Ergonomic evaluation of a novel robotic microscope in the field of neurosurgery

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***Abstract*—Ergonomics is a science that has been gaining popularity over the past years and decades in an ever-changing way of working. This includes the workplace of medical personnel who, especially in the operating room, are exposed to long and often unusual working positions and are thus at greater risk of contracting work-related musculoskeletal diseases. Therefore, in this paper, a study was conducted to analyze and reveal the differences in the ergonomics of two types of surgical microscopes. In this study, a traditional surgical microscope and a robotic exoscope controlled by a head-mounted display (HMD) are compared. In this study, 20 participants were invited to complete a threading test with both microscopes. Ergonomic data was recorded using an inertial measurement system that evaluates multiple sensors on the candidates. In order to finally convey a meaningful and comparable result, the *Rapid Upper Limb Assessment* (RULA) method was applied, which itself was implemented in a programmatic way. The results of this study show that there were differences especially in individual sub-areas of the RULA score, whereas the total score of both halves of the body did not differ significantly. This was clearest in the area of the head and wrists. Considering all RULA scores, it can be said that this technology can generally be assessed as low-risk. However, there is still room for improvement.**

***Index Terms*—Ergonomics, Exoscope, RULA, Inertial Motion Capture**

I. Introduction

ERGONOMICS - a concept that has been widely mentioned in the modern era regarding human health condition and the work environment. The term originates from the two greek words *ergon* and *nomos*, which can be translated to *work* and *laws* as a reference to science [1]. To this day, ergonomics focuses on the interaction between people and their work environment. The goals of ergonomics are to sustain an appropriate level of safety and comfort at the workplace without interfering with the performance of said worker while lowering stress. Achieving this can certainly be a huge challenge with work becoming more and more specific and routine-based at certain workplaces. Sitting and standing for multiple hours every day throughout the week is not uncommon anymore. Keeping uncomfortable postures and excessive / limited use of specific muscles can not only lead to fatigue, but also to long-term diseases, so-called *work-related musculoskeletal disorders* (WMSDs) [2].

One workplace where restriction of movements, awkward postures and a high stress level all come together is the operation room (OR) of hospitals. Hour long procedures are carried out on patients with the expectation that the surgeon will precisely execute every move in a robot-like fashion until the operation is done. Especially in the field of neurosurgery demands a high level of precision and accuracy to achieve successful results. Even just the smallest deviation can cause the prolonging of the operation, severe complications, or be potentially lethal for the patient. Despite tremendous technological advancements in the assistance for surgeons, they are still limited to factors such as their own dexterity, concentration and the capabilities of the tools in use, e.g. the resolution of imaging techniques [3]. Focusing on these key aspects will decrease the overall risk involved with operation and reduce recovery times of the patient.

As mentioned earlier, recent years have shown significant progress in the development of surgical tools for either assisting the surgeon or performing tasks autonomously. One major trend in the assistance of surgeons is the involvement of robots in the OR. Robots offer new opportunities to exceed the limitations of surgeons and improve the quality of surgical procedures. One specific use of medical robots is the field of microscopy, which results in the development of exoscopes. Exoscopes are devices that combine a robotic arm that can be controlled by the surgeon and high-definition imaging to support the surgeon with enhanced visualization while also giving them more flexibility and comfort during the author operation [4].

Recent studies have also shown that the usage of robot technologies in the surgical field has increased over last years and will continue to do so in the future, with the market size doubling from 2021 till 2030 [5]. Furthermore, lots of studies have already been published stating that the surgical outcomes have been lowering the complication rates and hospital stays [6]. Nevertheless, the ergonomic impact of these technologies on a surgeon have not yet been fully explored. A similar study has been done by Abramovic et al. [4] which will be mentioned in more detail in section III.

In addition to the surgical tools, methods to register the ergonomic impact of certain tasks have improved as well. Previously, ergonomics were measured with simple methods like using goniometers and reading the angle measurements manually by adjusting it to the correct position [7]. Nowadays,

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scientist are provided with more advanced technologies by making use of electromyography (EMG) and inertial measurement units (IMU) sensors. EMG sensors are able to record the muscle activity whereas IMUs obtain data regarding the orientation and acceleration with which angles and speed can be calculated. These sensors types have been included in several measurement systems, ranging from observing single limb activities to full body motion tracking [8].

