# The effects of episodic time pressure on learning simulated surgical procedures in novices

Bachelor Thesis

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# Abstract

**Introduction:** Many aspects of simulator training still seem unclear. In laparoscopic surgery both speed and accuracy are vital for a successful operation, therefore it is essential to find an optimal balance between the two in an effort to increase speed, to keep anaesthesia times short, but with the most amount of accuracy as the patient safety has priority. This study aims to investigate the effects of episodic time pressure on learning minimal invasive surgical procedures, to highlight a new area in which simulator-based training could be improved.

**Method:** An experimental, within-subject time-series design was employed. Participants completed a total of 70 trials on the LapSim virtual reality simulator, divided into two tasks, namely the Cutting and the Lifting and Grasping task. The tasks are divided into three phases with two conditions, time pressure and no time pressure. For each task a total of 35 trials is completed.

**Results:** The analysis of the population-level maximum performance parameter for the two measured by Time on task and Damage rate showed an effect on episodic time pressure. Participants were able to improve their estimated maximum performance for the measure of time on task. For the measure of time on task, the effects of the time pressure phase can be observed. Time pressure seems to affect the asymptotes for time on task.
The correlations for all three phases and also for the two performance parameters come with a high uncertainty. The correlations for the Damage parameter come with a high uncertainty for Phase 1 (95% Cl [-1,39; -0,90]), similar high uncertainty is shown for Phase 2 (95% Cl [-1,81; -1,61]) and Phase 3 (95% Cl [-1,57; -0,95]). The correlations for Time on task all include 0, therefore it cannot be said with certainty that they were correlated at all.

**Conclusion**

This study was the first attempt to investigate the effects of episodic time pressure on learning simulated surgical procedures in novices. With the use of a multi-level non-linear mixed effects model, learning curves were estimated to assess changes in predicted maximum performance. Episodic time pressure showed a positive effect on execution time. The study was able to demonstrate that training with episodic time pressure can change estimated maximum performance. Participants are predicted to perform faster and simultaneously maintain a good level of accuracy for the given task.


*Keywords: Minimal invasive surgery; Laparoscopy; LapSim; episodic time Pressure; Simulator training*

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## 1 Introduction

Surgeons today have a wide array of technology available to them which changes the way procedures are performed. New procedures allow for better and safer ways to treat patients and a shift from invasive surgeries to less invasive procedures (e.g. laparoscopy) can be seen in modern operating theatres (Kopelman, Lanzafame & Kopelman, 2013). Laparoscopy is a low risk minimally invasive surgical procedure, also known as keyhole surgery, which requires only small incisions into the body. The procedure is performed using an instrument called a laparoscope which is inserted into the abdominal wall. This instrument is equipped with a high-resolution camera, of which the images can be seen on a monitor ("Laparoscopy: Purpose, Preparation, Procedure, and Recovery", 2019). This minimal invasive procedure offers many advantages to classical open surgery, such as a shorter recovery time for patients and less scarring, but it poses new challenges for the surgeons performing and training this procedure. Many problems associated with Laparoscopy are due to perceptual, spatial, cognitive and psychomotor difficulties (Gallagher, Smith, 2003). To meet these new challenges better ways of training are sought out and studied, as it was shown that the ability to successfully perform MIS depends largely on the duration and quality of the training (Gallagher, Smith,2003).

In the past the “Master-apprentice-model” was used to teach medical residents these procedures. Here a resident would watch a ´master surgeon´ perform the procedure multiple times and then gradually take over some of the tasks during the procedure until sufficient proficiency is reached and the apprentice can perform the procedure without assistance (Kramp, 2016). Now there is a shift towards a different way of teaching residents’ laparoscopic procedures with the use of Simulator training. Simulator training is attractive, because it avoids the use of patients for skill practice and it ensures that trainees have some experience before treating patients (Sutherland et al., 2006). Research by Aggarwal et al. (2007) showed that a proficiency-based VR-training for Laparoscopic surgery shortened the learning curve on real procedures compared to traditional training. Other studies showed similar results and suggest that through Simulator based training learning curves can be shortened and performance in the procedure can be improved without compromising patient safety (Ali, Mowery, Kaplan & DeMaria, 2002); Kopelman, Lanzafame &Kopelman, 2013; Cook et al., 2012).

Most studies on simulator-based training deal with the effectiveness of the training procedure and look for predicting factors for good performance on these procedures. A study by McGaghie, Issenberg, Petrusa & Scalese showed that long hours of high-fidelity simulator practice have a positive, functional relationship with standardised learning outcomes (2006). Simulator training is beneficial for medical education, but not all aspects of this method have been fully investigated to improve training procedures and make better predictions in future performance in trainees. A systematic review by Cook et al. (2012) looked at the effectiveness of instructional design features in simulation-based education. They found a few features to be important such as multiple learning strategies, repetitive practice, range of difficulty and feedback, but also highlighted the need for further research to clarify for whom and under what circumstances these features are beneficial. Many aspects of simulator training still seem unclear. In laparoscopic surgery both speed and accuracy are vital for a successful operation, therefore it is essential to find an optimal balance between the two in an effort to increase speed, to keep anaesthesia times short, but with the most amount of accuracy as the patient safety has priority. Therefore, this study aims to investigate the effects of episodic time pressure on learning minimal invasive surgical procedures, to highlight a new area in which simulator-based training could be improved.

# Theoretical Background

## Cognitive Factors of MIS

A surgeon performing minimally invasive surgery faces different challenges compared to open surgery. Laparoscopy is a complex technical skill. Surgeons need to overcome the perceptual, spatial, cognitive and psychomotor problems associated with MIS. One such problem comes with the use of the monitor. The surgeon is working in one direction with his hands but is looking at the monitor, while standing in a position that can cause strain on the arms, neck and shoulders (van Det et al., 2008) The use of the monitor causes perceptual difficulties. During the procedure depth perception is distorted as the image is only displayed in 2D on screen. The surgeon thus needs to fill the gap themselves, forming complex mental models of the insides of the patient (Lin & Chen, 2013). The surgeon depends on the use skills like Mental Rotation, which is less used in open surgery. Further, the range of motion is limited compared to classical open surgery, due to the use of longer instruments. These instruments also change the tactile feedback and magnifies the hands' natural tremors (van Det et al., 2008). However, the biggest ergonomic problem in laparoscopic procedures is the ´Fulcrum effect´: when an instrument is moved to the right on the display the working end of the instrument appears to move to the left, this makes the motion of the instrument counterintuitive as the instrument motion is inverted inside the abdominal wall (Gallagher et al., 1998).

## Speed Accuracy Trade off

The balance between Speed and Accuracy is an important part of any surgical procedure, therefore the speed-accuracy trade-off should be considered.

The speed-accuracy trade-off is a phenomenon that describes that increased speed leads to an increase in error. This was shown from a variety of tasks from low to high level of difficulty (MacKay, 1982). In some cases, increased speed can lead to a better accuracy, but generally accuracy is traded for speed (Fairbrother, 2010). For movements that require to be performed rapidly, which are movements with a time under 200ms, it has been demonstrated that increased speed can lead to better accuracy (Schmidt et al, 1979). This suggests that increased speed could potentially lead to better accuracy for certain types of movement. By introducing a time pressure episode during the learning process, increased errors are to be expected, which can be explained by the speed-accuracy trade-off. An increase in errors can also show potential benefits, as demonstrated by a study from Dyre, Tabor, Rinsted &Tolsgaard (2016). Their research focused on the effects of error management in contrast to error avoidance training, where it was found that medical students instructed to deliberately make errors during simulator training showed improved transfer learning to the clinical setting, compared to error avoiding.

## Learning under Time pressure

There are no studies investigating the effects of time pressure on learning surgical procedures directly. Time is an element in surgical training procedures but is not yet specifically investigated as a tool to improve training (Pusic et. al,2014). There are however other fields where time limitations were investigated. A study by Beilock, Bertenthal, Hoerger, & Carr (2008) looked at the effect of time pressure in novice and skilled golfers. Novice golfers performed better in conditions with unlimited time and showed increased errors in the time pressure condition, while skilled golfers seemed to benefit from the time constraint. The positive effect on the skilled golfers was assumed to be caused by a lack of time to reconsider learned execution processes, which decreased the possibility of new errors (Beilock, Bertenthal, Hoerger & Carr, 2008). Similar findings have been found in a study about expert system-based training for emergency management. Here an improved level of decision accuracy after expert training with time pressure was observed. It indicated that people adapt to the time restriction by accelerating their processing of rules (Lin & Su, 1998). One study by Gas et al. investigated how time pressure influences the speed-accuracy trade-off in surgical training. Their results showed that medical students were able to maintain or improve their accuracy with increased speed, but it was noted that this could have potential negative effects in novices (2018). Further, in their study some senior residents showed negative effects to the time pressure. This likely unmasked some technical errors that were not apparent at lower speeds. The aforementioned studies all show different effects of time pressure on skill acquisition and execution, but also outlines a research gap on the effects and possible benefits time pressure can have during training.

