Original Article

Spaced Education Improves the Retention of Laparoscopic Suturing Skills: A Randomized Controlled Study

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Abstract

Background Spaced learning has been shown to be superior in complex motor skill acquisition like laparoscopic suturing and knot tying. By using a pre–post follow-up design, the aim of the study was to evaluate the long-term impact of implementation of the spaced learning concept in laparoscopic training.

Methods To evaluate the effectiveness of spaced learning, subjects were asked to perform four surgeon's square knots on a bowel model within 30 minutes—prior and after 3 hours of hands-on training. To examine the long-term skills, the same students were asked to perform a comparable, but more complex, task (four slip knots in a model of esophageal atresia) 12 months later as follow-up measurement. Total time, knot stability (evaluated via tensiometer), suture accuracy, knot quality (Muresan scale), and laparoscopic performance (Munz checklist) were assessed. Moreover, motivation was accessed using Questionnaire on Current Motivation.

Results Twenty students were included in the study; after simple randomization, 10 were trained using the "spaced learning" concept and 10 via traditional methods. Both groups had comparable baseline characteristics and improved after training significantly, regarding all aspects assessed in this study. Subjects that trained via spaced learning were superior in terms of speed ($p = 0.021$), knot quality ($p = 0.008$), and suture strength ($p = 0.003$). Additionally, spaced learning significantly decreased anxiety ($p = 0.029$) and probability of success ($p = 0.005$).

Conclusion The spaced learning concept is very suitable for long-term complex motor skill acquisition, like laparoscopic suturing and knot tying. It is superior to conventional training regarding speed and, most importantly, knot quality and stability, resulting in improved confidence and motivation. Thus, we strongly recommend to incorporate the spaced learning concept into training courses and surgical programs.

Keywords

- laparoscopy
- training
- spaced learning

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Introduction

Within laparoscopic training, the spaced learning concept has shown to be more effective than traditional continuous training.[1] It facilitates skill acquisition and long-term retention which is attributed to improved memory consolidation during sleep.[2–4] The concept is based on the temporal pattern of stimuli for creating long-term memories.[5,6] Spaced learning consists of blocks with highly condensed content that is repeated three times and interrupted by 10- to 20-minute breaks during which distractor activities, such as physical activity, are performed. It has been shown that surgical training in the setting of a training course is more effective when spaced into three consecutive weeks than the same amount of training during a single day.[2,3] Moreover, it appears to be superior to training with napping breaks, regular breaks, and traditional massed training.[3] However, considering the economic conditions of universities, a 3-day training program would be difficult to integrate into the curriculum. Hence, efficient training programs in a realistic setting are necessary to prepare future surgeons.[7]

Recently, we reported that the spaced learning concept is superior to conventional training, regarding laparoscopic skill acquisition.[1] Until today, it has not been established if spaced learning remains superior for transferability and long-term acquisition of motor skills. In this study, we used a more elaborate design on a new set of subjects to analyze long-term retention of laparoscopic skills and tested transferability, by using a realistic model of esophageal atresia. Moreover, the effects of the training method on motivation were investigated.

Methods

Study Design

All participants were randomly assigned to one of the two treatment conditions in the 12-month follow-up study. To access the influence of spaced versus conventional training, a modified setup as described by our research group was utilized.[1] In this previous study, solely the short-term effects of spaced training were evaluated by testing the study participants prior to training and one day after the training. In comparison, in this study subjects were tested prior to training and directly after training. The long-term evaluation was 1 year later in a different setting to test transferability.

The Medical Ethics Committee of the Medical Association of Hamburg (Ethik-Kommission der Ärztekammer Hamburg) declared that no formal ethical approval was needed for the study.

