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Towards an effective MIS simulator-based training with basic laparoscopic tasks: The impact of time pressure on the learning process

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Abstract

Background: Laparoscopy has become the new standard for operating within the human body. The new technique comes with very different demands for the surgeon in order to be successful during minimally invasive surgery. Learning the skills was usually done with the model of apprenticeship, however recent studies suggest that this is not the ideal process of learning motor skills for laparoscopy anymore. Simulator-based training provides an effective alternative to acquire the necessary skills in a safe environment. In order to optimize the training with the simulators, it was found that errors could improve the learning process. To evoke a higher error rate, we saw the possibility to insert a time pressure episode to the simulator-based training. Based on previous experiments (Gas et al., 2018), it was expected that time pressure would have an impact the performance. Therefore, we assumed that time pressure could evoke a change in the learning process.

Methods: To test for the influence of time pressure, we employed a time-series study with 40 participants. Each participant had to run through three phases, the first one without time pressure, the second one with verbally induced time pressure and the last phase again without time pressure. Each phase was modeled in a learning curve and bundled together to population-averaged learning curves. We were interested in the population-level maximum performance reflecting the best performance one can reach if continuing the training. A lower asymptote would reflect a better performance and an enhanced learning effect of the training. Additionally, the individual-level maximum performance gave insights into the influence on time-pressure on the performance of each individual. Furthermore, a pairwise correlation between the phases has been calculated, to assess the internal consistency of the tasks.

Results: The findings suggest that the time pressure phase shows observable changes in the maximum performance of the learner. Furthermore, comparing the maximum performances of the first and the last phase revealed that the time pressure phase has a positive effect on the maximum performance in terms of time-on-task and damage in the long run. The correlation between the phases was mediocre, however with a high degree of uncertainty.

Conclusion: Findings suggests that time pressure improves the performance in simulator-based training. This confirms earlier findings on induced time pressure during training and adds, that time pressure has an observable impact on the learning process. The high error rate during the time pressure phase would suggest that training with provoked errors certainly has a positive impact on skill acquisition. Further research needs to investigate how time pressure can be implemented in a training program in the most effective way.

Keywords: MIS; Laparoscopy; Simulator-based training; Time pressure; Learning curves

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1. Introduction

Throughout the last decades, Minimally Invasive Surgery (MIS) has been one of the greatest advances in medicine and has become the standard for operating within the human body. This alternative to open surgery minimized post-operative pain and made it possible to work precisely on the affected parts, therefore reducing tissue damage (Darzi & Munz, 2004; Pache, Hübner, Jurt, Demartines & Grass, 2017). Through minimal incisions on the abdominal wall, different customized tools and a camera are inserted into the body, to the place of surgery. The camera transmits the internal processes onto a screen and the surgeon uses this representation to conduct the surgery with the different tools (Cao, MacKenzie, & Payandeh, 1996). Compared to old ways of surgery, MIS proved to be more effective in regard to medical care and economic concerns (Pache et al., 2017).

However, this new technique entails different demands for the surgeon in comparison to traditional open surgery. The surgeons need to develop a different set of skills, in order to be successful during their MIS (Gallagher, Leonard, & Traynor, 2009). These skills were usually learned via the apprenticeship model. This model suggests that the trainees watch the actions of a mentor, in order to learn the set of movements to perform the surgery on their own. After a certain number of observations of the trainees, the mentor can decide, if the trainees are able to perform the MIS on their own (Spruit, Band, Hamming, & Ridderinkhof, 2013; Cameron, 1997). However, recent studies about learning motor skills suggest that this training method is no longer the ideal process of acquiring new motor skills for MIS (Wong & Matsumoto, 2008). Training on virtual-reality simulators has opened up a new way of training aspiring surgeons and proved to have some advantages for the trainees, as well as for the assessment of their development towards becoming a proficient surgeon (Colt, Crawford, & Galbraith, 2001).

While looking at other domains, simulator-based training is already an integral part of education, including air traffic, nuclear power plants and the oil industry (Aggarwal & Darzi, 2006; Basdogan, Sedef, Harders & Wesarg, 2007). A common approach is to imitate high-risk procedures with induced time-pressure, so training resembles real-life situations as much as possible (Tichon & Wallis, 2010). Similar research was conducted in the context of laparoscopy. In the respective studies, time pressure was recognized as a constant factor for all surgeons during MIS, because the general aim was to optimize their own efficiency without harming the patient (Arora, Sevdalis, Nestel, Woloshynowyh, Darzi, et al., 2010; Andreatta, Hillard & Crain, 2010). However, these studies focused more on simulating realistic circumstances during MIS, rather than investigating the effect of time pressure on the learning outcomes.

Time pressure during training sessions, as introduced above, is reflected by an effect called speed-accuracy trade-off. This phenomenon is the influence of time on the error rate. Errors could be measured by means of slower reaction time or a wider range of movements (Gas, Buckarma, Cook, Farley, & Pusic, 2018). Although the effects of time constraints during MIS simulator-based training could provide important insights, they have not been investigated yet. One first study by Gas et al. (2018) has just begun trying to explain the effects of time pressure. They revealed that time constraints have a positive impact on the learning performance for novice learners during MIS simulator-based training. Using time constraints and thus, provoking a higher error rate would be beneficial for enhanced long-term performance of the learner. Relating this to effective simulator-based training in MIS, assessing the influence of time constraints on the performance could be one possibility to gain more insights into how MIS skills training could be optimized. On that account, time pressure could be one possible variable to reinforce the learning process.

In order to assess the learning process, learning curves are one available option that can be used. Learning curves are mathematical functions, which pair the outcome variable with the amount of experience on a particular task (Rogers, Elstein & Bordage, 2001). Usually, the learning process shows quick and strong improvements of the performance in the beginning and then with ongoing practice, rather slow progress with more learning effort (Wanzel, Ward and Reznick, 2002). Wanzel et al. (2002) further stated that these learning curves are a suitable option to assess performance during surgical skills training. The analysis could provide insights into understanding the influence of different variables on the motor tasks learning (Wanzel et al., 2002). In order to understand the effects of different variables on the performance and therefore the learning process, Arendt (2017) further pointed out that maximum performance is a stable and valid measure to do so. Since maximum performance indicates the level of proficiency reached after continued training, the observation of the predicted value has different practical implications. Higher maximum performance in MIS training would compromise fewer errors and shorter operation times. As mentioned above, one possible variable to assess is time pressure. Using learning curves to assess the effect of time pressure on the learning process during MIS training procedures seems to be appropriate.

This study aims to examine the impact of time pressure on the learning process of upcoming surgeons for MIS on basis of learning curves. According to previous research, it can be hypothesized that induced time pressure during simulator-based training has a positive effect on the long-term performance of the trainees.

2. Background

2.1. Challenges during MIS

MIS is a new technique in the field of surgery with very different demands for the surgeon. The work with endoscopes and new surgical instruments during MIS demands that the surgeons have to develop a new set of skills, in order to be successful during this kind of surgery. Gallagher and Smith (2003) divided the challenges of learning the technique into three different factors: Cognitive, ergonomic and training.

Cognitive factors deal with the underlying psychological problems during surgery. One problem is the monocular vision. As only one camera displays the inner process on a screen, the 3D vision is reduced to a 2D vision, which demands the surgeon to interpret the 2D representation into known 3D structures, e.g. organs, tissues. Besides the restriction on depth perception for the surgeon, also the visual information provided through monitors is poorer compared to the information the human visual system provides during open surgery (Gallagher et al., 2009). Furthermore, changes in the camera angle by an assistant challenge the orientation of the surgeon in regards to localizing the area of treatment and the surgeons mental model of the anatomy (Gallagher et al., 2003).

Ergonomic factors are based on the interaction of the surgeon with the instruments. The long thin instruments used during MIS restricts the surgeons´ range of motion drastically and demands to adopt awkward body postures, in order to be successful during the surgery (Gallagher et al., 2003). Furthermore, the instruments provide only reduced tactile feedback to the surgeon, which makes it even more difficult to employ the appropriate movements (Basdogan et al., 2007). Another problem, known as the fulcrum effect, is described as the counter-intuitive movements of the instruments in the patient´s abdomen compared to movements of the surgeons' hand. This effect challenges the precision of the surgeon's movements during the MIS and makes the procedure more prone to errors (Spruit et al., 2013). All these new challenges cause physical fatigue of the surgeon and an overall longer operation time (Gallagher et al., 2003).