## Learning Curves

To overcome the difficulties posed by Laparoscopic procedures, extensive training is needed. In order to evaluate candidate training features, it is necessary to measure their effects on the learning process. Because learning is a non-linear process a non-linear model is most suitable for its assessment. One such model comes with the application of learning curves, which can be used to assess current learning status and predict future performance.

The exponential learning curve model described by Heathcote, Brown and Mewhort (2000) is used to model the learning curves. It consists of three parameters: Amplitude, rate and asymptote. This is shown in Figure 1 and described by the following formula:

$$Y_{ptN} = Asym_{pt} + Ampl_{pt}exp(-Rate_{pt}N)$$

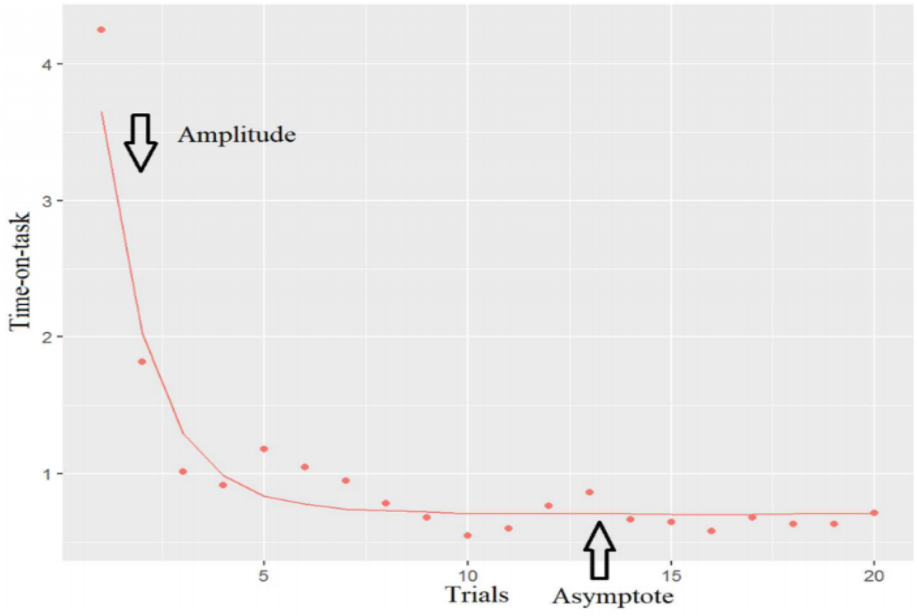


*Figure 1 – Exponential Learning curve model. The x-axis shows the trials, time on task is shown on the y-axis. Amplitude shows the total amount of learning; the asymptote shows the predicted maximum performance. From "Towards reliable and valid prediction of MIS-performance with basic laparoscopic tasks in the LapSim and low-fi dexterity tasks" by Alexander Arendt, 2017, unpublished Master Thesis. University of Twente*

The amplitude shows the total amount of learning, the rate describes the learning speed and the asymptote removes the learning process by assuming it infinite and shows predicted maximum performance over time.

For this study the amplitude has been reparametrized into a parameter for virtual previous trials. This can account for any previous experience of participants and is necessary for the analysis and comparison of the different conditions in this study. Therefore, the previous trial parameter is more meaningful than the Amplitude parameter. If a participant has had previous experience, the function must be moved to the left on the x-axis for it to become flatter in the observed range. Figure 2 shows a visual representation of the reparameterization. The formula for this model is:

$$Y_{ptN} = Asym_{pt}\left(1 + exp\ (-Rate_{pt}\ (N + Prev_{pt}))\right)$$

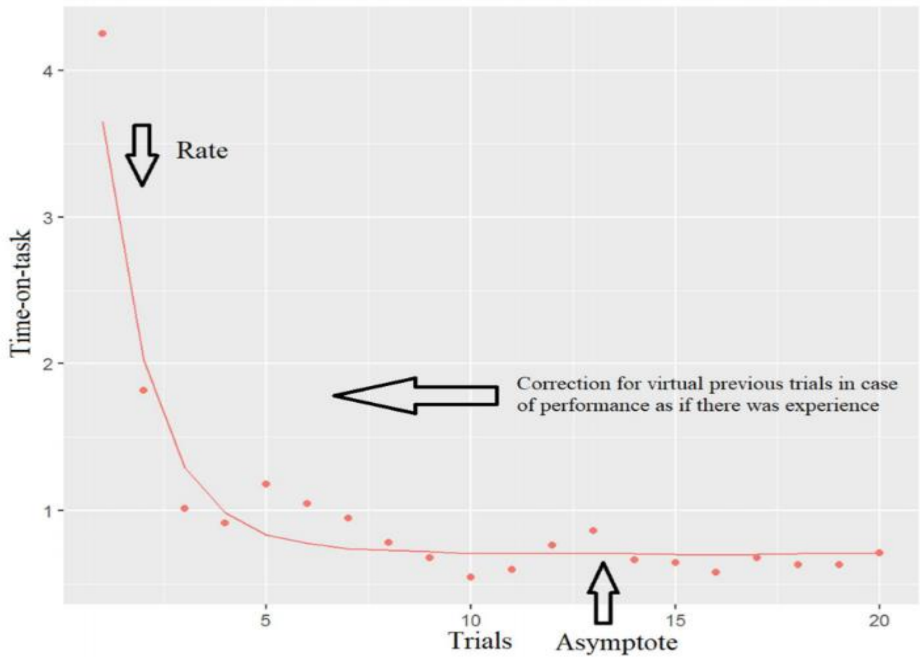


*Figure 2 Reparametrized exponential Learning Curve model. From "Towards reliable and valid prediction of MIS-performance with basic laparoscopic tasks in the LapSim and low-fi dexterity tasks" by Alexander Arendt, 2017, unpublished Master Thesis. University of Twente*

## Research Question

This study aims to investigate the effects of episodic time pressure on learning simulated surgical procedures in novices, by introducing an episode of time pressure during the training. As of now there has not been much research on the effects of time pressure in relation to skill acquisition in laparoscopic surgery. Learning curves and multiple performance measures are used to assess changes in predicted maximum performance before and after training with time pressure to determine what effect time pressure has on learning outcomes.

# 2. Method

## 2.1 Design

An experimental, within-subject time-series design was employed. Participants completed a total of 70 trials on the LapSim virtual reality simulator, divided into two tasks: The Cutting and the Lifting and Grasping task. The tasks are divided into three phases with two conditions. For each task a total of 35 trials is completed. For the first Phase the participant was instructed to try to be as quick but as accurate as possible (Condition 1). After the completion of Phase 1, the participants received a different objective: being 20% faster than in the previous trials, time pressure phase (Phase 2; Condition 2). The aim time was calculated by the experimenter and the participants were told to aim for this speed regardless of errors that may occur. In the third Phase, the participant was again asked to be quick and as accurate as they can (Phase 3; Condition 1).

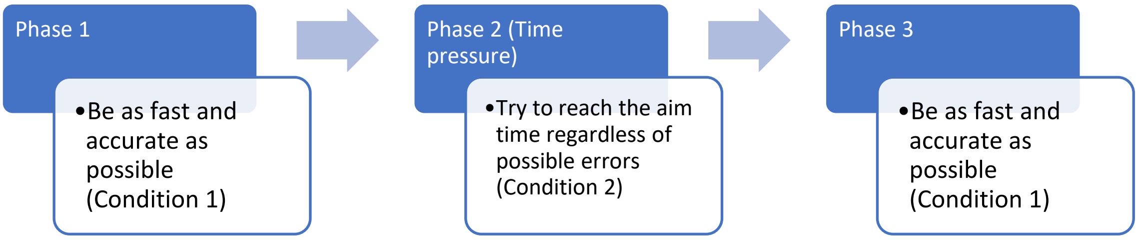


*Table 1 Flowchart describing the three phases of the study with participant instructions*

## 2.2 Participants

The study was completed by N=40 participants (18 men and 22 women) who were either students or affiliates of the University of Twente. Participants´ mean age was 24, their nationalities were German (37,5%), Dutch (42,5%) and Other (20%). Compensation in the form of Course Credit (SONA Points) was provided for some participants enrolled in a specific undergraduate study. Participants were recruited through SONA Systems, an online platform for undergraduate Psychology Students of the University of Twente and through direct recruitment on the University Campus and through Messengers (Facebook and WhatsApp). All participants have signed an informed consent form, a copy of this form can be found in Appendix 6.6.

## 2.3 Apparatus

The study used the LapSim© virtual reality simulator using Virtual Laparoscopic Interface (VLI) hardware. The simulator is used to simulate a variety of surgical task used in laparoscopic procedures and other basic laparoscopic tasks. The simulator consists of three SimBall-modules in which the different endoscopic tools are inserted, a desktop computer and a 23” LC-Display (see Figure 3). The SimBall-modules represent the insertion points into the abdominal wall. These modules are capable of detecting the movements of the inserted endoscopic tools, which are similar to tools used in actual surgery except for the forcipes at the end of the instrument. The modules can detect the angle in which instruments are inserted and the degree to which they are pushed and pulled out of the modules. These movements are then translated and displayed onto the LC-Display. The LapSim has been shown to be a suitable tool for the assessment of laparoscopic skills and was able to show differences in overall scores and efficiency between novice and experienced surgeons (van Dongen et al., 2007).