Pre–Post Measurement Period

For the pre and post measurement, a similar setup as described before was utilized.[1] In short, all participants received a standardized explanation of their task and were shown a short instructional video prior to the first assessment. Participants were not told what the specific endpoints of the study were. They were asked to perform four surgeon's square knot laparoscopically—done with an initial double-wrap throw followed by two single throws in alternate directions—prior to a 3-hour training session. After simple randomization, subjects were assigned and trained one-on-one according to their group by M.B., S.M., L.K., and J.B. Instructors changed every hour. In the spaced learning group, subjects were asked to train for 40 minutes, followed by 20-minute break with standardized physical activity coordinated by a trained and licensed physiotherapist (F.G.). This was repeated twice. In the control group, subjects trained for 3 hours without any interruptions. In both groups, the subjects were asked to perform the same tasks during the 3-hour training. All subjects were tested a second time directly after the 180-minute training period. To limit confounding factors, distractors like smartphones were forbidden.

Because of the nature of the intervention, blinding for randomization allocation was not possible. Lack of data regarding the transfer of the spaced learning concept from a classical class room environment onto procedural motor skill training prevented a formal sample size calculation. Sample size was estimated based on the complexity of the intervention and the results of previous study that used a similar setting.[8,9] Sample size calculation was performed using G*Power 3.1. A sample size of 20 subjects was calculated to give 90% power to detect a significant difference between spaced and conventional training for the parameters.

Follow-Up Measurement Period

To guarantee transferability prior to the follow-up assessment, all participants were given a standardized explanation and a short instructional video of a different knot in a different setup (esophageal atresia model) which was used in the pre–post measurement period (►Fig. 1). Then, participants were asked to perform four slip knots laparoscopically in a time period of 30 minutes.

Participants

Participants were between 23 and 34 years old (mean: 26.00 ± 2.63 years) studying medicine at Hamburg University. Sixty-two percent of the participants were female in both groups (13 female vs. 5 male); reflecting the gender distribution at German and U.K. medical schools.[10,11] Exclusion criterion was prior open or laparoscopic operations or experience in intracorporeal suturing to eliminate operative experience as a confounder. To assess potential bias, participants were asked about their previous participation in operations, operation courses, and hobbies like sports, playing of instruments, or computer games. To control natural maturation effects, participants were reassessed regarding the above-mentioned questions.

Setup

Pre–Post Measurement Period

For the first assessment, a P.O.P. Simulation Trainers (Pulsating Organ Perfusion, OPTIMIST, Innsbruck, Austria) were used with predefined openings, through which two instruments (one straight and one curved 5-mm needle holder, HiQ + , Olympus, Germany) at 30-degree angles either side of a midline positioned 5-mm laparoscope with 30 degree optics (EndoEye HD II, Olympus) were placed. The remaining setup consisted of the Visera Elite video system (Olympus, Germany) and the image was visualized on a 26″ monitor placed at a defined height directly in front of the subject. A standardized wet double-layer bowel model (outer diameter 30 mm, 3D-Med, Franklin, Ohio, United States) with four marked points on the ventral side of the intestine was used. For better standardization, a 12-cm long suture (Ethibond 4 × 0, Ethicon, Norderstedt, Germany) was utilized for each knot. All procedures were recorded for blinded assessment.

Follow-Up Measurement Period

For the second assessment, a 15 × 10 × 10 cm box was placed into a P.O.P. Simulation Trainers. The box was sized to reflect the dimension of a neonatal thorax.[12] A standardized bile duct model (outer diameter 11 mm, 3D-Med) was utilized as trachea and a customized double-layer bowel model (outer diameter 15 mm, 3D-Med) was used with four marked points on the ventral side of the esophagus (►Fig. 1). All other aspects were as described above.

Assessment

For every assessment, the primary endpoint with respect to efficacy of either spaced or conventional training were time, knot quality, suture placement accuracy, knot strength, as well as overall laparoscopic and knotting performance. The participants' time was measured from the moment the needle holder touched the suture until the suture was placed and secured with three throws.

The knot quality was assessed blindly by three referees (M.B., S.M., J.B.) using a quantifiable 5-point scale by Muresan et al.[13] Interrater reliability was computed with intraclass correlation (ICC) for each knot. An excellent reliability was found between each of the four measurements of the knots (ICC = 0.759–0.953). In this 5-point scale, the knot quality is based on tightness (knot without visible gaps between throws = 1 point, knot tight at base = 1 point), adaptation (edges are opposed without extra tissue in the knot = 1 point), and stability (knot holds under tension = 2 point).

