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ORIGINAL ARTICLE

Sequential learning of psychomotor and visuospatial skills for laparoscopic suturing and knot tying—a randomized controlled trial "The Shoebox Study" DRKS00008668

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Abstract
Purpose Learning curves for minimally invasive surgery are prolonged since psychomotor skills and visuospatial orientation differ from open surgery and must be learned. This study explored potential advantages of sequential learning of psychomotor and visuospatial skills for laparoscopic suturing and knot tying compared to simultaneous learning.
Methods Laparoscopy-naïve medical students were randomized into a sequential learning group (SEQ) or a simultaneous learning group (SIM). SEQ ($n = 28$) trained on a shoebox with direct 3D view before proceeding on a box trainer with 2D laparoscopic view. SIM ($n = 25$) trained solely on a box trainer with 2D laparoscopic view. Training time and number of attempts needed were recorded until a clearly defined proficiency level was reached.
Results Groups were not different in total training time (SEQ 5868.7 ± 2857.2 s; SIM 5647.1 ± 2244.8 s; $p = 0.754$) and number of attempts to achieve proficiency in their training (SEQ 44.0 ± 17.7; SIM 36.8 ± 15.6; $p = 0.123$). SEQ needed less training time on the box trainer with 2D laparoscopic view than did SIM (SEQ 4170.9 ± 2350.8 s; SIM 5647.1 ± 2244.8 s; $p = 0.024$), while the number of attempts here was not different (SEQ 29.9 ± 14.1; SIM 36.8 ± 15.6; $p = 0.097$). SEQ was faster in the first attempts on the shoebox (281.9 ± 113.1 s) and box trainer (270.4 ± 133.1 s) compared to the first attempt of SIM on the box trainer (579.4 ± 323.8 s) ($p < 0.001$).
Conclusion In the present study, SEQ was faster than SIM at the beginning of the learning curve. SEQ did not reduce the total training time needed to reach an ambitious proficiency level. However, SEQ needed less training on the box trainer;

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thus, laparoscopic experience can be gained to a certain extent with a simple shoebox.

Keywords Laparoscopy · Training · Education · Minimally invasive surgery · Suturing and knot tying

Introduction

Minimally invasive surgery (MIS) is well established but requires psychomotor skills and visuospatial orientation that are different from open surgery. The learning curve for MIS is lengthened due to the lack of three-dimensional (3D) vision, narrow two-dimensional (2D) field of view, pivoting and fulcrum effects, reduced haptic feedback, and limited degrees of freedom [1–3]. Different training modalities have been developed including virtual reality (VR) simulators, box trainers, and live animal training to provide novice surgeons with an effective and safe training environment outside the operating room (OR) in order to increase patient safety [4–6]. It has been shown that laparoscopic skill acquisition and particularly the training of laparoscopic suturing and knot tying through simulation in MIS training centers successfully transfers to the OR [7, 8].

Training laparoscopic suturing and knot tying requires both psychomotor and visuospatial skills to adapt to the laparoscopic orientation [9–11]. Box trainers with 2D laparoscopic view allow for training with real instruments and have proven to be useful for training of suturing and knot tying [12]. However, in standard box trainers with 2D laparoscopic view, the psychomotor and visuospatial skills have to be learned simultaneously. Thus far, it is not well investigated whether the current training approach of learning both psychomotor and visuospatial skills simultaneously is superior to a stepwise sequential learning approach. In sequential learning of psychomotor and visuospatial skills, the trainees train their psychomotor skills first on a transparent shoebox with a direct 3D view before training their visuospatial orientation skills on a common box trainer with a 2D laparoscopic view. By providing trainees with an easier start into the training of laparoscopy, sequential learning could shorten the total training time compared to trainees who started directly on the box trainer with 2D laparoscopic view.

The aim of this study was to investigate if sequential learning of psychomotor and visuospatial skills for laparoscopic suturing and knot tying is superior to simultaneous learning of these skills.