For this paper, medical professionals in the form of neurosurgeons will be involved. The neurosurgeons will be made familiar with the robotic exoscope previous to performing the ergonomic assessment. The ergonomic assessment will cover a neurological procedure carried out on medical dummies. While performing the procedure, the surgeon's posture will be tracked by a fully body motion capture system alongside a camera to compare the measured data and the calculated avatar with the actual visible posture of the surgeon. Later on, the data will be evaluated and compared with a second measurement concerning conventional microscopes in neurosurgery.

The objective of this paper is to evaluate the ergonomic impact of a novel robotic exoscope in neurosurgery and to find out whether it improves the posture of the surgeon. It should also help to identify improvements of the exoscope itself. The outcome of these measurements will then be compared to conventional microscopes used in surgery to provide more insight of the advantages of exoscopes. These insights should help to provide the surgeon with a more comfortable work environment and reduce the risk of long-term disorders related to work, in addition to the quality of care for patients undergoing neurological procedures.

To sum up, surgical robots are a growing technology within the medical field of robots and continue to gain popularity. With the help of ergonomic measurements, these robots can be further improved and therefore make the lives of surgeons easier with patients being exposed to less risk.

II. Literature Research

Before heading directly towards the experiments, a plan for confronting this issue had to be laid out. First up was the question of what exactly are WMSDs, how are they triggered and what can be done to reduce the risk of getting one. The focus therefore was laid on WMSDs like tendonitis [9] and the tension neck syndrome [10]. Next up, the question arose on how to quantify ergonomics. After searching applicable methods to this task, the methods RULA [11], REBA [12], ROSA [13] and OCRA [14] have been investigated in more detail. As these methods compared the ergonomics of different postures rather statically using a spreadsheet, a method of collecting data about the kinematics of the human body was searched for. Methods such as marker-based motion capture [15], markerless motion capture [16] and the usage IMUs [17] were examined. Finally, the decision on which of these components to include for the measurement was made and will be discussed in further sections.

III. Methods

After conducting the literature research, this section will point out which tools have been chosen to accomplish the task of evaluating the ergonomic burden of both types of microscopes and the reasons for selecting them. Furthermore, the characteristics of the selected tools are described in more detail, as well as their parameters for data acquisition. Then the structure and the process of the study are described in detail, and finally it is explained which ergonomic framework was applied and how it was implemented programmatically.

A. Microscopes

As far as the microscopes required for the test were concerned, the choice fell on the *Tivato 700* model from *Zeiss* for the conventional surgical microscope, and the *RoboticScope* from *BHS Technologies* was used for the robot-controlled variant. The reason for choosing these two microscopes is the tender for the paper of the Management Center Innsbruck (MCI), which contacted BHS Technologies and the Innsbruck University Hospital in search of available surgical microscopes and thus the availability of two different surgical microscope systems could be guaranteed.

The main difference between these two microscope is the way of accomplishing the desired angle to look at during an operation. The Tivato 700 uses two joysticks which are located on both sides next to the camera module at the end of the machine's arm. In order to get the Tivato in the right position, the surgeon has to steer it by putting both hands on the joysticks and pressing the appropriate buttons on them. After releasing the joysticks, the Tivato remains in its position and the surgeon is able to look through the oculars while holding his posture. The RoboticScope on the other hand controls the camera module at the end of the robotic arm though an HMD. The surgeon is able to manipulate the robotic arm by head movements (twisting and nodding) and can take a look at the area of interest without changing the initial position of standing or sitting. Furthermore, multiple actions are included that are not related to positioning the cameras, such as adjusting the working space, altering the light intensity or changing the focus. Achieving this is made possible by detecting head movements from various sensors in the HMD and two displays, with each screen being connected to one of the two cameras to create a sense of depth. This means that the surgeon does not rely on keeping a position related to the camera module and can move the camera in position while being able to head back into a neutral position. Also, no hand movements are required and therefore the surgeon does not have to lay down any instruments. What both systems have in common is the feature of recording the video footage captured by their cameras, which will be reviewed later in the paper.