Accuracy was determined by measuring the distance (mm) between marked entrance and exit points of the bowel model.

The quality of suturing was assessed for each knot by a validated 23-point checklist by Munz et al.[14] Three blinded referees (M.B., S.M., J.B.) assessed the videos and completed the checklist for each knot independently. Interrater reliability was computed with ICC for each knot. An excellent reliability between each of the four measurements could be found (ICC = 0.731–0.913).

To test knot strength a tensiometer was used. The knotted sutures were placed into the tensiometer and the loops subjected to tensile for forces of 50 mm/min until the knot broke or slipped as described by Dorsey et al and Goldenberg and Chatterjee.[15,16] Force until slip or break in Newtons (N, a unit of force equal to 0.225 lb) was evaluated.

The training is part of the curriculum. Overall performance was evaluated and counted as exam. To evaluate the motivation of the subjects, an 18-item questionnaire (Questionnaire on Current Motivation [QCM]) measuring four motivational factors (anxiety, probability of success, interest, and challenge) was utilized before the training session, after training, and before the long-term endpoint.[17]

Statistics

All data were analyzed with SPSS Statistics 24 and GraphPad Prism 7. Differences between groups were calculated using Student's *t*-test. For ordinal data differences were calculated using the Mann–Whitney or Kruskal–Wallis test. Data are presented as mean ± standard deviation. Covariance analysis was performed using the multivariate analysis of covariance. To evaluate the gain pre-, post-, and follow-up training, repeated measures analysis of variance (ANOVA) or Friedmans' ANOVA were used. The level of significance was set at 0.05.

Results

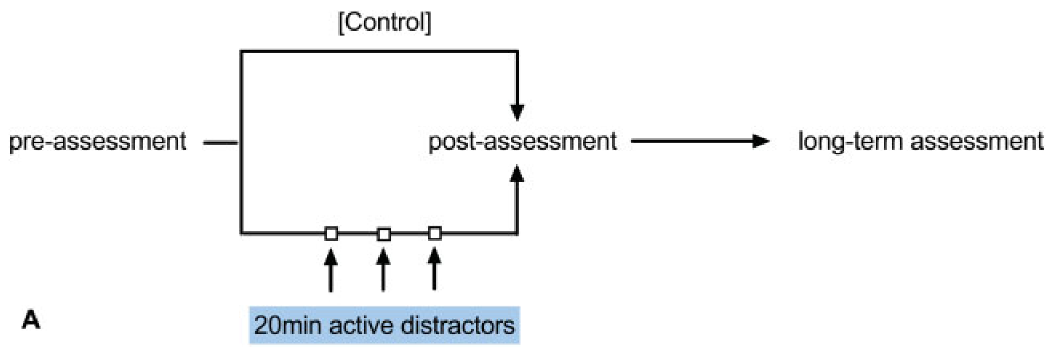
Ten students were trained using the spaced learning concept and 10 conservatively. No subject was excluded before or after allocation to a group and two subjects were lost to follow-up (►Supplementary Fig. S1, available in the online version).

Subjects in both groups had similar age (spaced 25.89 vs. 26.11 years, $p = 0.86$) and gender (spaced 3/9 vs. 2/9 male, $p = 0.62$) distribution. All subjects were right handed. The majority in both groups did not have any operation experience (both 7/9 subjects, $p = 1.00$) and none had participated in any open surgery or laparoscopy course. Regarding past time activities, there were also no significant differences. In both groups, the majority used to play an instrument (spaced 7/9 vs. 6/9 subjects, $p = 0.62$), but none was practicing currently. More than half of the subject used to play computer games (spaced 5/9 vs. 6/9 subjects, $p = 0.65$) and only a few are playing computer games currently (both 1/9 subjects, $p = 1.00$). In terms of sportive activities, there was also no significant difference. Subjects in both groups performed sports on a regular basis (> 3 time per week). There was no significant difference between groups (spaced 8/9 vs. 9/9 subjects, $p = 0.32$).