Finally, the last factor proposing a challenge to MIS is the training factor. This is necessary, in order to ensure high-quality patient care. New technologies like VR simulators have some advantages over the traditional box trainers and should be incorporated into a curricular training program with gradually increasing difficulty, dependent on the skills and knowledge of the trainee (Gallagher et al. 2003). Recently, first attempts have been made to standardize the learning programs on simulator-based training (Zevin, Dedy, Bonrath & Grantcharov, 2017). Zevin et al. (2017) pointed out that distributed practice of training session with the simulator significantly improves the performance of the aspiring surgeons. However, MIS simulator-based training programs still lack validated practices about which training is the most beneficial for the learners, in order to prepare them in the best way possible. One of the not yet investigated types of simulator-based training is time-pressure episodes. We chose this kind of training, because it is still unknown if time pressure episodes incorporated in a training program could have benefits for the learning process. Furthermore, Pusic and colleagues (2014) suggested that time pressure is an effective instructional strategy to vary the challenge of the task. Keeping the learner optimal stressed with time pressure could, in turn, have benefits for the learning retention in the long run (Guadagnoli, Morin & Dubrowski, 2012).

2.2. Benefits of Simulator-based Training

Over the last few decades, major advances in the possibilities of how to acquire surgical skills for MIS procedures took place. The commonly used apprenticeship model was challenged by new technologies, which promised a more effective way of learning (Wong et al., 2008). As previously mentioned, virtual-reality simulators enabled surgeons to learn surgery skills more effectively as well as to assess their progress in an efficient manner (Colt et al., 2001).

A virtual-reality training session takes place in a low-risk environment, where the trainees can fully focus on learning new skills without jeopardizing the health of a patient (Lee, Qui, Teshome, Raghavan, Tedesco et al., 2009). The trainees are asked to accomplish a certain task which simulates a situation of real surgery. This can differ in the degrees of difficulty and duration, depending on the goal of the session and the individuals' abilities (Tichon et al., 2010). While the trainees perform the tasks, the simulator is able to collect a great amount of data, available to assess the performance of the trainee afterward in a transparent and objective way, for example, using learning curves. Furthermore, the data can be used as meaningful feedback for the trainees and give them the opportunity to reflect personally on their performance (van Dongen, Tournoij, van der Zee, Schijven & Broeders, 2007). Previous research generally found that simulator-based training progressively improves the performance of the trainee (Derossis, Bothwell, Sigman & Fried, 2014), shortens the time used for a procedure (Larsen, Soerensen, Grantcharov, Dalsgaard, Schouenborg et al., 2009) and significantly reduces the error rate during the first ten surgeries (Ahlberg, Enochsson, Gallagher, Hedman, Hogman, et al., 2007).

Although general simulator-based training has already been proven to be beneficial for aspiring surgeons, there is still a lack of knowledge regarding the instructional design features. Cook and colleagues (2013) used a meta-analysis to compare different instructional designs to assess their effectiveness. They found out that the instructional designs “range of difficulty”, "repetitive practice" and "distributed practice" were most beneficial for the learning outcome. They criticized, however, that the potential variables underlying the instructional designs remain unclear. Therefore, examining potential variables to test for their impact on learning outcomes could provide practical insights to advance the training program. Thus, investigating the effect of time-pressure, as it has not previously been investigated, seems reasonable. Not only could these insights help to clarify the effect of time pressure on the learning outcome, but could also help to develop specified training programs tailored to certain target groups.

2.3. Effects of Time Pressure and the Speed-accuracy Trade-off

The influence of time pressure in the context of simulator-based training for MIS has not been extensively investigated yet. However, looking at other domains like sports could give insights about the influence of time pressure on the performance and the learning process. For example, the study by Beilock, Bertenthal, Hoerger, & Carr (2008) about learning golf revealed the possible influence of induced time pressure on the performance. The study showed that novice golfers perform better under conditions of unlimited time. This was explained by having more time to put their attention on the performance. The very opposite pattern was observed by skilled golfers, which performed better under time constraints. It was assumed that during the condition of time pressure, the skilled golfers would rely on automatized procedures, therefore minimizing the probability to make new errors (Beilock et al., 2008). Following this finding, experience would be closely related to the performance and outcome of the task under the conditions of time pressure.

However, a very different outcome was found in the context of learning surgical tasks under time pressure. A recent study by Gas et al. (2018) revealed that novice learners maintain or improve their accuracy while increasing their speed of the task. It was reasoned, that the effect partially appeared due to learning but also due to responding to the time-pressure. Furthermore, the findings on induced time pressure for intermediate learners revealed small unknown errors in their technique, which were not evident before. Finally, looking at the advanced learners, the increased speed led to an increasing amount of errors. This was explained by the stage of expertise that the learners already reached their optimal balance of speed and accuracy and further improvements of speed would only be restricted by their physical limits. Overall, the most significant effect was found at the novice level, which showed a potential positive effect of time pressure on learning.

A possible explanation for the previous findings by Gas et al. (2018) was written by Dyre, Tabor, Ringsted, and Tolsgaard (2016), who stated that errors during a training session would lead to a better performance in the long run, rather than avoiding errors during training. Therefore, exposing the learners to time pressure in order to challenge their performance to their personal limits, can evoke more errors in comparison to no-time pressure conditions. This would be more beneficial for the learning process in the long run.

Another possible side-effect of time pressure is the speed-accuracy trade-off, which needs to be taken into account when looking at the results. In the case of MIS simulator-based training, this would mean trading more time to decide for the appropriate operation during the surgery for a time efficient decision, in order to have more time to perform the operation accurately. Therefore, showing a correlation between time and error rate. The study by van Galen and van Huygevoort (2000) on the effects of the speed-accuracy trade-off on surgical performance revealed that time pressure leads to increased variability in movements and an increased error rate, as well as, higher pressure in the cursor control.

Overall, these findings suggest that it is not only of interest to be faster during MIS surgeries, but also take the error rate into account. “A fast surgeon is not necessarily a good surgeon” Darzi and colleagues (1999) once said, showing the importance that speed cannot be treated as the only criterion for quality. Therefore, it is of practical importance for MIS surgery to not only look at the improvement of time but also at the error rate during training sessions. Since these effects have not yet been investigated for simulator-based training in MIS, the question arises if the same learning pattern would also hold for this type of training. The introduction of time pressure into simulator-based training could be a promising first step towards a more effective training for aspiring surgeons.

2.4. Learning curves and the parameter maximum performance

In order to assess the development of performance during the training programs, learning curves are recommended. Learning curves show the influence of training and experience on performance. The analytical representation of a learning curve is an exponential graph (see figure 1). Therefore, achieving expertise in a certain task is described by a decrease in time and effort along with an increasing number of repetitions (Wanzel et al., 2002). Heathcote, Brown, and Mewhort (2000) stated that a three-parameter exponential learning function best described the learning process of the individual.

The three-parameter exponential function quantifies the ongoing learning process in terms of three meaningful parameters, namely the overall learning effect (Amplitude), the strength of improvement (Rate) and maximum performance (Asymptote). The first parameter, Amplitude, represents the maximum learning capacity of the participant. To do so, the difference between the total knowledge at the beginning of the study and the total knowledge at the end of the study is compared. The second parameter, the Rate, showed the learning speed of the participant. Looking at the slope of the learning curve, the steepness provides information about how fast the participant acquires the demanded set of skills. The third one, Asymptote, reflects the maximum performance of the participant. This parameter indicates the expectation, which performance level will be reached in the future if the training would be continued (Heathcote et al., 2000).

