risk thresholds (should not be exceeded and must not be exceeded, as described in Chapter 2.2.1) and the definition is given in an information box. In this sheet, the users can interact with the data by selecting the muscle group of interest (lumbar, neck or trapezius) and their side (left, right or both sides).

The fifth sheet (Figure 3- a) shows the muscular activity as time series data in line graphs (with datetime on the x-axis and average muscle activity in %MVC on the y-axis) by comparing the selected surgeries. The graphs are thereby colored in green and red according to the definition of a SULMA period which is explained in an information box. This sheet provides the same interactive selection options as the previous one.

The last sheet is shown in Figure 3- b) and concludes the report by providing take home messages about the highest individual ergonomic risks from the report and several suitable recommendations about corrective behaviors for the surgeon. The take home message box was generated manually from the highest risks of the risk assessment results from the previous sheets. The corrective action box was based on relevant ergonomic guidelines that aim at reducing the prementioned risks.

3.3 Basic ergonomic guideline

The basic ergonomic guideline for the control group to be used in the educational session was designed in form of a two-page-handout. It provided general information about ergonomic risk factors for surgeons during surgery, ergonomic equipment, and recommendations on how to adopt ergonomic principles, e.g., microbreak to avoid prolonged static positions, as shown in C.1 Appendix. The guideline starts with brief statements about the prevalence of musculoskeletal disorders among surgeons and its main causes, followed by suggestions on ergonomic behaviors. The optimal angles for the arms and head postures are thereby explained as well as recommendations about an ideal stance and height of the operating table. The next section describes various stretching instructions of the upper and lower body to prevent prolonged static positions. At last, additional ergonomic equipment (e.g., anti-fatigue foot mat, supportive footwear, and new prismatic loupes) is presented and its functions are explained. Various pictures were furthermore added in the guideline to illustrate selected parts of the content.

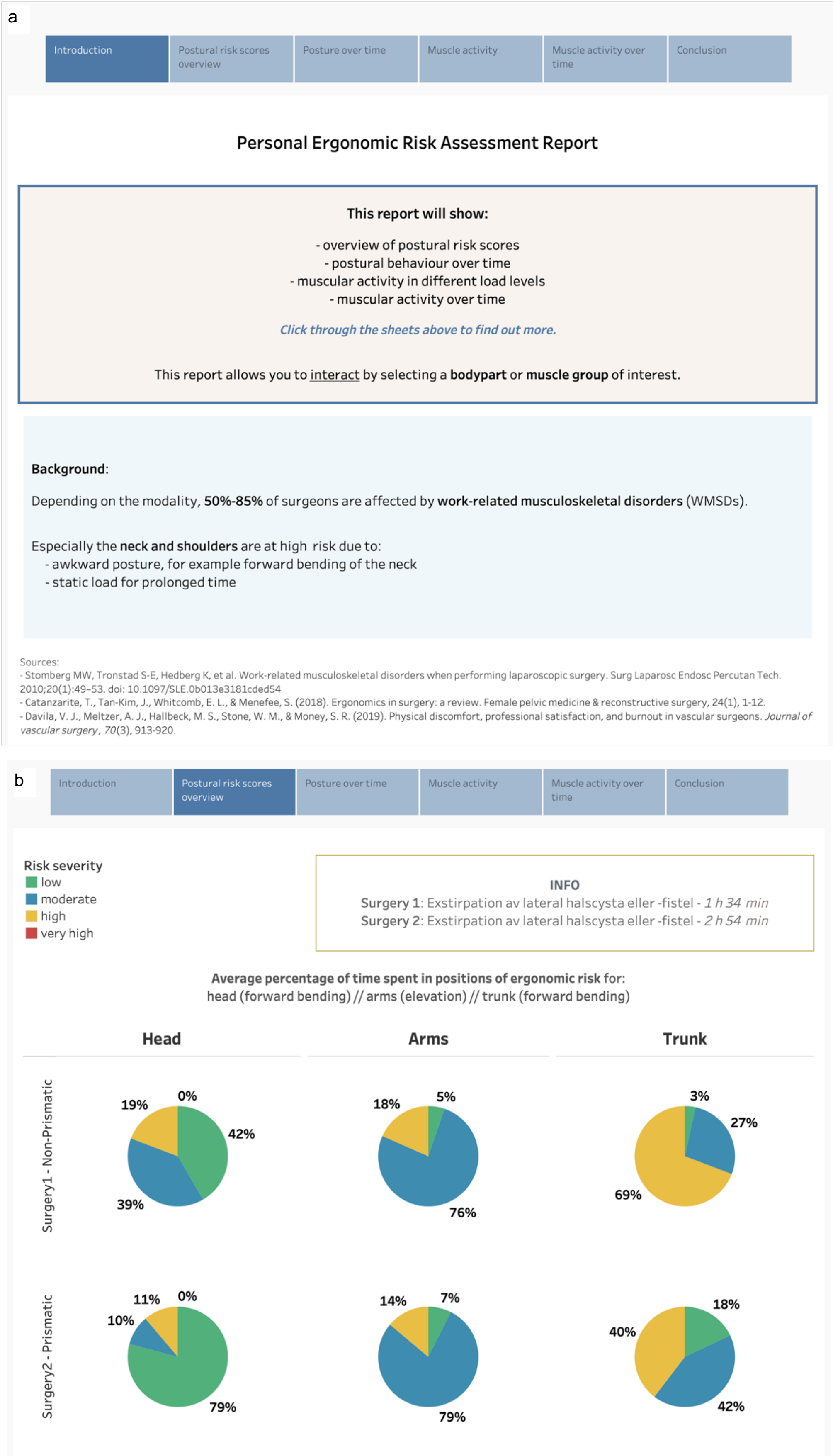

Figure 3-1 Tableau sheets of ergonomic report: a) introductory sheet; b) postural risk scores overview

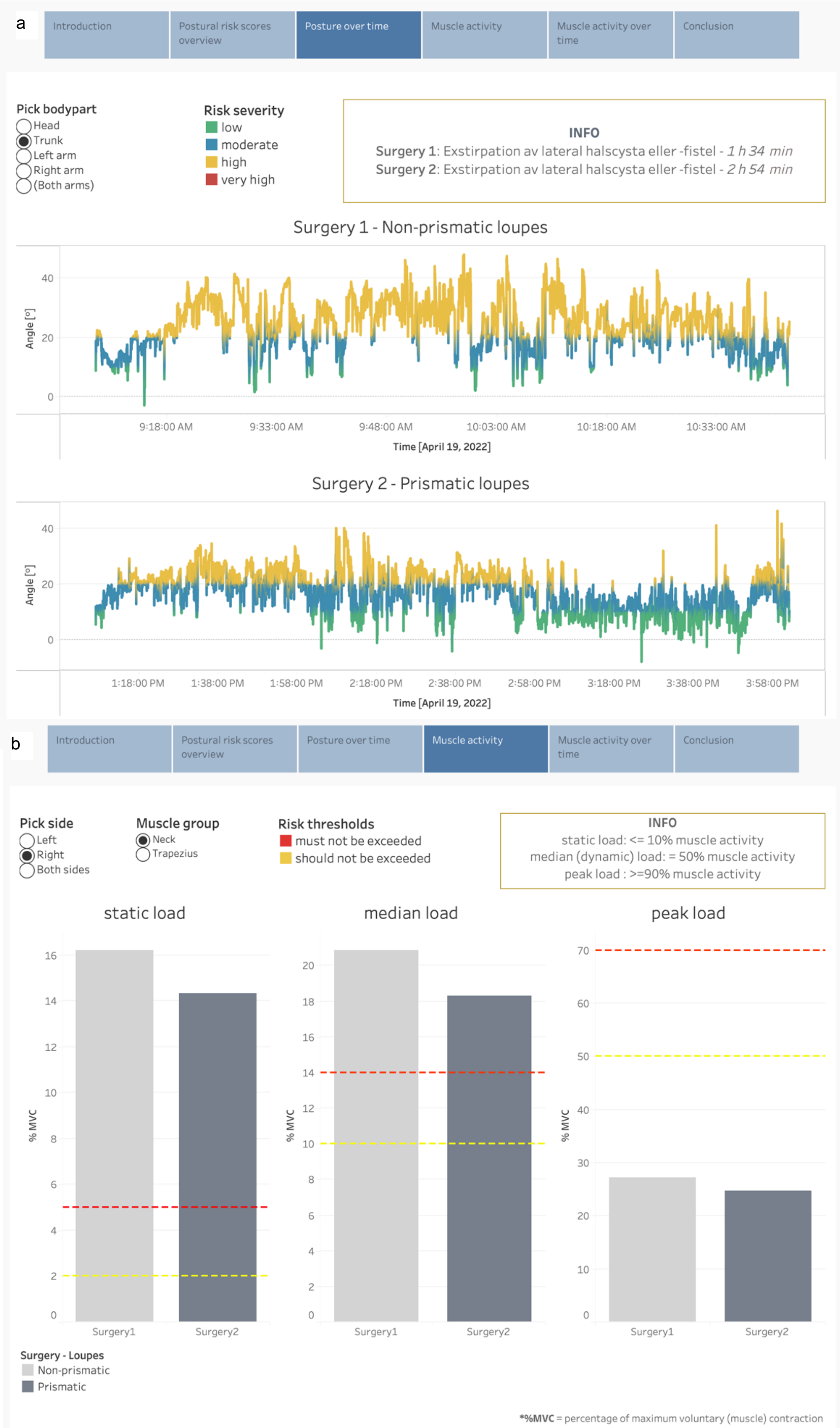

Figure 3-2 **Tableau sheets of ergonomic report: a) postural angles over time; b) muscle activities in different load levels**

Figure 3-3 Tableau sheets of ergonomic report: a) muscle activity over time; b) conclusion sheet

3.4 Analysis of questionnaires

Since the number of participants was limited, the analysis was conducted without any statistical test and was therefore evaluated with descriptive analysis. The analysis of the questions about usability are shown in Figure 3-4. The first two questions a) and b) showed the same result for both intervention and control group. The other questions c) to e) presented slightly more positive ratings from the intervention group. In questions c) and e), slightly less positive scales in the answers were chosen by the control group, which ranged from "neutral" to "agree". In all questions, the intervention group demonstrated only positive answers of agreement (agree to strongly agree).