Speed

The number of knots tied within 30 minutes was significantly lower in the pre- than in the post- and the follow-up measurement, independent of the training method. Significance was $p < 0.001$ as shown in ►Fig. 2A. Follow-up analysis indicated that the spaced learning group performed significantly better than controls (►Fig. 2A). Number of knots was not affected by age, gender, or past time activities (instruments, sports, video games).

In terms of speed, there was a significant short- and long-term improvement after training (►Fig. 2B). Significance was $p < 0.001$ as shown in ►Fig. 2B. At follow-up, subjects trained using spaced learning were significantly faster than controls. Both groups started similarly and improved significantly after training (►Fig. 2B). Task time was not affected by age, gender, or past time activities (instrument, sports, video games).



A

B

Fig. 1 Experimental design and treatment strategy. (**A**) Experimental design. Controls were trained for three uninterrupted hours. In the spaced learning group, 40 minutes of training were followed by active pauses. The subjects were instructed by a professional physiotherapist. Long-term effects were examined using a general linear model repeated-measured procedure for each dependent variable with group (spaced learning vs. conventional learning) as the between-subject variable and time (pre, post, follow-up) as within-subject variables. (**B**) Esophageal atresia model that was placed in box with a P.O.P. trainer to test temporal and request transferability. The subjects were asked to perform four slip knots using the preformed marks.

Accuracy

Training led to a significant linear improvement of accuracy ($p = 0.005$) as shown in ►**Fig. 2C**. On follow-up, there were no significant differences between both groups ($p > 0.05$). Accuracy was not affected by age, gender, or past time activities.

Suturing and Knot-Tying Performance

Laparoscopic performance improved from pre- to post- and follow-up measurement ($p < 0.001$). The Munz performance score did not differ between the two training methods ($p > 0.05$) as shown in ►**Fig. 2D**. Suturing and knot-tying performance was not affected by age, gender, or past time activities.

Knot Quality

There was significant improvement of the knot quality after training ($p = 0.019$). Subjects in the spaced group had significantly higher Muresan knot scores than controls as shown in ►**Fig. 2E**. Knot quality was not affected by gender or past time activities but age. Subjects older than 25 had significantly lower post- ($p = 0.038$) and long-term knot strength ($p = 0.018$).

Knot Strength

Knot strength improved significantly in all subjects from pre- to post- and follow-up measurement ($p = 0.018$). Subjects in the spaced group had significantly higher values than controls as shown in ►**Fig. 2F**. Knot strength was not affected by age, gender, or past time activities.

Questionnaire on Current Motivation

Training was associated with a significant decline in anxiety ($p < 0.001$) and feeling of challenge ($p = 0.022$) in the QCM for both groups. The probability of success ($p < 0.001$) increased significantly from pre to post to long-term (as shown in ►**Fig. 3**). Training did not significantly influence the interest of the subjects ($p > 0.05$). The spaced learning was superior regarding probability of success ($p = 0.005$) and

