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Transferability of laparoscopic skills using the virtual reality simulator

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Abstract

Background Skill transfer represents an important issue in surgical education, and is not well understood. The aim of this randomized study is to assess the transferability of surgical skills between two laparoscopic abdominal procedures using the virtual reality simulator in surgical novices.

Methods From September 2016 to July 2017, 44 surgical novices were randomized into two groups and underwent a proficiency-based basic training consisting of five selected simulated laparoscopic tasks. In group 1, participants performed an appendectomy training on the virtual reality simulator until they reached a defined proficiency. They moved on to the tutorial procedural tasks of laparoscopic cholecystectomy. Participants in group 2 started with the tutorial procedural tasks of laparoscopic cholecystectomy directly. Finishing the training, participants of both groups were required to perform a complete cholecystectomy on the simulator. Time, safety and economy parameters were analysed.

Results Significant differences in the demographic characteristics and previous computer games experience between the two groups were not noted. Both groups took similar time to complete the proficiency-based basic training. Participants in group 1 needed significantly less movements (388.6 ± 98.6 vs. 446.4 ± 81.6; $P < 0.05$) as well as shorter path length (810.2 ± 159.5 vs. 945.5 ± 187.8 cm; $P < 0.05$) to complete the cholecystectomy compared to group 2. Time and safety parameters did not differ significantly between both groups.

Conclusion The data demonstrate a positive transfer of motor skills between laparoscopic appendectomy and cholecystectomy on the virtual reality simulator; however, the transfer of cognitive skills is limited. Separate training curricula seem to be necessary for each procedure for trainees to practise task-specific cognitive skills effectively. Mentoring could help trainees to get a deeper understanding of the procedures, thereby increasing the chance for the transfer of acquired skills.

Keywords Skill transfer · Laparoscopic training · Virtual reality simulator · Mentoring

Transfer of skills and knowledge from one task to another plays an important role in education. In education, time and money have been invested based on the theory that learned skills and knowledge are transferable to novel contexts [1]. This theory of skill transfer was originally introduced by Thorndike and Woodworth [2]; however, conflicting results were reported regarding transferable skills, the extent of transferability, the frequency and context of its occurrence, etc. [3, 4]. Based on the identical element theory of Thorndike [5], it is proposed that transfer of learning occurs when the learning context is similar to the transfer context: the more similar skill or context components are, the more possible will be the positive transfer [6]. On the contrary, Lee postulated in his transfer-appropriate-processing view that transfer occurs due to similarities between the learning processes required for performance situations instead of task characteristics [7].

Surgical performance requires motor and cognitive skills. There is little agreement about the transferability of laparoscopic skills in the literature. Some of the previous trials reported high task specificity [8, 9], and others assumed

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that positive skill transfer is possible if different procedural tasks share many identical elements, such as isolated skills integration, decision-making and error awareness [10]. Bjerrum et al. demonstrated that practising laparoscopic appendectomy first with subsequent laparoscopic salpingectomy results in a reduced number of attempts and time to reach proficiency in the latter procedure, compared with only practising laparoscopic salpingectomy without previous training [11].

In the new era of surgical training, surgical education is partly conducted in skills labs prior to surgical training in the operating room. Since virtual reality simulators (VRS) were first introduced into laparoscopic training, these machines have become an important part in skills labs. Using VRS, trainees are able to practise complex procedural training before performing surgeries on patients, which is reported to improve patient safety. Due to restricted work hours and desired work–life balance of the modern surgical generation, a time-effective training curriculum is needed for skill acquisition.

In this randomized trial, we focused on the cognitive learning of laparoscopic surgeries and tested the hypothesis that skills and knowledge transferability exists between two abdominal surgeries on a laparoscopic simulator in surgical novices. Based on the results, we aimed to provide data for an evidence-based laparoscopic training curriculum.