Material and methods

Participants and preparation

Medical students ($n = 56$) between their third and sixth year of studies without prior experience in laparoscopic surgery were included in the study. Students who had previously taken part in a laparoscopy course of more than 2 h were excluded. First, all participants received detailed information about the study and were informed that they could quit the study at any time without further reason or consequences. Informed consent was obtained from all individual participants included in the study. Questionnaires concerning hobbies such as playing an instrument or playing video games or sports activities were answered. Participants were then randomly assigned to either the sequential learning group (SEQ) or to the simultaneous learning group (SIM). The randomization was done in a 1:1 ratio with the closed envelope technique, based on a computer-generated randomization list created by an employee of the hospital who was otherwise not involved in the study. The present study was approved by the local ethics committee at Heidelberg University (S-334/2011) [13].

Materials

The shoebox was a custom-made transparent box with incisions for the instruments (Fig. 1). The Szabo-Berci-Sackier box trainer was used on a standard laparoscopy unit (KARL STORZ GmbH & Co. KG, Tuttlingen, Germany) with two needle holders (KARL STORZ GmbH & Co. KG, Tuttlingen, Germany). A standardized silicone suture pad (Big Bite Medical GmbH, Heidelberg, Germany) and a Polysorb 3-0 braided absorbable suture with a CV-23 Taper ½ 17-mm needle (Covidien™, Minneapolis, USA) were used [13].

Study design and setting

This was a monocentric, prospective, two-armed, randomized controlled trial in the MIS training center of the Department for General, Visceral, and Transplantation Surgery at Heidelberg University. The study protocol was officially registered in the German Clinical Trials Register (DRKS00008668) and recently published [13]. All participants trained in pairs of two students. Prior to hands-on training, all participants watched a standardized instructional video on how to perform laparoscopic suturing and knot tying with the C-loop technique. Students were allowed to watch the video as often as they wanted. After a specially trained tutor provided a thorough and standardized introduction to the terminology, instruments, and checklists, the participants trained and rated each other in pairs during their training. The tutors were available for assistance for both groups throughout the whole study. This approach has proven to be beneficial by Van Bruwaene et al. in a study evaluating how much training assistance is needed while learning laparoscopy [14].

Checklists for knot quality and procedural competency were used for skill assessment (Tables 1 and 2). The knot quality checklist was introduced earlier in a study by Muresan et al. [15]. The procedural checklist was published initially by Munz et al. [16]. Accuracy was attained if the stitches were within 2 mm of the predefined entry and exit points on the suture pad.

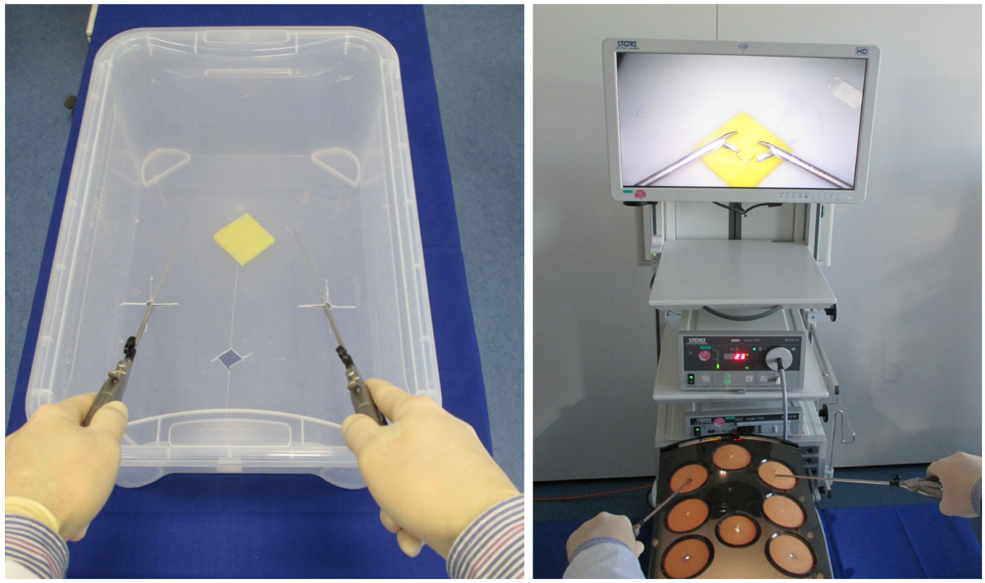

Fig. 1 Transparent shoebox with direct 3D view and box trainer with laparoscopic 2D view