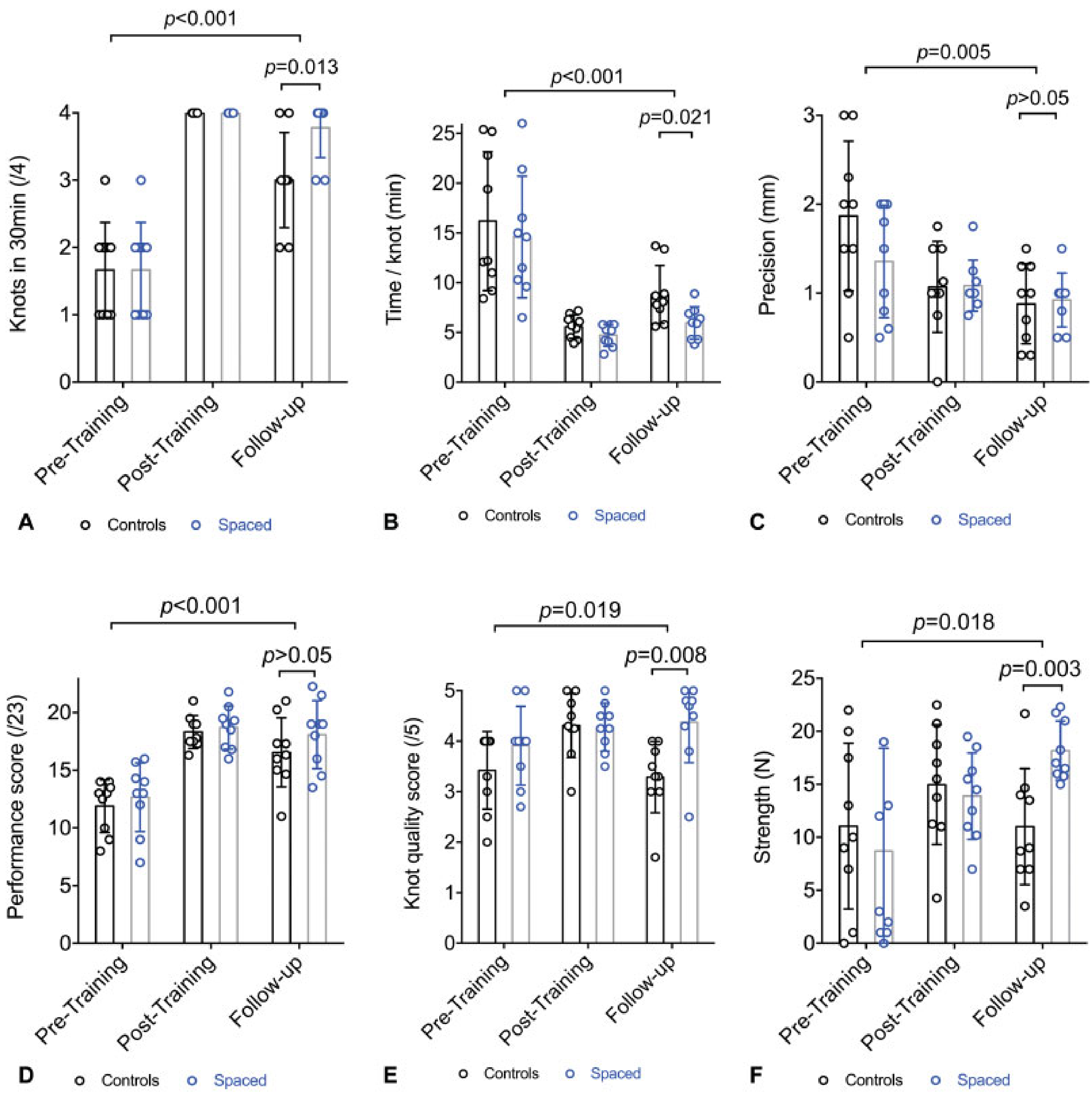


Fig. 2 Comparison of pretraining, posttraining, and follow-up results in control and spaced learning group. All aspects examined in the study showed a significant long-term improvement after training (**A–F**). Spaced learning was superior in regards to speed (**A**, **B**) and knot quality (**E**) and strength (**F**). Data are shown as mean ± standard deviation (SD). Statistics: *t*-test, analysis of variance (ANOVA), or Mann–Whitney or Kruskal–Wallis test.

anxiety ($p = 0.029$). Lastly, the QCM was not affected by age, gender, or past time activities.

Discussion

Long-term acquisition and transferability of complex motor skills, like laparoscopic suturing, are essential to improve surgical skills during the limited surgical training time during medical school and the subsequent residency program. This study shows that laparoscopic training is an effective tool to become proficient in complex laparoscopic tasks, like suturing and knot tying. It also shows that the spaced learning concept is superior to conventional training methods in the long run for the key performance metrics of minimal invasive surgery: speed and quality. There was no difference between both training methods regarding accuracy and procedure performance. However, previous studies have reported that knot quality and time are better indicators of laparoscopic skill level, as opposed to accuracy and procedural performance.[14,18] Spaced practice trended toward better procedure performance but did not reach significance; most likely due to the small sample size.

There are several explanations for the superiority of spaced learning compared with traditional skill acquisition.