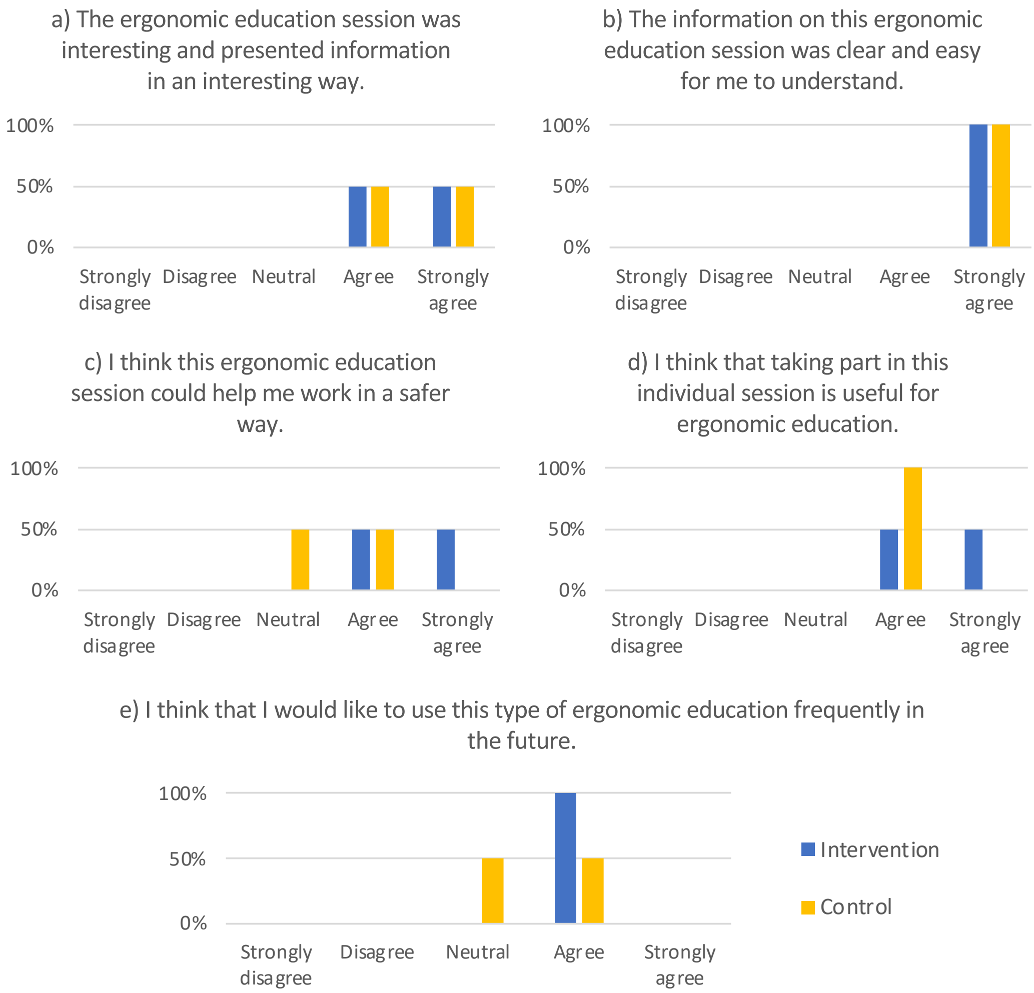

Figure 3-4 **Results from survey questions about usability as comparison of intervention and control group in percentage of responses on 5-item Likert scale**

The results of the analysis of questions about the perceived impact of the ergonomic education session are presented in Figure 3-5. The intervention group answered all questions with a positive statement of agreement (agree, strongly agree), while the control group showed a larger variation in the answers ranging from "neutral" to "strongly agree" in questions a), d) and e). The only negative answer (disagree) was seen in the control group in question b). The strongest positive answers were selected by the intervention group in question d), where both participants rated "strongly agree". Questions a) and e) gave the same result pattern.

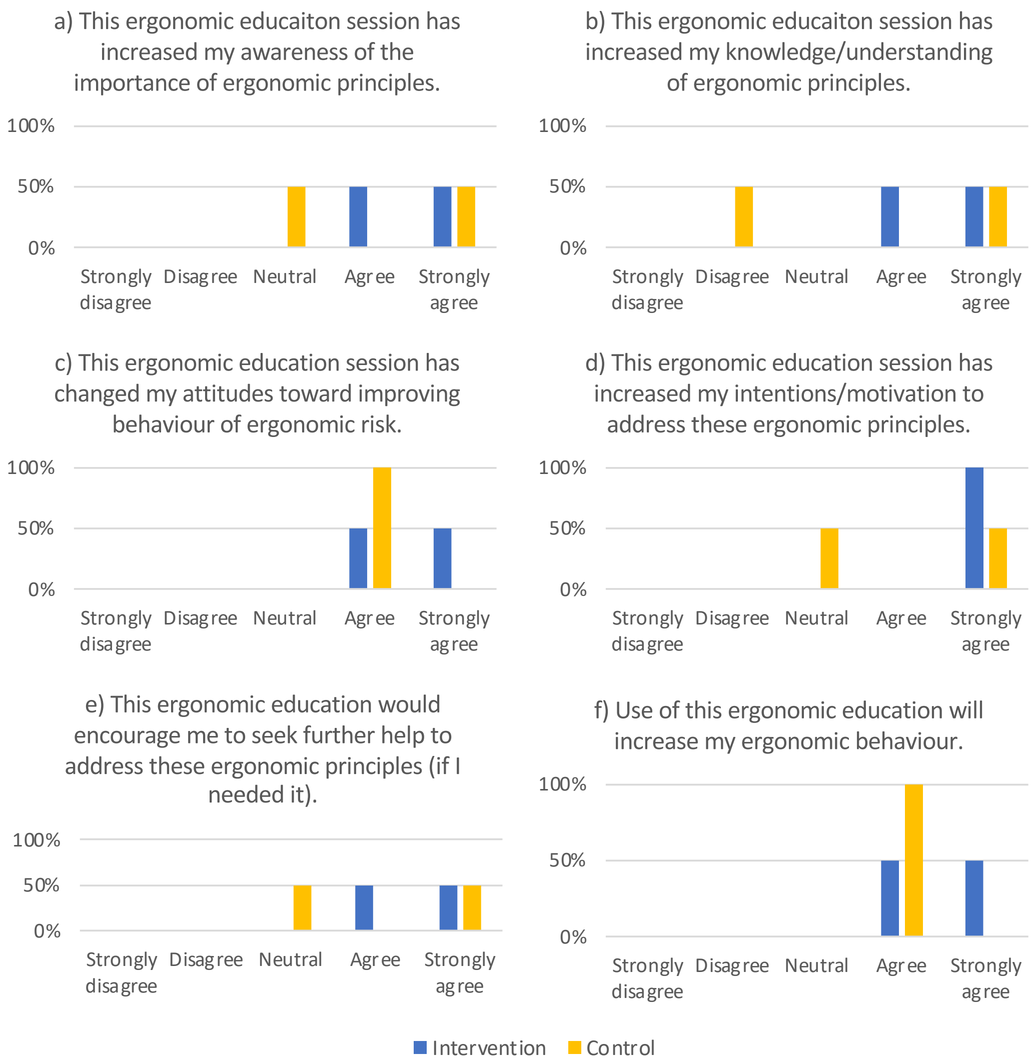

Figure 3-5 **Results from survey questions about perceived impact as comparison of intervention and control group in percentage of responses on 5-item Likert scale**

The results from the Net Promoter Score (NPS) indicating the participants' likelihood to recommend the ergonomic education session showed the same results for the intervention and control group (see Figure 3-6). Two participants were thereby interpreted as 'Passives' (grade of 7 to 8) and two as 'Promoters' (grade of 9 to 10). Since the NPS is calculated with subtracting the relative number of 'Detractors' (grades from 0 to 6) from the relative number of Promoters and neglecting any Passives, these outcomes show that the participants are very likely to promote both types of ergonomic educational session.

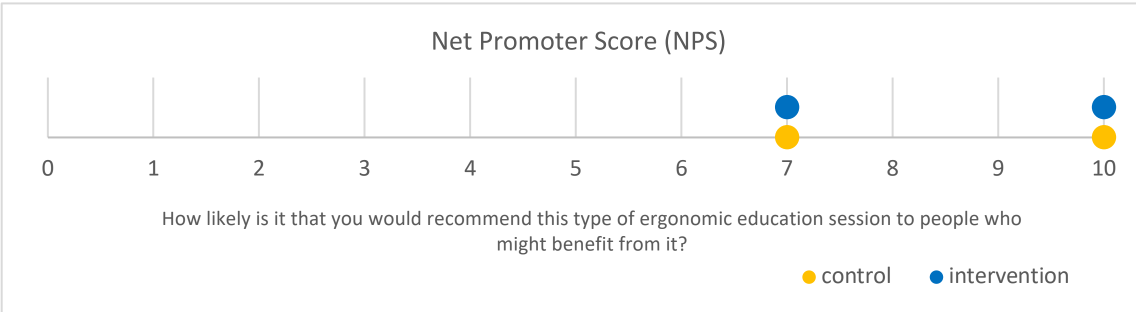

Figure 3-6 **Evaluation of Net Promoter Score (NPS) from control and intervention group**

3.5 Analysis of interviews

The final user interviews following the ergonomic educational session were evaluated with thematic analysis. The extraction of open codes and identification of the themes were performed individually and then reviewed together with another research team member. Four main themes were thereby identified for both intervention and control group: user experience and learning outcomes of the educational session, as well as the perceived facilitators and barriers for improving surgical ergonomics, and the ways to improve surgical ergonomics. Two of those themes could be compared between intervention and control group (user experience and learning outcomes) whereas the other two themes (perceived facilitators and barriers, and the ways to improve surgical ergonomics) are not dependent on the group type and were therefore analyzed jointly.