Time taken and scores for knot quality and procedural checklists were recorded for each participant per attempt; the total number of attempts was also recorded. A participant was considered competent if he or she met the following criteria: participants scored at least 18 out of 23 points on the procedural checklist (Table 1), scored a minimum of 4 out of 5 points on the knot quality checklist (Table 2), were deemed accurate, and time to completion was 75 s or less. The term proficiency was only used

Table 1 Procedural checklist [16]

Procedure assessment			YN
Needle position 1	1	Held at 1/2 to 2/3 from the tip	
	2	Angle 90° ± 20°	
	3	Uses tissue or other instrument for stability	
	4	Attempts at positioning (≤3)	
Needle driving 1 (Entry to incision)	5	Entry at 60°–90° to the tissue plane	
	6	Driving with one movement	
	7	Single point of entry through the tissue	
	8	Removes the needle along its curve	
Needle position 2	9	Held at 1/2 to 2/3 from the tip	
	10	Angle 90° ± 20°	
	11	Uses tissue or other instrument for stability	
	12	Attempts at positioning (≤3)	
Needle driving 2 (Incision to exit)	13	Driving with one movement	
	14	Removes the needle along its curve	
Pulling the suture	15	Needle on needle holder in view at all times	
	16	Uses the pulley concept	
Technique of knots	17	Correct C-loop (no S- or O-loops)	
	18	Smoothly executed throw, no fumbles	
	19	Correct inverse C-loop (no S- or O-loops)	
	20	Smoothly executed throw, no fumbles	
	21	Knot squared (capsized/reef/surgical)	
	22	Correct third C-loop (no S- or O-loops)	
	23	Smoothly executed throw, no fumbles	
Total points			

Table 2 Knot quality checklist [15]

Knot quality assessment	Available points
No visible gaps between stacked throws	1
Knot tight at base	1
Only edges are opposed (no extra tissue in knot, e.g., back wall)	1
Knot holds under tension	2
Maximum	5

if a participant was competent for all criteria twice in a row. Each attempt needed to be completed; a restart was not permitted. In the event of technical errors such as rupture of the thread, participants were asked to mark this attempt with "N/A" and provide a short note in their score sheet. Furthermore, each participant was not allowed to perform more than five consecutive knots before switching positions with his or her peer. As soon as a participant reached competency for the first knot, one of the tutors had to observe the second attempt. Each participant had a maximum number of 75 attempts to become proficient [13].

The SEQ group had to train until proficiency on a transparent shoebox first. The shoebox was used without laparoscopic camera equipment. The shoebox provided a direct 3D view of the operating field, thereby allowing participants to focus on psychomotor skills only. They had to train until they reached proficiency, defined by criteria for time, procedural competency, and knot quality for two consecutive attempts. Then, the SEQ group had to transfer their psychomotor skills to training on a box trainer with a standard laparoscopic 2D view, forcing them to adapt to new visuospatial demands until they reached the same proficiency criteria as on the shoebox. In contrast, the SIM group trained directly on the box trainer with a standard laparoscopic 2D view until they reached proficiency. Training on the box trainer required the immediate use of both psychomotor and visuospatial skills simultaneously.

Outcome parameters

The primary outcome of this study was the total training time needed to reach proficiency in laparoscopic suturing and knot tying. Secondary outcomes included differences in number of attempts and procedural and knot quality subscores. Attempts and training time on the box trainer alone were analyzed to determine whether previous training on a shoebox can shorten training time needed with expensive laparoscopic equipment or in the OR (Fig. 2). Gender effects and influences of individual experiences such as gaming were explored as well. The sample size calculation was done with respect to the primary endpoint using data from a previously evaluated pilot study with a two-sided significance level $\alpha = 0.05$ and a power of $1 - \beta = 0.8$. This resulted in a group size of 28 participants for each group including an additional participant per group to account for possible dropouts [13].

Statistical analysis

Statistical analysis was calculated by a faculty member of the Department of Medical Biometry at Heidelberg University who was otherwise not involved in the study. Data were entered into a spreadsheet (Microsoft Excel™); the statistical evaluation was done with SAS 9.4 Win (SAS Institute, Cary, NC, USA).

The empirical distribution of continuous data was reported with means and standard deviation, with absolute and relative frequencies in case of categorical data. Possible differences between groups were analyzed using *t* tests for continuous data and chi-square tests for categorical data. A *p* value less than 5 % was considered statistically significant. Statistical graphics were used to visualize the findings.

