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Learning Curves in Laparoscopic Training: Comparative Analysis of Two Training Models

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Abstract:

Background: Laparoscopic surgery is widely used due to its minimal invasiveness, shorter recovery times, and improved patient outcomes. However, it demands advanced psychomotor skills, such as spatial awareness, precision movements, and hand-eye coordination. Mastering these skills requires structured and effective training strategies. Developing and maintaining laparoscopic proficiency is essential for medical students preparing for clinical practice.

Aims: This study aimed to compare the efficacy of intensive and distributed laparoscopic training models in developing and retaining laparoscopic surgical skills among medical students.

Methods: A prospective study was conducted from July to December 2024, involving 10 medical students (6 females, 4 males, aged 20-26 years) with no prior laparoscopic experience. Participants were divided into two training groups: intensive (daily sessions over 10 days) or distributed (twice weekly sessions over 5 weeks). Training included standardized exercises (peg transfer, circle cutting, needle guidance, ball allocation) using the Laparo Advance box trainer with E-BLUS-modified protocols. Performance was evaluated based on task completion times and errors, with follow-up assessments one month post-training.

Results: Both training models improved laparoscopic skills, but the distributed group showed superior skill retention and consistency. One month follow-up evaluations showed significantly shorter task times completion in the distributed group for peg transfer ($p=0.014$, $d=1.97$) and cutting a circle ($p=0.036$, $d=1.74$).

Conclusions: Distributed training demonstrated superiority in skill retention, error reduction, and consistent task performance, especially in tasks requiring precision. These findings support integrating distributed training into laparoscopic education to improve skill acquisition and better prepare trainees for clinical practice.

Keywords: laparoscopy; learning curve; simulation training; surgical education; students

1. Introduction

In the rapidly evolving field of modern surgery, laparoscopic techniques are particularly notable for their minimal invasiveness, offering benefits such as reduced postoperative pain, better operating field visualization, and shorter recovery periods [1,2]. Despite these advantages, adopting laparoscopic techniques requires substantial training and expertise. Box trainers, as physical simulators, allow trainees to practice laparoscopic skills using real instruments in a cost-effective and accessible manner [3]. They improve basic laparoscopic skills such as suturing, cutting, and camera handling [4,5]. Simulation-based training is invaluable in surgical education. It allows trainees to practice techniques in a risk-free environment and receive immediate feedback, helping them learn faster and build confidence more effectively [6,7]. Standardized training modules, including proper trocar placement and careful handling of instruments, make the learning process more efficient and consistent across different educational contexts [8]. One important concept in training is the learning curve. These curves measure various metrics, such as the time taken to complete tasks and the number of errors made [9]. It helps us understand how quickly and effectively trainees acquire new skills, including areas of rapid improvement, as well as those requiring further focus [10]. In laparoscopic training, the learning curve can vary widely among trainees, influenced by factors such as the frequency of practice sessions and the training methods employed [3].

This study explores the effectiveness of different laparoscopic training models by analyzing their learning curves. The aim was to evaluate the efficacy of intensive versus distributed laparoscopic training models in developing and retaining surgical skills among medical students.

2. Materials and methods

Our prospective study was conducted from July to December 2024 at the Department of Urology and Andrology in the University Hospital No. 1 in Bydgoszcz, Poland. The study involved ten medical students (six females and four males) with no prior laparoscopic experience. Participants were at various stages of their education, ranging in age from 20 to 26 years. Two participants were in their 2nd year, two were in their 3rd year, two were in their 5th year, and four were in their 6th year. All participants were right-handed.

Our research received ethical approval from the Ethics Committee of Nicolaus Copernicus University in Torun, Ludwik Rydygier Collegium Medicum in Bydgoszcz (approval number KB 231/2024). All participants provided written informed consent before participation in the study, and the research was conducted in accordance with the Declaration of Helsinki.

2.1 Simulation equipment and setup

Everything was facilitated using the Laparo Advance laparoscopic training box, equipped with a Full HD USB camera mounted on a 30° ball joint (Fig. 1A) [11]. The simulator included essential laparoscopic tools: a dissector, grasper, scissors, needle driver, and six training modules, with exercises designed to develop various surgical skills. We specifically used modules aligned with the European Basic Laparoscopic Urological Skills (E-BLUS) [12], a recognized European Association of Urology training program. The exercises focused on needle guidance, peg transfer, precise circle cutting, and laparoscopic suturing. However, laparoscopic suturing was excluded from our study due to its complexity and the initial skill level of participants. In its place, we introduced the "ball allocation" exercise. The setup included a personal computer connected to the simulator's camera to capture images of the participants' maneuvers.

2.2 Training exercises and assessment

Participants were assigned to one of two groups, each following a distinct training schedule. The intensive training group (n=5) completed daily sessions for ten consecutive days, while the distributed training group (n=5) attended sessions twice weekly over five weeks. All participants completed ten training sessions, followed by a day evaluation one month after the last training date to assess skill retention. Performance was measured using task completion time (using a stopwatch) and number of errors.

2.2.1 Peg Transfer

It required participants to transfer pegs from one side of a board to another and back (Fig. 1E). Participants began the task using two graspers, starting with their dominant hand to pick up each peg, transferring it mid-air to their other hand and placing it accurately on a designated peg on the opposite side. After transferring all the pegs to the opposite side, they repeated the process this time starting with their other hand. [12]. The timing began when the first object was touched and continued until the last peg was placed back on its original side of the pegboard. The transferred elements could not leave the field of vision or be dropped. An error was noted if a peg was dropped and dropped objects were not to be picked up.