Materials and methods

Study design and participants

This prospective, randomized study was conducted at the University Hospital Dresden from September 2016 to July 2017. The study has been approved by the ethics committee of the University Dresden (EK 285072016).

Participants were laparoscopically naive medical students in clinical semesters at the Technische Universität Dresden and showed a special interest in surgery. They were recruited through advertisements on the campus. Written informed consent was obtained from all participants. The participation was voluntary and all students agreed to the assessment of their results. Prior to the training, a questionnaire was used to assess demographic details (gender, age, dominant hand, etc.) and experience of computer games.

Participants were randomized into group 1 or 2 using an online randomizer. All training and test sessions were supervised by co-author UK, who offered an introduction to the VRS before the trainings started. Both groups underwent a proficiency-based basic training consisting of five selected laparoscopic tasks using the VRS [clipping and grasping, cutting, electrocautery, peg transfer and pattern cutting (training gauze)], which have been previously described and validated [12, 13]. All students were required to perform the tasks for at least three times and reach proficiency in two consecutive attempts (Table 1).

In group 1, participants started with an appendectomy training on the VRS. After reaching the defined proficiency, they moved on to the tutorial procedural tasks of laparoscopic cholecystectomy (LC). The proficiency levels were derived from the performance of a group of surgical residents and medical students with laparoscopic experience in a pilot study prior to this study. The proficiency levels had to be reached in two consecutive attempts. Participants in group 2 started with the tutorial procedural tasks of LC directly. Finishing the training, the participants of both groups were required to perform a complete LC on the VRS. After completing the tests, physical and mental burden during the LC were assessed using a 10-point scale, with 1 indicating 'extremely easy' and ten indicating 'extremely exhausting'.

Virtual reality simulator LapMentor®

Training and test sessions were performed on the LapMentor® (2nd generation, 3D Systems, Cleveland, OH, USA). The LapMentor® is a VRS that provides a laparoscopic training curriculum consisting of basic laparoscopic tasks alongside tutorial procedural tasks and complete procedure training. After each training/attempt, an immediate feedback including time to completion, accuracy, efficiency and safety is displayed on the screen.

Table 1 Definition of proficiency

Trainings	Proficiency(s)	Penalty time
Clipping and grasping	≤ 109	5 s for each lost clip
Cutting	≤ 124	10 s for 5% decreases of cutting manoeuvers performed without causing injury
Electrocautery	≤ 217	10 s for each non-highlighted band that was cut
Peg transfer	≤ 129	10 s for each lost peg
Cutting (training gauze)	≤ 161	1 s for accuracy error in mm^2

The penalty time was added to the actual time needed for the tasks. The proficiency was reached if the total time was not greater than the defined proficiency

Tutorial procedural tasks of LC

Both groups completed a step-by-step tutorial of the LC procedure: clipping and cutting a retracted gallbladder; clipping and cutting—two hands; dissection—achieving "critical view of safety" and gallbladder separation from the liver bed. Each task was repeated three times.

Complete procedure

In the test session, all participants performed a simulation case of LC with normal anatomy using the VRS. The procedure was repeated three times by each participant. Parameters concerning time of completion, safety and economy were documented and presented by the computer. Eight relevant parameters that were chosen in a previous pilot study of our group were analysed in our study.

Time to extract the gallbladder was documented from appearance of instruments on the screen until the complete separation of gallbladder from the liver bed. Safe cautery was defined as the time in which cautery was applied more than 5.0 mm from the biliary system in percent. Numbers of non-cauterized bleedings, lost clips, liver perforations as well as serious complications were recorded, whereby serious complications included cutting and/or cautery of unclipped ducts or arteries with any tool or clipping of common bile duct or hepatic artery.

Minimum of 3-mm continuous movement counted as a movement and the total path length was documented in centimetres.

Randomization

After enrolment into the study, participants were given a unique study number. The randomization was performed using an online randomizer (http://www.randomizer.org). Entering numbers per set and number range, a set of numbers were generated (i.e. $p1=2$, $p2=1$, $p3=1$, $p4=1$, $p5=2$, $p6=1$, etc.).