Results

Fifty-six medical students were randomized into either the SEQ group ($n = 28$) or the SIM group ($n = 28$). A total of 53 participants completed the study with three dropouts in the SIM group. There were 24 men and 29 women in the study, and there was no significant difference for the gender distribution between the SEQ and SIM groups ($p = 0.353$). There were 27 gamers and 26 participants without previous gaming experience in the study. Significantly, more men than women played computer games (men 19; women 8; $p < 0.001$).

There was no significant difference in total training time until proficiency between the SEQ ($n = 28$) group and the SIM ($n = 25$) group (SEQ 5868.7 s ± 2857.2 s vs. SIM 5647.1 s ± 2244.8 s; $p = 0.754$). There was no significant difference between the two groups in the total number of attempts needed to reach proficiency (SEQ 44.0 ± 17.7 vs. SIM 36.8 ± 15.6; $p = 0.123$). The SEQ group needed a lower mean time per attempt than did the SIM group (SEQ 132.9 s ± 26.7 s vs. SIM 158.0 s ± 30.1 s; $p = 0.003$) (Fig. 3). The SEQ group was significantly faster at their first attempt on the shoebox compared to the first attempt of the SIM group on the box trainer (SEQ 281.9 s ± 113.1 s vs. SIM 579.4 s ± 323.8 s; $p < 0.001$).

Looking at training only on the box trainer showed a significant difference in favor of the SEQ group for total training time until proficiency (SEQ 4170.9 s ± 2350.8 s vs. SIM 5647.1 s ± 2244.8 s; $p = 0.024$), but not for mean time per attempt (SEQ