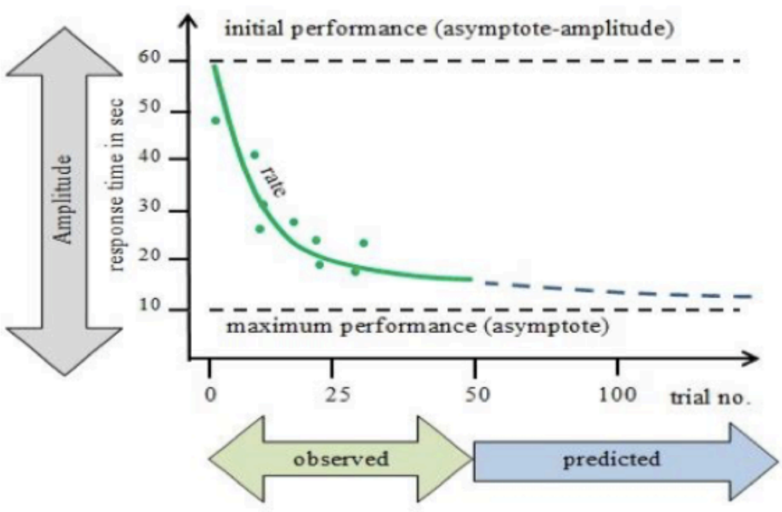

Figure 1. Displayed is a three-parameter exponential learning curve. The x-axis represents the number of trials and the y-axis the time on task. The rate is the speed of improvement, the amplitude the learning effect and asymptote the expected maximum performance if the training would be continued. The number of trials and response times are invented in order to illustrate the course of a learning curve.

To test for the effects of time-pressure, maximum performance has several advantages over the other parameters. First, in regards to the practical implication of the results, it makes sense to choose for maximum performance, since the parameter reflects the final outcome on performance apart from the performance during practice. In this study, it is not of interest if learning with time pressure episodes results in better or faster performances during the training, but rather in improvements in the long run. Furthermore, Huijser (2015) found that the parameters rate and amplitude are relatively unstable factors, as they rely heavily on personal abilities to perform the tasks during training. However, these differences have little to no influence on the later maximum performance, therefore add no further insights into the effect of time pressure on the later performance. Follow-up studies by Arendt (2017) and Kaschub (2016) showed that maximum performance is the most reliable factor to compare different individual learning outcomes in terms of practical implications, as it remains stable after a learning phase has been finished.

Furthermore, it was stated by Westerhof (2018) that the asymptote indicates a physical limit of the individual. In the study, they argued that after a certain amount of training and reaching one´s own maximum performance, further practice would not result in any improvements in one´s own performance due to physical constraints. Changing the training program, however, could result in a revision of the learned technique and therefore having an effect on the asymptote of the learning curve. In terms of MIS training, this would mean that time pressure could lead to a revised mental model of the technique (Gas et al., 2018). The revision could lead to either more efficient or inefficient movements and thus change the outcome of maximum performance.

2.5. Research Question

The aim of this research is to investigate the impact of time pressure on the learning process of acquiring new motor skills for MIS. It can be hypothesized, that during time pressure episodes an increase of errors and a reduction in the time needed for a task can be observed. Overall, however, can it be expected that a more efficient information processing takes place and thus the acquisition of motor skills could be accelerated (Southard, 1989). Moreover, if an increasing amount of errors would occur, this could lead to a better understanding of the surgical technique of MIS and in the end, could have practical benefits for the surgeons (Dyre et al., 2016).

As the effect of time pressure on learning with simulator-based training is explored in a very new context, here MIS laparoscopy, is the research exploratory in its nature. The focus of interest is on practical insights for an effective training program and how to advance the performance of surgeons, thereby gaining improved patient care in the long run.

3. Methods

3.1. Design

A within-subject time-series design was used. All of the participants received the same instructions and went through the same procedures. Each participant first participated in 35 trials of the simulated Cutting task and afterward in 35 trials of the simulated Lifting and Grasping task. Each of the tasks included three phases, which were applied as followed. The first phase, consisting of 15 trials, was without any time pressure. In the second phase, trial 16 to 25, time pressure was introduced. In the third phase, the time pressure has been removed again.

The three phases were selected, in order to be able to test for a before-after treatment effect. The first phase was used to have an estimate on how the learner would develop without any changes in the conditions. The second phase showed the effect of time-pressure itself. The last phase was used to have a measure, in order to compare the differences between the first and the last phase, in that way checking on the influence of the time-pressure on the maximum performance.

3.2. Participants

Overall, a convenience sample of 40 participants, with a mean age of 23.5 (SDG_{age} = 3.2, range 19 to 31) was drawn. The sample included 17 males, 22 females and one not disclosed. Eighteen were from Germany, 17 from the Netherlands and five from other countries (Iran, Mexico, India, the USA and Spain). In total, 23 of the participants reported no impaired vision. 17 participants indicated to have impaired vision. Eleven of them mentioned to wear glasses, four reported wearing contact lenses, one participant indicated impaired vision without wearing glasses or contact lenses and one mentioned to be color blind. Two participants further indicated to have dyslexia. Exclusion criteria for participants were based on physical impairments regarding hands and legs, due to the ability to use the simulator appropriately. One participant dropped out due to physical impairments.

All participants signed the given informed consent (Appendix A) and the Ethics Committee of the University of Twente approved the study (Request No.: 190375)

3.3. Apparatus

The LapSim simulator

The simulation of the MIS and the data collection were conducted on the LapSim. The LapSim is a virtual reality simulator, invented to train upcoming surgeons on different tasks of laparoscopy. To simulate such tasks, the simulator consists of three SimBall-modules, in which the different endoscopic tools are inserted. Furthermore, a desktop computer runs the simulation and a 23” LC-Display displays the simulation to the participant. The SimBall-modules replace the insertions of the tools through the abdomen wall. The modules can detect the movements (degree of turning and pushing or pulling) of the tools and represent those exactly on the LC-Display. The endoscopic tools are the same as in real MIS, with the exception, that they feature no actual forcipes at the very end.

Figure 2. The set-up of the LapSim. On the left, the whole simulator including the desktop computer, the LC-display and the SimBall-modules with the endoscopic tools. On the right, the SimBall modules with one endoscopic tool in more detail. The table can be adjusted in height and the LC-Display in height as well as in closeness (Arendt, 2017).

Demographics Questionnaire

Furthermore, a demographics questionnaire was provided via the website "www.surveymonkey.com". The website provides anonymized cloud-based online surveys. The questionnaire aims to collect demographic data about the participants. In addition, this data is used to check, if any of the exclusion criteria were met.

3.4. Tasks

The two tasks Cutting and Lifting and Grasping were chosen for this research. A previous study by Luursema, Rovers, Groenier, & van Goor (2014) concluded, that these tasks incorporate three of the core skills needed for the laparoscopy procedure. Furthermore, as the tasks are bi-manual in their nature, they can be easily learned by non-medical students.

Cutting Task

Cutting in MIS consists of two parts: Grasping the tissue with the grasping forceps and cutting it with the ultrasonic-scissor forceps. The grasping task starts by approaching the tissue with an open grasping forceps until it is in a position to grasp the tissue. The grasper then can be closed via closing the handles. The cutting task includes approaching the tissue with the scissor forceps in the same way as in the grasping task. If the scissor forceps is in place, the scissor can be closed via the handles. If the scissor is closed at the right place, heat can be applied with a pedal, in order to cut and cauterized the tissue.

The simulation on the LapSim simulates such a procedure in a way, that a vessel connected to the abdominal wall needs to be cut off. The vessel has to be grasped at the very end and a particular part of it needs to be cut off with the ultrasonic-scissor forceps. Afterward, the separated piece should be put into the endoscopic bag. This procedure is repeated three times until the trial is finished.