*Figure 3 Set up LapSim; on the left complete simulator with LC-Display, computer and Sim-Ball Modules with instruments; on the right close up of Sim-Ball Modules with inserted instrument. From “Towards reliable and valid prediction of MIS-performance with basic laparoscopic tasks in the LapSim and low-fi dexterity tasks” by Alexander Arendt, 2017, unpublished Master Thesis. University of Twente*

### 2.3.1 Simulator tasks

The selected tasks for this study are the Cutting and Lifting and grasping task from the LapSim© Basic Skills Set v3.0. These subtasks are identified as relevant subtasks in laparoscopic procedures, such as cholecystectomy and are used in simulator training for laparoscopic procedures (Aggarwal et. al, 2009; Wherry, Marohn, Malanoski, Hetz, & Rich, 1996).

## Cutting

Cutting is one of the subtasks needed for laparoscopic procedures. Here tissue is grasped with grasping forceps and with a second pair of ultrasonic-scissor forceps the tissue can be cut and cauterized at the same time. The purpose of the cutting task in the simulator is to grasp a vein with one instrument and then cut the marked area of the vein with the second instrument. To do this the instruments need to be inserted into the modules. When the graspers are close to the vein it can be grasped by closing the handle. With the second instrument the vein needs to be grasped at a highlighted area and then cut, by pressing a pedal on the ground. Figure 4 shows part of the task.

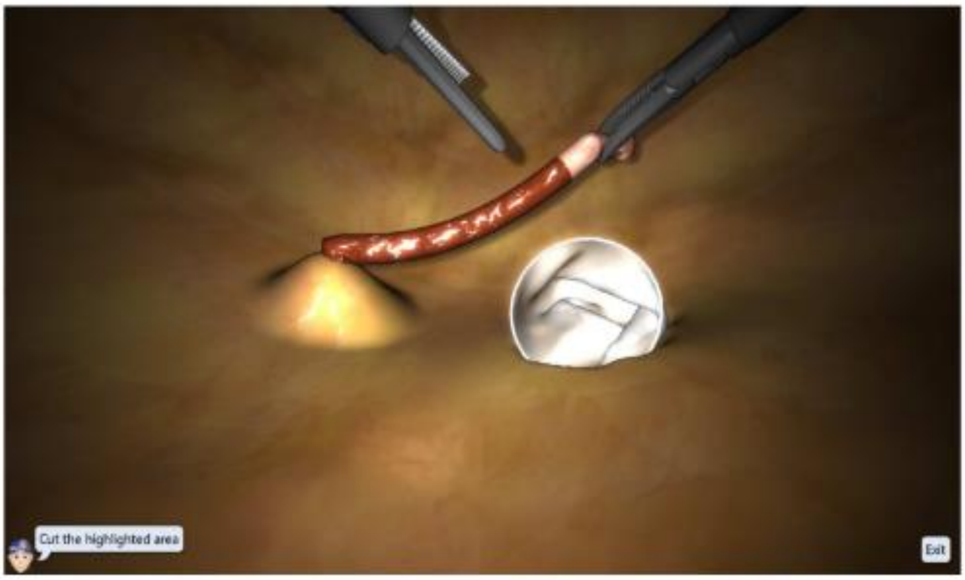


*Figure 4 Screenshot of the Cutting task. The left instrument shows an ultrasonic scissor. The right instrument is a grasper. The to be cut area is highlighted. From "Towards reliable and valid prediction of MIS-performance with basic laparoscopic tasks in the LapSim and low-fi dexterity tasks" by Alexander Arendt, 2017, unpublished Master Thesis. University of Twente*

## Lifting and Grasping

For the lifting and grasping task a probe instrument is used. This instrument is used to lift tissues up, so the surgeon can then operate underneath. The objective of the lifting and grasping task is to grasp a needle, which is located under a box shaped object, and then move it to the target location. The box shaped object needs to be lifted with the probe instrument, when this is achieved the needle like object needs to be grasped with the second instrument and then transferred into a disposal bag shown on screen. During this task the object and target location vary, which also results in a switch of grasper and probe instrument. A screenshot of the task can be seen in Figure 5.

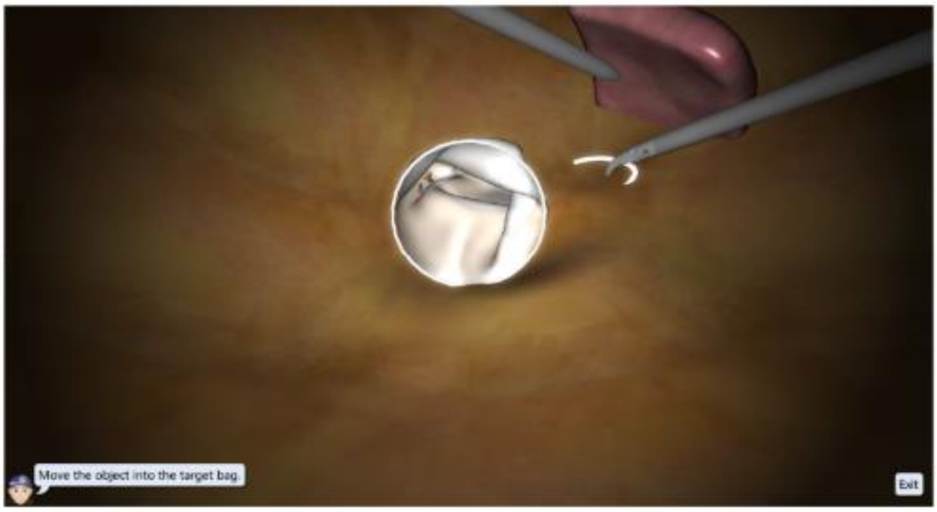


*Figure 5 Screenshot Lifting & Grasping task. Right instrument is a grasper. The left instrument is a probe, which is used to lift the tissue, which enables to grasp the target objects shown in white. From "Towards reliable and valid prediction of MIS-performance with basic laparoscopic tasks in the LapSim and low-fi dexterity tasks" by Alexander Arendt, 2017, unpublished Master Thesis. University of Twente*

### 2.3.2 Demographic Questionnaire

A demographic questionnaire is given to the participants (see Appendix 6.1). This questionnaire collects general demographic data and also checks for any exclusion criteria.

## 2.4 Measures

**Simulator performance measures**

The LapSim© simulator tracks the performance of the participant over a range of modalities such as tissue damage, instrument path length, angular path length, etc. For this dataset the parameters time-on-task and damage rate were chosen. The parameter time on task is measured in seconds. The damage rate is measured by quantitative damage, which shows the quantity of damage done. These two parameters show if accuracy is traded for speed. With these values an individual learning curve can be produced for each participant and a prognosis for maximum performance can be made.

**Mental Workload**

After each trial the Mental Workload of the participants is assessed. A question from the NASA TLX - Task load index was used. This scale has been widely used for the assessment of workload scores and has shown good reliability and validity and is therefore an appropriate measure to assess the perceived mental workload. The participants are asked to indicate their perceived mental workload on a scale from 1-10.

## 2.5 Procedure

**Greeting and Briefing**

When the participants arrive, they are welcomed and thanked for their participation. They are then informed about the purpose, by giving an explanation about the procedure and purpose of the study. Once all questions participants might have are answered the participants are asked to read and sign the informed consent forms. When the consent is signed, they are asked to fill in a short demographic questionnaire.

**LapSim**

After completion of the questionnaire, they are taken to the simulator. The participants are introduced to the simulator and the researcher shows which tools to use and adjusts the table to a comfortable height for the participant. The participants are instructed to read the instructions and watch the additional instruction video, which is given on the screen of the simulator.

The two tasks are performed on different days to prevent fatigue in the participants, on the first day the Cutting task is performed and the Lifting & Grasping task on the second day. As described earlier the participants completed 35 trials per task, divided into the three phases with two conditions. After each trial the participants are asked about their Mental Workload and can take a short break and are offered a refreshment.

**Debriefing**

After all trials are completed, participants are told about the full purpose of the study. Before leaving they are again thanked for their participation and offered to leave their email if they wish to receive the results of the study. For a detailed version of all instructions refer to Appendix 2.

## 2.6 Data Analysis

A multi-level non-linear mixed effects model with learning curves as likelihood function was employed to construct a non-linear regression model. The model estimates learning curves for all participants per task and condition and bundles them together for analysis on a population-level. The parameter asymptote previously described is needed to construct the learning curves. For the error component a gamma distribution has been chosen assuming that error effects are stronger in the initial learning phase for the participants. The final model used estimate random effects for the learning curve parameters based on damage rate, time on task and Mental Demand reflecting the two conditions, time pressure and no time pressure.