The theme '**user experience of educational session'** showed some differing results for control and intervention group. While both educational sessions received positive general feedback, participants from the intervention group stated the individual report was *"very interesting"* and that they *"enjoyed it"* and *"liked the report"*.

"I think it was very interesting. I had no idea that you could get that much information."

The control group stated that the basic ergonomic guideline was *"good"*. Regarding the presented information, it was expressed as *"substantial"* for the intervention group. For the control group, the basic guideline was considered *"quite sufficient"* for surgeons who are not aware of surgical ergonomics principles.

"for them who don't know so much about ergonomics, this is good to just get the idea".

But for surgeons who already had high ergonomic awareness, it could be considered as *"not much novelty"*. The comprehensibility was graded in a different variation, with the intervention group finding the report to be *"quite easy to understand"* and the control group stating the guideline to be "*clear*" and *"very easy to understand"*. Furthermore, after the provision of the individual report, an interest for a follow-up after the ergonomic education was mentioned for the intervention group. For the control group, suggestions to the guideline were made to add further information via video or live practical demonstrations, e.g., of the stretching and ergonomic mat.

Regarding the **'learning outcomes'**, both surgeons from the intervention group felt an increased awareness about their way of working after the educational session with the individual report.

"I will definitely think about it more. Definitely."

A member of the control group answered that the basic guideline has potential of increasing knowledge and awareness about ergonomic principles.

"in general, it will be some sort of highlighting and they will understand that this is important. It can help them."

At the same time, both groups were aware of awkward postures that present ergonomic risk during their surgical work in the OR. Other factors were also mentioned, e.g., increased bending over the table when assisting with junior surgeons.

These first two themes are visualized in Figure 3-7 which shows the differences and similarities of statements from the intervention and control group.

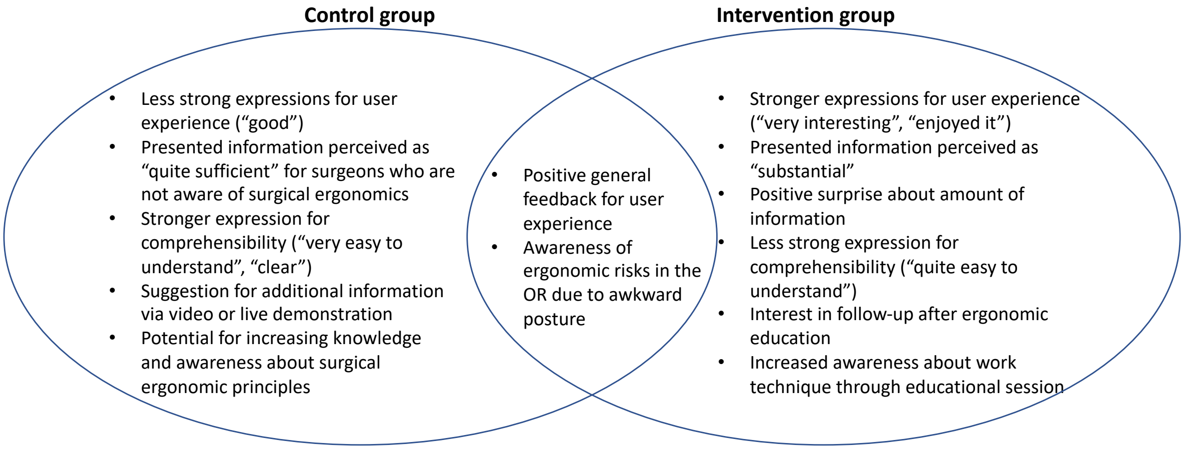

Figure 3-7 **Venn diagram showing differences and similarities of themes 'user experience' and 'learning outcomes' for control and intervention group**

The third theme was identified as the '**perceived facilitators and barriers for improving surgical ergonomics'**. One common reason of adopting ergonomic principles was the experience of back and neck pain. Another reason was the knowledge that came from research experience in the field of surgical ergonomics. Additionally, to avoid MSD problems and stay healthy in the future were mentioned as a motivation – *"to have a nice pension, I guess"*. Furthermore, the importance of the work culture as well as an earlier adoption of ergonomic principles were mentioned as facilitators for improving surgical ergonomics and behavioral change.

Some barriers of improving ergonomic in the OR were also mentioned. Surgeries with longer durations were thought to be harder to change to new ergonomic ways of working. Established work habits or routines can also challenge the implementation of new ergonomic tools. Finally, not realizing the need of ergonomic practices when there is no sensation of pain was one perceived barrier.

"Why do I have to do that? I don't feel that. I feel I have no pain. I'm feeling good and so forth".

The fourth identified theme was the '**ways to improve surgical ergonomics'** as perceived by surgeons. A summary of all suggestions is listed in Table 3-2. This theme consisted of the highest number of codes, which showed a high interest in the topic of different types of measures for improving surgical ergonomics. It was mentioned that establishing an ergonomic work culture was important.

"I think it's more of adopting a specific culture to me and my colleagues. So that we can encourage each other to actually improve how we work."

Peer support and collaboration for adopting ergonomic principles in the OR was another factor that was proposed, both among surgeons on the same operating table and surgeons from different generations.

"it's important for both surgeons to have these good positions… when they stand beside the (operating) *table"*

Also, the ergonomic education was suggested to be incorporated in early surgical career/education.

"I think that (younger) group is more important to inform about this, because they have a long life now than when they would work."

Furthermore, it was mentioned that there was a need of ergonomic equipment, such as the use of ergonomic chairs, and the prismatic loupes, which were thought to be effective in adapting a better ergonomic posture by all surgeons. The interest in learning more about micro-breaks in the OR and maybe implement it in the surgical practice was express by three participants. Further suggestions for future measures to achieve ergonomic change for surgeons include decreasing the sedentary time at work, implementing practical ergonomic educational sessions with live demonstration of surgical equipment (e.g., the ergonomic foot mat), and getting external feedback on surgeons' posture in the OR either via technical devices or from an observer.

"*The immediate feedback from an observer would be quite good… I think that would be worth if it could be even, objectively done with electrodes to prove that another movement would be less demanding. That could perhaps strengthen the course*".

Table 3-2 Overview of all suggestions for ways to improve surgical ergonomics as perceived by surgeons

Suggestions	Ways to improve surgical ergonomics
1	Providing better ergonomic equipment (e.g., ergonomic chairs)
2	Learning about and implementing stretching in the OR
3	Establishing an ergonomic work culture and peer support
4	Decreasing sedentary time at work
5	Collaborating between surgeons (working on both sides of the operating table and surgeons from different generations/age groups)
6	Incorporating ergonomic education in early surgical education
7	Receiving external feedback of surgeons' postures in the OR (from an observer or technical device)
8	Conducting practical sessions or videos (e.g., how to stretch, and demonstration or test of ergonomic equipment)

4 Discussion

This chapter discusses the main results from the study, followed by the limitations of the applied methods and design of the study. Lastly, potential work for future research based on this study is proposed.

4.1 Discussion of results

In this degree project, an individual interactive ergonomic risk assessment that was based on objective measurements of physical workload from surgeons was developed and validated against a self-designed basic ergonomic guideline. At the same time, facilitating actors and challenges for ergonomic change and ways to improve surgical ergonomic were to be investigated. The aim of the individual report was to raise the participating surgeons' awareness about ergonomic principles and their own ergonomic risks. The main findings were the importance of including surgeons as end users into the participatory design of the ergonomic assessment report, a general positive reception of both ergonomic educational types with similar statements about ergonomic knowledge post-session but with indications of slightly higher perceived impact and intention to pursue ergonomic behavior for the intervention group. In addition, a general interest of all surgeons in further ergonomic interventions such as stretching or creating an ergonomic work culture was identified inspiring approaches for future studies in surgical ergonomics.

Besides the definition of risk parameters through extensive literature research, many other decisions were to be made when designing the report. The software Tableau was chosen due to its popularity for data visualization, applications on multiple platforms, and possibility of interactivity with the data. The choice of colors for the postural risk severity levels was tested on different digital device screens and discussed with other members of the research team to generate an intuitive interpretation while being objective. Since the perception of colors depends on the viewer the colors were adapted from a renowned research paper from the Mayo Clinic (Rochester, Minnesota) which also presents a visualization of ergonomic risk based on IMU measurements (29). The contents of the Tableau sheets were formed with regards to achieving a report that is intuitive to use as well as easy to understand due to the nature of a surgeon's profession being highly extensive in time investment and responsibility. The demand for keeping the time of data collections with the surgeons as short as possible was realized while taking the measurements of physical workload in the OR.

The selection of the contents and thereby the length of the individual ergonomic report can furthermore be edited if more user feedback is gathered and point to potential improvement. For instance, a Swedish research group has developed a shorter ergonomic report for practitioners which shows postural data of arms and trunk (44). While this report consumes less time for the viewer and has therefore the potential of increased comprehensibility and knowledge transfer, it misses time series data that can show a specific work task at ergonomic risk. The current individual ergonomic report also includes information from EMG in order to show the cumulative risk for staying in low static muscular activity for prolonged time, which is a common risk factor for surgeons (see Appendix A.1.4). Furthermore, the aforementioned shorter report serves the purpose of giving a risk assessment result while this project's individual interactive report was designed additionally as an educational material. It was developed as a starting point for surgeons to consider risk assessment in the OR together with providing ergonomic education. In future studies, the length and content of the ergonomic report can be tested and evaluated among end users.