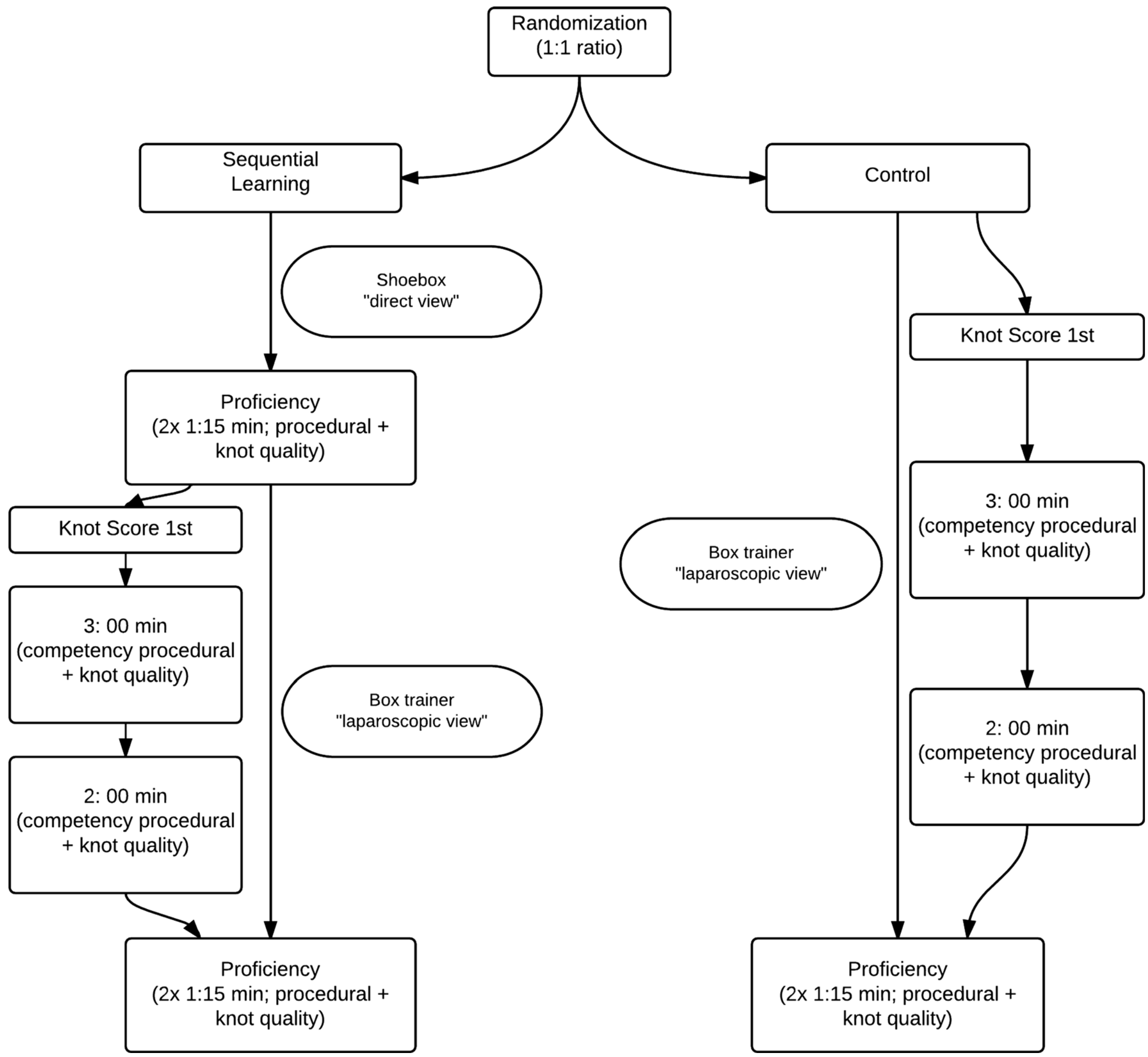

Fig. 2 Flowchart with schematic explanation of comparisons

137.5 s ± 24.7 s vs. SIM 158.0 s ± 30.1 s; $p = 0.478$). The number of attempts needed to reach proficiency while training on the box trainer showed a trend in favor of the SEQ group (SEQ 29.9 ± 14.1 vs. SIM 36.8 ± 15.6; $p = 0.097$) (Fig. 4). The SEQ group needed less time for the first attempt on the box trainer than did the SIM group (SEQ 270.4 s ± 133.1 s vs. SIM 579.4 s ± 323.8 s; $p < 0.001$). There was no significant difference between the SEQ group and the SIM group for the number of attempts until competency for the procedural and knot-tying scores (SEQ 3.9 ± 2.6 vs. SIM 4.9 ± 2.9; $p = 0.183$). The SEQ group needed significantly less training time (SEQ 1025.2 s ± 692.0 s vs. SIM 1981.5 s ± 1087.1 s; $p < 0.001$) and fewer attempts (SEQ 4.4 ± 2.7 vs. SIM 6.3 ± 2.8; $p = 0.017$) to reach competent procedural and knot-tying scores under 3 min on the box trainer. The SEQ group also needed significantly less training time (SEQ 1738.1 s ± 1388.0 s vs. SIM 2523.8 s ± 1046.8 s; $p = 0.023$), but not significantly fewer attempts (SEQ 8.3 ± 5.7 vs. SIM 9.2 ± 2.8; $p = 0.418$) to reach competent procedural and knot-tying scores under 2 min on the box trainer.

There were no significant differences between men and women for total training time (men 5434.9 s ± 2248.9 s vs. women 6036.7 ± 2808.9 s; $p = 0.391$), mean time per attempt (men 151.0 s ± 34.3 s vs. women 139.4 ± 27.1; $p = 0.185$), or number of attempts needed to reach proficiency (men 37.6 ± 17.4 vs. women 43.0 ± 16.4; $p = 0.254$). Subgroup analysis concerning men and women between the SEQ and SIM groups revealed no significant differences for total training time or number of attempts needed to reach proficiency.

There were no significant differences between participants playing computer games and those who did not for total training time (gamer 5536.3 s ± 2574.8 s vs. non-gamer 6000.8 ± 2582.8 s; $p = 0.515$), mean time (gamer 147.1 s ± 32.4 s vs. non-gamer 142.2 s ± 29.5 s; $p = 0.566$), or number of attempts needed to reach proficiency (gamer 38.9 ± 18.6 vs. non-gamer 42.4 ± 15.2; $p = 0.452$). Subgroup analysis concerning gaming experience between the SEQ and SIM groups revealed no significant differences for total training time or number of attempts needed to reach proficiency.