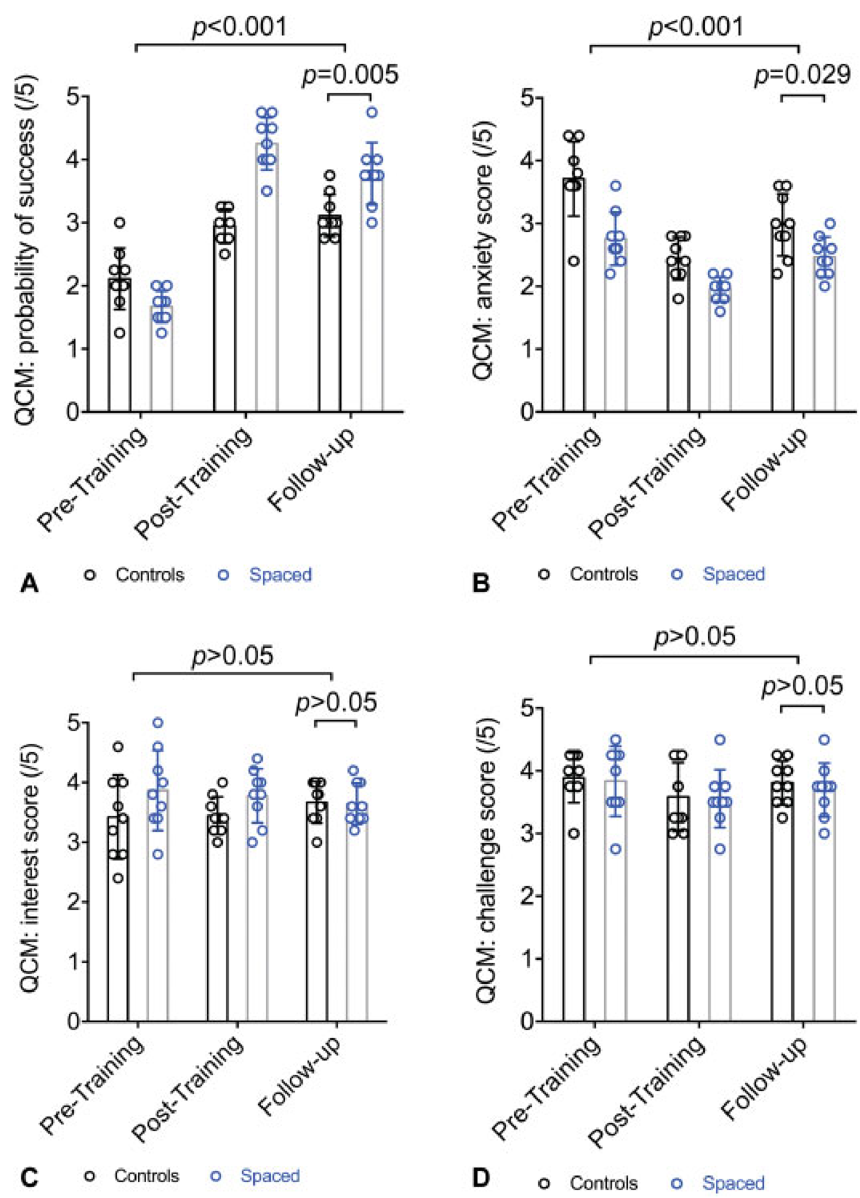


Fig. 3 Comparison of pretraining, posttraining, and follow-up results in terms of current achievement motivation. Probability of success (**A**) increased significantly and anxiety (**B**) was significantly reduced after training. There were no differences in regard to interest (**C**) and feeling of challenge (**D**). Spaced learning was superior in reducing anxiety (**B**) and improving probability of success (**E**). Data shown as mean ± standard deviation (SD). Statistics: Mann–Whitney test.