The design of the individual ergonomic report was conducted with a participatory approach by developing a demo version of the report that was presented to a representative group. This group consisted of two surgeons and two ergonomists. Due to these different types of participants, the results from the user evaluation of the demo report showed varying responses about the general comprehensibility of the report *("report is clearly described"* and *"report is too complicated to understand"*) and the presented amount of information *("report is short, that is good"* and *"sheet has a lot of information"*). This outcome highlights the importance of including the end user (surgeons) into the evaluation of a demo version. The suggestions for improvement stated by the surgeons were therefore prioritized since they represent the possible users of the final version of the individual report. The main findings from this evaluation were the demand for additional information and further explanation of ergonomic risk scores on the one side and the positive feedback about the interactive nature of the report on the other side. These outcomes showed a general interest of the surgeons in their individual results from the ergonomic assessment and a positive experience with an interactive digital format.

When evaluating the final educational session, a combination of qualitative and quantitative data collection was applied by using the survey followed by the short semi-structured interview which gives strength to the outcome. The analysis of the questionnaires thereby showed that the usability, interest and understanding of the contents was graded with the same statements from the control and intervention group. On the contrary, the effectiveness of raising ergonomic awareness and the surgeons' perception about the impact of the ergonomic education on their future posture and workstyle differed in its gradings with more positive values for the intervention group, which was expected to a certain degree. The intention to address ergonomic principles was thereby assessed with the highest positive gradings (100% of strongly agree) for the individual report (intervention group) while the results from the control group contained a neutral grade. Even though all questions show similar results for both groups, the control group answered with neutral gradings on two questions about usability and three questions about the perceived impact while the intervention group gave no neutral gradings. These findings again demonstrate the surgeons' general interest about ergonomics with a higher potential of the individualized interactive report to be more effective in the surgeons adopting ergonomic principles in the future. Furthermore, the only negative grading (disagree) was selected by the control group in one of the perceived impact questions about whether the ergonomic education session has raised the participant's ergonomic knowledge. This finding could be attributed to this participant having a higher degree of knowledge about ergonomics to begin with, which is why the educational session seemed not more impactful to him/her.

The final analysis of the semi-structured interviews supports the main findings from the questionnaire evaluation by showing overall positive feedback about the user experience of both the individual report and basic ergonomic guideline. Subtle differences between the group types were found in the choice of words indicating a slightly higher usability of the individual report. The basic guideline was characterized as *"good"* and with *"quite sufficient"* information whereas the individual report received more and stronger expressions: *"very interesting"*, *"enjoyed it"* and *"liked the report"* with the presented content appearing to be *"substantial"*. In line with the questionnaire analysis, the interview questions also showed a slightly higher increase of ergonomic awareness for the intervention group (*"I will definitely think about it more. Definitely.")* although both groups gave similar statements about what postures at work they thought to be at ergonomic risk after the educational session.

The interviews furthermore revealed facilitators and barriers for implementing ergonomic changes as well as ways to improve surgical ergonomics. While these aspects do not depend on the type of ergonomic educational session, they were not comparable between intervention and control group. The main findings still gave valuable insights from surgeons such as the need of a collaborative work culture for implementing ergonomic intervention in the OR or an interest in stretching and micro breaks. Those suggestions were incorporated for future work approaches, which are stated under 4.3.

4.2 Limitations of methods and study design

This study's methodology and analysis of results were limited by different factors. Firstly, due to the small number of four subjects taking part in the final user evaluation of the ergonomic education session, no statistical analysis of the results from the questionnaires was conducted. The results were therefore difficult to interpret because the answers could all be accredited to individual characteristics of the subjects.

Another limitation is the lack of randomization of grouping the subjects in the ergonomic educational session. One subject was intentionally placed in the control group because of measurement errors from the data collection of physical workloads in the OR. These errors were attributed to several practical issues such as not sticking of the EMG sensors due to perspire on the skin, ripping of cables connecting the EMG sensors to the loggers due to larger movements and body type of the subject.

The selection of the contents presented both in the induvial report as well as the basic ergonomic guideline is limited by having focused on objective measurements of physical workload of the upper body. There are further factors that can contribute to the risk of developing MSDs such as high levels of mental strain (see A.1.5). While the choice of the presented information in the individual report was based on the areas of the highest ergonomic risks for surgeons, other body parts could still impose ergonomic risk for surgeons such as the lower back due to bending or twisting the trunk while operating (45). The EMG measurements for the lumbar erector spinae were neglected after an initial data screening due to lower relevance and risk indication.

Furthermore, the chosen risk criteria for muscular activity were proposed by Jonsson (30) back in 1982. There are other more recent action limits from Arvidsson et al. (46) in 2021. However, they are based on the physical load over a whole 8-hour working day. Since the individual ergonomic report focusses on the surgeons' ergonomic risks while operating and their workday varies in activities (e.g., computer work between surgical cases), using the risk criteria of muscular activity over an eight-hour workday is not suitable and might lead to overestimation of the risks. In addition, these proposed action limits by Arvidsson et al. are much lower (i.e., 20% MVE at the peak load) and if applied here, it would show that surgeons' muscular activity in the OR constantly surpassing the threshold. The threshold limits in the individual report can be updated if more appropriate criteria for surgeons' workload in the OR are found.

There is also potential for participant bias resulting in the subjects tending to be more positive about the individual ergonomic report as well as the basic ergonomic guideline due to their interest in participating in the larger research study of testing the new prismatic loupes to begin with. Yet, this limitation did not affect the reliability of the results too much, since the intervention group still showed a more positive attitude towards the individualized report in comparison to the control group.

Although the questionnaires following the ergonomic education were assembled with parts of validated user experience scales (UMUX-LITE and uMARS), the combination of questions were self-designed which opens the possibility of missing items of interest. A similar limitation applies for the interview questions with an additional lack of unity due to the nature of semi-structured interviews not giving each subject the same follow-up questions. On the other hand, conducting this form of interview encourages a more open and natural conversation between the interviewer and interviewee which leads to deeper and more sincere answers.

The analysis of the interviews after the final user evaluation demonstrated a variation in the level of ergonomic knowledge which indicates that the participants of the control group had higher ergonomic education before the educational session. This would explain why the basic ergonomic guideline did *"not* (show) *so much novelty"*. The conduction of a semi-structured interview following the questionnaires was chosen because of this possible variation in ergonomic knowledge before the educational session to get more insights about its perceived impact and strengthening the results.

4.3 Future work

In this study, an interactive individual ergonomic risk report was designed, and its usability and perceived impact was evaluated on four surgeons. At the same time, facilitating or barring actors and ways to improve surgical ergonomics were investigated giving relevant insights for future research based on this degree project.

While the individual report was assessed in an early design stage as demo report by potential end users and a final user evaluation conducted on further surgeons it still needs to be applied and validated with a larger number of study participants. Since a surgeon's work is time and responsibility intensive the subject recruitment was identified as a challenge. At the same time, this project's participants and other surgeons that have been contacted during the study showed interest and curiosity for their individual ergonomic risk assessment. Future research with a higher number of subjects would decrease the chance of attributing the results to individual characteristics and make statistical analysis possible.

The results from the last question about the surgeons' willingness to use this type of ergonomic education in the future did not show the highest grading of agreement (strongly agree) for the intervention group. This finding could be attributed to the choice of phrasing ("would like to use this (...) *frequently* in the future") which might indicate that there is no need providing an individual ergonomic report frequently. This could suggest the potential of a follow-up study to evaluate the impact of the individual report on the surgeons' ergonomic awareness over a larger time interval. One surgeon's comment from the final semi-structured interviews about the whish for conducting a follow-up supports this suggestion.

Another insight from the final user interviews with the surgeons was the possibility of implementing this type of ergonomic intervention at an earlier professional stage. In future research, this study could be conducted with surgical residents or surgeons early in their career. This would on the one hand support a more equalized level of ergonomic knowledge as a baseline for evaluating the impact of the individual report. On the other hand, implementing ergonomic intervention earlier can improve the surgeons' postural behavior earlier which could decrease the risks of developing WMSDs. Surgeons with less working experience might also be more willing to adopt new workstyles through an ergonomic intervention. One similar study has recently found incorporating didactic ergonomic lectures into the educational stage of surgical residency to be effective in raising awareness about ergonomic principles (47).

Furthermore, the final user evaluation indicated a need for incorporating practical aspects in ergonomic education for surgeons, e.g., by conducting practical educational sessions on how to stretch in the OR. While the interactive format of the individual report provided the opportunity of active engagement of the participant, future studies could furthermore approach practical instructions about ergonomic principles. One example is given by a recent study that investigated personal teaching of stretching exercises for surgical residents (48). This approach can be linked to another comment about the importance of creating a collaborative work culture that incorporates ergonomic practices within the OR. Future research in surgical ergonomics should therefore focus on practical educational intervention formats that take the working culture among surgeons into account.

In addition, the analysis of the interviews revealed an insight about improving surgical ergonomics by receiving external feedback on surgeons' postures in the OR ("*the immediate feedback (...) would be quite good*"). This could be realized by giving vibrotactile feedback using a Smart Workwear

System which has been found to potentially help to decrease physical exposures of warehouse workers (49). The long-term effects of this type of real-time ergonomic feedback have yet to be assessed. In future studies, the effectiveness of a combination of providing an individual ergonomic assessment report and giving direct posture-correcting feedback for surgeons can be investigated.

While the individual report contained assessment of the upper body parts since previous research has shown that they are under the highest ergonomic risk, there are still other factors that contribute to the risk of developing MSDs (45). In future research, the individual ergonomic assessment could thereby explore additional parameters such as the surgeon's perception of mental strain during a full working day. Since multiple participants in the usability evaluation of the demo report mentioned the short format and limited use of parameters as positive feedback, the focus on few ergonomic risk factors should thereby still be kept.