2.2.2 Cutting a Circle

Participants were tasked with cutting a precise circle from a marked area within two black lines, using laparoscopic scissors and a grasper (Fig. 1C). Participants needed to carefully cut along the marked lines without deviating inside or outside the boundaries. Errors were recorded if the cut crossed or extended beyond the black lines. However, cutting the second layer of gauze beneath the top layer did not count as an error [12]. Crossing the line at the start was permissible and was not counted as an error. The objective was to maintain the cut within the boundary lines. Timing began with the first incision and ended when the circle was fully detached from the rest of the gauze.

2.2.3 Needle Guidance

The exercise involved guiding one 3-0 braided suture with a curved needle through a sequence of 10 metal rings along a designated path using two needle drivers (Fig. 1D). Errors were recorded if the needle entered a ring from the wrong side [12]. Timing began when the needle entered the first ring and ended when it passed through the 10th ring. The suture was placed in a corner of the setup to start the task. If the needle was dropped, participants were allowed to pick it up again while the time continued- this didn’t count as an error.

2.2.4 Ball Allocation

The exercise involved using a laparoscopic grasper to pick up a plastic ball from a central container, passing it to another laparoscopic grasper, and placing it on one of eight posts (Fig. 1B). The task was completed when all posts were covered with balls. Errors were recorded for dropping balls. Timing began when the first ball was touched and ended when all posts were covered.

Fig. 1: A- training box used in our study, with the following training modules:
B – ball allocation; C - cutting a circle; D - needle guidance; E - peg transfer.

2.3 Statistical analysis

Statistical analyses were performed using the IBM SPSS Statistics 25 package. Descriptive statistics were calculated, and normality was assessed with the Shapiro-Wilk test. Student's t-tests for independent and dependent samples, Mann-Whitney U tests, and Wilcoxon signed-rank tests were applied as appropriate. Cohen's d effect sizes were reported and interpreted as small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$). The significance threshold was set at $\alpha = 0.05$. Due to the small research group, the test probability results in the range of $0.05 < p < 0.1$ were interpreted as significant at the level of statistical trends. Confidence intervals (95% CI) were provided where applicable.

3. Results

3.1 Learning curves

Fig. 2-5 illustrates the learning curves for the peg transfer, cutting a circle, needle guidance, and ball allocation tasks, comparing the intensive and distributed training groups. Time to task completion and error rates are presented with 95% confidence intervals.

3.1.1 Peg transfer

The peg transfer learning curves compared task completion times and error rates between the intensive and distributed training groups (Fig. 2). The intensive group showed a rapid initial reduction in task completion time during the first two sessions. However, performance variability increased in the following sessions, with a noticeable plateau effect observed between the 4th and 6th training sessions. In contrast, the distributed group demonstrated a steady and consistent decline in task completion time across all training sessions. The most significant improvement occurred between the 1st and 3rd sessions. After this phase, the learning curve flattened, with more gradual improvements observed from the 4th session onward. By the 8th to 10th sessions, task completion times had stabilized.

Error rates in the intensive group were generally low but fluctuated, particularly during the 2nd and 6th sessions, with no consistent reduction trend. In contrast, the distributed group's error rates steadily declined, reaching zero by the 5th session and remaining there throughout the training.