B. Motion Capture System

For choosing the right motion capture system, it became obvious that deciding on a camera-based would not be suitable for this application. Sustaining one or even multiple camera angles constantly without obstructing the vision in any way for continuous motions and longer periods make these types of motion capture systems obsolete for this test. This means that using motion capture systems revolving around sensors is a more appropriate way to handle the data acquisition. After deciding on focussing on the posture of the surgeon rather than the muscle fatigue after operating, the idea of including EMG sensors was dropped and the IMUs have been selected. As the MCI has an inertial motion capture system at their disposal, the test data has been recorded using the *Ultium Motion System* manufactured by *Noraxon*.

The Ultium Motion System features 16 individual IMUs that can be attached to the body of the subject via straps or double-sided tape. Each of these sensors belongs to a specific region of the body and has to be place on the according anatomical landmark. The sensors cover the entire body with two sensors belonging two the feet, shanks, thighs, hand, forearms and upper arms (left and right) and four sensors along the spine covering the pelvis, lower and upper thoracic area and the backside of the head. The system is also capable of displaying a real-time avatar in its recording software in order to provide direct feedback during the recording. Additionally, it can work as camera replacement if no camera has been used during recording to gain a better understanding of what was happening in real-life. After saving or rewatching a record, the system also provides the possibility of generating reports on chosen channels to perform a quick analysis of the recorded data.

C. Ergonomic Evaluation

As the ergonomic evaluation of these two systems can be performed in multiple ways, previous assumptions on the importance of certain parameters have been made. First, the value of the sensor readings of the lower half of the body have been considered to be of low importance, as the test will be carried out from a sitting position. This reduces the amount of data to be analyzed greatly, and therefore the choice of ergonomic frameworks can be narrowed down to those focussing on the upper body. With the term "upper body" being brought up, the decision fell on the data being judged by the RULA method. This method includes angle measurements of the upper arm, forearm, wrist, head and spine combined with force and load scores. The final RULA scores ranges from 1-7 and will be calculated for every entry being sampled.

After this decision, the RULA method was digitalized in the form of a self-written script in *MATLAB*. In order to accomplish a meaningful result, some limitations and approximations were introduced in the coded version as shown in tab I.

Most of the modifications to the RULA are based on a paper written by Maurer-Grubinger et al. [18] because they have applied the method in a similar setup which also makes the results of this paper comparable to theirs. Another benefit of these approximations is the reduction of small distortions and noise during the measurement but not all modifications could be digitalized. The reason for that are the limitations of the Noraxon System as it has no sensors available to determine the score for *Shoulder Raising*. Furthermore, this system only measures rotation and no translation which makes the recognition of the score *Arm Working Across Midlane* a difficult task. A similar case is the detection of *Arm Support*. Therefore, it has been decided to evaluate these scores upon an analysis of a video recorded by a remote camera. Other scores like the *Muscle Use Score* and the *Force/Load Score* can be set to fixed values as the task is performed in a mainly static position and involves the holding of tweezers and a needle holder.

TABLE I: Modifications of the RULA Worksheet

	Movements	Modifications
STEP 1	Upper Arm Position	NONE
	Shoulder Raising	qualitative inspection
	Upper Arm Abduction	angle set to $45°$ [18], [19]
	Arm Support	qualitative inspection
STEP 2	Lower Arm Position	NONE
	Arm Working Across Midlane	qualitative inspection
STEP 3	Wrist Position	$\pm$ $2.5°$ in flat position
	Wrist Bend From Midlane	$\pm$ $5°$ from baseline
STEP 4	Wrist Twist Mid Range	angle set to $\leqq 45°$ [18], [19]
	Wrist Twist End Range	angle set to $> 45°$ [18], [19]
STEP 5	Posture Score in Table A	NONE
STEP 6	Muscle Use Score	Set to 1
STEP 7	Force/Load Score	Set to 0
STEP 8	Row in Table C	NONE
STEP 9	Neck Position	$5°$-$5°$ and $5°$-$20°$ [18], [19]
	Neck Twist	$10°$ deviation [18], [19]
	Neck Bend	$10°$ deviation [18], [19]
STEP 10	Trunk Position	$5°$-$5°$ and $5°$-$20°$ [18], [19]
	Trunk Twist	$10°$ deviation [18], [19]
	Trunk Bend	$10°$ deviation [18], [19]
STEP 11	Legs	Set to 1
STEP 12	Posture Score in Table B	NONE
STEP 13	Muscle Use Score	Set to 1
STEP 14	Force/Load Score	Set to 0
STEP 15	Column in Table C	NONE

D. Participants Inclusion

For this experiment, 20 volunteers (8 male, 12 female) have been included. None of the participants had prior knowledge about what the challenge they were going to face with both microscopes and neither of them had any experience in operating a surgical microscope.