5 Conclusions

In this degree project, an interactive individual ergonomic assessment report was designed and evaluated as means for risk assessment and ergonomic education for surgeons. The report was based on objective measurements of the surgeons' physical workload which were collected using EMG and IMUs during real surgeries. It is worth to mention that the development of Work-related Musculoskeletal Disorders (WMSDs) is multifactorial, this individual report only focuses on two of the most common ergonomic risk factors for surgeons: the postures and muscular activity of the neck and shoulders. A participatory design approach was used, which involved ergonomists and surgeons in the design process and gathered user feedback on a demo version before the final design. Varying responses between the user groups showed the importance of incorporating early evaluation from the end users. The finalized individual report was evaluated in an educational session by using a combination of quantitative (questionnaire) and qualitative (semi-structured interviews) methods. A comparison was made against a control group which was provided with a basic ergonomic guideline, as a common ergonomic educational session would use. While both educational formats showed similarly good ratings for their user experience, the intervention group graded the individual report higher for its perceived impact and gave much more positive responses in the interview. This finding was supported by statements about an increased thought process about ergonomic risks in the OR from participants of the intervention group. At the same time, the indications of varying ergonomic knowledge of the participants and the small number of subjects were identified as limitations. Therefore, more participants are needed to evaluate the individual ergonomic report in future studies.

In addition, the perceived facilitators, and barriers as well as ways to improve surgical ergonomics among the surgeons were identified. One facilitator was the motivation to avoid MSD problems for a healthy future, while not realizing the need of ergonomic practices when there is no sensation of pain was perceived as a barrier. A collaborative ergonomic work culture in the OR and the implementation of microbreaks are two examples of suggested ways to improve surgical ergonomics, which can be of value for future research.

Overall, the research in this thesis demonstrated the potential of an individual ergonomic assessment report both for risk assessment and ergonomic education for surgeons. The ergonomic report raised surgeons' awareness and knowledge about ergonomic principles. It may contribute to improved ergonomic work technique and use of ergonomic tool among surgeons in the OR. In the long term, it may reduce the risks of developing WMSDs, improve surgeon well-being and contribute to better surgical performance and patient safety.

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A Appendix: State of art

The following chapter provides an introduction of musculoskeletal disorders, their risk factors and prevalence in various surgical fields as well as necessary background information about ergonomics and their relevance in surgery. To identify ergonomic risk factors, physiological measurements (EMG and IMU) as well as survey results about workload and pain are evaluated. Therefore, an interdisciplinary approach for generating surgical ergonomic intervention that targets the adaption of the work system together with the worker has been chosen.

The literature review is performed by using different academic online databases, such as Google Scholar, PubMed and Scopus. The most used keywords are thereby 'risk assessment', 'surgical ergonomics', 'ergonomic awareness', 'physical workload' and 'WMSDs'. The search results have been filtered for sources that are more recent than 1980 and a focus was placed on peer-reviewed papers from published journals and academic books.

A.1 Musculoskeletal disorders

The musculoskeletal system consists of the skeleton, the attached muscles, and the neural coordination of the muscular activity (1). Musculoskeletal disorders (MSDs) occur as defects of the musculoskeletal apparatus that can lead to a chronic impairment or complete loss of its functions (50). Their basic characteristics, that have been identified as early as 1988, describe them as being the result of repetitive exposure for a prolonged time injuring a specific anatomical area (51). The first stage of MSDs is viewed as stressors, which are recognized as demanding scenarios that require physical or mental adaptation. Over continuous exposure, these adaptations can then induce strain and furthermore traumatization of the musculoskeletal system, generating a functional disorder. Therefore, tasks that are characterized by repetitive motions, cumbersome postures, rapid movements, heavy loads and insufficient time for recovery bear the highest risk (2,5).

Several studies have shown that most MSDs are concentrated in the back, neck, shoulders and upper limbs (2,5,52). While MSDs are often directly referred to specific motions or body postures, they can also appear in more distant areas, for instance in the form of headaches. The disorder usually begins with the sensation of fatigue, tensed or stiff musculoskeletal structures which can occur acutely and grow into more severe and long-lasting effects that can spread across the body (53).

Being a multifactorial health issue, besides the physical exposure, other factors contribute to the generation of MSDs: The organization of the work environment with its tasks' perquisites as well as the design of the working station and tools. Furthermore the psychosocial job environment and mental stress concerning the professional or personal life of the worker have shown to be impactful (52).

A.1.1 Work-related musculoskeletal disorders

MSDs that are categorized as an occupational illness have led to the definition of Work-related musculoskeletal disorders (WMSDs, sometimes also stated as WRMDs) (5). WMSDs can be found in research as being called occupational disorders, repetitive strain or motion injuries or overuse injuries. They are characterized by damages of physiological structures of the musculoskeletal apparatus which are either initiated or increased by the actual work tasks or by the occupational environment. Besides causing or triggering, work can have adverse health effects by impairing healing or rehabilitation processes, which can result in an MSD (5).

Several studies have shown that, predominantly, WMSDs have adverse effects on the upper and lower limb as well as the lower back (45,52,54). Thereby, especially the shoulders, neck and hands are strongly affected (54). With MSDs varying in the localization of the affected body parts they can be caused and intensified by different demands, such as workload or other stressors in personal life (5). Disorders commonly start with the sensation of fatigue, accompanied with increasing pain over a prolonged time that can result in chronic disability to work and early pension (5).

Occupational illness can affect all work systems and has been identified as critical health issue in multiple studies across the globe: Workers in a welding company in South Africa with more than 60% suffering from lower back pain (LBP) (55), a recent study on carpet weavers in India identified postural risks for developing a disorder in most of the participants (56) and even working in an office has been demonstrated as bearing possible harm, as a study from Iran found almost 30% of the office workers to be at high-level risk of developing an MSD (57).

Still, work in the healthcare industry remains among the occupations with the highest risk of developing WMSD. For instance, a literature study revealed that physical therapists suffer from occupational disorders in up to 91% of the reviewed cases (58). The prevalence among Malaysian nurses was found to be 73% (59) and a recent study examining dental professionals identified 58,3% occurrence of MSDs (60). Those, that are in direct contact with the patient are especially affected (58). Surgeons have therefore been found to be one of the highest risk groups among healthcare professionals with prevalence of MSDs reaching up to 100% for laparoscopic surgeons (8).

A.1.2 Ergonomics in surgery

With its origins in the Greek language, “ergon” and “nomos” is translated literarily to “work-law” and is defined as a field of science that deals with the relationships between humans and objects with its purpose of achieving an optimal design in respect to the humans’ health as well as the level of performance of the working system. Various principles, theories and methods are applied by ergonomics professionals in order to analyze and develop an ergonomically optimized working environment (37). Ergonomics (often also stated as human factors) are furthermore defined as the discipline of fitting the work task in accordance with the human’s capabilities and restrictions to optimize the overall work performance and the worker’s well-being. Therefore, most of the discipline of ergonomics contains the analysis of human physiology to develop characteristic principles. Moreover, the field of applied ergonomics, or human factors engineering, is concerned with the design an re-design process of the work system, equipment or ergonomic tools according to these principles (10,61).

There are multiple causes of WMSDs and although the exact identification of the affected tissue is challenging, researchers have identified certain characteristics of surgical work that is assumed to be the most contributing (53,62): Being under static load for a prolonged time, working in awkward postures and having high levels of mental demand.

A.1.3 Awkward postures and load from loupes

The posture has been found to have significant effects on the muscle force (63): It affects the muscles’ maximum torque, the level of possible support from other body parts, the amount of strain on the involved muscle groups and most importantly, it influences the injury risk by the amount of load on the musculoskeletal structures. Surgery may require recruitment of smaller muscle groups that generate less strength, but the physical performance, muscle fatigue and strain is dependent on the amount of load as well as the individual maximum capacity of the muscles involved. This means that high precision work in surgery can require maximum contraction of the relevant finger muscles while the lifting of a heavy weight, for instance, can demand much less of the maximum force of the muscles of the upper arm. The posture of a surgeon furthermore influences the recruitment of other muscles groups than the ones conducting the surgical tasks to stabilize the body. Being in an awkward body position, the force cannot be generated under the usual optimal physiological perquisites which increases the risk of injury (63).

The work environment of a surgeon is subject to one of the main postural constraints: the distance of the working hands from the trunk, also defined as reach distance. This space can furthermore be increased by barriers such as operating equipment that requires the surgeon to work around. An extension of the reach distance decreases the produced strength while increasing the force arm which results in a larger torque on the joints of the upper body and the spine. This cascade of adverse effects leads to a heightened risk of injury (63).

The flexion of the neck for a prolonged time has been identified as risk factor for developing MSDs in the neck or upper limbs by multiple clinical studies: Aaras et al. (64) examined the postural load when using a Visual Display Unit by evaluating EMG (electromyography) signals and Inclinometers (for obtaining postural angles). The main findings show a relationship between pain in the neck and shoulders and visual strain as well as strain on the neck extensors with greater neck flexion. Since surgeons work with a sightline directing downwards for a continuous time, the forward head posture (FHP) is accompanied with flexion of the neck, lower cervical spine and spreading of the shoulder blades (protraction of the scapulae). These abnormal postures furthermore cause compressive force on the surrounding soft tissue and neural structures. Although it has been shown that this posture is prevalent in diagnoses of MSDs around the neck, it has been challenging to draw a causal linkage (14).

Visual magnification using loupes are vision enhancing lenses that are placed on glasses (65). They put additional load on the cervical spine, which again has been identified as risk factor for developing an MSD. The usage of those loupes is common and has been demonstrated to be useful for augmented identification of differences in tissues and positioning of surgical instruments, besides the overall visual enhancement. A 2013 study by Nimbarte et al. (65) examined the relation between postural data of microsurgeons using loupes and risk factors for developing an MSD in the neck area. The results showed that the general use of loupes raised the load on the neck by 40% and the impact of the loupes was stronger for extremer postures with >45° head bending (cervical flexion). This finding is explainable by biomechanical principles since the neck muscles need to produce more force when the head is bend and the loupes produce additional weight due to an increased moment. The study produces significant results of using loupes on the loading of the cervical spine, but no differentiation between different types of loupes was made although differences of mounting angles and weights influence the loading on the neck.