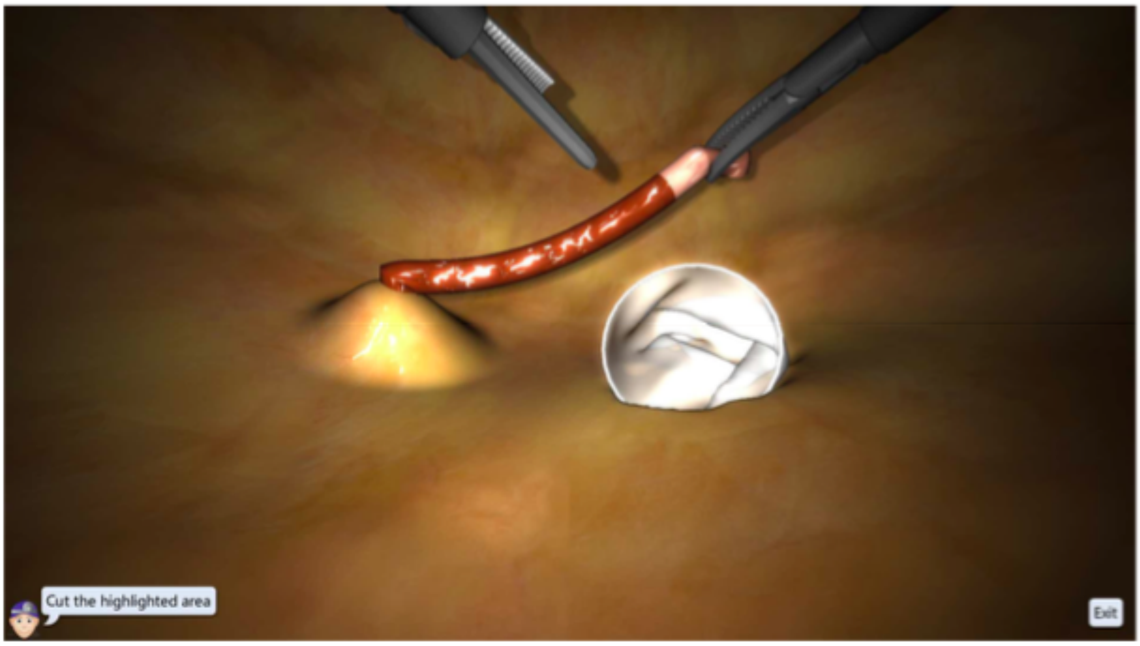

Figure 3. The Cutting task. The right endoscopic tool displays the grasping forceps and the left one the ultrasonic-scissor forceps. The vessel is distinguished in different colored areas as assistance where to grasp or to cut. The white endoscopic bag should be used to drop the separated part of the vessel in it (Arendt, 2017).

Lifting and Grasping Task

Lifting and Grasping in MIS, as the name already suggests, consists of lifting up a particular tissue, in order to operate underneath it. Thereupon, a probe instrument is pushed under the tissue in order to lift it up. Afterward, the second instrument with the grasping forceps approaches the area under the uplifted tissue and grasps a specific object.

During the simulation, there is a tissue box displayed either on the right or the left side of the screen. If the tissue box is on the right, the probe instrument is handled with the left hand and vice versa. The other hand handles the grasper. The task in the simulation demands, that the tissue box is lifted up with the probe instrument and a suturing needle is grasped with the grasping forceps. After grasping the needle, an endoscopic bag is displayed, in which the needle should be placed. This procedure is repeated six times until the trial is finished.

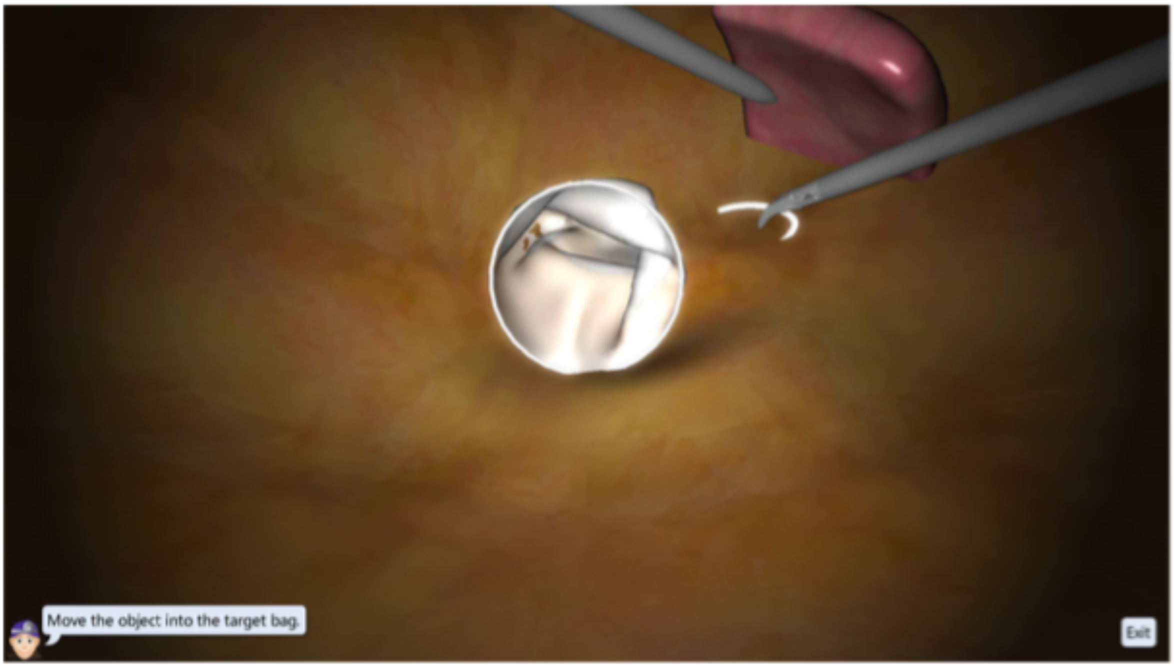

Figure 4. The Lifting and Grasping task. In this case, the left endoscopic instrument displays the probe instrument and the right one the grasping forceps. The probe instrument lifts up a tissue box in order to grasp with the grasping forceps a needle laying underneath it. The white endoscopic bag should be used to drop the needle in it (Arendt, 2017).

3.5. Procedure

Greeting and Briefing

Upon arriving at the Experimental Centre for Technical Medicine (ECTM) desk, the participants were taken to the laparoscopy room, where the experiment took place. The participants were welcomed and thanked for their participation. They received a complete verbal instruction about the aim of the study and their upcoming task. They were asked if they would have any questions about the study or the procedure. Afterward, they signed the informed consent and filled in the questionnaire about their demographics (see Appendix A).

The Simulations on the LapSim

After the general introduction into the study, the participants were introduced to the LapSim. They were asked to read the instruction and watch the video for the Cutting task provided by the simulator. The participants then were verbally instructed to perform the task as quick and accurate as possible. Afterward, they started with the task. After each of the 15 repetitions of the task, the participants received a break of at least 30 seconds. The break could be used for gymnastic exercises, drinking some water or eating some sweets. During each break, the participants were asked to rate their mental demands. Following the experimental set up of Gas et al. (2018), the participants subsequently received verbally new instructions to perform the task 20% faster than their last time of the first phase. It was further instructed, that the participants should focus on the speed of the task, rather than the accuracy. The participants started the task and repeated it for another ten repetitions. After each trial, the same break as in the previous phase was applied. Afterward, the participants were instructed to do the next ten trials again as quick and as accurate as possible, like in the first phase. The participants completed the ten last simulations with a break after each trial, the same as before.

The same procedure, as described above, was applied to the Lifting and Grasping task. In total, each participant completed 35 trials of each task.

Debriefing

After the completion of the tasks, the participants were thanked for participating and asked, if they would like to receive the results of the study via email. Furthermore, they could take their version of the informed consent with them, which included the contact details of the researcher.

3.6. Measures

The LapSim collects different performance parameters during the simulations. With regards to the expected speed-accuracy trade-off, the parameters time on task and damage rate were chosen for the dataset. Time on task was measured in seconds. The damage rate was measured in the number of errors. Both measures, time on task and damage rate, can determine the impact of time pressure on the participants' error rate and thus effectively test for the time-accuracy trade-off. If these values are taken together, the initial performance of a person could be allocated, how the learning curve is sloped and when the maximum performance may be reached.

3.7. Data Analysis

The reparametrized Learning Curve Model

The data was analyzed with a non-linear effects model, using an exponential learning curve as a likelihood function. This function, called ERY, was used to construct the learning curves of each participant. A reparametrized version of the learning curve model described by Heathcote et al. (2000) can be represented by the following formula:

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

In this formula, the parameter Amplitude has been reparametrized to virtual previous trials as this was considered to be a more meaningful measure (Arendt, 2017). This parameter indicates the previous experience as if the participant has performed the task before, in order to correct for different levels of expertise in the sample.

For each of the participants, three individual learning curves were designed based on time-on-task and three based on damage. Each learning curve contained three parameters, namely Asymptote, Rate and previous Experience. The asymptote parameter reflected the predicted maximum performance of an individual in the long run. The non-linear effects model was built with the brms package (Brückner, 2019) of R 3.5.3.

The three Learning Curves

In this study, each of the three learning curves reflected one of the three phases we introduced: Pre-time pressure phase (trial 1-15), time pressure phase (trial 16-25) and post-time pressure phase (trial 16-35). For each part or phase, three parameters were used to model a learning curve for each individual. Therefore, in total nine parameters were taken into calculation.