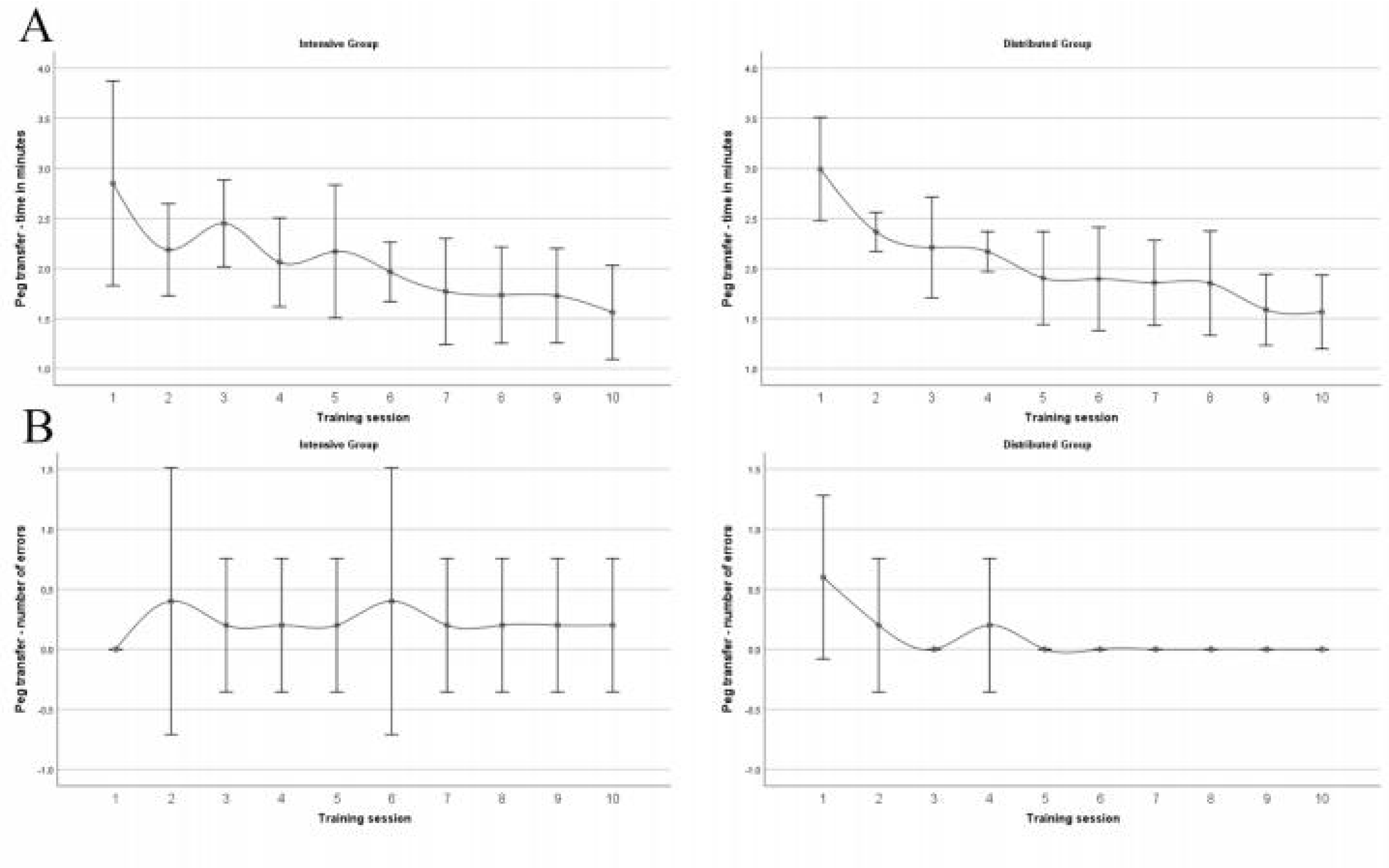

Fig 2. Learning curves for the peg transfer task comparing A- completion time and B- number of errors between the intensive and distributed training groups.

3.1.2 Cutting a circle

The cutting a circle learning curves compared task completion times and error rates between the intensive and distributed training groups (Fig. 3). In the intensive group, task completion times gradually declined over the first two training sessions. However, performance variability increased between the 3rd and 5th sessions, with task times temporarily rising before resuming a downward trend. From the 6th session onward, task completion times stabilized, although some variability among participants persisted through the final training session. In the distributed group, task completion times steadily decreased throughout all training sessions. The most notable improvements occurred between the 1st and 4th sessions. After this, task times declined more gradually, with variability among participants consistently narrowing over time. By the final sessions, the performance had stabilized.

Error rates for the intensive group displayed significant fluctuations across sessions, with peaks around sessions 4, 6, and 7 and generally wide error bars. Error rates in the distributed group followed a steady decline with less fluctuation overall compared to the intensive group.

However, a noticeable peak occurred in session 8, followed by a decrease in the final sessions. Error bars were wider in earlier sessions but narrowed over time.