A.1.4 Prolonged low static load

The last chapter showed that performing work in an awkward posture holds a risk factor for developing an MSD but holding the awkward posture for a prolonged time adds another adverse effect. In surgery, the hands perform most of the work which is why static load is most dominant on the neck area, the shoulders, and the upper limbs since they are working constantly to stabilize the manual movements. The causal relationship of musculoskeletal disorders and continuous static load has been under research for many years. While no definite singular explanation has been found so far, it underlies multiple factors for which various models have been proposed (53,66).

Theories for the relationship of static load and MSDs:

- **Cinderella Hypothesis**

  In 1991, Hägg (67) formulated a hypothesis suggesting that the generation of low muscular force induces an activation of certain motor units (MUs) that are responsible for lower loadings which become overloaded when movements are static for prolonged time. Those motor units that have low threshold for activation are referred to as "Cinderella units": Their fibers are fired for the longest time because according to the "size principle" of Henneman et al. (68) smaller sized muscle fibers (type I) are activated first and disconnected as last. The name of the theory is provided by the reference to the tale of Cinderella, who is the first to be working and the last person to be resting (66,69).

Contrary to the activation of the units for heavier muscle force, the Cinderella units can be recruited for a prolonged time since they don't induce sensible signals of discomfort or fatigue as an acute response (53). With those fibers being constantly fired until the muscle relaxes, they become overloaded while the larger MUs are not recruited as much during sub-maximal activity, which causes damage to the muscle cells and impairment of the calcium homeostasis. Both of these factors are seen as possible contributors to the sensation of muscle pain (69).

The Cinderella theory aims at explaining how continuous static movements with low-level loadings induce illness or dysfunctions of the musculoskeletal apparatus (53). Multiple studies have evaluated and verified the model by placing EMG sensors onto MUs which have demonstrated that the Cinderella units are fired for the longest time. This was not only shown for static muscle contractions, but furthermore in slow motions and for mental strain without any physical force.

This model highlights the necessity for not solemnly decreasing physical load but furthermore generating variation of muscle group activation and phases of resting the Cinderella units to minimize the risk exposure for developing MSDs.

- **Muscular imbalance due to static postures**

The mechanism of muscular imbalance caused by prolonged static postural strain has been formulated by Mackinnon et al. (70) explaining the under-usage of certain muscle groups and the over-usage of others. This usage imbalance leads to a respective imbalance of muscle size and therefore muscular strength which results in a continuous circle of further unequal muscle group activation (71).

- **Neural pathomechanisms**

Another theory explains how remaining in awkward or static postures for prolonged time can produce pressure on peripheral nerve trunks (71). By stretching them, tension is built up inside leading to continuous nerve compression, which can again induce inflammatory processes and thereby swelling of the surrounding tissue and blockage of blood supply. The vascular impairment can favor the generation of fibrosis restricting the neural passage and the gliding movements of the neural fibers even further. These pathological mechanisms can ultimately result in dysfunction of the nerves. Additionally, certain tasks where the limb is remaining static for a prolonged time can affect the somatosensory cortex permanently which is suggested to change the recruitment pattern of motor units (71).

- **Mitochondrial damage**

Researchers in sports physiology have demonstrated that endurance training can harm the mitochondria that are responsible for the provision of energy by producing ATP. This is explained by the process of electrons that leak from the mitochondria which can react with oxygen and create strongly reactive radicals such as hydrogen peroxide. Already a small damage of the mitochondria's DNA, can cause fatigue and muscle weakness. Since the main indication for the harmfulness of endurance sport is prolonged muscle exertion, it has been suggested that tasks that require long-term exertions on low-level can be subject to this mitochondrial damage (71,72).

- **Vascular damage - Reperfusion injury & impaired blood flow**

The theory of reperfusion aims at explaining muscle pain due to awkward working positions (71). It explains the process of restoring the blood flow after a posture or movement that has created a vascular blockage leading to tissue damage. Besides the adverse effects on tissue deprived of oxygen (e.g., necrosis), the biochemical procedure of reperfusion is harmful as well since it is comparable to inflammation with neutrophil cells generating toxic oxygen to kill microbes and prevent infections. Despite the absence of microorganisms, the stimulation of an inflammatory response after an impeded blood flow therefore damages soft tissue explaining the sensation of muscle pain (71).

Another explanatory model describes how continuous muscle contractions have adverse effects on the blood flow (53): Muscle activation causes increased pressure between the muscles which impairs their perfusion. Static muscle action lacks the relaxation of the muscle fibers and thereby the reduction of the intramuscular pressure which can cause prolonged obstruction of blood circulation. As described above, an impaired blood flow can lead to insufficient oxygen supply, which in turn induces the generation of lactic acid, causing a decrease of pH value and furthermore tissue swelling. Tendons become inflamed as a result of the oxygen deficiency and higher pressure due to swollen tissue structures (53).

The ladder model needs to be verified since there has been contradictory findings: Some research opposing the concept of the impaired blood flow as singular causing factor for MSDs [16], while other studies have detected vascular defects in subjects that suffered from muscle pain in the trapezius muscles and demonstrated intramuscular pressure increase in the supraspinatus muscle (covering the shoulder blade below the trapezius) when lifting the shoulder joint only by 30° [37].

A.1.5 High levels of mental strain

Another risk factor for occupational health in surgery is the amount of mental demand that is needed to perform precise surgical tasks (53,74). The requirement of high accuracy is increasing mental stress which can cause muscle tension without awareness, such as shrugging the shoulders or clenching the jaw. This high cognitive load is caused by a dense and high proportion of cognition restricting the working memory, which allows the reflection of thinking processes. There are many other psychological factors can contribute to further stress: Social conflicts, financial troubles, or time pressure are called “mental stressors” (74). Feasible disturbances within the working environment like uncomfortable air condition or noises, so called “physical stressors”, can also add to mental strain (74). It is important to note that the experience of these psychosocial influences is highly dependent on the individual perception.

A.2 Measurement techniques for assessing risk for developing MSDs

There are different measuring techniques for quantifying the risks for developing MSDs for surgeons. To acquire objective data of the surgeons’ physical workload, surface electromyography (EMG) is often used to measure the activity of a selected muscle or muscle group (75). The placement of Inertial Measurement Units (IMUs) give further information about postural data such as the joint angles and angular velocity (76). These techniques measure the technical data concerning the physical workload directly, but simpler methods have also been used to generate risk scores using observation (29,77,78). Subjective data about the perceived workload and sensation of pain give further information about physical and mental strain.

A.2.1 EMG for workload assessment

Surface Electromyography (sEMG) is a common choice for measuring muscle activity during surgery (79). Kraemer et al. (75) analyzed laparoscopic surgeons when using a hand piece that can be rotated. They studied the muscular activity of the shoulders and arms from intraoperative sEMG data to draw conclusions on the surgeons' muscular fatigue and physical stress. High levels of normalized electrical activity thereby indicate high muscular stress and accompanied by a decreasing median power frequency; this data pattern resembles muscular fatigue. However, Kraemer and his colleagues were not able to show significant changes in the indications for muscle fatigue between the usage of the standard fixed laparoscopic handle piece and the rotatable one. They contribute this finding to measuring only during the preparation phase of single laparoscopic surgical cases instead of the whole workday because there they suggest that muscular stress can be an accumulated outcome.

Dalager and colleagues (80) recorded surface EMGs for assessing physical exposure for comparing laparoscopic procedures with robotic surgery. The electrodes were placed on the neck and lower arms, as Figure A-1 shows. To analyze the measurements from the EMG signals the following steps are required: Before surgery, the subjects performed exercises of maximum isometric contraction to be used as reference data for normalization. An APDF (amplitude probability distribution function) is then applied to the resulting data that is expressed as $\%EMG_{max}$ which categorizes different patterns of muscular activity: static, medium, and maximum. The resulting patterns of muscular activity show that laparoscopic surgery generates differing intensities over shorter periods of time but both surgery types have about 3% EMG_{max} for static muscular activity which is higher than the acceptable threshold (81). Due to the relation of low muscular activity for prolonged time and generating musculoskeletal fatigue and pain, Dalager et al. (80) have performed an exposure variation analysis (EVA) to examine the course of the varying levels of muscular activity over time, revealing prevalence of long-lasting low muscle activity for the laparoscopic surgeons' shoulders especially.

Figure A-1: Placement of electrodes on the lower arm and neck (80)

A recent study by Wong et al. (82) has assessed robotic colorectal surgeons' posture as an ergonomic deficit by evaluating surface electromyography from different muscle groups of the upper body in a laboratory setting. The EMG results have thereby shown muscle strain especially in the neck. More than half of the surgeons furthermore reported physical discomfort and stiffness of the neck. They concluded that although robotic surgery is not as physically demanding as other surgery modalities in general, the low muscular activity for a prolonged time leads to physical and mental fatigue which increases with time. Evaluating the surgeons' postures as an ergonomic risk via electromyography has therefore been useful to demonstrate the cumulative effects of static muscle contraction on physical strain.