E. Experiment Design

Each participant was given a short introduction about formalities of the test being performed. The test itself had been a threading test. The object on which the threading test was being performed was a more advanced version of a similar test being carried by Abramovic et al. [4]. This test consisted of a custom-made microsurgical training tool that contained ten eyelets set at different angles, which obligated the participants to maneuver both the traditional and novel microscope in a lesser or more extreme position. These eyelets had an inner diameter of 1 mm and metal pins were fixated on a baseplate and bent in various angles. The newer version of this test tool provided by BHS Technologies was reduced to nine eyelets and had been printed out of a durable PET from a 3D-printer. Each eyelet has also been given a direction from which side the needle should be threaded. This was indicated by a small circle on one side around the eyelet. The RoboticScope has been placed in *Position 7* and the sensitivity of the HMD has been set to 50%. A working distance of 450 mm has been chosen for beginning the threading test. To provide a better understanding of the object, an image of it can be seen in fig 1.

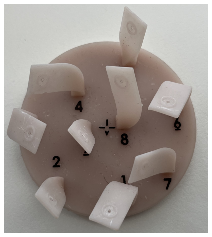

Fig. 1: 3D-Printed Threading Test

After the general test introduction, the IMUs were zeroed attached to the participants. Each of the available 16 sensors had been fixated on the participant using straps provided by Ultium Motion System with one exception being the upper thoracic sensor. This one had to be fixated using double-sided tape. Each of the volunteers had been made aware of informing the investigator whether the straps were too tight or too loose without the risk of the sensors slipping. An image of the full sensor setup can be looked at in fig 2.

Fig. 2: Sensor Setup with Straps on Participant

Following that, the participants were provided a 5-10 min introduction to both surgical microscope systems. Knowledge on how to operate these systems with only basic controls have been communicated and after that the participants were given a tweezer and a needle holder with a 6/0 suture material out of polyamide. Before starting the test, each participant had to stand in the standing calibration pose to reduce artifacts of disturbances of the surrounding magnetic field. No time limit had been enforced and the test was completed once every of the nice eyelets had been threaded correctly. After completing the test on one microscope, the candidate switched to the next one. In order to avoid creating a bias towards the test tool, the participants started the test in an alternating way.

IV. Results

In this chapter, the results of the research work dealing with the ergonomics of a new surgical microscope are presented. The aim of this study was to determine ergonomic properties of the surgical microscope and subsequently the difference between it and conventional surgical microscopes, as well as to contribute to the understanding of the ergonomics of a neurosurgeon's workplace. Although this work was started with great enthusiasm and a clear research strategy, it must be emphasized at this point that the path to knowledge was not without challenges.

The research effort began with the expectation of proceeding smoothly and according to plan. Experiments were carefully planned, hypotheses were developed, and data were collected, but as is often the case in scientific research, the effort soon faced unexpected difficulties and initial setbacks. It is important to note that these challenges did not only affect the work, but also deepened the understanding of how to collect usable data on ergonomics.

The following results shortened to tables and are presented in chronological order.

A. *1st Test Series*

The first test series started with inviting 15 participants (5 male, 10 female) to the OR. A small introduction was given to understand the task. The hardware was set up correctly and the sensors were zeroed. After attaching all sensors, the participants went into the standing calibration pose before the measurement started. When the calibration ended, the participants began threading the suture material through each eyelet.

While performing the task, the Noraxon system was able to receive data, but some signals were either heavily distorted, creating an offset or a linear increase or decrease which did not resemble the actual position of the participant at all. This led to horrible representations of the avatar displayed in the software and made the data impossible to use for any meaningful analysis. Smaller and bigger deviations were no surprise during live data recording, as this has happened while testing the system before and are usually smoothed after the data collection has finished. These distortions were not expected, though. An example of this can be seen in fig 3.