## 3. Results

The data was analysed using a multi-level non-linear regression model to plot individual learning curves for all participants in each condition with a total 240 learning curves (see Appendix part 6.4). First, the population-level maximum performance parameter for the two tasks are shown, measured by Time on task and Damage rate. Then individual learning curves are presented to show individual differences in the population. Lastly, correlations of the population-level maximum performance parameter of the two tasks are reported. The data of the Mental Workload scores have not been considered in this work, as it was beyond the scope of this thesis.

### 3.1 Population-level Maximum Performance

To answer the main research question, namely what effect episodic time pressure has in learning simulated surgical procedure in novices, the Population-level maximum performance was analysed for the three phases. A difference in maximum performance between conditions would indicate an effect of time pressure on learning. Figure 6 shows the graphical representation of the population level maximum performance for both tasks during the three phases.

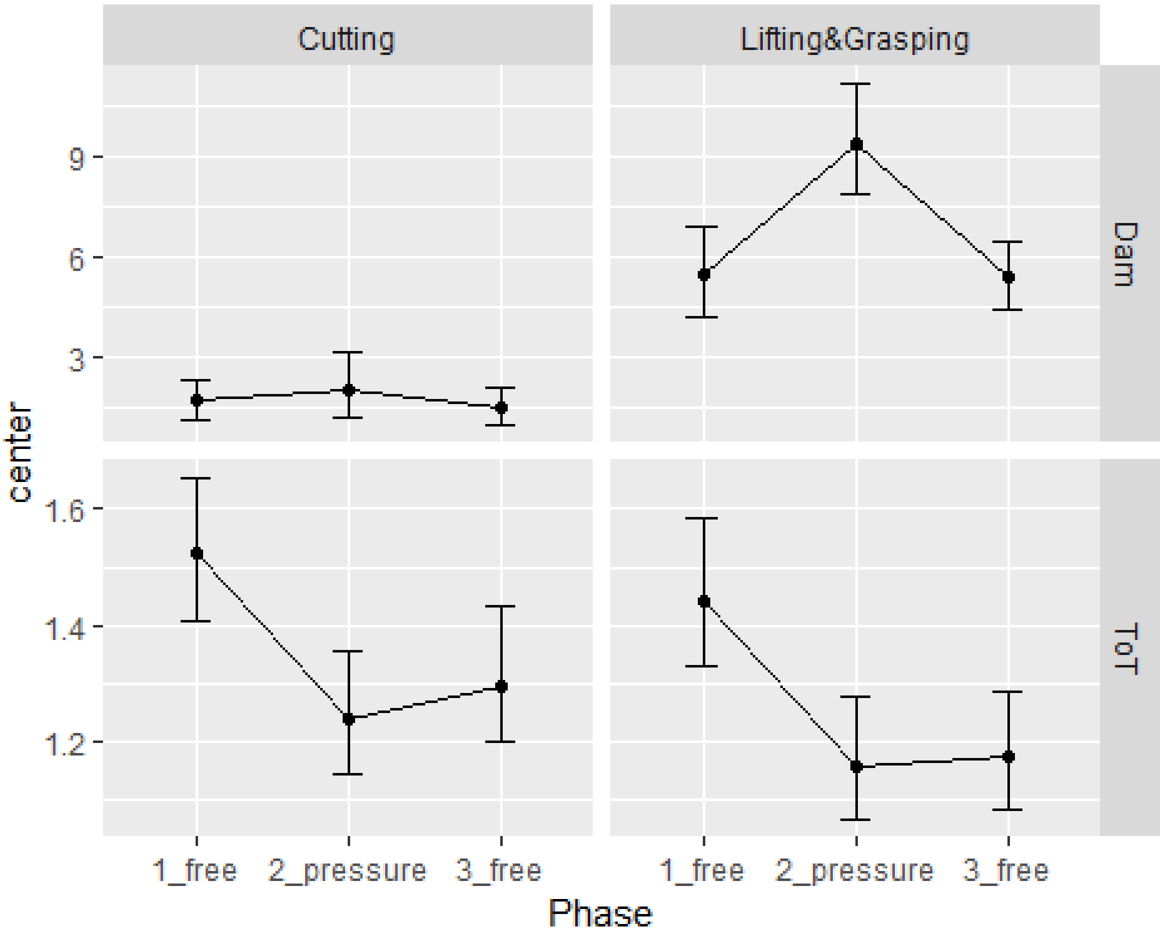


*Figure 6 Population Maximum performance for the tasks Cutting and Lifting & Grasping during the three phases.*

Both tasks show similar patterns in terms of damage and time on task. The overall pattern is the same for the Cutting and the Lifting & Grasping task, though in the Lifting & Grasping task the range of performance scores is higher. The increase in damage from the first to the second phase in the cutting task was not high, with an error count of 1,69 in phase 1 to 2,01 in the time pressure phase. In the third phase an overall decrease of 1/6 in terms of damage on the estimated maximum performance rate was achievable (Phase 1: 1.69; Phase 3: 1.46). A bigger difference can be seen in the Lifting & Grasping task where the damage increases from phase 1 with an error count of 5,46 to 9,35 in phase 2. After the time pressure the damage rate decreases to 5,38, which shows a slight decrease compared to the first phase.

For the measure of time on task, the effects of the time pressure phase can be observed. Time pressure seems to affect the asymptotes for time on task. In phase one the predicted scores for the cutting tasks were 1,52min and 1,44 for the Lifting & Grasping task. This decreases to 1,24min for the cutting and 1,15min for the Lifting & Grasping task in Phase 2. After the time pressure the time on task performance stays low compared to the first phase with an overall decrease of 1/5 the original predicted time. For the cutting task from 1,52min (phase 1) to 1,30min (phase 3) and from 1,44min (phase 1) to 1,17min (phase 3) in the lifting &grasping task. The participants responded to the time pressure with an increase in speed, but a simultaneous increase in damage.

After the time pressure, the third phase time improved significantly compared to the first phase while the damage stayed at a comparable level, which shows that the time pressure had a positive effect on execution speed. Participants were able to improve their estimated maximum performance for the measure of time on task. For a full representation of the population-level maximum performance measure refer to Appendix 6.3.

## 3.2 Individual-level Maximum performance

For each participant individual learning curves were modelled. This part-level analysis is performed to show individual differences to check if the effects of time pressure are uniform in the population. In total 240 learning curves were modelled. The learning curves for participants 05, 10, 21 and 39 are shown in Figure 7 to show individual differences of the population. To review all learning curves, see Appendix 6.4. For all four participants time on task and the damage rate decrease over the first 15 trials (Phase 1, condition 1). Participant number 5 and 39 show a pattern similar to the population-level maximum performance. Damage rate decreases in the initial 15 trials together with time. In phase 2 the damage rate increases for both tasks, but more for the Lifting & Grasping task, while time on task drastically decreases. In the third phase damage rate decreases again to similar levels of phase

1, while time on task stays at the level of phase 2, indicating a strong effect of time pressure on time on task performance.

In participant 10 the first two phases follow the same pattern in regards of time and damage. In the third phase the participant is significantly faster than in Phase 1, but his damage rate is higher than it was before in phase 1. For the cutting task the damage rate is similar to that in the time pressure phase. Time pressure made the participant faster, but this appears to be traded for accuracy.

In participant 21 the damage rate steadily decreases with no obvious peaks, which can be observed in other trials. The participant does perform faster in the time pressure phase and is able to stay on the same level of time, although this seems to have no effect on damage.

Most participants show similar effects to the time pressure with an increase of damage in the time pressure episode and a decrease in time. In the third phase, participants are able to perform better on time compared to the first phase and the damage rate goes back to the first phase level. Looking at the data, individual differences can be seen and not everyone shows the same effect to the time pressure episode.