A.2.2 IMU for postural assessment

Assessing the physical exposure of the upper body is commonly used for evaluating harmful movements and ergonomic risk factors for the head, trunk, and upper limbs. More traditional approaches use a combination of kinematic and kinetic assessment together with functional measurements, such as the heart rate as well as subjective values, such as the perception of discomfort or pain. Biomechanical modeling can also be used to examine internal forces on joints, but they are less common (83). More advanced wireless technology makes up the IMU (Inertial Measurement Unit) which uses algorithms to approximate the position and direction of an object by processing data from various sensors that measure the acceleration (accelerometer), angular orientation and velocity (gyroscope), and magnetic fields (magnetometer) electromechanically. Other measurement methods such as marker-based two-dimensional video analysis or subjective inspection might generate more accuracy of kinematic measurements, but IMUs have shown to provide advantages of being used outside of a laboratory setting. This benefit is obtained by the IMU's ability to being set up only by placement on the body part of interest and securement with a strap or tape. Taking the sterile working environment into account, the usage of IMU sensors for acquiring postural data in a surgical field study is furthermore advantageous (76).

Acquiring data of the movement and posture of the relevant body segment during the actual activity is important to understand the generation of occupational injuries and MSDs. IMUs have therefore been validated for assessing the kinematics of the upper or lower body by many researchers and Morrow and her colleagues thereby focused on the performance of surgical tasks (84): The main objective was the validation of the accuracy of commonly used IMUs in comparison to motion capture using markers in a laboratory setting. While the IMU values showed larger angles for bigger joint angles and smaller values for angles of small joints, the overall accuracy was reported to be acceptable. The conclusion of this study needs to be put in perspective since it was conducted within a laboratory, comparing only selected measurements such as the maximum and minimum joint angle. The study furthermore uses a rather small sample size of six surgeons.

Schall et al. (76) performed a similar study comparing IMUs to a motion capture system but within a field-study setting during a full day of milking parlor work. The IMU measurements of the posture of the trunk and the upper arms were examined and found to have good accuracy and stability for postural measurements for a prolonged time. While the researchers have pointed out that they were not able to use the IMU's magnetometer due to ferromagnetic materials that are present in the field-study setting, which leads to decreased accuracy of the IMU values, due to their stability they are declaring them as suitable for evaluating occupational ergonomic risk factors for developing an MSD.

To generate objective values that represent risk level for developing an MSD, obtaining measurements of the surgeons' posture during the surgery is necessary. The use of IMUs is thereby common for assessing postural demands: Norasi et al. (77) examined ergonomic risk factors for vascular surgeons with postural sensors to obtain objective measurements during surgical procedures. They found that the neck was held in the strongest deviation from a neutral position with an average angle of around 37°. With the addition of the report of the most pain from subjective surveys the researchers concluded the alliance of extreme postural data, the sensation of pain and the likelihood of generating a disorder in the musculoskeletal apparatus.

Together with the Karolinska Institutet, researchers from the Mayo Clinic have tested the feasibility of IMU sensors for assessing biomechanical workload during robotic surgeries and found them to be an effective measurement tool for quantifying ergonomic risk factors (85). Figure A-2 shows how they applied IMUs on the head, sternum, on the upper arms and the pelvis to track the surgeon's motions during the procedure. The values from the accelerometer, magnetometer and gyroscope were converted into postural angles with the use of a MATLAB script and later evaluated as defined postural patterns, such as static postures and those that are physically demanding with reference to the postural angles and their duration of time. For illustrating the surgeons' postures and postural patterns during the procedure, the angles of the neck, torso and shoulders were plotted over time. The study concludes that the usage of IMU can facilitate the identification of ergonomic risks and the localization of those areas that require an ergonomic intervention. In order to conduct the latter, Yu et al. furthermore addresses the need for the surgeons' ergonomic awareness that should be fueled by adequate training, education and moreover feedback from the ergonomic assessment (85).

Figure A-2: Placement of IMUs on surgeon on the back of the head, the sternum, upper arms and pelvis. (85)

Furthermore, technically measured physical exposure at work can be used for predicting future health: A recent study by Gupta et al. (86) has investigated the influence of technical measurements of trunk forward of blue-collar workers bending using accelerometry on the risk of sick leave. A dose-response association was thereby found between trunk inclination and future risk of long-term sick absence. However, no similar study has yet been conducted among surgeons and more research is needed to gather the relevant data.

A.2.3 Observational assessment of physical workload

In addition to direct measurements, physical workload can also be evaluated using observational methods. There is a variety of assessment techniques that aim at identifying risk factors for developing MSDs, but it has been shown that their results can differ depending on the choice of method (87). Multiple researchers have applied the RULA (Rapid Upper Limb Assessment) to obtain risk scores based on postural observation (29,77,78). While it is easy to use, requiring only pen and paper, its level of accountability has been questioned since RULA results in an overall risk score that is based on observing single work tasks (88). Another disadvantage of observational methods is the low level of reproducibility between different observations and different observers (89).

A.2.4 Surveys for measuring workload and pain

In addition to the objective data, subjective ratings are commonly gathered via questionnaires. Different indices are thereby applied, with the NASA-Task Load Index (NASA-TLX) and the Surgery Task Load Index (SURG-TLX) being the most common ones [1, 2]. Both indices measure the workload from the surgeon's perspective regarding mental and physical demand as well as other aspects such as grading of their performance and frustration. Further subjective rating include the subjects' sensation of pain and discomfort, which is often evaluated using the standardized Nordic Questionnaire and the Borg CR-10 Scale (77,85).

A.3 Surgical ergonomic intervention strategies

Due to the high prevalence of ergonomic risk factors in surgery that can lead to developing an WMSD and the possibilities of measuring them accordingly, one objective of ergonomics is the implementation of intervention (45). These interventions can be approached by designing an ergonomically appropriate work surrounding in accordance with the subjects' physical and mental needs ("fitting the work to the human"), and by adapting the working behavior or physical conditions ("fitting the human to the task") (22).

A.3.1 Fitting the work to the human

Multiple surgical tools have been improved in order to decrease physical and mental strain of surgeons and simultaneously increasing the work performance: Tung et al. (91), for instance, have found that the ergonomic design of a laparoscopic tool handle led to a decrease of the surgeons' experience of discomfort in the hand as well as an increase in productivity. Many similar studies (11–13) demonstrate decreased physical strain, increase in work performance together with a general preference of the surgeons towards the design which considers ergonomic principles.

Prismatic loupes as an example for ergonomic tool design

Developing an WMSD in areas of the neck and upper limbs back is a common ergonomic risk for surgeons due to the prolonged neck flexion (64). Since the prevalence of pain and discomfort in the neck increases when surgeons are wearing loupes for visual magnification due to their additional weight, their re-design provides an ergonomic approach of improving the work system for the human's well-being (65). Simple visual aids serve as an ergonomic intervention by decreasing the human's eye strain and more advanced magnification devices can furthermore help to decrease the risk for harming the musculoskeletal apparatus (92). This finding has been proven especially in dentistry: A recent study by Pispero et al. (93) reports the evaluation of the impact of different types of visual aids (eyes, microscope and surgical loupes) on a dentist's postures. The results show that the loupes improve the dentist's postural behavior with decreased neck bending while the lowest risk score was found for the usage of a surgical microscope. Although this study is strongly limited by testing on a single dentist, it demonstrates the potential of visual aids as ergonomic intervention.

Studies by Lindegård et al. (94) are able to demonstrate the successful potential of implementing prismatic loupes as ergonomic intervention to reduce risk factors for developing an WMSD for dental personnel. In 2012, the researchers have studied the potential of prismatic loupes as ergonomic intervention by examining their effect on the kinematics of head and neck of 45 dental professionals and in 2016 (95) they have evaluated the impact of prismatic spectacles on neck pain, work ability and exertion perceived by further dental personnel. The results show a significant decrease of the intervention group's grading of neck pain, work ability and perceived exertion, as well as a significant improvement of the clinical examination of the neck. The study's strength, showing the long term (12 months) success of the intervention has been examined in a clinical setting using two kinds of assessment (subjective via questionnaires and objective via clinical examination) is clear, but with no objective data directly measured and no group randomization, there remains potential bias.

In 2007, Kim et al. (96) designed novel prismatic spectacles with an increased refraction angle that can allow more neutral postures of the head and neck. This objective is achieved by integrating two prisms into the binocular loupes that are placed onto the surgeons' glasses, which is displayed in Figure A-3. These prisms let the light reflect on four surfaces resulting in a downward sightline angle of 48°. Furthermore, the optics are placed on to the upper part of the surgeons' glasses enabling them to see actual dimensions through the lower half. This setting decreases further neck flexion when an unmagnified view is required, for instance, when reaching for a surgical instrument. The light weight of the loupes (88-97 g) provides another potential strength regarding the decreased moment and required muscle force of the neck and upper body. Besides the promising characteristics of the novel prismatic spectacles and having evaluated multiple prototypes, the technical article does not give information about testing trials in real surgery.

Figure A-3: Novel design of prismatic loupes mounted on eyeglasses (A: side view, B: frontal view). (96)

A.3.2 Fitting the human to the work

Although multiple researchers (4,10,97) regard the purpose of ergonomics as modifying the work to the most suitable form for the worker, they imply that a collaborative approach with the worker himself is important.

Raising ergonomic awareness as example for fitting the human to the task

Sluchak (10) states the recommendation of the Occupational Safety and Health Administration (OSHA) that contains the ergonomic education and participation of employees as one of the guiding four steps. Buckle (4) furthermore postulates the workers' commitment and educational training as one of the pillars of successful ergonomic intervention. These findings suggest that applied ergonomics take a more holistic approach where fitting the human to the task complements the objective of solemnly engineering the work system.

A study from 2017 (17) analyzed the level of ergonomic knowledge within the construction industry by conducting a survey questionnaire asking about safety and ergonomic programs implemented by the employers. The results showed that although 50% of the respondents the thought of ergonomics as extremely important, only one third mentioned that they have conducted an ergonomics program and only one fourth has had an ergonomic analysis of their working task. With around 45% of the injuries that have been reported being due to the movement or posture of the worker and thereby about 44% percent being typed as sprain or strain, both the workers and the managers have stated to have only slight awareness about the prevalence of WMSDs. The study concludes furthermore, that the management plays an important role in the successful implementation of ergonomic programs, which is why they require adequate ergonomic training themselves (17).