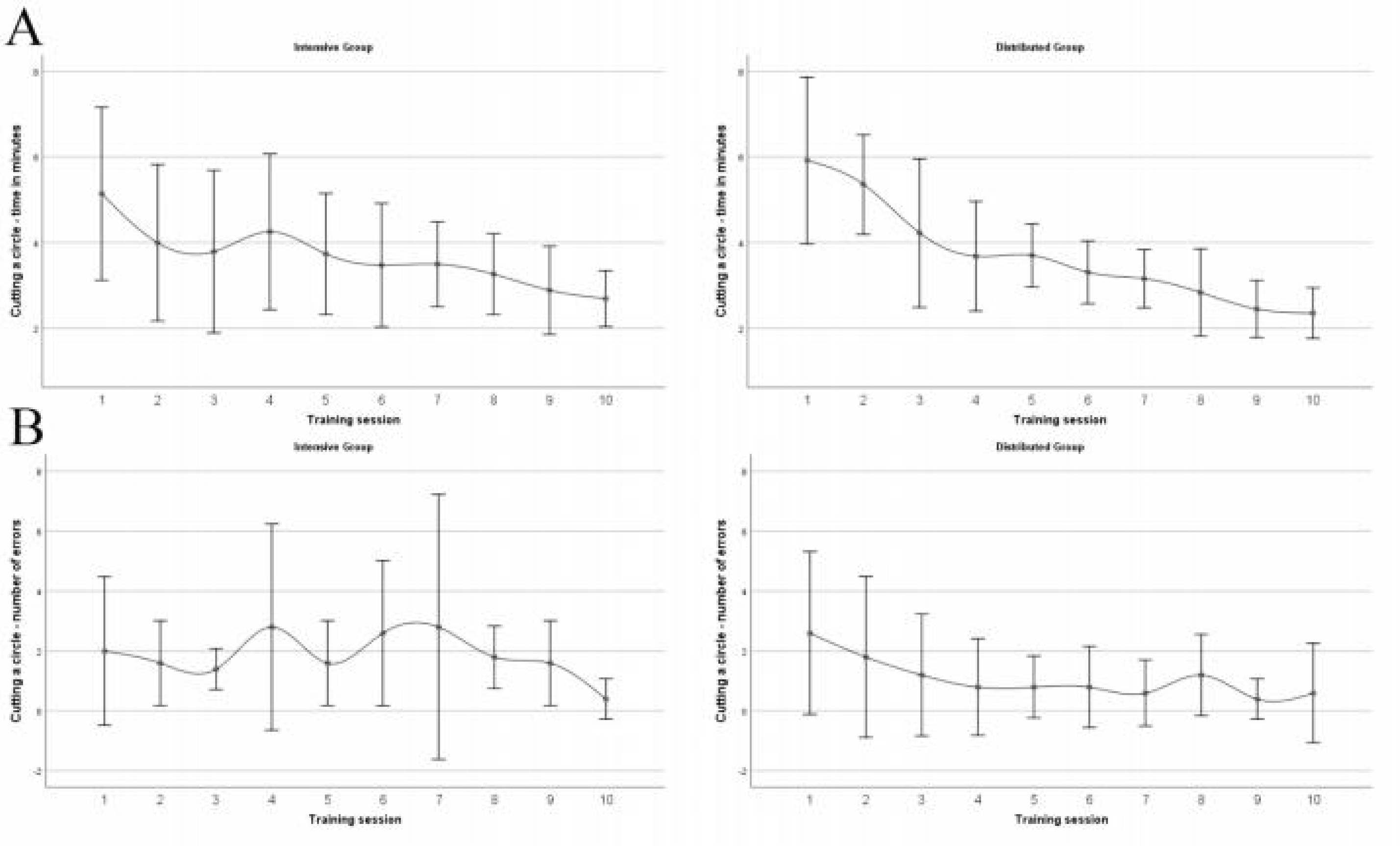

Fig 3. Learning curves for the cutting a circle task comparing A- completion time and B- number of errors between the intensive and distributed training groups.

3.1.3 Needle guidance

The needle guidance learning curves compared task completion times and error rates between the intensive and distributed training groups (Fig. 4). In the intensive group, task completion times declined during the first few trainings. After the rate of improvement slowed, and task times stabilized by the 6th training session. The variability in performance also decreased over time, as indicated by smaller performance differences across participants. In the distributed group, task completion times also showed a significant reduction during the first few trainings. followed by continued gradual improvement without a plateau. Minor fluctuations were observed around training 4-7, but overall performance continued to improve, with task completion times consistently declining through the final session.

Error rates remained consistent, with no recorded mistakes across all training sessions in the intensive group. In the distributed group, a few errors were observed during the 1st session, but these quickly dropped to zero by the 2nd session and stayed at zero for the rest of the training.

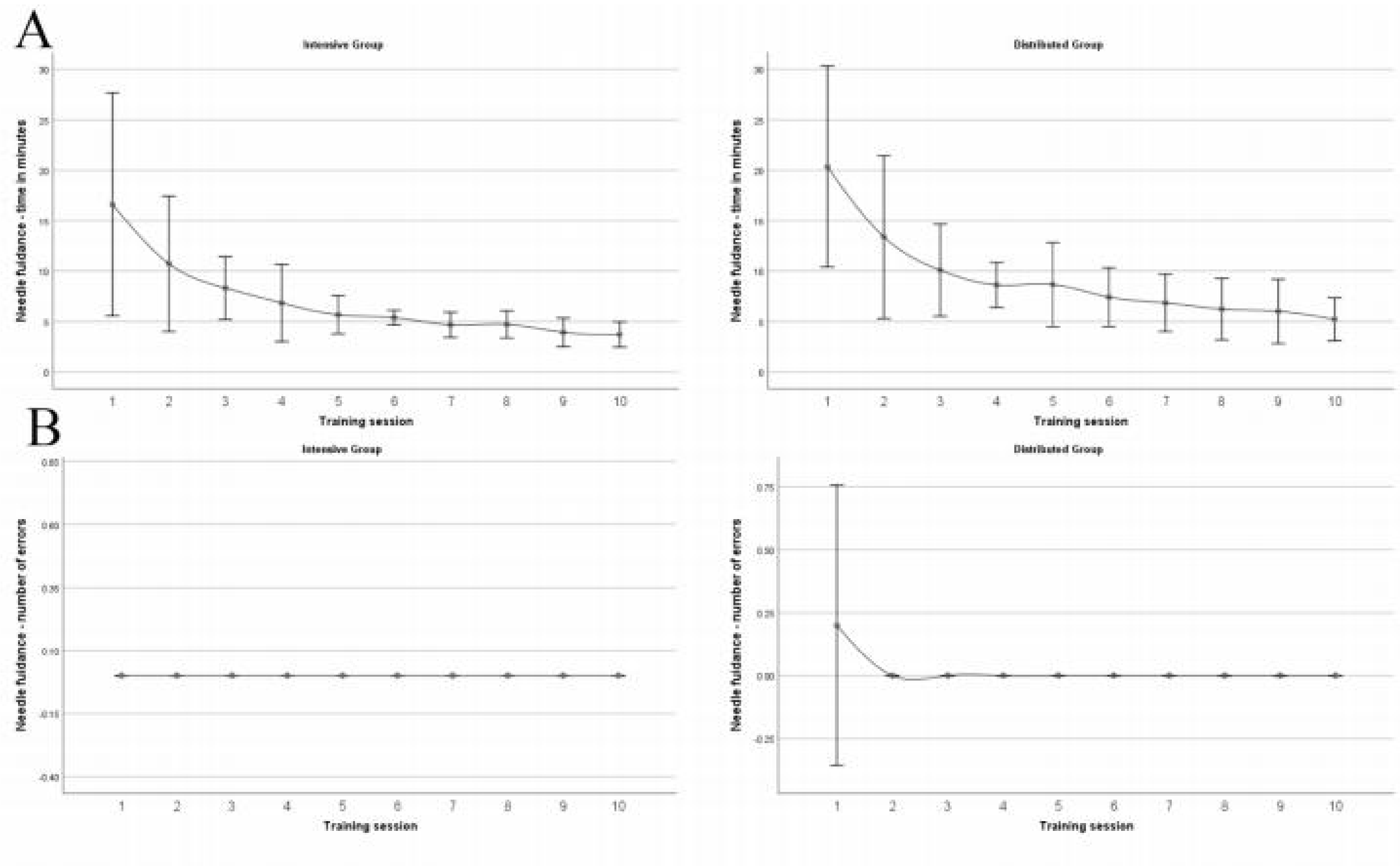

Fig 4. Learning curves for the needle guidance task comparing A- completion time and B- number of errors between the intensive and distributed training groups.