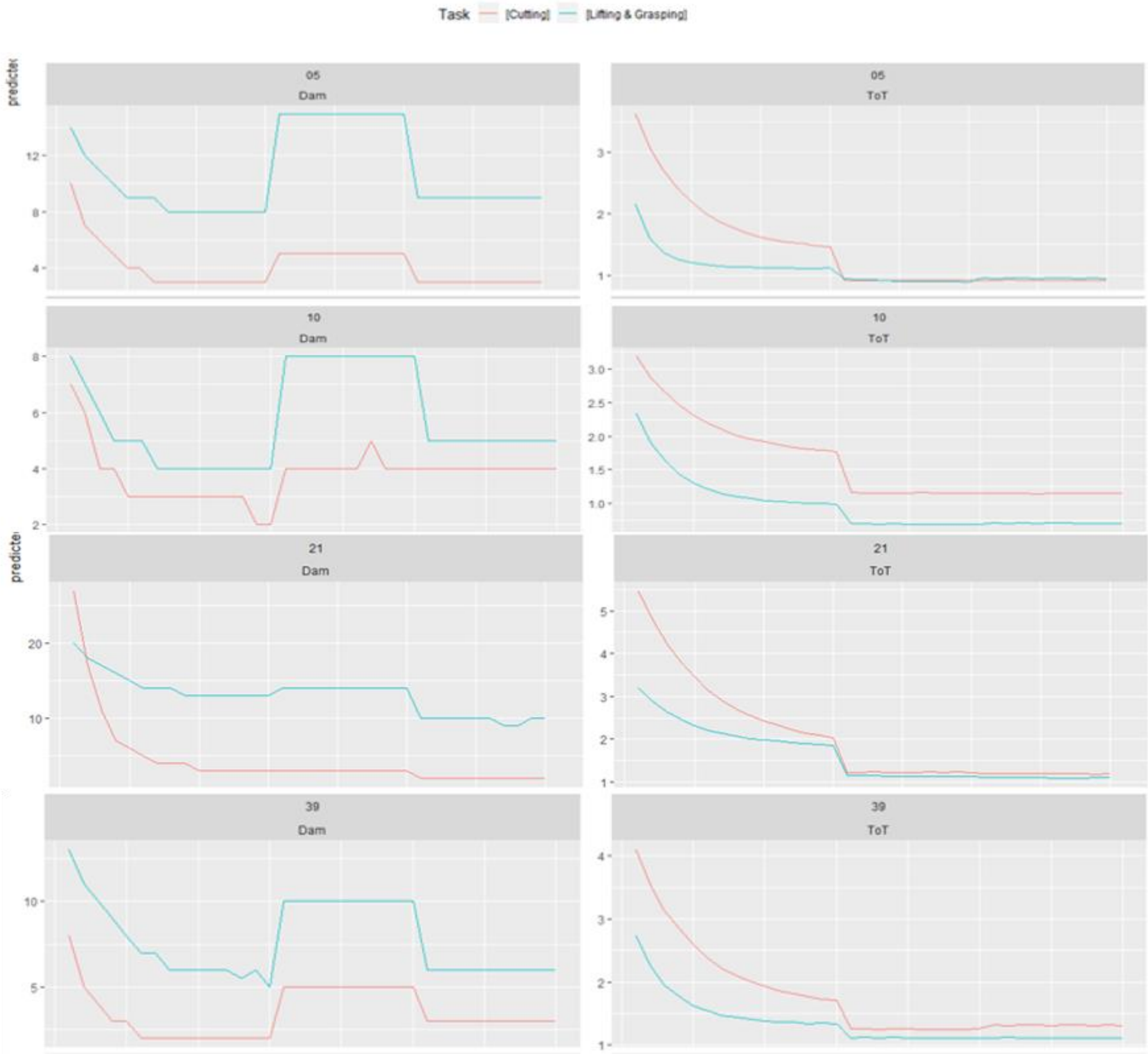


*Figure 7 the Individual learning curves for participant 05, 10, 21 and 39 for the tasks cutting (red) and Lifting & Grasping (Blue). The damage scores and the scores for time on task are shown on the y-axis. Each column on the x-axis shows 5 trials.*

### 3.3 Correlations of Population Maximum performance

To assess the internal consistency reliability of the two laparoscopic tasks, pairwise correlations were estimated on the population maximum performance for the three conditions and for the performance parameters Damage and Time on task. The correlations are shown in Table 2. All correlations were positive, but that does not allow for judgment regarding Internal Consistency. To assess the certainty of the correlations, 95% credibility limits have been calculated, this says that there is a 95% chance that the true value lies within the found range. Great certainty can only be concluded if the credibility limits only deviate by a maximum of 0.2. Credibility limits that include 0, but no values under -0,1 show high uncertainty, if any effect at all.

The correlations for all three phases and also for the two performance parameters come with a high uncertainty. The correlations for the Damage parameter come with a high uncertainty for Phase 1 (95% Cl [-1,39; -0,90]), similar high uncertainty is shown for Phase 2 (95% Cl [-1,81; -1,61]) and Phase 3 (95% Cl [-1,57; -0,95]). The correlations for Time on task all include 0, therefore it cannot be said with certainty that they were correlated at all.

*Table 2: Pairwise correlations of population maximum performance of the task Cutting and Lifting & Grasping by Phases and performance parameters*

| Phase | Damage | Time on task |
|---|---|---|
| 1 | r =0,643, [-1,39; -0,90] | r =0,583, [0,09; 0,22] |
| 2 | r =0,611, [-1,81; -1,16] | r =0,501, [0,06; 0,21] |
| 3 | r =0,464, [-1,57; -95] | r =0,570, [0,05; 0,19] |

95% credibility limits in square brackets

## 3.3 Individual-level maximum performance scatterplots

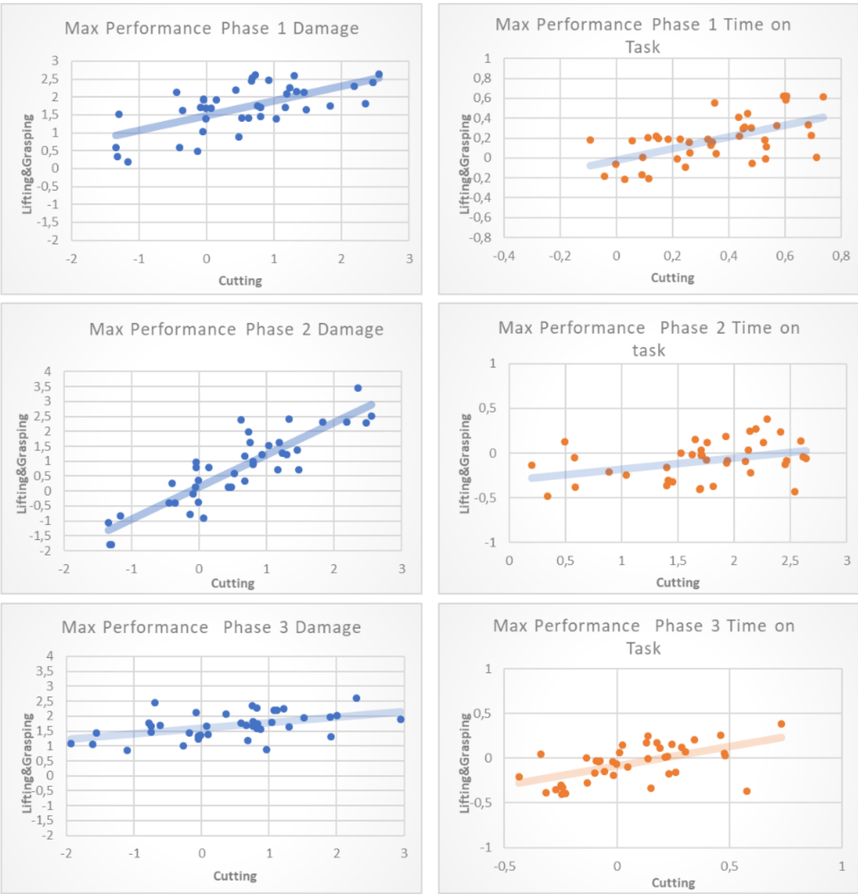


*Figure 8 Scatterplots comparing individual-level maximum performance between the cutting and the Lifting & Grasping task. The axis depicts the random effect sizes of the maximum performance on the task. Each datapoint is one participant.*

As part of the posterior analysis of this study, scatterplots comparing individual level-maximum performance between the two tasks were plotted. The better the points fit in an ascending line, the more comparable the parameters are with each other. The scatterplots in Figure 8 compare the individual-level maximum performance parameters of all participants between the two tasks. The axis depicts the random effect sizes of the maximum performance on the tasks.

The points of all conditions are closely assembled. The points for Phase 3 Damage seem to be the closest assembled on the line, followed by Time on task in phase 3. All phases show similarities in the participant-level maximum performance parameter.

## 4. Discussion

The aim of the current study was to investigate the effect of episodic time pressure on learning simulated surgical tasks in novices, in order to fill a research gap in surgical training and find potential new ways of training medical residents.

The results from the population level maximum performance show an effect of time pressure on the performance measure Time on task. Participants performed faster after the time pressure episode. In the cutting task the time improved by 16,9% in predicted max performance. For the Lifting & Grasping task the time gain was higher; a decrease in time by 23,0% compared to the first phase, see Figure 5 in the results section. However, there is no strong effect on the damage rate after the time pressure episode, although the damage rate went down in the cutting task by 15,9% and for the Lifting& Grasping task only by 1,4%. While the estimated time improves, the damage rate seems to plateau. The episodic time pressure appears to have had a positive effect on the participants learning progress, as they were able to improve their time without sacrificing accuracy.

Generally, the task Lifting & Grasping is more error prone than the Cutting task and participants performed better on the cutting task, this is reflected in the damage rate for both tasks. In regard to the Speed Accuracy Trade off it seems that an appropriate balanced in terms of execution speed and accuracy can be reached after the episodic time pressure.

The findings of this study are in line with the findings in medical students by Gas and colleagues (2018), as they too were able to increase their speed but maintain their accuracy. However, this study also noted that the time pressure could have some negative effects on the medical students. In regard to other studies mentioned before it is difficult to draw direct comparisons with the findings of this study, due to the differences in population and analysis. The study by Beilock, Bertenthal, Hoerger & Carr (2008) only showed an advantage in the advanced golfer. These findings would contradict the findings of this study, as the participants had no prior experience, but the estimated maximum performance assumes the learning to be infinite therefore assuming a higher level of proficiency, which would in turn not be in disagreement with the findings. Further, it was hypothesized that the advanced golfers were able to perform faster, because they were able to rely on rule-based behaviour. The used model does not explicitly account for rule-based behaviour, so conclusions in this regard cannot be drawn.