Such a vehement divergence has not happened prior to performing the tasks in the OR which made responding to such an event a difficult task on site. Even after the first couple participants, it was not possible to come up with a solution for this problem, which ultimately rendered the data of all participants useless.

B. *Failure Analysis*

After a resounding defeat in the operating room, the search for the origin of these inconsistencies was launched. Since there had been no gross deviations in previous tests at *BHS*

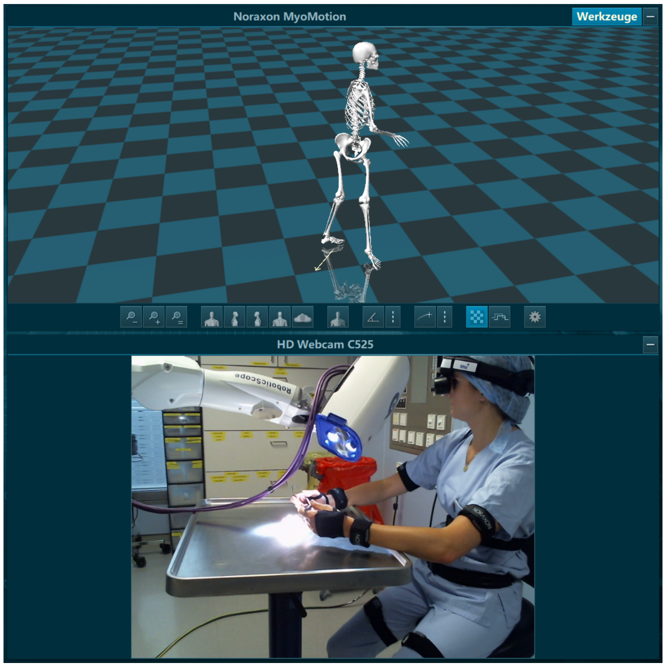

Fig. 3: Failed Measurement with high Distortions

Technologies and in the lab at the university, it stood to reason that conditions in the operating room were responsible for the distorted signals. After consulting with people working in the lab, the fact was expressed that the Noraxon system behaved strangely near metallic objects. High-frequency power lines, such as those found in medical equipment or lamps, could also be the cause. In fact, the measurements used a stainless steel table on which the thread test was placed. As far as the power lines of surgical lamps are concerned, no statement could be made about this.

After it became clear how the error might have occurred, an attempt was made to recreate the test situation as best as possible. Due to scheduling difficulties, the OR could not be booked for this project. Therefore, it was decided to recreate this situation with a person in a room with as many metallic objects as possible, as seen in fig 4.

Fig. 4: Simulating Signal Distortions with Metallic Objects

The success of the error investigation made it clear that the influence of metallic elements, in particular the stainless steel table, was the primary culprit for the signal distortions.

A strategy was then developed to keep this error in check for the next measurement. Apart from the use of a different table, the residual risk of unknown magnetic field influences in the OR still remained. This residual risk could also be estimated poorly, since the simulation of this situation was not performed in an OR.

As a result, the manufacturer of the Noraxon system was contacted to obtain his opinion on this matter. The manufacturer revealed that the ”walking” calibration method would be best suited for a measurement in the environment of high magnetic field influences. Furthermore, the manufacturer recommended a maximum continuous measurement duration of 90 seconds in such an environment. After these 90 seconds, the reference position should be taken again in any case to minimize the error. Thus, this remained the only alternative besides the suggestion of changing the premises.

Promptly after this conversation, the new strategy with the 90-second stops was tested. This plan of action turned out to be a huge improvement in signal quality and was able to eliminate the negative effects of the metal objects. After these successes, it was clear how the next series of tests could be started.

C. 2nd Test Series

After the failure analysis, an attempt was made to get the OR again for another series of tests. However, this turned out to be more difficult than expected, as due to scheduling obstacles, no date could be found in the given time for this paper. This means that no comparison between the two surgical microscopes was possible, as the conventional operative microscope was only available in the clinic. Consequently, the assumption of interference due to the external influences of the OR could not be verified either.

This meant that the following tests were carried out at BHS Technologies itself, as the RoboticScope could be booked at their company. Further test subjects (3 male, 2 female) were then organized and the investigation of the ergonomic properties of the RoboticScope could be continued at BHS Technologies.