3.1.4 Ball allocation

The ball allocation learning curves compare task completion times and error rates between the intensive and distributed training groups (Fig. 5). In the intensive group, task completion times showed a gradual decline during the first three training sessions rather than a significant drop. After this initial improvement, performance fluctuated between sessions 4 and 6, with some variability in task completion times. By session 7, task times began to stabilize, and gradual improvements were observed through the final training, with reduced variability among participants in later sessions. In the distributed group, task completion times consistently decreased over the training sessions. The most noticeable improvements occurred during the first three sessions, after which performance fluctuated slightly between sessions 4 and 6. From session 7 onward, task times continued to decline steadily, reaching a plateau by the final sessions. Variability among participants was higher in the earlier sessions but progressively narrowed as training advanced.

In the intensive group, error rates gradually declined during the first three sessions but fluctuated between sessions 4 and 7 before decreasing steadily to near-zero levels by the final session. Variability was high initially but narrowed over time. In the distributed group, error rates also declined during the first three sessions, followed by minor fluctuations between sessions 4 and 7. From session 8 onward, error rates consistently decreased, with minimal errors in the final sessions and greater consistency among participants.

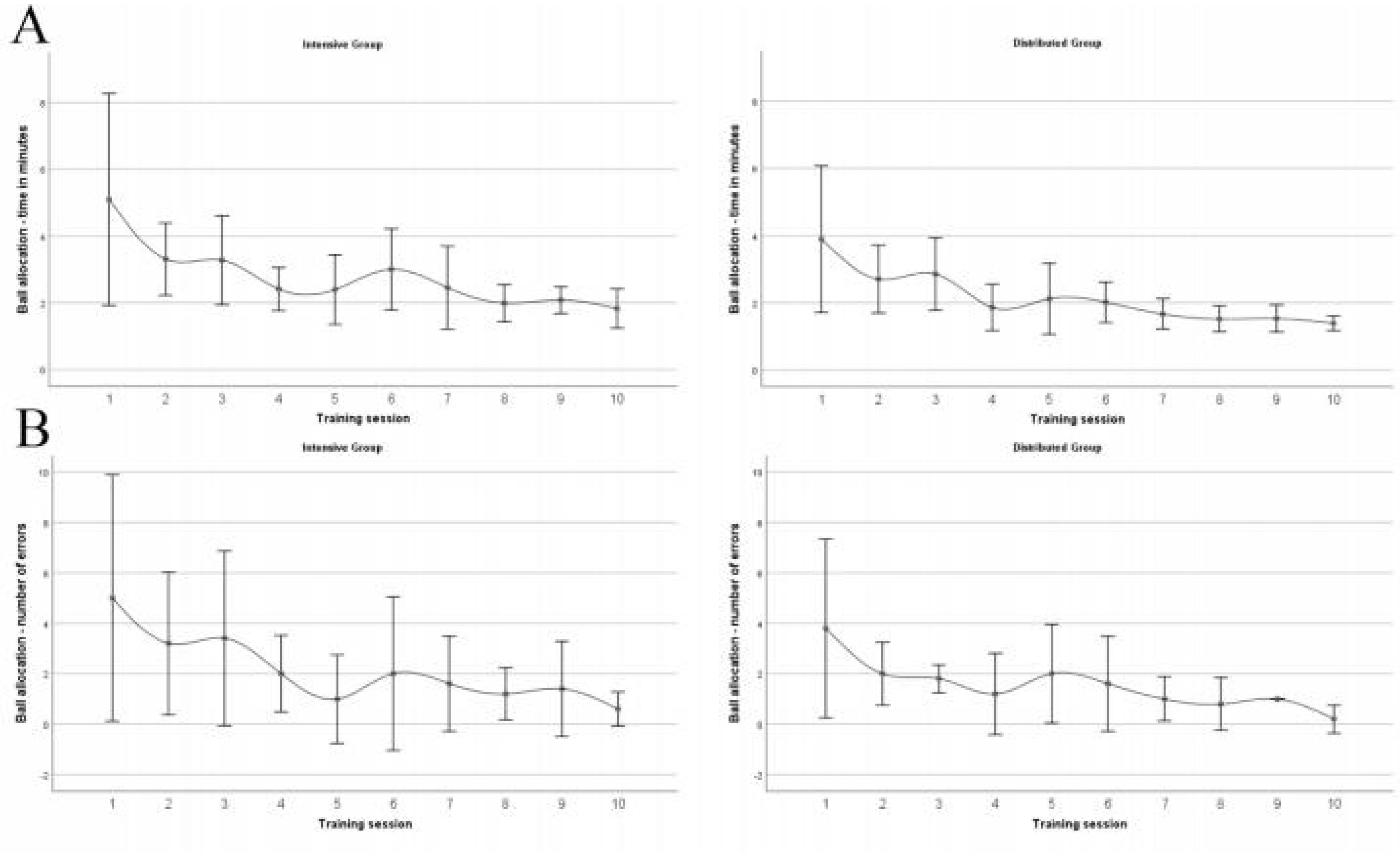

Fig 5. Learning curves for the ball allocation task comparing A- completion time and B- number of errors between the intensive and distributed training groups.