This also seems to be the case for the study of Lin & Su (1998) on emergency training where the findings suggested that the acceleration was due to a faster rule processing. The participants in the aforementioned studies all had prior experience and were further along in their learning process and not novices like in this study, which makes comparing these results difficult.

In the study by Dyre, Tabor, Ringsted & Tolsgaard (2016), medical students that had no prior experience in training ultrasound procedures on simulators were able to improve their learning through error management and it was stated that learning from error occurred when it was expected. The medical students in this study were instructed to deliberately make errors, similarly to the participants in the current study, who were told to focus on reaching the time limit and disregard for an eventual increase in errors made during the time pressure phase. The greater occurrence of errors during the time pressure episode could be a possible alternative explanation for the change in maximum performance of the third phase.

The time pressure episode changed the predicted maximum performance parameter, which contradicts its interpretation as maximum performance as a fixed estimate as it appears to be malleable. Thereafter a possible explanation for this issue is offered. The projected learning curves are corrected for previous experience. When the third phase is used to construct new learning curves the number of previous trials is taken into account as virtual experience. This assumes that any single trial is a constant measure of experience. However, if the experience gained from a trial correlates positively with the number of errors produced within that trial then the virtual experience gained in phase two is underestimated. Which means that the x offset of the Phase 3 data in constructing the post time pressure learning curves underrepresents the participants actual experience. One way to investigate this issue is to compare the slope in the Phase 3 data with that of the Phase 1 learning curve for trials 26 to 35. If the measured data shows a significantly flatter slope than predicted, that could be an indication that the data is actually further along the learning curve.

## Individual differences in Maximum Performance

To account for individual differences and to check if the observed effect was also visible on an individual level, these were also analysed. The estimated maximum performance for time on task changed, participants are expected to perform faster after training with episodic time pressure. The effect of time pressure for the estimated maximum performance for the damage measure did not show the same patterns across individuals. Some participants showed patterns of increase in damage even after the time pressure phase (see Figure 7). This could be an indicator that time pressure could have a negative effect on learning in some individuals, which was also suggested by Gas et al. (2008). Alternatively, they might have developed a habit or adjusted their error tolerance. They might have also tried to stay within their previous time and therefore continued to make more errors, and hence did not try to be as accurate as they can.

## Internal consistency reliability of the laparoscopic tasks in the LapSim

To assess the internal consistency reliability of the two laparoscopic, pairwise correlations were estimated on the population maximum performance for the three conditions and for the performance parameters Damage and Time on task. This analysis of the correlations showed high uncertainty across all Phases. The correlations for the Damage parameter come with a high uncertainty for Phase 1 (95% Cl [-1,39; -0,90]), similar high uncertainty is shown for Phase 2 (95% Cl [-1,81; -1,61]) and Phase 3 (95% Cl [-1,57; -0,95]). The correlations for Time on task all include 0, therefore it cannot be said with certainty that they were correlated at all. These findings are in line with the findings of Arendt (2017).

## Limitations

The experimental paradigm of this study was good, some bias could have been introduced, but no significant compromise could be identified. The sample of this study does not reflect the target population, which poses a possible limitation to the findings of this study. To see if results differ, further research is required.

## Further research

The results of this study show that episodic time pressure is worth investigating. This study could be the start of a series of new research in the field of surgical simulator training. To further investigate this, it could be started to see if the results are replicable not just in novice participants, but also in medical professionals, to check if the effect is stable over time. Another point of interest is to see whether this effect can also be seen for more complex simulated tasks, as the here tested tasks only represent a small subsection of laparoscopic basic skills needed.

The estimated Maximum performance measures changed, as discussed above this contradicts the interpretation of maximum performance as a fixed estimate as it appears to be malleable. Research could look into how to approach the concept of maximum performance in the future.

# Conclusion

This study was the first attempt to investigate the effects of episodic time pressure on learning simulated surgical procedures in novices. With the use of a multi-level non-linear mixed effects model, learning curves were estimated to assess changes in predicted maximum performance.  Episodic time pressure showed a positive effect on execution time. The study was able to demonstrate that training with episodic time pressure can change estimated maximum performance. Participants are predicted to perform faster and simultaneously maintain a good level of accuracy for the given task.

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# 6. Appendix

## 6.1 Appendix 1 Demographic Questionnaire

### Demographic survey for LapSim+time pressure

1. What is your gender? _male _female
2. Please enter your date of birth: Date / Time
3. Please enter your nationality: ____
4. Do You have impaired vision?

   -Yes, I wear glasses

   -Yes, I wear contact lenses.

   -Yes, but I do not wear glasses or contact lenses.

   -Yes, I am colour-blind.

   -Yes, I have eye cataract (grijze staar).

   -Yes, I have glaucoma (groene staar).

   -No.

   -Other (please explain)
5. Are you colour-blind? _Yes _No
6. Are you dyslectic? _Yes _No _I don't know
7. Are you experienced with playing video- or computer-games? _Yes _No
8. If yes, how much time in hours do you spend in a week on average? __
9. Did you ever partake in a cognitive ability test? _Yes _No _I don't know

## 6.2 Appendix 2 Instruction Guide

**Session 1**

Before the session:

- Set up the demographic questionnaire via survey monkey: https://www.surveymonkey.com/r/ZVL9XKD
- Log in onto the LapSim with the current participant number

Prepare the observation sheet (see below), mentioning the participant number and which LapSim is used: The left one is called red, the middle one is called blue and the right one is called green.

During the session: At first, the participant is welcomed by the researcher and introduced to the topic. You can introduce it by using something like this:

“This study is about “minimal invasive surgery” (MIS). Do you maybe know what it is? (Explain it if the answer is “no”, otherwise skip it). MIS is a rather new way to do surgery. Other than in normal surgery, you go in with long surgical instruments through a small opening, like a small cut or through mouth/nose. Also, a camera is put into the body the same way. The surgical tasks are then performed within the body while the surgeon is looking on a screen. MIS have the advantage that they are more efficient and less harmful to the body than traditional surgery.

However, MIS requires a lot of skill from the surgeon and the techniques currently are trained on virtual reality simulators like the LapSim you can see here. We want to study the learning behaviour of trainees on the LapSim. You will therefore perform two basic tasks on the LapSim, Cutting and Lifting& Grasping.

Next step:

“You will receive instructions on the specific tasks before you start the exercise. First, you will have to fill out an informed consent form. This study consists of two simulator tasks as I have just explained to you. You will receive instructions on the specific tasks before you start the exercise. First, you will have to fill out an informed consent form. [Give informed consent form and make sure that participant signs it. Write down participant number and name on the front page of the informed-consent folder!] Next is a demographics questionnaire asking about some personal information, such as your age and handedness. This is online-based and takes about two minutes to complete. After that, you will do the cutting task 35 times. After each time there will be a 30-second break. In this break you will have time to relax your muscles, you can also quickly drink something. We will also ask you to rate your mental workload by answering a short question during that pause. You can ask questions any time. Do you have any questions thus far? Participant starts with the demographic questionnaire.

After that, the participant is introduced to the LapSim. Show them how they can change the height of the simulator to their own level and make them aware not to touch the sensitive parts of the LapSim (The inner sites of the laparoscopic instruments and the “balls”). Then instruct the participant to start with the first laparoscopic task:

“You are about to start practicing a basic laparoscopic task called cutting. You can read the instructions for each exercise and view videos of performance of these tasks during an actual procedure as well as in the virtual environment. You must repeat the task 35 times. Please try to be as accurate and quick at the same time as possible. Do not falter just because you are getting low scores – this is a very difficult task which professionals train years for, and your actual performance does not matter as much as the progress, or the absence thereof, that we can observe. Only make sure that you do not hurt your patient, which is indicated by the screen flashing in red.”

During the breaks, always ask and record the mental workload of the participant.

After 15 trials, the time limit condition is introduced. Make sure you calculate the time limit x first. x will be calculated by the time needed during the 15th trial y. x=0.8y:

“During a real surgery a whole team of specialists is present, among which is the anaesthesiologist. His role during the surgery is to overwatch the vital signs of the patient and to take care of the anaesthesia. Your anaesthesiologist tells you now that you have to finish your task more quickly, within x seconds. If you fail to do so, the anaesthesiologist is forced to insert drugs into the patient to make sure he stays unconscious. However, this may lead to potentially harmful side-effects. Therefore, you really have to focus on being faster this time.”

After 10-time pressure trials (25 overall), we remove the time pressure condition

“I can see from your responses on the mental workload scale that your stress level has increased. (This can be a lie) We will therefore go back to the initial instructions.