For each participant per part was one learning curve created and for the purpose of an analysis, all the learning curves in one part were combined to a population-level estimate. The estimate was calculated on the basis of a 95% credibility interval, meaning that there is a 95% chance that our true value is in the found range. This estimate was calculated to compare the internal trends between tasks.

In addition, a Pearson correlation was used to test for the internal consistency of the two tasks. The correlation was implemented to test and replicate the findings by Arendt (2017) if the two tasks share the same motor skills. The correlation was calculated with a 95% confidence interval. In order to carry out this analysis, the first phase of the first task was linked to the first phase of the second task, the second to the second and the third to the third.

4. Results

To answer the research question of whether time pressure has an effect on the maximum performance while performing simulator-based training, this section is split into two parts. The first part focuses on the population-level effects for the outcome variables of the maximum performance parameter and the second part focusses on the individual-level effects for the outcome variables. Based on the individual-level effects, the internal consistency of the first task and the second task was determined and illustrated.

4.1. The analysis on population-level

In order to test the influence of time pressure on maximum performance, differences in the outcome variables damage and time on task were analyzed on population-level. If there are differences detected in the outcome variables of maximum performance between the phases, it could provide insights into the effects of time pressure on the learning process.

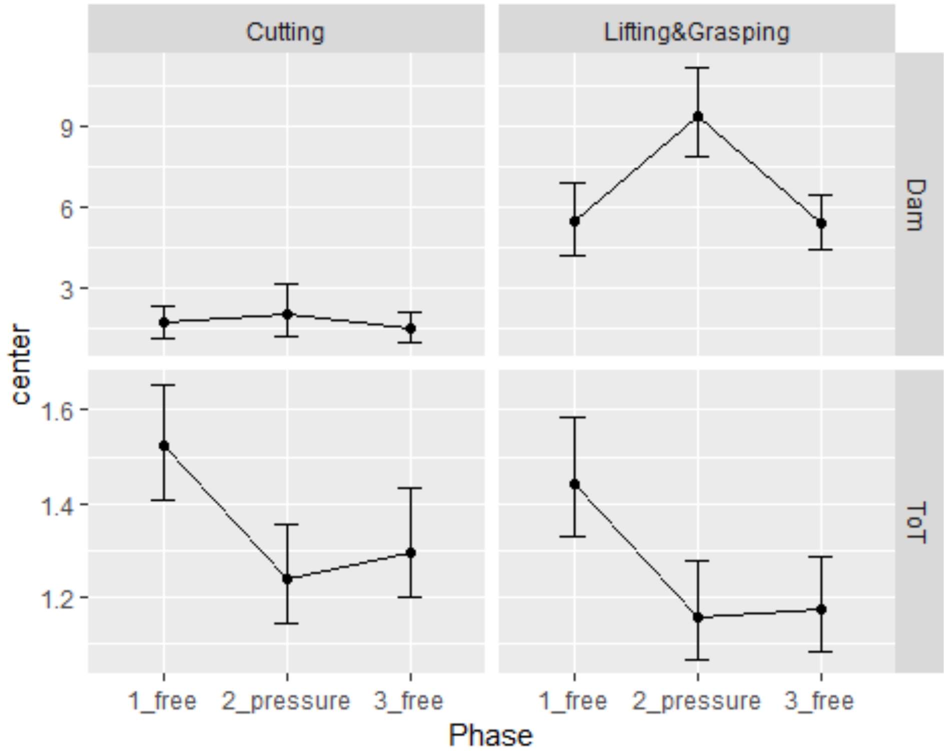

Figure 5. Population-level effects for maximum performance per task.

First, the population-level effects for the parameter asymptote were drawn from the posterior distribution. The results of the estimates of the parameter maximum performance are summarized in table 1 and shown graphically in figure 5. For time on task and damage, the estimated maximum performance was calculated. It can be seen from the table as well as the figure, that both tasks show a similar pattern. In particular, for time on task it can be seen that from the first to the second phase a visibly strong reduction of time on task took place, which means that the time pressure treatment had an effect on the performance outcome. Looking at the last phase without time pressure, only a slight increase in time on task in comparison to the second phase can be observed. This indicates that the participants would maintain approximately the same maximum performance after the elimination of time-pressure. Overall, an improvement of 20% in the maximum performance from the first phase (Cutting: 1.52 sec.;

Lifting & Grasping: 1.44 sec.) to the third phase (Cutting: 1.30 sec; Lifting & Grasping: 1.17 sec.) can be observed.

In terms of damage, both tasks showed similar patterns either, although the changes are more extreme for the Lifting and Grasping task. The maximum performance was higher in the second phase than in the first phase, which meant that the induced time-pressure evoked a higher number of errors. From the second to the third phase, however, the maximum performance decreased again, which indicates a clear improvement in terms of errors. Overall showed the Cutting task an improvement of one-sixth in the number of errors from the first to the last phase (Phase 1: 1.69; Phase 3: 1.46), whereas the Lifting and Grasping task did not show considerable improvement (Phase 1: 5.46; Phase 3: 5.38). However, the total amount of damage in the Lifting and Grasping task was twice as high as in the Cutting task (Lifting & Grasping: 5.38, 9.35; Cutting: 1.46, 2.01).

Overall, it can be stated, that the participants on both tasks responded to time pressure in the second phase with an increased amount of errors and a clearly visible decrease in time on task. Moreover, for both tasks, the time on task during the last phase remained approximately the same as in the previous time pressure phase without an increased amount of errors. However, the overall decrease in estimated damage from the initial phase to the final phase was higher in the Cutting task than in the Lifting and Grasping task.

Table 1. *Population-level effects for maximum performance per task*

Task	Outcome	Phase	center	lower	upper
Cutting	Damage	1	1.69	1.14	2.32
		2	2.01	1.16	3.12
		3	1.46	0.93	2.10
	Time on Task	1	1.52	1.41	1.65
		2	1.24	1.14	1.36
		3	1.30	1.20	1.44
Lifting &Grasping	Damage	1	5.46	4.14	6.92
		2	9.35	7.86	11.10
		3	5.38	4.42	6.45
	Time on Task	1	1.44	1.33	1.58
		2	1.15	1.06	1.28
		3	1.17	1.08	1.29

Estimates with 95% credibility limits

4.2. The analysis on individual-level

Individual learning curves

This analysis was conducted, in order to answer the research question on the influence of time pressure on the parameter maximum performance on an individual-level. Since the population-level effects cannot be generalized to every participant, an individual-level analysis was applied. Differences in the maximum performance could show different types of responses to time pressure and make it possible to come up with meaningful statements about the speed-accuracy trade-off.

On first sight, all the learning curves for the outcome variable time on task of both tasks seem to show the same pattern. Based on visual inspection, the learning curve of each participant shows a significant decrease in time on task when confronted with time pressure, and no change in time on task after the time pressure episode (figure 6). Four exceptions were found, which displayed no decrease or even a slight increase of time on task when starting the second phase of time pressure (figure 7).

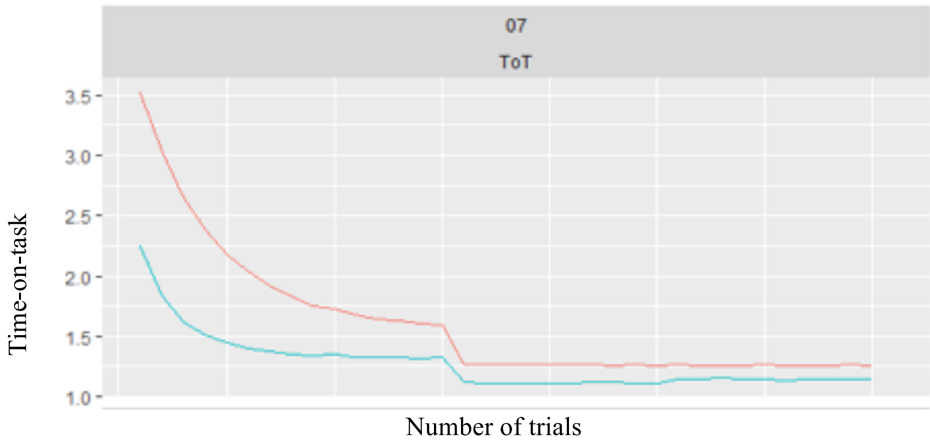

Figure 6. The usual course of a learning curve on individual-level, which displays the outcome variable time on task. The blue line displays the Lifting and Grasping task and the red line the Cutting task.