Sample size determination

Based on a previous study, participants in group 2 were expected to complete a LC on the VRS in 512 s. For a clinically relevant difference, group 1 was supposed to take 25% less time to finish a LC (= 384 s). The standard deviation of 137 s was assumed to be equal in both groups. We set alpha to 0.05 and power to 0.9, resulting in a sample size of 22 participants per group.

Statistical analysis

Data were analysed using SPSS version 24 (IBM SPSS Chicago, IL, USA). Kolmogorow–Smirnow test was used to check the distribution. For non-normally distributed data, Wilcoxon rank-sum test was used. Pearson correlation coefficient measures correlations between two variables. A P value of <0.05 was defined as statistically significant.

Results

Demographics

48 medical students provided informed consent of participation and were randomized into two groups. After randomization, four participants dropped out (two participants in each group): three participants did not complete the basic training due to lack of time; one participant dropped out for physical complaints using the VRS. 44 medical students completed the trainings as well as the final test. Significant differences in the demographic characteristics and previous computer games experience between the two groups were not noted. Both groups took similar time to complete the proficiency-based basic training (Table 2).

Performance

The complete LC procedure was repeated three times by each participant and eight selected parameters including time to completion, safety and economy were analysed (Table 3).

Time parameter

The additional appendectomy training did not result in a significant effect on the time to extract the gallbladder.

Table 2 Participant demographics and baseline characteristics

	Group 1	Group 2	*P*
Personal details			
Age (years)	24.1 (21–29)	25 (22–33)	n.s.
Sex (m/f)	6/16	6/16	n.s.
Dominant hand (R/L)	22/0	21/1	n.s.
Semester	7 (5–11)	8 (5–11)	n.s.
Previous computer games (years)	3 (0–10)	2 (0–12)	n.s.
Total time of basic training (h)	1.37 (0.65–2.29)	1.50 (0.79–3.04)	n.s.

Values are shown as means. Group 1 = with previous appendectomy trainings, group 2 = without previous appendectomy trainings

R/L right/left hand, *n.s.* not significant

Table 3 Comparison of time, safety and economy parameters for both groups in the complete laparoscopic cholecystectomy procedure

	Group 1		Group 2		P
	Mean	SD	Mean	SD	
Time to extract gallbladder (s)	382.9	99.3	421.7	74.5	0.151
Safe cautery (%)	73.2	6.2	74.2	8.5	0.650
Number of non-cauterized bleedings	0.08	0.18	0.33	1.00	0.405
Number of serious complications	0.23	0.28	0.41	0.46	0.133
Number of lost clips	0.32	0.35	0.27	0.35	0.622
Number of liver perforations	0.54	0.67	1.54	1.94	0.053
Number of total movements	388.6	98.6	446.4	81.6	**0.041**
Path length (cm)	810.2	159.5	945.5	187.8	**0.011**

All values are shown as means. Significant *P* values are highlighted in bold. Group 1 = with previous appendectomy trainings, group 2 = without previous appendectomy trainings

Safety parameter

The safety parameters including safe cautery, number of non-cauterized bleedings, lost clips, liver perforations and serious complications did not differ between both groups.

Economy parameter

Participants in group 1 needed significantly less movements as well as shorter path length to complete the procedure ($P > 0.05$) compared to group 2.

Experience with computer games did not show significant correlations with any of the parameters in both groups.

We analysed the correlation among all assessed parameters as shown in Table 2. A longer time to extract the gallbladder was associated with significantly increased movements as well as a longer path length ($P < 0.001$). Furthermore, the more movements the participants needed, the longer the path length was.

Physical and mental load

No significant difference was found between group 1 and group 2 concerning physical and mental burden during the performance of laparoscopic cholecystectomy.