**Session 2**

Welcome the participant and continue with the second task, same procedure:

You will now do the lifting and grasping task 35 times. After each time there will be a 30-second break. In this break you will have time to relax your muscles, you can also quickly drink something. We will also ask you to rate your mental workload by answering a short question during that pause. You can ask questions any time. Do you have any questions thus far? Show them how they can change the height of the simulator to their own level and make them aware not to touch the sensitive parts of the LapSim (The inner sites of the laparoscopic instruments and the “balls”). Then instruct the participant to start with the second laparoscopic task:

“You are about to start practicing a basic laparoscopic task called lifting and grasping. You can read the instructions for each exercise and view videos of performance of these tasks during an actual procedure as well as in the virtual environment. You must repeat the task 35 times. Please try to be as accurate and quick at the same time as possible. Do not falter just because you are getting low scores – this is a very difficult task which professionals train years for, and your actual performance does not matter as much as the progress, or the absence thereof, that we can observe. Only make sure that you do not hurt your patient, which is indicated by the screen flashing in red.”

During the breaks, always ask and record the mental workload of the participant.

After 15 trials, the time limit condition is introduced. Make sure you calculate the time limit x first. x will be calculated by the time needed during the 15th trial y. x=0.8y:

“During a real surgery a whole team of specialists is present, among which is the anaesthesiologist. His role during the surgery is to overwatch the vital signs of the patient and to take care of the anaesthesia. Your anaesthesiologist tells you now that you have to finish your task more quickly, within x seconds. If you fail to do so, the anaesthesiologist is forced to insert drugs into the patient to make sure he stays unconscious. However, this may lead to potentially harmful side-effects. Therefore, you really have to focus on being faster this time.”

After 10-time pressure trials (25 overall), we remove the time pressure condition

“I can see from your responses on the mental workload scale that your stress level has increased. (This can be a lie) We will therefore go back to the initial instructions.

**After the last trial, thank the participants for their participation and debrief them:**

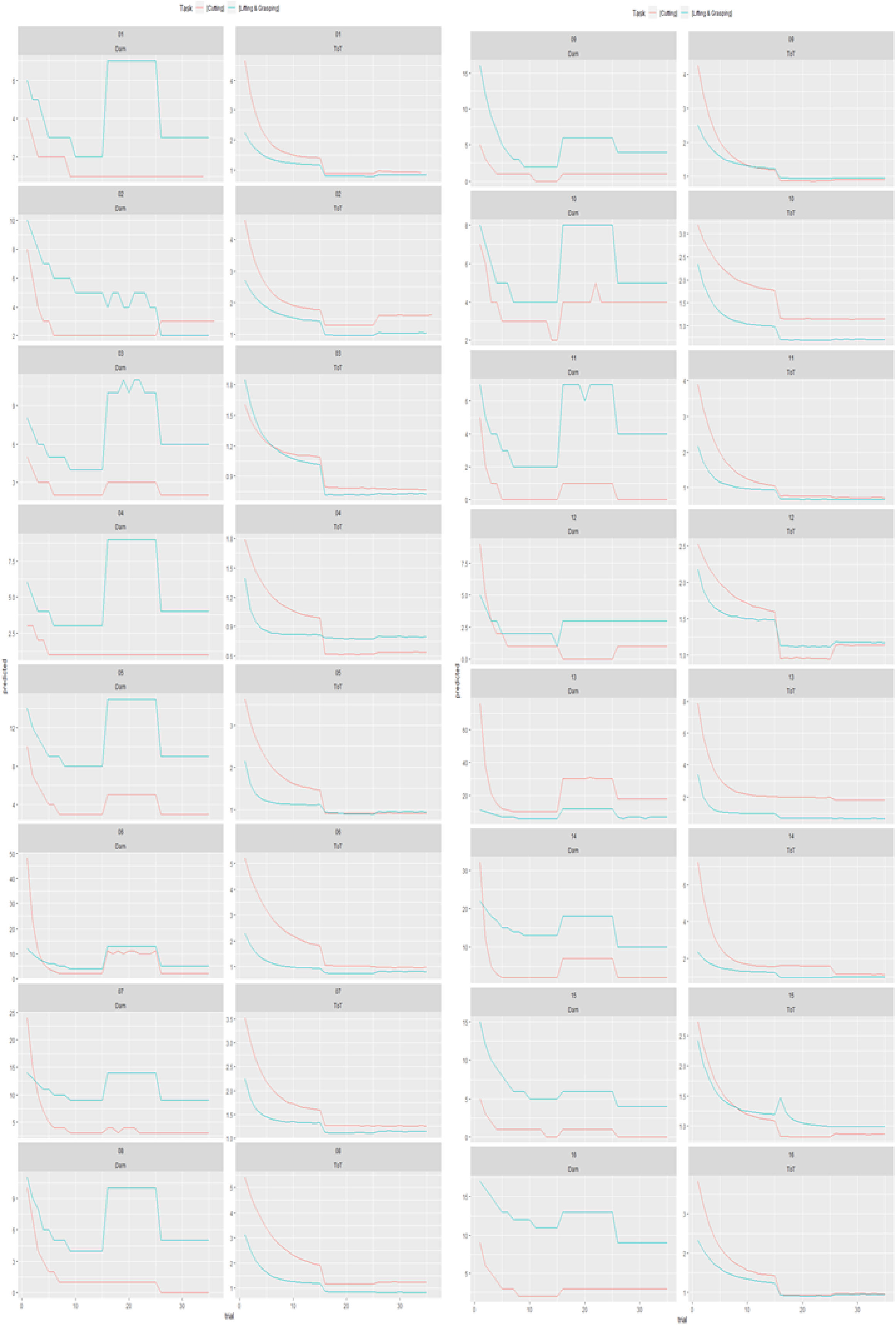
- Tell them that we started with an initial learning phase in the beginning, introduced time pressure in the second phase of the experiment and reduced it in the third.
- We wanted to test if the participants benefited in the third phase from their learning experiences in the second phase.

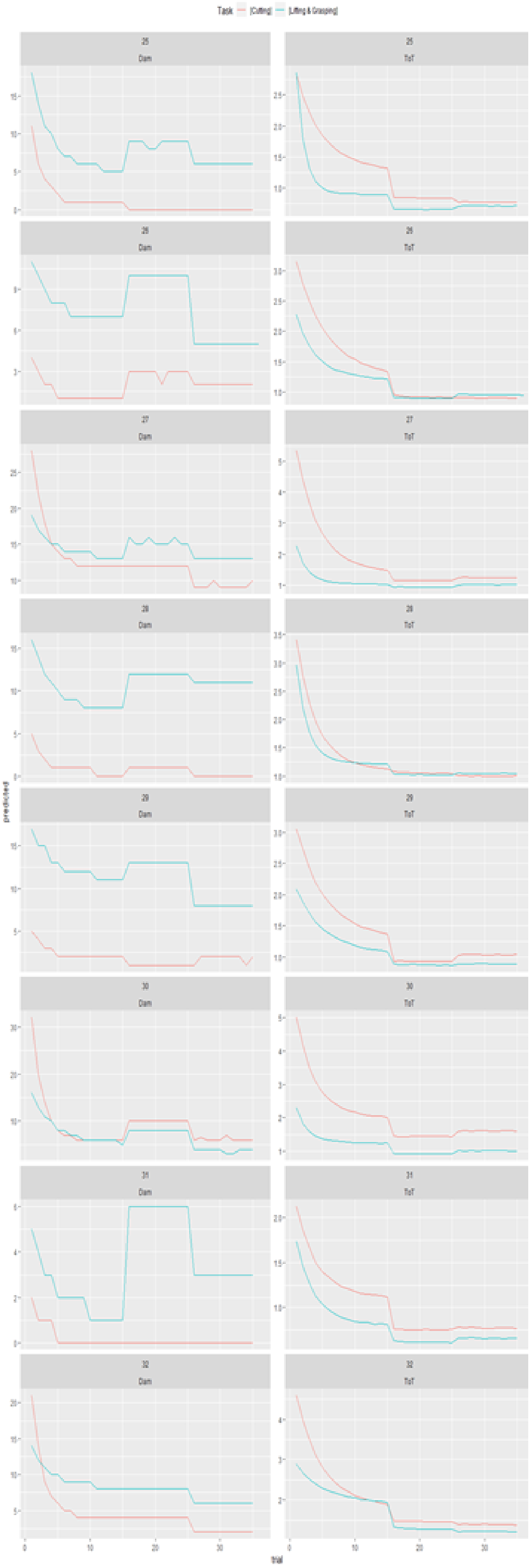
## 6.3 Scores Population level Maximum performance