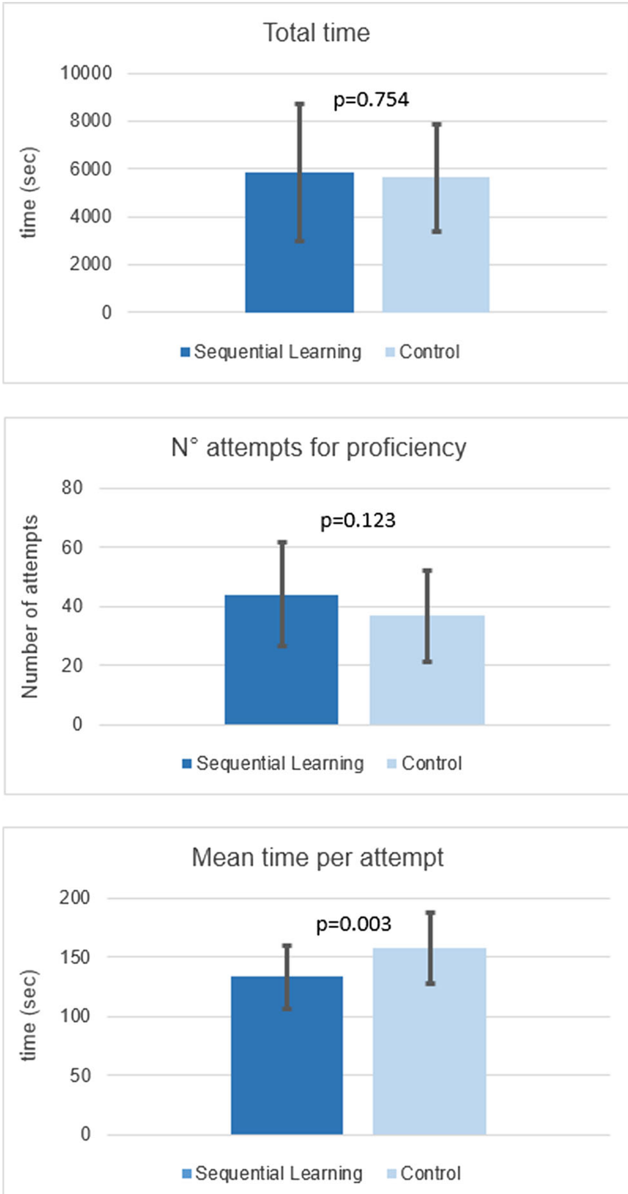

Fig. 3 Overall comparison of total time, mean time, and total number of attempts of each training group for the whole training