First, according to the theories of attention, one has finite attentional resources.[19] Thus, long training sessions without breaks might be suboptimal for novice surgeons with limited resources. Moreover, it has been reported that uninterrupted training leads to mental fatigue, which impairs long-term motor skills acquisition.[20] Anterograde interference is thought to be the main factor limiting during this process.[21] If new information is processed before the synaptic patterns have been processed and consolidated, motor skill acquisition and retention gets impaired.[22] As spaced learning purposefully includes activities between training sessions intended to distract learners, it appears to be more resistant to interference and, hence, improves acquisition and consolidation of motor skills trained in close succession.[6] Apparently, these factors lead to a better long-term preservation of skills. Additionally, the superiority of the spaced learning concept is reflected on higher QCM scores showing significantly lower anxiety and higher probability of success. The short breaks during practice appear to improve not only skill consolidation but also motivation.

Nevertheless, there is always the question of transferability: effective learning concepts should result in skills that endure long term (temporal transferability), that can be transferred to other tasks (request transferability), and finally that can be transferred to other contexts (situational transferability).[23,24] A recent trial showed that skills which are learned in simulation-based training can be later transferred to operative settings.[25] The spaced learning concept appears to bring excellent transferability in the context of acquisition of complex motor skills. The subjects showed a much better temporal and request transferability than controls.

The study uncovers one concerning subject, which is typical for the curriculum of medical schools in Germany. It has been shown that higher surgical skills are only attained if the skills are taught throughout the program and that younger subjects are better able to acquire the higher surgical skills, relative to their older peers.[26] Thus, it is concerning that the majority of students, despite having a mean age of 26 years and being in the last third of their studies, had not yet participated in any open or laparoscopy training. Age was the only cofactor that showed a significant effect on the posttraining performance of the subjects. Subjects younger than 25 years had significant higher knot quality than older participants. All other cofactors, such as playing video games, musical instruments, or sports, which are frequently discussed to impact laparoscopic performance and acquisition, showed no influence in the study.[27–30] As a consequence, a standardized surgical training program should be implemented early in the curriculum of the medical students; preferably using the spaced learning concept.

The main strengths of the study are the randomization of the participants, utilization of predefined specific criteria, and a validated setup.[8,31]

The main limitation is the small number of randomized participants that might limit generalization of our findings into other settings. However, previous studies have shown an excellent transfer of simulation-based training models to the operative setting even in pilot studies.[32] Moreover, a potential limitation of this study is the participation of medical students, rather than surgical residents. Previous studies have shown that medical students and surgical residents, with minor laparoscopic experience, show comparable baseline performance and improvement capabilities.[8,33,34] Ultimately, training in a skills laboratory setting might limit transferability. Several aspects like navigation skills, decision making, team dynamics, and knowledge of anatomy, patient, and procedure have not been evaluated and, therefore, situational transferability could not be assessed. However, several randomized controlled trials showed an excellent transfer into practice after training in basic models, like intracorporeal suturing and knot tying.[25]

In conclusion, the spaced learning concept is very suitable for long-term complex motor skill acquisition, like laparoscopic suturing and knot tying. It is superior to conventional training, regarding speed and, most importantly, knot quality and stability, resulting in improved confidence and motivation. Thus, we strongly recommend to incorporate the spaced learning concept into training courses and surgical programs.

Authors' Contributions

Johannes Boettcher: Acquired the data, conceptualized the questionnaire, validated statistics, and approved the final manuscript as submitted. Lea Klippgen: Acquired the data, conceptualized the questionnaire, validated statistics, and approved the final manuscript as submitted. Stefan Mietzsch: Acquired the data, acted as course instructor, and approved the final manuscript as submitted. Friederike Grube: Acquired the data, acted as course instructor, and approved the final manuscript as submitted. Thomas Krebs: Acquired the data, acted as course instructor, and approved the final manuscript as submitted. Robert Bergholz: Acquired the data, acted as course instructor, and approved the final manuscript as submitted. Konrad Reinshagen: Conceptualized and designed the study, and approved the final manuscript as submitted. Michael Boettcher: Conceptualized and designed the study, acquired the data, acted as course instructor, performed statistics, drafted the initial manuscript, and approved the final manuscript as submitted. All authors approved the final manuscript as submitted, and agree to be accountable for all aspects of the work.

Conflict of Interest

None declared.

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