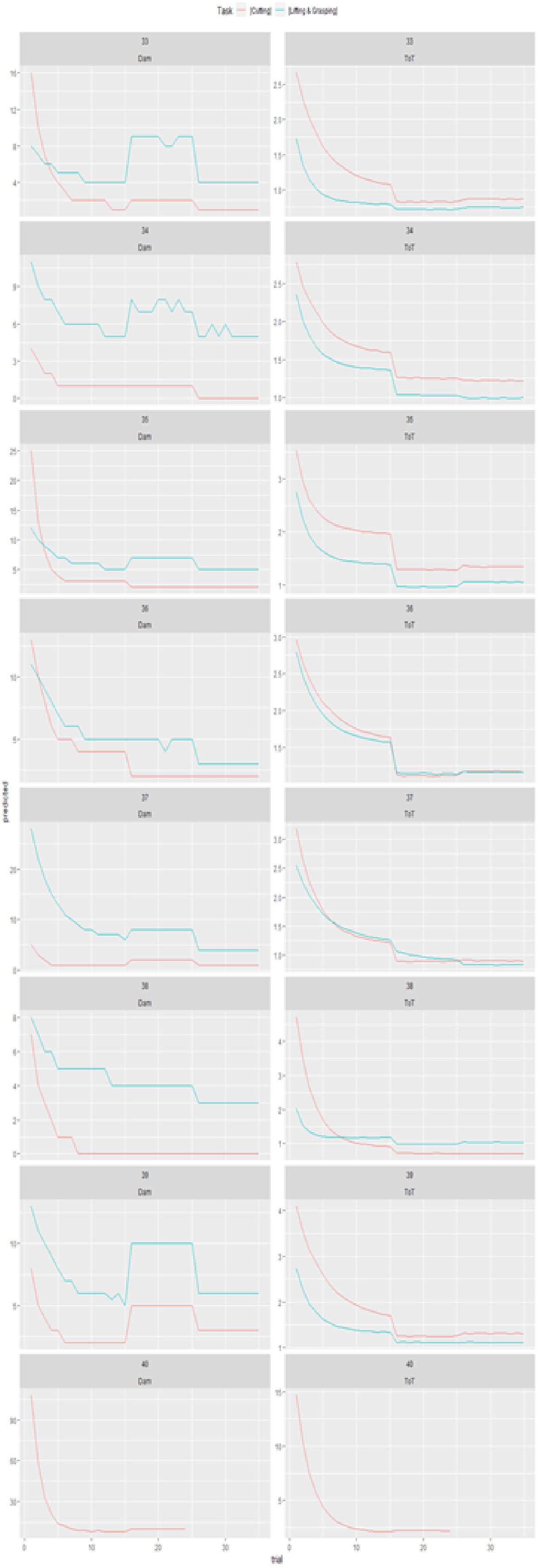
| Outcome | Phase | Task | center | lower | upper |
|---|---|---|---|---|---|
| | | | | | |
| 1 Dam | 1_free | Cutting | 1,69 | 1,14 | 2,32 |
| 2 Dam | 2_pressure | Cutting | 2,01 | 1,16 | 3,12 |
| 3 Dam | 3_free | Cutting | 1,46 | 0,934 | 2,1 |
| 4 Dam | 1_free | Lifting &Grasping | 5,46 | 4,14 | 6,92 |
| 5 Dam | 2_pressure | Lifting &Grasping | 9,35 | 7,86 | 11,1 |
| 6 Dam | 3_free | Lifting &Grasping | 5,38 | 4,42 | 6,45 |
| 7 ToT | 1_free | Cutting | 1,52 | 1,41 | 1,65 |
| 8 Tot | 2_pressure | Cutting | 1,24 | 1,14 | 1,36 |
| 9 Tot | 3_free | Cutting | 1,3 | 1,2 | 1,44 |
| 10 Tot | 1_free | Lifting &Grasping | 1,44 | 1,33 | 1,58 |
| 11 ToT | 2_pressure | Lifting &Grasping | 1,15 | 1,06 | 1,28 |
| 12Tot | 3_free | Lifting &Grasping | 1,17 | 1,08 | 1,29 |

Table 3 Population level asymptotes

## 6.4 Individual Learning curves




Task
(Cutting)
(Lifting & Grasping)
25 Dam
25 ToT
26 Dam
26 ToT
27 Dam
27 ToT
28 Dam
28 ToT
29 Dam
29 ToT
30 Dam
30 ToT
31 Dam
31 ToT
32 Dam
32 ToT
predicted
trial


Task
(Cutting)
(Lifting & Grasping)
33 Dam
33 ToT
34 Dam
34 ToT
35 Dam
35 ToT
36 Dam
36 ToT
37 Dam
37 ToT
38 Dam
38 ToT
39 Dam
39 ToT
40 Dam
40 ToT
predicted
trial

## 6.5 Spss Syntax Correlations

```
PRESERVE.
 SET DECIMAL COMMA.

GET DATA  /TYPE=TXT
  /FILE="C:\Users\alexi\OneDrive\Desktop\T_asym_scores.csv"
  /ENCODING='UTF8'
  /DELIMITERS=";"
  /QUALIFIER='"'
  /ARRANGEMENT=DELIMITED
  /FIRSTCASE=2
  /DATATYPEMIN PERCENTAGE=95.0
  /VARIABLES=
  Part AUTO
  Dam_Cutting_1_free AUTO
  Dam_Cutting_2_pressure AUTO
  Dam_Cutting_3_free AUTO
  Dam_LiftingGrasping_1_free AUTO
  Dam_LiftingGrasping_2_pressure AUTO
  Dam_LiftingGrasping_3_free AUTO
  ToT_Cutting_1_free AUTO
  ToT_Cutting_2_pressure AUTO
  ToT_Cutting_3_free AUTO
  ToT_LiftingGrasping_1_free AUTO
  ToT_LiftingGrasping_2_pressure AUTO
  ToT_LiftingGrasping_3_free AUTO
  /MAP.
RESTORE.
CACHE.
EXECUTE.
DATASET NAME DataSet1 WINDOW=FRONT.
```

```
T-TEST PAIRS=Dam_Cutting_1_free Dam_Cutting_2_pressure Dam_Cutting_3_free
ToT_Cutting_1_free
  ToT_Cutting_2_pressure ToT_Cutting_3_free WITH Dam_LiftingGrasping_1_free
  Dam_LiftingGrasping_2_pressure Dam_LiftingGrasping_3_free ToT_LiftingGrasping_1_free
  ToT_LiftingGrasping_2_pressure ToT_LiftingGrasping_3_free (PAIRED)
 /CRITERIA=CI (.9500)
 /MISSING=ANALYSIS.
```

**The scatterplots were made using Excel.**

## 6.6 Informed Consent

**Introduction**

Hello and welcome, thank you for taking part in this research. You may talk with anyone you like about this experiment and take time to decide if you want to participate or not. If there are things that are unclear or if you have questions in general, feel free to ask. This also goes in case you have questions later.

**Purpose of the research**

This research focuses on improving training for surgeons who perform minimal invasive surgeries (MIS). In MIS, long surgical instruments and cameras are inserted into the patient with only small or no cuts. This approach leads to advantages like less recovery time for patients, but also is more difficult to perform and needs extensive training. Virtual reality simulators like the LapSim enable this training without putting the lives of patients in danger. Since these simulators are rather new, it is still unclear which circumstances benefit learning results. This research tries to shed some light into this.

**Type of research intervention**

As a participant in this research, you will do two basic tasks on the LapSim, a virtual reality simulator for MIS. Both tasks will be done 35 times with short breaks between every trial. In those breaks we will ask for a short feedback on your subjectively experienced mental workload in form of one question. The two MIS tasks don’t require medical background knowledge and can be performed by novices.

**Participation selection**

We have chosen to recruit participants from SONA systems to ensure that we find enough participants in a short period of time. Furthermore, we can compare the results of this research with results from another research with a similar design.

**Voluntary Participation**

Participation in this research is voluntary. You can decide to not participate or opt out at any time with or without giving any reasons.

**Procedures**

After a short demographic questionnaire, you will be introduced to the LapSim. The tasks will be done while standing. You can adjust the LapSim to your preferred height before you start performing the task. There will be also an introduction on the LapSim for both tasks. We will give you specific instructions/goals for the tasks. Those instructions can slightly change after a number of trials, but the nature of the task will remain the same. After every trial you will take a 30-second break. In this break you may relax your muscles and eat or drink something. We will also ask you to quickly rate your subjectively experienced mental workload in those breaks. After you finished both tasks, you will be debriefed on this research.

**Duration**

We expect you to take 1 ½ hours per task/session.

**Risks**

It is possible that you will get physically uncomfortable since you have to stand and keep your arms and shoulders steady for a long time. The breaks are supposed to prevent that from happening. It is also possible that you will get frustrated since the LapSim will give you feedback on your performance after each trial. However, don't be discouraged if this feedback is not positive. MIS procedures are difficult and take years to master even for experts.

**Benefits**

By participating in this study, you may help us by providing insights in more efficient training for surgeons. As a result of this, the quality of surgical care might improve.

**Reimbursements**

You will receive 1,5 points on SONA systems per session, therefore 3 points in total. If you choose to participate for only one session, you will get only 1,5 points.

**Confidentiality**

All data will be treated carefully. No personal information will be asked or saved, the data from the

demographic questionnaire will be saved separately from the experimental data.

**Sharing the Results**

If you are interested in the results of the experiment, feel free to send me an email (see: Who to

Contact?)

**Right to Refuse or Withdraw**

Your consent to take part into this study can be withdrawn at any time and with or without

mentioning of reasons. Note that all data provided can be used in this research until the moment of

withdrawal of consent.