One advantage that arose from this approach was the elimination of the presumably disturbing influences of high-frequency power lines in the operating room. Nevertheless, it was decided that the ”walking calibration” would continue to be used because of its robustness to interference. The new measurement procedure was additionally supplemented by first taking the reference position after starting the measurement, then again at eyelet 5 and finally shortly before stopping the recording. Before calculating the RULA score, these transition phases have been removed from the measurement manually in order to evaluate only the time of performing the actual task.

In the following sections, the outcomes of each participant are shown by tables presenting the distribution among the individual scores scored.

TABLE II: Percentage Distribution of Person 1

	Left Side in %	Right Side in %
Score 1	0	0
Score 2	7.75	3.40
Score 3	41.93	42.57
Score 4	32.81	27.49
Score 5	4.88	13.91
Score 6	12.63	12.63
Score 7	0	0

1) Person 1: Table II indicates that Person 1 scored 82.49% of all scores within the range of 1-4 on the left side and 73.46% on the right side with 3 being the represented most. Also, the table points out the fact that Person 1 never reached scores lower than 2 and higher than 6. With the scores 3 and 4 taking up big amounts of the overall scores, Person 1 fulfilled the task on the lower end of the RULA scoring system with a few exceptions, which tend to be more constant on the right side than on the left.

TABLE III: Percentage Distribution of Person 2

	Left Side in %	Right Side in %
Score 1	0	0
Score 2	43.67	29.79
Score 3	29.92	44.03
Score 4	10.74	10.98
Score 5	4.70	10.25
Score 6	10.92	4.95
Score 7	0	0

2) Person 2: Next, table III show that Person 2 scored 84.33% on the left and 84.8% on the right of all scores lower than 5. Surprisingly, the results of the scores of 2 and 3 are almost identical with them being switched out for each side. Higher scores resemble a similar fashion. Score 4 seems to be constant on both side. The limits of 1 and 7 have not been reached.

TABLE IV: Percentage Distribution of Person 3

	Left Side in %	Right Side in %
Score 1	0	0
Score 2	7.18	4.23
Score 3	17.08	15.08
Score 4	46.29	40.38
Score 5	10.94	26.02
Score 6	15.32	14.05
Score 7	3.19	0.24

3) Person 3: Table IV indicate that the RULA scores differ 70.55% on the left and 59.69% on the right side when looking at scores under 5. The mode of both sides is the value 4. This bigger difference in percentage means that the right side scored overall higher results and therefore performed significantly worse than the left. Furthermore, Person 3 is the only person to score the RULA score of 7, although on rare occasions. Score 1 was never reached.

TABLE V: Percentage Distribution of Person 4

	Left Side in %	Right Side in %
Score 1	0	0
Score 2	4.06	11.05
Score 3	70.92	65.63
Score 4	14.83	13.13
Score 5	5.47	6.42
Score 6	4.72	3.77
Score 7	0	0

4) Person 4: Just by taking a quick glance at table V it should become clear Score 3 dominates this measurement. As for a comparison, scores lower than 5 appeared for exactly 89.81% of time on both sides. Scores higher than 5 just reach a little more over 10%. Values of 1 and 7 have not been measured.

TABLE VI: Percentage Distribution of Person 5

	Left Side in %	Right Side in %
Score 1	0	0
Score 2	12.18	12.50
Score 3	6.68	6.36
Score 4	68.32	68.43
Score 5	12.50	12.61
Score 6	0.32	0.10
Score 7	0	0

5) Person 5: At last, the analysis of Person 5 begins with presenting the results of table VI. Remarkable about this measurement is that every score is almost identical on both sides. Around 87% of all scores under 5 on both sides are reached and the extremes of 1 and 7 have not been measured.

V. Discussion

In this chapter, the research results are critically analyzed and interpreted. The aim of this discussion is to reflect on the answers to the original research questions and to illuminate the significance of these findings for the broader scientific field. The key results of this work are presented and discussed in the context of existing literature.

This research focused on the use of new technologies in neurosurgery. Extensive data analysis was carried out to find answers to the questions about the ergonomic impact of this technology.

The results of this study are of particular importance as they not only help to expand the understanding of ergonomics, but also could provide practical applications and theoretical insights. The following sections present the most important results and analyze their significance in the context of our research questions. Additionally, the limitations of the study are discussed.