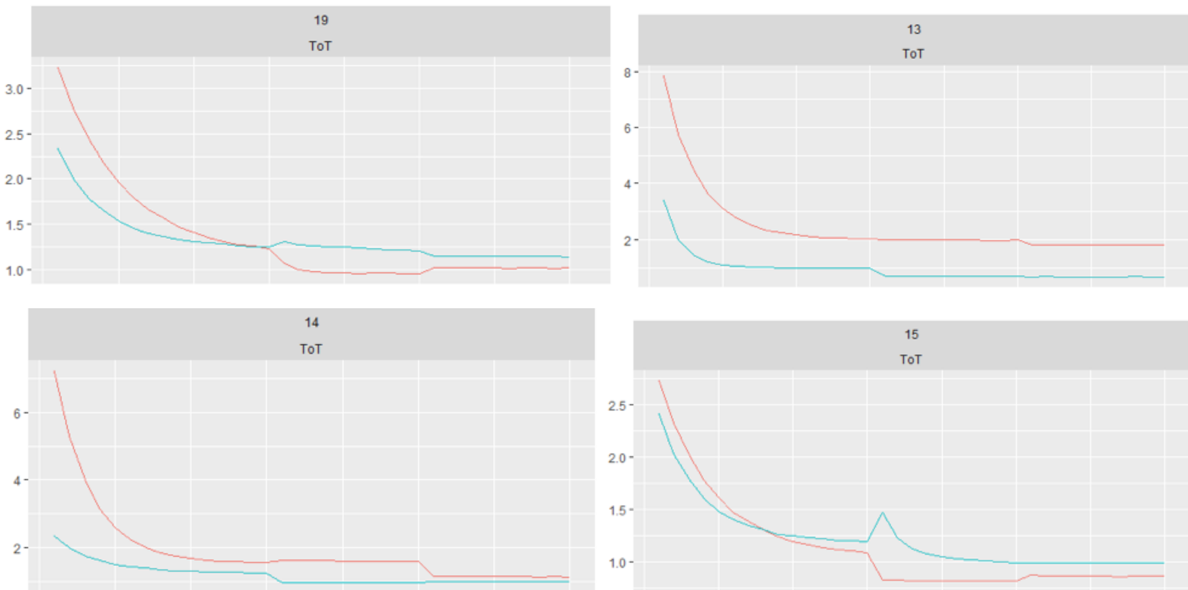

Figure 7. Three learning curves on individual-level displaying the outcome variable time on task. The x-axis depicts the number of trials while the y-axis displays the predicted seconds per trial. The blue line displays the Lifting and Grasping task and the red line the Cutting task. The learning curves display no decrease or a slight increase of time on task after the introduction of time pressure.

The same applies to the learning curves on the estimated outcomes of damage in the Lifting and Grasping task, which display a very consistent pattern. Usually, a significant increase in the number of errors during the time-pressure phase became apparent. Nonetheless, six participants showed no increase in errors but rather maintained the same number of errors over the time-pressure phase, without showing any observable differences in time-on-task in comparison to other participants (figure 8). However, the learning curves on the outcome of damage of the Cutting task show more variation than in the Lifting and Grasping task. The main pattern was similar to the one of the Lifting and Grasping Task, showing an increased amount of damage during the time pressure phase (figure 8). However, not all the individual learning curves show an increased number of errors during the time pressure phase. Since this observation may in some cases be related to the scaling of the y-axis, in the cases where the scaling does not affect the visualization of the curve, the error rate remains stable or decreases during the time pressure phase. Six participants showed obvious decreases in the error rate, while the decrease in time on task was no less than that of other participants.

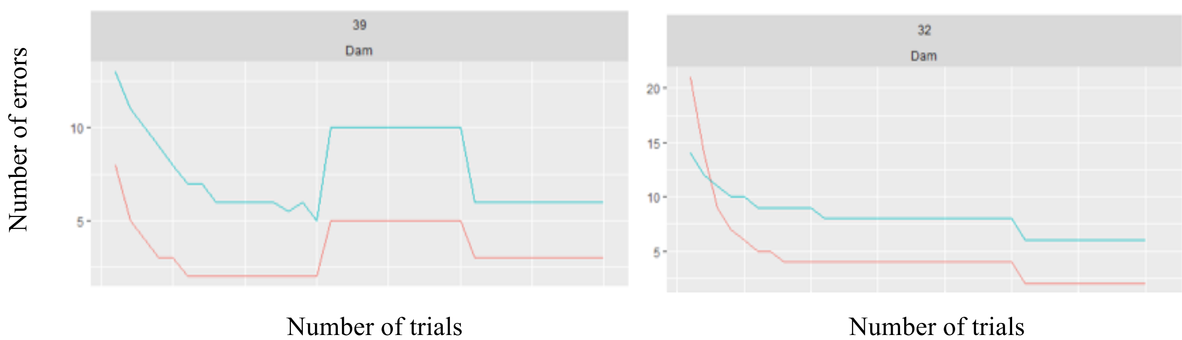

Figure 8. Displayed are four learning curves on participant-level of the estimated outcome variable damage. The blue line displays the Lifting and Grasping task and the red line the Cutting task. The left graph shows the usual course of the learning curve, while the right one shows an unusual one.

Comparing both outcomes of the tasks, it can be stated that both tasks largely confirm the findings at the population-level. Almost all the participant took less time during the time pressure phase in both tasks and remained with that speed afterward. In addition, an increased number of errors during the time pressure phase in both tasks could be observed. However, some participants showed no change or an increase in the number of errors during time pressure, not confirming the findings on the population-level. These observations stress the importance of examining the individual-level learning curves and indicate that not all participants reacted in the same way to time pressure.

Pearson Correlation

To investigate the internal consistency of the Lifting and Grasping task with the Cutting task on the basis of the maximum performances in each phase, a Pearson correlation was applied to the data. In a previous work by Arendt (2017), the correlation between different LapSim tasks was tested in order to analyze the internal consistency. The paper suggested that depending on the similarity of skills needed for a task, the internal consistency would change. This would give insights on which skills need to be included to construct an effective learning program in order to prepare the surgeons in the best way possible. They found that the correlation between the outcome variable time-on-task of the Lifting and Grasping and Cutting task was the strongest (r = .68). This analysis aims to replicate this finding.

The Pearson correlation between outcome variable time on task of the Cutting task and the outcome variable time on task of the Lifting and Grasping task was applied and a medium, positive correlation between the linked phase was found (figure 9). Whereas the first two phases had stronger correlations (r = .64; r = .61), the third phases showed somehow smaller correlation (r = .46) (table 2). This means that in the third phase the internal consistency between the tasks is lower. Comparing these findings with the findings of Arendt (2017), it can be determined that the first two phases have a similar correlation between the tasks (r = .68). However, the correlation in the third phase is smaller than the one found by Arendt (2017).

The same analysis was run for the outcome variable damage. Again, a medium, positive correlation between each phase of the tasks was found (table 3). In this case, no real difference was found between the correlations of the phases, therefore showing a possible consistent and constant internal consistency between the tasks.

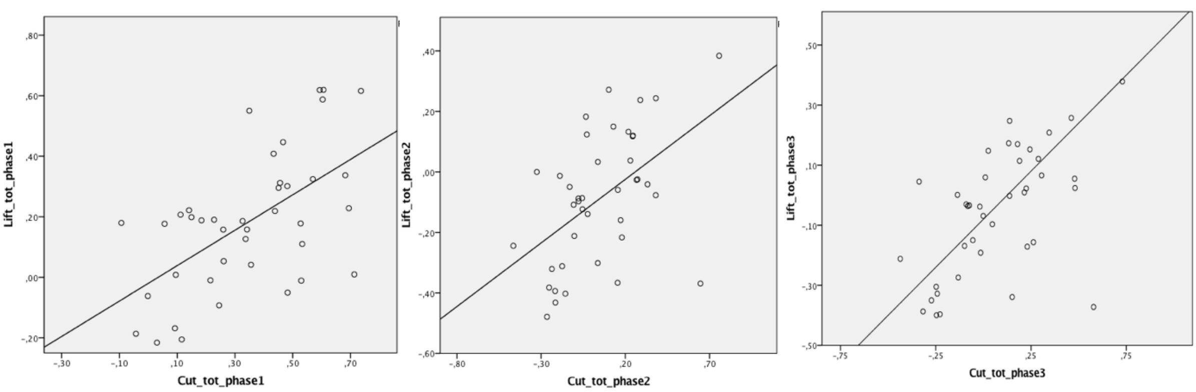

Figure 9. Scatterplots showing the correlation of the individual-level maximum performance scores of the time on task in the Cutting and Lifting and Grasping task. Each plot represents one phase (phase one: left; phase two: mid; phase three: right). The x-axis depicts the Cutting task and the y-axis the Lifting and Grasping task. All three scatterplots show a medium, positive correlation.