Van Det et al. (19) performed an ergonomic assessment on laparoscopic cholecystectomy surgeons' neck posture in relation to the positioning of the monitor within the operating room. Since the monitor has direct effect on the posture of the surgeon's neck, spine, and upper limbs due to the adjusted sight line the positioning of the screen creates a possibility for an ergonomic intervention. While this redesign of the work environment showed significant improvements for the surgeons' (and the other operating personnel's) postures, the researchers underline the need for ergonomic education. To ensure the postural improvement, it is necessary to highlight the importance of ergonomics by raising awareness about the risk factors that can lead to musculoskeletal disorders and the possible solutions through applying ergonomic practices to surgical work.

Another study by Linden et al. (18) directly targeted the impact of ergonomic education on the postural behavior of surgical assistants. While all participants took part in a theoretical course on ergonomic practices, the intervention group was additionally given individual feedback in form of an ergonomic risk report and their postures were evaluated using IMUs before and afterwards. The results state significant improvements of neck and arm postures, achieving a lower risk score in the selected body segments. Results from surveys that have been distributed after the study support this conclusion by grading the ergonomic reports useful for intentionally adapting their postural behavior by all surgical assistants from the intervention group. Despite its limitations such as the small sample size, this study shows the potential of the ergonomic intervention in form of personalized feedback reports by the significant postural improvements.

A.4 Summary

WMSDs are defects of the musculoskeletal apparatus that are caused or fueled by the occupation. Surgeons are among the highest risk groups to develop these putting them in discomfort, pain and possible early pension or need for rehabilitation. The upper body including the neck, shoulders, upper limbs, and lower back is mostly affected by the surgeons being statically in an awkward posture for a prolonged time. Additionally, visual enhancing surgical loupes are placing additional weight on to the surgeon's head increasing the load on the neck and different factors can add to mental strain during surgery. EMG data give therefore information about the muscular activity to identify pattern which serves to evaluate risky physical effort using thresholds for static behavior. IMUs provide data about the surgeons' posture which can then be examined to find postural behavior that bear risk for developing MSDs.

A novel design of prismatic loupes is expected to have advantageous effects on physical exposure by allowing a more neutral angle of the surgeon's head. There has not been any empirical investigation of effectiveness of these loupes in real life surgery. Since ergonomic awareness is found to be an important factor when applying an ergonomic intervention this study will design and evaluate an individual ergonomic assessment report based on the surgeons' muscular activity with EMGs and postural behavior with IMUs.

B Appendix: Study materials

B.1 Presentation script for Think Aloud session and user interview for evaluation of demo report

Demo Report – Presentation script & User evaluation

Presentation script

- Informed consent:
  - o Individual Ergonomic report as measure for ergonomic risk assessment and ergonomic education
  - o Aim:
    - ▪ design interactive individual ergonomic assessment report based on objectively measured postures and workload &
    - ▪ examine impacts of providing surgeons with such report as an in-person education on their ergonomic awareness

  (Study objective: Providing individual risk reports used as potential means for increasing ergonomic awareness, improving adherence to ergonomic principles & decreasing risk of developing WMSDs among surgeons)

- (Report is based on first trial of measurements of real surgeon (2 different loupes used in 2 surgeries))
- Would like to get feedback on demo report for further development → Feedback from user interviews will be gathered and implemented in the design process of the report

Ask to **'think aloud'** during using the report to get your experience as user → record!
→ ask permission & start recording (say "today is dd/mm/yy")

QUESTIONS:

1. How do you feel about interacting with this demo report?
2. What would you like to be improved?
3. Is there any other information that you would like to receive from this report?
   a. Duration of surgery
   b. Type of surgical case
4. Is there any redundant information given in this report?

- Further comments?
- Compare devices

Information in case

- Static load (10th percentile): level exceeded during 90% of operating time
- Median load (50th percentile): average muscle activity level
- Peak load (90th percentile): level exceeded during 10% of operating time
- SULMA: different theories on why low-level muscle activity is linked to muscular discomfort/pain: "Cinderella Theory" (prolonged activation of single muscle motor units)
- Posture Angle definition: Postures defined as angles of a body part during a defined motion
  → head and trunk: angle is the sagittal inclination angle of the head and the trunk (positive values indicating 'forward' inclination)
  → upper arms: angle defined as the elevation angle

B.2 Questionnaire for evaluation of ergonomic education

Page **1** of **2** Case ID (subject+date): E00520220627

QUESTIONS AFTER ERGONOMIC EDUCATION SESSION

USABILITY

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
i. The ergonomic education session was interesting and presented information in an interesting way.	☐	☐	☐	☐	☐
ii. The information on this ergonomic education session was clear and easy for me to understand.	☐	☐	☐	☐	☐
iii. I think this ergonomic education session could help me work in a safer way.	☐	☐	☐	☐	☐
iv. I think that taking part in this individual session is useful for ergonomic education.	☐	☐	☐	☐	☐
v. I think that I would like to use this type of ergonomic education frequently in the future.	☐	☐	☐	☐	☐

PERCEIVED IMPACT

i. This ergonomic education session has increased my awareness of the importance of ergonomic principles.	☐	☐	☐	☐	☐
ii. This ergonomic education session has increased my knowledge/understanding of ergonomic principles.	☐	☐	☐	☐	☐
iii. This ergonomic education session has changed my attitudes toward improving behaviour of ergonomic risk.	☐	☐	☐	☐	☐
vi. This ergonomic education session has increased my intentions/motivation to address these ergonomic principles.	☐	☐	☐	☐	☐
v. This ergonomic education would encourage me to seek further help to address these ergonomic principles (if I needed it).	☐	☐	☐	☐	☐
vi. Use of this ergonomic education will increase my ergonomic behaviour.	☐	☐	☐	☐	☐

vii. How likely is it that you would recommend this type of ergonomic education session to people who might benefit from it?

Not likely										Very likely
0	1	2	3	4	5	6	7	8	9	10

B.3 Semi-structured interview guide for evaluation of ergonomic education

Page **2** of **2** Case ID (subject+date): E00520220627

SEMI-STRUCTURED INTERVIEW

**ask for permission to record*
**say 'today is DATE'*

1. **Usability**
   a. How do you feel about this ergonomic education session (individual report / ergonomic guideline)?
   b. What <u>other type of information</u> would you like to receive?
   c. What would you like to be <u>improved</u>?

2. **Ergonomic awareness**
   a. How do you understand (see) surgical ergonomics?
   b. Do you adopt ergonomic principles in the OR? <u>Why?</u>
   c. What <u>postures or activities</u> in your work in the OR do you think are at ergonomic risk?
   d. (What did you <u>learn</u> from this ergonomic education session?)
   e. How will this ergonomic education session <u>affect your way of working in the OR</u>? (*Posture, breaks, set-up of OR)* (changes that are already possible/available)
   f. What would you like to do in order to <u>seek further improvements</u> in surgical ergonomics at your workplace? *(new surgical tools, environments, seeking for professional advice, etc.)* (changes/things that are not already available)

Further comments?

C Appendix: Results

C.1 Basic surgical ergonomic guideline

Surgical Ergonomic Basic Guideline

Surgeons are one of the **highest risk groups to develop work-related musculoskeletal disorders** which can lead to burnout, early pension and affect the surgical performance and patient safety.

The upper body, especially the neck and shoulders, is mostly affected due to operating in a **static and awkward posture for a prolonged time**.

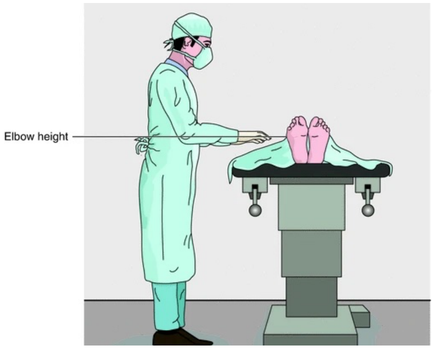
Posture during surgery

The left surgeon holds the correct posture, the right surgeon stands with too much flexion in the neck and back.[1]

The left surgeon holds the incorrect posture with a twist and lateral flexion of the back.[1]

Joints should be held in a **neutral position** to avoid maximum possible amount of strain:

- The head should be held in a neutral position in line with the shoulders, ideally flexed no more than 20°.
- The back should be kept in a straight position with the shoulders in line with the pelvis (without lateral flexion) for symmetric loading on the spine.
- The arms should be held with an elbow flexion between 90° - 120° and the angle of the wrists should not exceed 15°.
- The height of the operating table should be adjusted for a working position of 5cm above and below the height of the surgeon's elbow.
- In a stance, the feet should be kept in distance of the hip and there should be a slight bend in the knees.



The correct height of the operating table is at height of the surgeon's elbow.[1]

Avoid prolonged static position

- Prolonged static postures should be avoided. Frequent short breaks decrease muscular fatigue. Every 20-40 minutes, **stretching** for 90 seconds is recommended through:
  - Flexion and extension of the neck
  - Backwards rolling of the shoulders to stretch the chest
  - Upper back stretching
  - Hand stretching
  - Flexion and extension of the lower back with squeezing of the gluteus maximus
  - Lifting of the heel and forefoot to stretch the lower limbs and ankles

Stretching of the neck (left) and stretching of the shoulder (right).[2]

→ *(Available guided stretch in video, see 'OR-Stretch' by Mayo Clinic.)*

- An **anti-fatigue foot mat** can provide cushion and increased comfort for longer surgical cases and allow small varieties of the stance.

Anti-fatigue foot mat for surgery[3]

- **Supportive footwear** with closed toes and cushioned insoles should be chosen for a stable and comfortable stance to decrease the risk of prolonged static standing and muscle fatigue.

Choice of equipment

Ergonomically designed equipment can support surgeons' comfort, for example:

- New types of **prismatic loupes** are designed to enable a more neutral position of the neck due to a higher declination angle of the lenses.

Sources

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