After the RULA score had to be calculated for one half of the body, the differences on both sides began to be examined.

As can be seen from the results, the overall scores do not really differ much from each other. The biggest difference occurs in Persons 1 & 3, who performed about 10% better on the left hand. What's interesting is that Person 1 was better on the left, even though this person is known to be right-handed. All other candidates had similar results on the left and right, with the exception of Person 3.

Statements regarding WMSDs can only be made speculatively. Since the greatest differences were found in the areas of neck and wrist position, an increased risk of carpal tunnel syndrome and tension neck syndrome is assumed. However, given the general situation, this risk should be limited.

The following is an overall assessment of the ergonomic features of the exoscope for the user.Since on average 82.7% of all results achieved by the five candidates are in the RULA value range below 5, it is generally assumed that there is a low risk of long-term consequences with regard to the ergonomics of this technology. However, this also suggests that the RoboticScope still leaves room for improvement.

One option would be to set the HMD's sensitivity higher, but this leads to increased shaking of the camera head attached to the robot arm. If this jerking could be reduced on a technical and mechanical level, it would potentially lead to better ergonomic posture. The video recordings show that the candidates increasingly tried to achieve this in one continuous movement when approaching the eyelet. The better alternative would have been to make short stops and start again from a neutral position. This also makes it clear that longer training for this device would have been necessary. Although the candidates were able to operate the RoboticScope without any problems, it is possible to achieve ergonomically better postures if the candidates were made aware in advance of the device's movement limitations. The RoboticScope itself also had difficulty finding a better approach correction for some eyelets, which further unsettled the candidates.

Another limitation of this study is the accuracy of the Noraxon system. Although on inspection of the remote camera recordings and the avatar, it is assumed that the final measurements appear true to reality, but small inconsistencies might have gone unnoticed since it has not been possible to determine the accuracy of the system in said circumstances.

At last, it should be mentioned that this study has been performed by no real neurosurgeons on a test object. The RULA evaluations would be more meaningful if an actual operation was performed by an actual neurosurgeon in an OR. Of course, this was not possible due to time limits of getting into an OR with the permit of an ethical committee. Furthermore, it should be pointed out that the test object was designed to force the exoscope into extreme position, which might not represent usual angles during a neurosurgical operation. Also, the task was designed so that the candidate immediately moves to a different camera position after threading and starts with the next eyelet. During a real operation, there are not that many changes in viewing angles, which is why the true strength of the RoboticScope could be revealed so little. The advantage of this technology compared to conventional surgical microscopes is that it can be switched to a neutral position after setting the correct viewing angle. This time window was significantly reduced due to the task design.

VI. Conclusion & Outlook

After completing the literature research, the development of a plan for a concrete measurement to assess the ergonomic parameters using conventional and new surgical microscopes began. First, it was decided which surgical microscopes should be used. A suitable measurement method and an ergonomic framework were then selected. The measurement process was then designed and a test object was chosen.

When the measurements began, the first difficulties were noticed. The results of the first series of tests could not be usefully recorded due to technical difficulties and were therefore not analyzed. After an error analysis for the origin of these technical discrepancies, measurements of a second series of tests began. However, this meant that measurements could no longer be carried out using a conventional surgical microscope due to scheduling difficulties.

The results of the second series of tests were still able to provide information about the ergonomic properties of the posture during the task. Values were most often achieved in an area that cannot be classified as immediately critical. However, individual body parts should be further investigated.

As can already be seen in this paper, there is still a lot to be done in researching the ergonomics of surgical microscopes. First and foremost, this research could be continued by proceeding consistent measurements to be carried out using a conventional surgical microscope. A plan on how to conduct the measurements has already been laid out. This would allow a comparison with the exoscope and could provide important information about the differences between these technologies.

Furthermore, experiments should be carried out in the context of a real operation in the operating room. Since there are currently only results from a dummy and a clearly structured procedure, it would make sense to carry out several measurements under clinical conditions. This would better capture the everyday postures of neurosurgeons and more accurate results could be achieved.

The results already recorded could also be used to improve the RoboticScope. With the reduction of camera head wobble and a refinement of the path optimization, it would be easier to set a higher sensitivity.

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