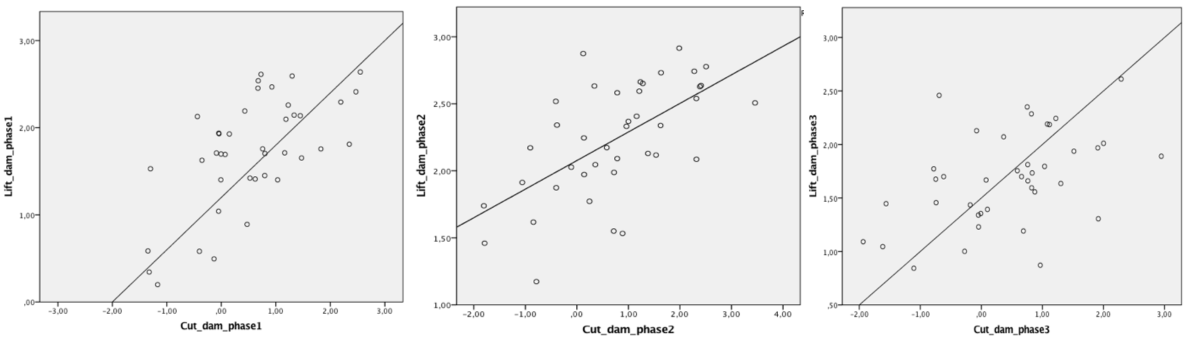

Figure 10. Scatterplots showing the correlation of the individual-level maximum performance scores of the damage in the Cutting and Lifting and Grasping task. Each plot represents one phase (phase one: left; phase two: mid; phase three: right). The x-axis depicts the Cutting task and the y-axis the Lifting and Grasping task. All three scatterplots show a medium, positive correlation.

To control for the certainty of our results, the 95% credibility limits have been calculated. Only if a deviation of maximum .2 is observed, the results can be regarded as highly certain. It can be observed in table 2 that all the correlations for the outcome variable time on task show considerable uncertainty. The same holds for the outcome variable damage (table 3). The correlations between the linked phases range from weak to very strong, therefore we cannot be certain how strong the internal consistency is. However, all the correlations are positive, so we can say that the tasks correlate to some degree.

Table 2. *Pairwise correlation between phases of the individual-level maximum performance of the outcome variable time on task.*

Task (phase)	Cutting (1)	Cutting (2)	Cutting (3)
Lifting & Grasping (1)	.643 [.424; .781]		
Lifting & Grasping (2)		.611 [.389; .772]	
Lifting & Grasping (3)			.464 [.166; .692]

95% credibility limits in the square brackets

Table 3. *Pairwise correlation between phases of the individual-level maximum performance of the outcome variable damage.*

Task (phase)	Cutting (1)	Cutting (2)	Cutting (3)
Lifting & Grasping (1)	.583 [.345; .766]		
Lifting & Grasping (2)		.501 [.166; .742]	
Lifting & Grasping (3)			.570 [.218; .811]

95% credibility limits in the square brackets

In general, it can be stated, that both predicted outcome variables, namely damage and time on task, of the first task Cutting and the second task Lifting and Grasping show throughout the phases mediocre internal consistency. However, the correlations between the tasks are highly uncertain.

5. Discussion

The main goal of this paper was to investigate the impact of time pressure on participants´ maximum performance during simulator-based MIS training. The aim of this research was to draw conclusions, how surgical simulator-based training could be enhanced. For the investigation, we introduced two different surgical tasks on the LapSim simulator with three different phases each. Specifically, we looked at the participants' performances if the training would have been continued and how the different phases differentiated in that way. Additionally, we investigated how internally consistent the first task is with the second regarding their performance demands. The results are going to be discussed briefly in next few sections. Moreover, the limitations of our study and recommendations for future research will be provided.

5.1. The implication of the findings on time-pressure

The influence of time pressure

The hypothesis of this study was to find out if verbally introduced time pressure affects the performance of the learner. To check this hypothesis, the observed speed-accuracy trade-off was used as an indicator to determine if time pressure would have an influence on the performance. It became obvious while looking at the time-pressure phase in both tasks that time-pressure had a strong effect on the performance of the learner. A decrease in time was associated with a higher rate of errors, representing the speed-accuracy trade-off.

This outcome was expected since, according to the findings of Beilock et al. (2008), we assumed that novice learners would in regard to damage perform worse in conditions of time-pressure. This was explained by having less time for attentional monitoring and not having established automated pattern yet. However, comparing the results of Gas et al. (2018) with our results, the usual performance pattern would rather fit the intermediate level of learners. Only some participants showed a decrease in time, as well as, an increase in accuracy during the time-pressure phase, which was attributed to the novice learners. Therefore, we can assume that a certain difference between skills and experiences existed across the participants. Nevertheless, time-pressure had a significant effect on each of the learners' experience during training, regardless of their level of expertise. Therefore, we cannot determine the level of expertise of each learner, but we can state that time-pressure considerably changes the way of practicing.

The effect of time pressure on learning

In order to determine the effect of the time-pressure episode on simulator-based training, the maximum performance on the first and last phase was compared. The results showed that participants considerably improved their performance from the first to the last phase. The estimated performance of learners after experiencing time pressure was faster and showed lower rates in damage compared to the initial training phase. This result was expected since we hypothesized that the improvements in performance are partly caused by the induced time-pressure, but also the learning effect. With these findings, we can now assume that not only the usual learning effect contributes to better performance, but also time pressure has a considerable influence on the learning process. Therefore, we can be certain that time pressure is beneficial for the learner in simulator-based training for laparoscopy.

The question arises, how time-pressure influences the learning process. Looking at the study by Gas et al. (2018), which was the starting point for this study, it was proposed that the type of training determines how learners make up their mental model of the task. In this study, the induced time pressure changed the type of training. This can be explained by the findings on the speed-accuracy trade-off. The induced time-pressure had a considerable influence on the performance of the learner, showing an increased speed connected to an increased error rate. The changes in the performance imply a change in the nature of the task and therefore, it can be argued that the time-pressure phase displays a different kind of training. These findings are in line with the recent study by Luursema, Kengen and van Goor (2019), who revealed that different instructions lead to different ways of approaching a task. They found out, that learners who focused on time also displayed faster times on task during training, whereas learners with the focus on damage showed significant improvements in damage. These are two different approaches to fulfill the task. Therefore, the question remains, what is different in the time-pressure episode that people improve significantly afterward.

The main difference between the phases can be found in the error rate. During the time pressure phase, the error rate increased considerably for almost all participants in both tasks. The increased number of errors during training, King, Holder and Ahmed (2013) argued, should not be regarded as drawbacks but rather as informative and beneficial for the learning process. This finding was supported by the paper of Dyre et al. (2016), in which it was stated that more errors would lead to an active exploration and deeper understanding of the task. Stimulating the metacognition during the task would help novice learners to adjust their own performance in a conscious way, resulting in a better performance. In that sense, pushing the participants to the limits of their ability through time-pressure would lead to a more mentally active involvement in the learning process, resulting in a better performance.

However, Grierson, Lyons and Dubrowski (2013) suggested the exact opposite. They stated, that a simplified way of learning motor tasks would lead to a better understanding of the movements since more attention could be dedicated to the optimization of the movements. This would contradict the findings of Dyre et al. (2016) as well as our findings. Dyre et al. (2016) further explained, that low demands in the training would lead to better analogical transfer performances, whereas high demands would lead to adaptive transfer performances. What kind of transfer performance was developed during the simulator-based training cannot be answered. But it is certain, that the change in conditions introduced by time pressure is beneficial for the learner for MIS tasks on the LapSim. If the introduction of time pressure episodes, however, would create a more adaptable or flexible performance, it would not be detrimental for the learner. Working with significant differences in the anatomy of the patients always requires a certain ability to adapt their own procedures.