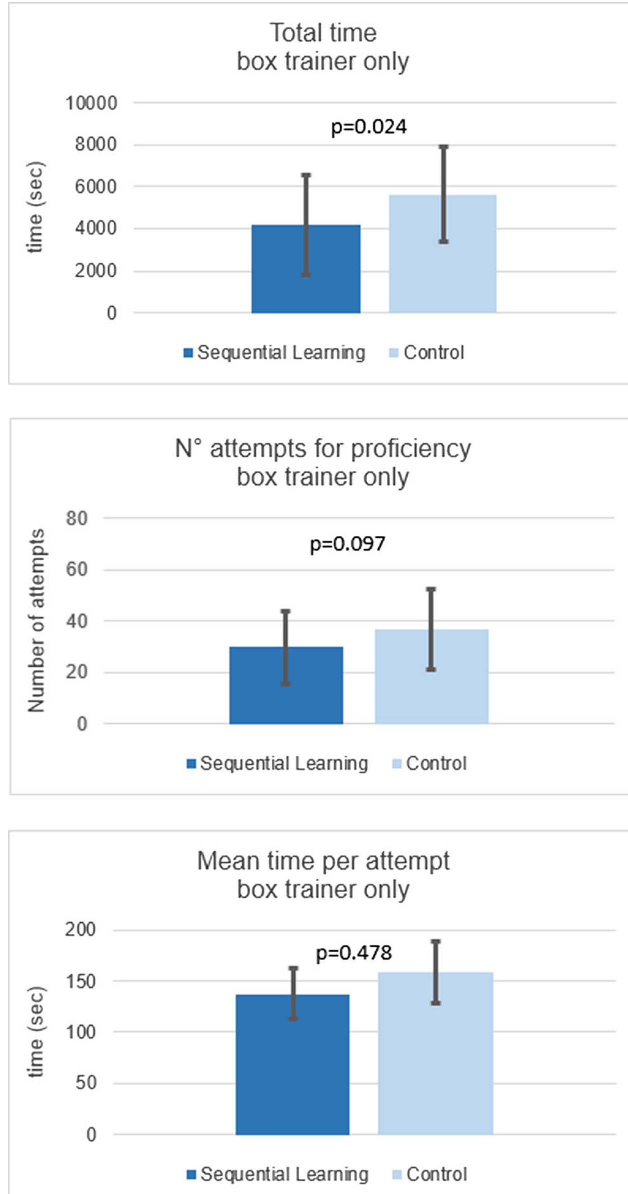

Fig. 4 Comparison of total time, mean time, and number of attempts for the training phase of each group on the box trainer only

Discussion

In the present study, there were no significant differences in total training time and total number of attempts to reach proficiency in laparoscopic suturing and knot tying between SEQ and SIM, but SEQ had a significantly shorter mean time per attempt. Furthermore, SEQ needed significantly less training time on the box trainer to achieve proficiency in laparoscopic suturing and knot tying. Subgroup analysis of gender effects and gaming showed no differences between men vs. women and gamers vs. non-gamers, respectively.

Training time and total number of attempts needed to reach proficiency in laparoscopic suturing and knot tying did not differ between SEQ and SIM. However, SEQ had a significantly shorter mean time per attempt, which reflected the trend for a higher number of attempts in the same training time for SEQ compared to SIM. In line with these findings, another study by Cicione et al. found a better performance score under 3D conditions compared to 2D, but no reduction in operative time for pyeloplasty and partial nephrectomy that were performed by surgeons without previous laparoscopic experience [17]. Another important finding in the present study was that SEQ had a significantly shorter learning curve and reached competency for all criteria significantly faster for time limits of 3 and 2 min. SEQ also needed fewer attempts to become competent in the procedural and knot quality scores than did SIM. In addition, SEQ needed only half the time for the first attempt in comparison to SIM both on the shoebox and the box trainer. The shorter attempts could lead to better motivation in SEQ compared to the more time-consuming attempts in SIM.

SEQ needed significantly less training time on the box trainer with 2D laparoscopic view than did SIM. Several other studies investigated if participants trained in 3D had advantages when they later operated in 2D, which is still the most common setting in the OR. Nolan et al. found that training with 3D systems comparable to the shoebox shortened the training time in comparison to 2D systems for both continuous and intracorporeal suturing [18]. The findings of the current study showed that even if total training time and attempts were not different between SEQ and SIM, starting training on the shoebox with 3D direct view could shorten the learning curve on the box trainer with 2D laparoscopic view. In addition, shoeboxes with direct 3D view are less costly than box trainers with 2D laparoscopic view as shoeboxes do not depend on the availability of laparoscopic camera units for training. Although total training time needed was not different between SEQ and SIM in the present study, SEQ needed less time on the box trainer. Therefore, trainees should start training on low-cost shoeboxes first before they proceed to box trainers with expensive full laparoscopic equipment as this could improve the efficiency of training.

Analysis of gender aspects revealed no significant differences for total training time or number of attempts between the two training groups. These findings are in contrast to the findings by Thorson et al. who reported that women do not perform as well as men on a MIS trainer [19]. Another study from our own research group found that men performed significantly faster, but without a better performance score, for laparoscopic cholecystectomy after laparoscopy training [2]. Ali et al. found in a systematic review that men tended to perform better than women among medical students but not for residents [20]. The training course in the present study was offered on a voluntary basis; thus, only interested students took part. This prevented possible confounding factors, like a participant's motivation. Similar results were found after analysis of previous experience in gaming. Other studies showed that gaming could positively influence learning curves or performance time for basic laparoscopic tasks as stated by Fanning et al. [21]. Giannotti et al. also reported an improvement for metrics such as path length for basic tasks among students who trained first on a Wii console [22]. However, laparoscopic suturing is a more advanced laparoscopic task and is not only dependent on dexterity but also on a thorough understanding of the technique itself.