Discussion

This study focused on the transferability of skills and knowledge in laparoscopic surgeries. Using the VRS, the skill transfer between appendectomy and cholecystectomy was evaluated in surgical novices. Our data showed that previous training of a laparoscopic appendectomy did not result in a better performance when conducting a laparoscopic cholecystectomy regarding time and safety parameters. However, the movements were more economical if participants practised laparoscopic appendectomy prior to cholecystectomy.

Accumulating evidence demonstrated that it is feasible to train operative skills using the VRS [14–16]. Thus, many surgeons agree that VRS should be included in laparoscopic training curricula. An important question in our modern surgical education is how to implement VRS within the training of surgeons and which VRS training is effective.

In the cognitive learning theory, it has been discussed if learning curricula should impart generalizable skills or more specific forms of transfer [4, 17, 18]. In surgery, contradictory opinions exist in the literature whether laparoscopic skills are generalizable. In the present study, participants with previous appendectomy training demonstrated superiority for economy of movements. This finding might indicate that motor skills learned in the first procedure (appendectomy) were positively transferred to the second procedure (cholecystectomy). Through repeated training, trainees could practise their hand–eye coordination with the use of complex instruments and gain better control over their movements [19]. The number of required movements was used as an economy parameter, since the need for more movements can lead to distress and muscular fatigue in operating rooms, which could be an extra source of errors, especially during major surgeries [20, 21].

In contrast to the positive effect on motor skills, no cognitive skill transfer was noted: participants were not superior regarding procedure planning and surgical error awareness, since their speed and safety components did not vary significantly from the control group. This result is in line with the findings of previous trials, which showed procedural specificity and limited skill transfer between procedures in laparoscopic surgeries [22, 23]. According to cognitive psychology, the success of skill transfer is multifactorial. A positive transfer effect is more likely if the content to be transferred and the context to which it is transferred are similar [24]. However, it does not seem to be plausible to say that appendectomy is more similar to cholecystectomy than to salpingectomy simply because both procedures comprise dissection and transection of a small-sized organ within the abdominal cavity. Barnett et al. suggested that the characteristics of transfer should be broken down into content and context, which again are subdivided into multiple dimensions [24]. This is generally not practical in the complex clinical routine. Therefore, despite some positive transfers between these surgeries, the procedures should be practised separately. Taken together, procedure-specific training curricula seem to be necessary for effective acquisition of surgical skills.

A further explanation of missing skill transfer might be due to the form of training on the VRS, which gives instructions about what to do but without explaining why to do or not to do it. The absence of an understanding at a deep, strategic level might have led to an inability to transfer the cognitive components [4, 24]. This finding is consistent with the observation that mentoring is an important aspect of professional development of surgical trainees [25, 26]. Therefore, surgical trainees could benefit from additional mentoring during their VRS training.

A reduction of physical and mental burden during cholecystectomy was not noted in participants with previous appendectomy training. We assume that this result is based on the limited numbers of repetitions; participants in both groups required familiarization of the new procedure.

Limitations

This study has limitations. The participants in our study were surgical novices. Trained surgeons might have a different learning effect for new procedures, as they might have reached a plateau of motor skills and improvement can hardly be achieved through one procedure. Nonetheless, our study reflects the situation of young surgeons training their first laparoscopic surgeries. In addition, the transfer effect was assessed using the VRS only. The data and conclusion of the study need to be analysed in the operating room in the real-life scenario.

Conclusion

Our study assessed the transfer effect between two abdominal surgeries on the virtual reality simulator and demonstrated a relevant degree of procedural specificity. Therefore, procedural specific learning curricula seem to be necessary for an effective surgical training. Mentoring could help trainees to gain a deeper understanding of the strategic principles, which might improve the learning effect.

Compliance with ethical standards

Disclosures Cui Yang, Uljana Kalinitschenko, Juergen Weitz, Christoph Reissfelder, Jens R. Helmert and Soeren Torge Mees have no conflict of interest or financial ties to disclose.

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