One can conclude, that the increased number of errors during the time-pressure phase results in a better performance of the learner. Most certainly the errors trigger a mental mechanism, to improve the learning process in simulator-based training of laparoscopy. However, how this improvement can be explained in regards to cognitive mechanisms and motor learning is still open to debate and needs further research.

The internal consistency of the tasks

The results of the correlation showed, that the internal consistency of the Cutting tasks with the Lifting and Grasping task is medium, however with a high degree of uncertainty. This confirms the findings of Arendt (2017), who stated the same relation between both tasks. They explained the correlation of the tasks by their two-handedness, having the greatest impact on the internal consistency of both tasks. However, since the correlations are only medium, they further argued that both tasks probably draw on a different combination of skills.

We expanded the exploration of the internal consistency with the results of the time pressure phase. The internal consistency did not differ during that phase in either time on task nor in damage in comparison to the other two phases. Therefore, we can expand the explanation of Arendt (2017) that under time-pressure the demands of both tasks also differ. One can conclude that time pressure changes the demands within the tasks as we previously mentioned, but both tasks probably still draw on a different combination of skills.

The findings suggest that laparoscopy most likely draws on very different skills depending on the task. Therefore, it could be assumed that inventing a training program covering a broad spectrum of necessary skills is more beneficial for the learner than one that focuses on striving for strong internal consistency. A future evidence based curriculum for simulator-based MIS training aiming for the inclusion of all necessary skills has the potential to be the golden standard for learning MIS in the future.

5.2. Limitations

One limitation of this study can be found in the application of time pressure. The calculation of the time limit for the time pressure phase was based on the last trial of the first phase (trial no. 15). During the course of the data collection, it turned out that some participants showed an improvement of performance during the first phase, but had a higher error rate in the last trial and thus an increased time on task. In this case, the calculated time to trigger time pressure was not effective, because the participant already reached the time limit in previous trials. Therefore, no real time-pressure was applied or the experienced pressure varied widely from participant to participant. A suggestion would be, to average the times of the last five trials in the first phase, calculate a mean score and subtract 20% in order to get a time limit for the next phase. Furthermore, the 20% reduction was found in the work of Gas et al. (2018). Based on data from a pilot study, they suggested that 20% would be a reasonable amount of reduction to evoke time pressure. However, it still remains questionable how much percent of the time needs to be subtracted, in order to have a reasonable amount of time pressure for a learning effect.

Finally, the sequence of the tasks always began with the Cutting task followed by the Lifting and Grasping task. No research has been conducted yet if the order of the tasks has an influence on the outcome. However, in order to be able to make meaningful statements about the influence of time pressure, the same conditions had to be applied to all the participants. If we would have changed the order of the tasks, possible effects of variation had to be tested for and the sample size would presumably not have been sufficient.

5.3. Future research

The findings of this study can be seen as a starting point to work towards an effective training program. Especially the further exploration of time pressure remains to be a promising approach to enhance simulator-based training in terms of effectiveness.

It is crucial for future research to focus on the practical real world implementation of their studies. Working towards theoretical explanations for the different phenomena will not change the quality of patient care. In that sense, integrating time pressure not only to novice learners but also to other levels of expertise, could advance the insights, who would benefit from such time pressure episodes too. Gas et al. (2018) made a first attempt to test for the effect of time pressure during training and found that time pressure, especially among intermediate or even advanced surgeons, could reveal previously unknown errors in their procedures. Furthermore, if it turns out that time pressure would have benefits for the other levels of expertise, it needs to be examined which speed targets are optimal for each learning group. Finding the approximately perfect amount of time pressure to maximize the benefits in the learning outcome could lead to a more effective training.

Additionally, it is questionable, whether the induced time pressure would be the best way to enhance the learning process. It has not been investigated yet if time pressure has advantages over other manipulations of the training. Bjork and Bjork (2011) argued that the sole change in the conditions has an impact on the learning process. The change in conditions would evoke a reasonable difficulty for the learner, making it more difficult to fulfill the task. As a result, the later recall and performance would improve. Relating this finding to our study, time pressure was only the mean for the purpose of evoking a change in the conditions and therefore increasing the difficulty of the training. Therefore, implementing other manipulations like emergency situations or supervision by authority figures could be used as alternative variables in order to be able to compare the outcomes with the ones of time pressure.

Furthermore, since we worked with a fixed order of tasks and did not introduce any changes of tasks, future research could test for this effect too. It could be beneficial in a follow-up study to change the order of the tasks or split the group of participants in two, assigning two different orders. If differences would be found, it could provide further insights on how the effectiveness of a training program can be enhanced due to a certain order of the tasks.

Another approach for future research could be the investigation of long-term retention. It can be investigated which impact time pressure has on the long-term retention of the acquired skills. In order to test whether the effect of time pressure is stable over time, testing participants a few weeks later would be one possibility. If the same or improved maximum performance could be observed, it can be assumed that time pressure has an impact on the overall skill acquisition.

Furthermore, the introduction of time pressure to a single person only affects the acquisition of the technical skills required to perform laparoscopy. However, real surgeries are mostly a team effort and a great amount of communication and interaction is necessary to be successful. Therefore, integrating time pressure episodes in a team training session could be another possibility to not only advance technical skills but also teamwork. If both could be combined to advance technical skills while achieving better outcomes through more efficient teamwork, this could have a great impact on the success rate of the surgery.

Looking at the theoretical part of this study, we only used time on task and number of errors to test for a potential learning effect. However, the LapSim is able to collect a number of more meaningful parameters to determine the learners' development. In further studies, not only the amount of damage but also the quality of damage or movement efficiency would provide a more complete picture on the development of the learner. Arendt (2018) for example proved that the combination of damage rate and damage quality is a valid measurement for learners' performance.

6. Conclusion

Overall, the present study gave further insights into the learning process during simulator-based training for laparoscopy. It was found that time pressure has a significant effect on performance and previous findings regarding the speed-accuracy trade-off have been confirmed. More specifically, the influence of time pressure changed the expected maximum performance of the learner in terms of speed and accuracy in a positive direction, thereby enhancing the learning process of the learner.

The results are in line with earlier research on the learning process of surgical skills, however, the effects of time pressure add new insights into the effectiveness of training sessions with simulators. It remains to examine for whom and how time pressure should be incorporated into the learning program. A great amount of research remains to be conducted to give further insights regarding the effectiveness of time pressure. We can conclude that this study provides first information on a more effective training program, namely that the integration of time pressure has a positive influence on performance.

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Appendix A

Information Sheet and Informed Consent

INFORMATION SHEET – 13/03/2019

Introduction
My name is Thore Schröder and I invite you to participate in my research for my master thesis. 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.

Who to Contact
Thore Schröder: t.schroder@student.utwente.nl
2nd supervisor: Marleen Groenier: m.groenier@utwente.nl

Consent Form for "The influence of time pressure on learning basic laparoscopic tasks in the LapSim"

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [13/03/2019], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	O	O
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	O	O
I understand that taking part in the study involves a brief demographic questionnaire and two basic tasks on the virtual reality simulator (VR-simulator) for minimal invasive surgeries (MIS).	O	O
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: physical discomfort due to standing still for a long period of time; mental discomfort due to possible frustration about difficult tasks	O	O
Use of the information in the study		
I understand that information I provide will be used for a master thesis in the master Human Factors Engineering in Psychology.	O	O
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	O	O
Future use and reuse of the information by others		
I give permission for the data obtained by the VR-simulator that I provide to be archived on an UT-certified server so it can be used for future research and learning. Personal data will be anonymised.	O	O

Signatures

______________________	______________________	________
Name of participant [printed]	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

______________________	______________________	________
Researcher name [printed]	Signature	Date

Study contact details for further information: Thore Schröder

Email: t.schroder@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-bms@utwente.nl

Appendix B

Instructions

General Introduction

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.

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 laporascopic instruments and the "balls"). Then instruct the participant to start with the first laporascopic task:

Phase 1 – No Time Pressure

You are about to start practicing a basic laparoscopic task called cutting/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.

Phase 2 – Time pressure

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

Phase 3 – No Time Pressure

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.

Appendix C

Syntax of SPSS Analysis

Pearson Correlation

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