3.2 Retention performance comparison between final training and follow-up exam

Task completion times increased during the follow-up exam relative to the final training session. In the intensive group, significant increases were noted for peg transfer ($p = 0.031$, $d = 1.44$), cutting a circle ($p = 0.015$, $d = 1.83$), and needle guidance ($p < 0.001$, $d = 6.46$), with a near-significant trend for ball allocation ($p = 0.057$, $d = 1.18$). In contrast, the distributed group showed a significant increase only for needle guidance ($p = 0.007$, $d = 2.28$) and a trend for cutting a circle ($p = 0.055$, $d = 1.20$), while peg transfer ($d = 0.27$) and ball allocation (d =

0.76) remained stable. Error rates stayed low and did not differ significantly between sessions (see Table 1).

Table 1. Comparison of task completion times and error rates between the final training session and follow-up exam after a one-month break in both training groups.

Intensive training group

	10th Training		Exam day				95% *CI*		
Task	***M***	***SD***	***M***	***SD***	***t***	***p-value***	***LL***	***UL***	**Cohen's d**
Peg transfer (time)	1.56	0.38	2.21	0.49	-3.23	**0.031**	-1.20	-0.09	1.44
Peg transfer (errors)	0.20	0.45	0.00	0.00	1.00	0.373	-0.36	0.76	0.45
Cutting a circle (time)	2.69	0.53	4.25	1.00	-4.09	**0.015**	-2.62	-0.50	1.83
Cutting a circle (errors)	0.40	0.55	1.60	1.14	-1.81	0.144	-3.04	0.64	0.81
Needle guidance (time)	3.72	1.00	7.30	1.34	-14.43	**<0.001**	-4.27	-2.89	6.46
Needle guidance (errors)	0	0	0	0	-	-	-	-	-
Ball allocation (time)	1.83	0.47	2.56	0.94	-2.64	0.057	-1.49	0.04	1.18
Ball allocation (errors)	0.60	0.55	1.00	1.00	-0.78	0.476	-1.82	1.02	0.35

Distributed training group

	10th Training		Exam day				95% *CI*		
Task	***M***	***SD***	***M***	***SD***	***t***	***p-value***	***LL***	***UL***	**Cohen's d**
Peg transfer (time)	1.57	0.30	1.50	0.12	0.61	0.577	-0.22	0.35	0.27
Peg transfer (errors)	0	0	0	0	-	-	-	-	-
Cutting a circle (time)	2.35	0.47	2.91	0.44	-2.68	0.055	-1.13	0.02	1.20
Cutting a circle (errors)	0.60	1.34	0.00	0.00	1.00	0.373	-1.07	2.27	0.45
Needle guidance (time)	5.22	1.70	6.46	1.33	-5.09	**0.007**	-1.91	-0.56	2.28
Needle guidance (errors)	0	0	0	0	-	-	-	-	-
Ball allocation (time)	1.39	0.18	1.53	0.32	-1.70	0.164	-0.37	0.09	0.76

Ball allocation (errors)	0.20	0.45	0.20	0.45	-	-	-	-	-

M- Mean; **SD**- Standard Deviation; **t**- Student's *t*-test statistic for independent samples; ***p*-value**- statistical significance level; **95% CI**- 95% Confidence Interval; **LL**- Lower Limit of the Confidence Interval; **UL**- Upper Limit of the Confidence Interval; **Cohen's *d***- Cohen's *d* effect size.

3.3 Between-group comparison of task performance after a follow-up exam

Between-group comparisons during the follow-up exam indicated that the distributed training group generally outperformed the intensive group with faster task completion and fewer errors (Table 2). In the peg transfer task, the intensive group required significantly more time (M = 2.21 min, SD = 0.49) than the distributed group (M = 1.50 min, SD = 0.12, p = 0.014, d = 1.97). A similar pattern emerged in the cutting a circle task, where the intensive group also exhibited longer completion times (M = 4.25 min, SD = 1.00) compared to the distributed group (M = 2.91 min, SD = 0.44, p = 0.036, d = 1.74) and made significantly more errors (M = 1.60, SD = 1.14 versus none, p = 0.035, d = 1.98). Although no significant differences were observed in the needle guidance task (intensive: M = 7.30 min, SD = 1.34; distributed: M = 6.46 min, SD = 1.33, p = 0.351, d = 0.63), and the ball allocation task showed a trend toward longer times in the intensive group (M = 2.56 min, SD = 0.94 versus M = 1.53 min, SD = 0.32, p = 0.070, d = 1.46), the overall findings support better skill retention in the distributed group. Fig. 6 visually confirms these findings, illustrating the consistently shorter completion times and lower error rates in the distributed group, especially in precision-demanding tasks such as peg transfer and cutting a circle.

Table 2. Comparison of task completion time and errors between intensive and distributed training groups during follow-up exam.

	Intensive Group (*n* = 5)		**Distributed Group (*n* = 5)**				**95% *CI***		
Task	***M***	***SD***	***M***	***SD***	***t***	***p-value***	***LL***	***UL***	**Cohen's d**
Peg transfer (time)	2.21	0.49	1.50	0.12	3.12	**0.014**	0.18	1.23	1.97
Cutting a circle (time)	4.25	1.00	2.91	0.44	2.75	**0.036**	0.12	2.56	1.74
Needle guidance (time)	7.30	1.34	6.46	1.33	0.99	0.351	-1.11	2.78	0.63
Ball allocation (time)	2.56	0.94	1.53	0.32	2.30	0.070	-0.12	2.17	1.46
Peg transfer (errors)	0	0	0	0	-	-	-	-	-

Cutting a circle (errors)	1.60	1.14	0.00	0.00	3.14	**0.035**	0.18	3.02	1.98
Needle guidance (errors)	0	0	0	0	-	-	-	-	-
Ball allocation (errors)	1.00	1.00	0.20	0.45	1.63	0.141	-0.33	1.93	1.03

M- Mean; **SD**- Standard Deviation; **t**- Student's *t*-test statistic for independent samples; ***p*-value**- statistical significance level; **95% CI**- 95% Confidence Interval; **LL**- Lower Limit of the Confidence Interval; **UL**- Upper Limit of the Confidence Interval; **Cohen's *d***- Cohen's *d* effect size.