Limitations

Possible limitations of the study can result from the interaction of training pairs. Interpersonal relations could have influenced the results in both positive and negative directions. A certain level of competition could be

Table 3 Risk of bias assessment [30]

Entry	Judgment	Support for judgment
Selection bias		
Random sequence generation	Low risk	Quote: "randomization […] based on a computer generated randomization list created by an employee of the hospital who was otherwise not involved in the study" Comment: properly done.
Allocation concealment	Low risk	
Performance bias		
Blinding of participants and personnel	High risk	Comment: not done.
Detection bias		
Blinding of outcome assessment	Low risk	Comment: the use of objective checklists with simple yes/no answers mainly prevented subjective influences.
Attrition bias		
Incomplete outcome data	Low risk	Quote: "with three drop-outs in the SIM group"Comment: reasons for drop-outs (participants needed time for exam preparation) are unlikely to be related to true outcome.
Reporting bias		
Selective reporting	Low risk	Comment: all outcomes were predefined in the study protocol which was published earlier.

motivating while a bad atmosphere could lead to a bad performance. Nonetheless, training in pairs is a well-accepted approach in medical education [23, 24]. In a separate study, our research group is currently investigating the optimal number of participants training at one work station [25]. Potential benefits include an increase in efficiency, since trainees could rate each other and give feedback [26, 27], and continued learning by students watching and interacting with their peers [28, 29]. Therefore, it can be reasonably assumed that the advantages of training in pairs outweigh possible disadvantages. Randomization of participants was not stratified for gender or gaming experience since participation was offered to students as an elective course on a first-come-first-serve basis. However, the distributions of gender (women 29; men 24) and gaming experience (gamer 27, non-gamer 26) were balanced, thus producing reliable data. In addition, gaming could be more specified in subgroups, e.g., ego-shooter versus strategy games. Ego-shooter games may provide better training for dexterity and steadiness. On the other hand, strategy games improve a trainee's ability to focus on a given task, which is also an important requirement for learning MIS. Therefore, simply being a gamer does not lead to a better performance. More research about different kinds of gaming is needed. Finally, in order to critically review the study, it was analyzed using the Cochrane Collaboration's tool for assessing risk of bias [30] (Table 3). Five out of six entries were found to be of low risk of bias, while only one was assessed as of high risk of bias. The blinding of tutors and participants was not possible since they had to actively train on the different training modalities. Blinding, as it is done with different treatments, e.g., with operations, was not feasible for this study design. Overall, after assessment with the Cochrane Collaboration's tool of assessing risk of bias, the study was of low risk of bias.

Conclusion

The SEQ approach provided a faster learning curve at the beginning of training. However, to reach an ambitious proficiency level, as required in the present study, SEQ did not reduce the total training time needed. Furthermore, the SEQ approach significantly reduced training time needed on the box trainer with expensive laparoscopic OR equipment. In summary, in the present study, the SEQ approach was particularly useful for learning laparoscopic suturing and knot tying because (1) it reduced time per attempt potentially leading to higher training motivation and (2) it reduced training time on expensive laparoscopic equipment.

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Authors' contributions Study conception and design were done by Nickel, Müller-Stich, Fischer, Kenngott, Hendrie, Kowalewski, and Romero.

Acquisition of data was done by Nickel, Hendrie, Kowalewski, Mantel, and Garrow.

Analysis and interpretation of data were done by Bruckner, Nickel, Kowalewski, Kenngott, Fischer, Romero, and Müller-Stich.

Drafting of manuscript was done by Hendrie, Nickel, Kowalewski, Mantel, and Garrow.

Critical revision of manuscript was done by Müller-Stich, Romero, Bruckner, Fischer, and Kenngott.

Compliance with ethical standards

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Conflicts of interest Felix Nickel received travel support by KARL STORZ and Johnson & Johnson. Jonathan D. Hendrie declares that he has no conflict of interest. Karl-Friedrich Kowalewski declares that he has no conflict of interest. Thomas Bruckner declares that he has no conflict of interest. Carly R. Garrow declares that she has no conflict of interest. Maisha Mantel declares that she has no conflict of interest. Hannes G. Kenngott declares that he has no conflict of interest. Philipp Romero declares that he has no conflict of interest. Lars Fischer declares that he has no conflict of interest. Beat P Müller-Stich declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The present study was approved by the local ethics committee at Heidelberg University (S-334/2011).

Informed consent Written informed consent was obtained from all individual participants included in the study.

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