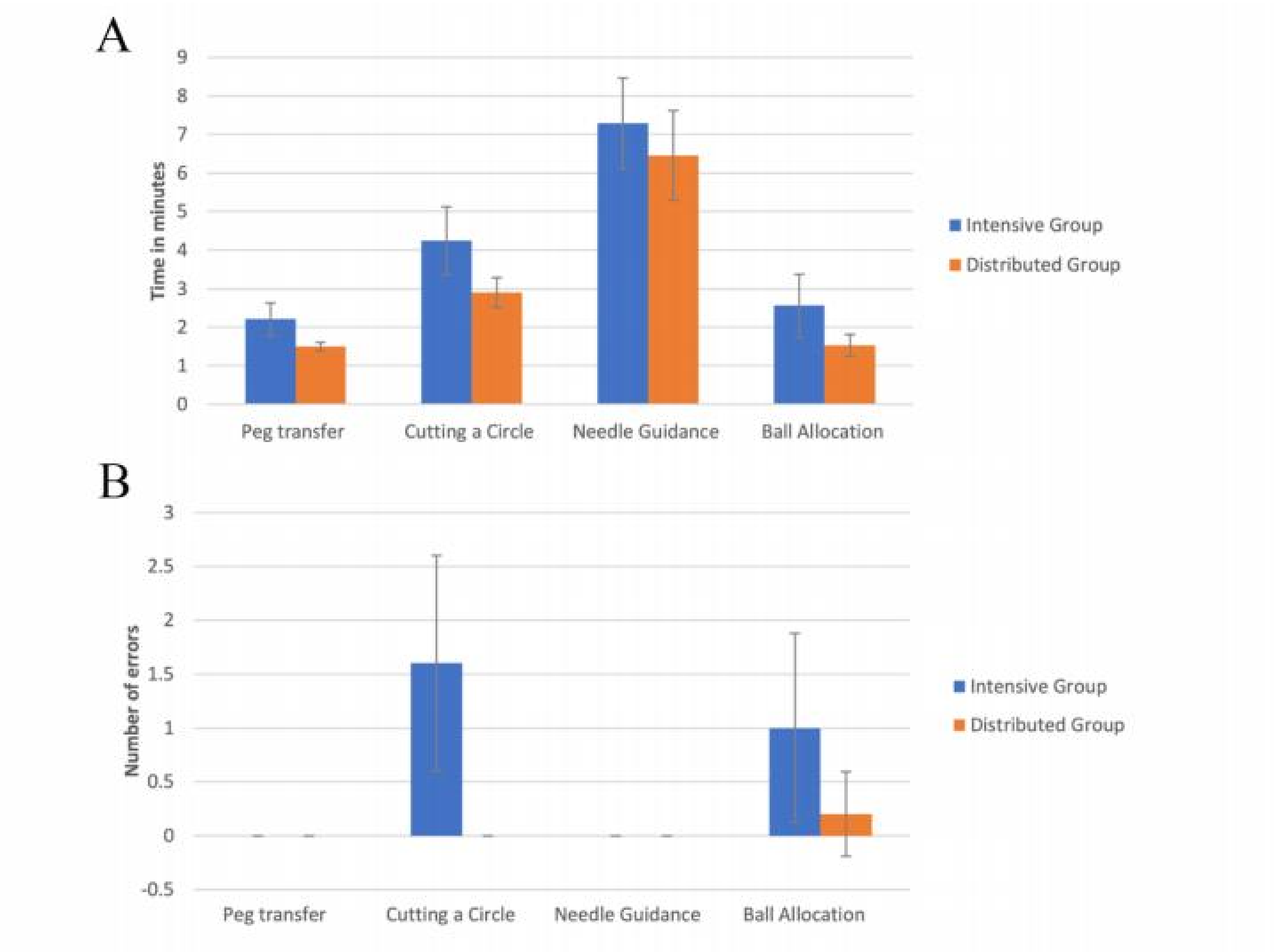

Fig 6. Between-group task performance and error comparison during a follow-up exam A- task completion time; B- error rates.

4. Discussion

Box trainers play an important role in laparoscopic skill development, offering a practical and accessible way to learn basic surgical techniques. This seemingly simple device allows students to practice using real surgical instruments in a controlled, risk-free environment. This study demonstrated that medical students with no prior laparoscopic experience could effectively acquire skills through structured simulation-based training. Notably, the distributed training model consistently outperformed the intensive model in skill retention, error control, and task performance during follow-up.

The retention analysis (Table 1) highlighted significant differences in skill maintenance between the training models. The distributed group retained shorter task completion times and near-zero error rates across most tasks. For the peg transfer task, the distributed group maintained a median completion time of 1.50 minutes (IQR: 0.12), while the intensive group exhibited a significant performance decline at follow-up ($p = 0.031$, $d = 1.44$). Similarly, for the cutting a circle task, the distributed group stabilized at 2.91 minutes (IQR: 0.44), outperforming the intensive group, which showed slower times (4.25 minutes, IQR: 1.00, $p = 0.015$,'s $d = 1.83$). The needle guidance task posed greater challenges for both groups, but the distributed group demonstrated more consistent retention, with lower variability and fewer errors. In the ball allocation task, retention differences were less pronounced. However, the distributed group showed a trend toward better performance, with slightly faster completion times and lower error rates ($p = 0.070$, $d = 1.46$).

Follow-up exam performance comparisons (Table 2) further emphasized the distributed group's superiority in task performance. In the peg transfer task, the distributed group completed the task significantly faster ($p = 0.014$, $d= 1.97$) and with fewer errors than the intensive group. Similarly, for the cutting a circle task, the distributed group demonstrated shorter completion times ($p = 0.036$, $d = 1.74$) and lower error rates ($p = 0.035$, $d = 1.98$). Although differences in the ball allocation task did not reach statistical significance, the distributed group's performance trend remained favorable ($p = 0.070$, $d= 1.46$).

Our findings align with previous studies comparing distributed (spaced) and intensive (massed) laparoscopic training models, with distributed practice frequently showing advantages in long-term retention and error control. Novice trainees require approximately 8-9 repetitions to stabilize their laparoscopic performance, while experienced surgeons need only 2-4 repetitions to reach a similar level of proficiency, indicating a slower learning curve for beginners [13]. This trend was evident in our distributed group, where task completion times steadily improved, while the intensive group plateaued after early rapid progress. A study comparing spaced and massed laparoscopic training models further supports this. The spaced group, training over three weeks, achieved 65% proficiency compared to 21% in the massed group, with 55% higher accuracy and faster completion times, especially in complex tasks like suturing [14]. Standardized, task-specific training models are crucial for improving technical proficiency and functional outcomes in robotic and laparoscopic surgery. Structured protocols reduce variability in skill acquisition [15]. Similarly, the PROVESA trial demonstrated that proficiency-based progression (PBP) training has significantly improved technical skills in robotic surgery compared to traditional training (TT). The PROVESA trial showed that 12 out of 18 participants in the PBP group reached a predefined proficiency benchmark compared to only 3 out of 18 in the TT group. Additionally, the PBP group showed a 51% reduction in performance errors from baseline to final assessment, while the TT group showed minimal improvement (15.94 vs. 15.44 errors) [16]. These findings demonstrate the effectiveness of structured, standardized training models. The PBP method maintains consistent task complexity and objective performance assessment, supporting the use of validated tools such as the E-BLUS standards and the Laparo Advance, box trainer for skill development in robotic and laparoscopic surgery.

The comparison between distributed and massed practice schedules in surgical education highlights significant implications for skill acquisition, retention, and curriculum design. Evidence strongly supports distributed training over massed practice in surgical education [17,18]. Spacing sessions over time allows learners to process and practice skills without mental overload [19,20]. This promotes better long-term memory consolidation and steady skill improvement, which are essential for learning surgical techniques. Moreover, adding planned rest periods into distributed training can make learning even more effective. Rest, especially naps, helps reduce the chance of forgetting and supports better memory for new skills [21]. For example, tasks requiring precision, like needle guidance or surgical suturing, benefit not only from distributed model training [18], but also from incorporating rest or naps immediately after practice sessions [21]. Regular, shorter sessions enable steady progress and consistent performance, minimizing variability often seen in intensive, massed training schedules [17].

This study had several strengths. Its prospective design minimized recall bias and allowed for real-time data collection, ensuring accurate tracking of skill progression. The use of the standardized box trainer and E-BLUS-aligned tasks ensured consistent training conditions. Multiple tasks provided a comprehensive evaluation of various laparoscopic skills, including precision, coordination, and depth perception. However, the study also had limitations. The small sample size (n=10) reduced statistical power and generalizability. The short follow-up period (one month) did not capture longer-term retention patterns. Finally, the exclusion of advanced skills, such as laparoscopic suturing, limited the applicability of findings to more complex procedures.

5. Conclusion

Both intensive and distributed laparoscopic training models effectively facilitated skill acquisition among medical students with no prior laparoscopic experience. However, distributed training proved more effective for long-term retention, reducing error rates, and maintaining consistent performance during follow-up assessments. These findings support the use of spaced learning models in laparoscopic training, especially for tasks that require precision and fine motor skills. Future studies should focus on validating these findings with larger groups of participants, more advanced tasks, and longer follow-up periods. Such studies are needed to understand the long-term benefits of distributed training and its role in developing advanced surgical skills.

6. Disclosure

Authors do not report any disclosures

7. Authors' contribution:

Conceptualization: Layla Settaf-Cherif and Adam Ostrowski; Methodology: Layla Settaf-Cherif, Adam Ostrowski, Oliwia Kwiatkowska, and Łukasz Paszylk; Formal analysis and investigation: Layla Settaf-Cherif, Adam Ostrowski, Oliwia Kwiatkowska, Łukasz Paszylk; Writing - original draft preparation: Layla Settaf-Cherif, Anmol Khan, Katarzyna Malinowska; Writing - review and editing: Adam Ostrowski, Paweł Lipowski; Funding acquisition: not applicable; Resources: not applicable; Supervision: Jan Adamowicz, Tomasz Drewa.
All authors have read and agreed with the published version of the manuscript.

8. Funding:

The authors did not receive support from any organization for the submitted work.

9. Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Nicolaus Copernicus University in Torun, Ludwik Rydygier Collegium Medicum in Bydgoszcz (approval number KB 231/2024).

10. Consent to participate

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

11. Acknowledgments

Not applicable.

12. Conflict of Interest:

The authors declare that they have no conflict of interest.

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