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Implementing Cognitive Training Into a Surgical Skill Course: A Pilot Study on Laparoscopic Suturing and Knot Tying

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Abstract

Mini-invasive surgery—for example, laparoscopy—has challenged surgeons' skills by extending their usual haptic space and displaying indirect visual feedback through a screen. This may require new mental abilities, including spatial orientation and mental representation. This study aimed to test the effect of cognitive training based on motor imagery (MI) and action observation (AO) on surgical skills. A total of 28 postgraduate residents in surgery took part in our study and were randomly distributed into 1 of the 3 following groups: (1) the basic surgical skill, which is a short 2-day laparoscopic course + MI + AO group; (2) the basic surgical skill group; and (3) the control group. The MI + AO group underwent additional cognitive training, whereas the basic surgical skill group performed neutral activity during the same time. The laparoscopic suturing and knot tying performance as well as spatial ability and mental workload were assessed before and after the training period. We did not observe an effect of cognitive training on the laparoscopic performance. However, the basic surgical skill group significantly improved spatial orientation performance and rated lower mental workload, whereas the 2 others exhibited lower performance in a mental rotation test. Thus, actual and cognitive training pooled together during a short training period elicited too high a strain, thus limiting potential improvements. Because MI and AO already showed positive outcomes on surgical skills, this issue may, thus, be mitigated according to our specific learning conditions. Distributed learning may possibly better divide and share the strain associated with new surgical skills learning.

Keywords

motor imagery, observation, minimally invasive surgery, learning, mental workload

Introduction

Minimally invasive surgery shows several benefits over open surgery: lower postoperative pain, lower morbidity, and shorter hospitalization duration.^{1–4} However, at the early stages of learning surgical skills, minimally invasive surgery is associated with increased risk of complications (eg, complications of access, vascular complications, perforation of the gallbladder, bile duct injury).^{5–7} Indeed, handling instruments with extended upper limbs and the hands while obtaining less accurate cues about depth and direct haptic feedback was likely to (1) increase difficulty in usual surgical skills performance and (2) elicit higher cognitive demands—for example, additional spatial abilities—resulting in higher mental load.

Moreover the “fulcrum effect,” arising from the insertion of long and rigid tools into the body via fixed ports, may elicit counterintuitive movements in a closed haptic space, with a risk of seriously limiting degrees of freedom during upper limbs movements. Learning these skills is a

major challenge that encourages the medical and surgical curricula to provide relevant solutions for young surgeons' training.⁸

Therefore, virtual reality is increasingly used in surgical training programs.⁹ It is available in several forms and at various levels of sophistication (eg, screen-based simulation or simulators). It gives the opportunity of

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training without fearing an error or harming patients' health. Repeating movements is a means for building automated skills, limiting execution variability, and increasing effectiveness. Nevertheless, some disadvantages such as high costs and training systems availability¹⁰ may explain the emergence of other surgical training methods. Therefore, simulators may be inaccessible to many trainees for regular personal use, thereby hindering skills retention.^{11,12}

Other complementary methods such as mental¹³ or motor imagery¹⁴ (MI) and action observation (AO)¹⁵ have also been explored. Mental imagery is the mental representation of objects or persons. It stimulates spatial abilities. In turn, spatial abilities may influence mental imagery.¹⁶ For example, surgeons must construct mental images of anatomical structures as well as their absolute and relative position before mentally manipulating them. This implicit imagery is believed to favor surgery skills learning.¹⁷⁻²³ On the other hand, MI is the mental simulation of actions while remaining motionless. This is also a complementary method of learning and improving motor skills in sport performance²⁴ or motor rehabilitation.²⁵ The effectiveness of MI is confirmed by the fact that neural networks that control MI share common cerebral regions responsible for motor execution.²⁶ Finally, AO is an externally guided motor simulation.²⁷ The discovery of the mirror neurons system²⁸ encourages AO in learning complex motor tasks. AO gives a clear representation of the expected action.¹⁵ Indeed, cortical activations recorded during AO also matched, although partially, those observed during covert motor activity.²⁹ Furthermore, stronger activations occurred when AO is combined with MI.²⁷ Several experiments have already confirmed the positive effect of cognitive training on surgical skills.^{13,30,31} Mental imagery training has been shown to improve cystoscopy performance¹³ and open surgery suturing,³¹ whereas MI improved simulated laparoscopic cholecystectomy performance.³⁰ The review by Schuster et al³² reported that cognitive training during supervised and nondirected sessions led to more successful outcomes. However, several features (eg, the discipline, duration of training sessions, and number of MI trials) should be taken into account while implementing cognitive training into an academic curriculum.³²

We selected a young surgeon panel to test the implementation of cognitive training in a core surgical skills course (ie, the basic surgical skill). More precisely, we aimed to test the impact of script-based MI and AO sessions on a laparoscopic suturing and knot tying task among first year postgraduate surgical residents (PGY-1). On the basis of the selected references that we described, showing the effect of mental training on motor performance, we hypothesized that MI and AO would improve

both suturing and knot tying performance as well as participants' spatial abilities.

Material and Methods

Participants and Training

A total of 28 PGY-1 surgical residents (20 men and 8 women, mean age = 24.6 years, SD = 3.03) enrolled in Lyon School of Surgery (France) agreed to participate in our study. The FY-1 level, the equivalent level of PGY-1 in Great Britain, requires 6 months in a surgical training position. All participants, thus, had the same level of practice. We informed the participants that the purpose of the study was to test a new learning method for laparoscopic suturing and knot tying. The local ethics research board approved the study, and all participants signed an informed consent form. We randomly split the participants into 1 of 3 groups: the MI + AO experimental group (EXP), the basic surgery skill group (BSS), and the control group (CTRL). Randomization in permuted blocks was conducted to achieve balance across groups using the package *blockrand*³³ of R.³⁴ The randomization scheme consists of a sequence of blocks such that each block contains a prespecified number of group assignments in random order. With the exception of the participants assigned to the CTRL group, all followed a 2-day training session based on basic surgery skills. The training was designed to provide the essential basic technical skills required for surgery. More precisely, on completion of the course, participants should be able to: (1) explain the principles of knot tying, suturing, hemostasis, anastomosis, surgical diathermy, and ergonomics for endoscopic surgery; (2) describe correct handling and use of instruments; (3) know the standards for gowning and gloving; (4) tie reef and Aberdeen knots as tying at depth; (5) suture skin, bowel, vascular tissue, and tendons effectively; (6) perform abscess drainage and wound management and finally demonstrate small bowel, vascular, and tendon anastomoses (for detailed information, see <https://www.rcsed.ac.uk/events-courses/event-entry?courseDefId=506>).

The EXP group (n = 10) underwent the basic surgery skill training. They additionally underwent cognitive training for laparoscopic knot tying. The MI training included 2 sessions a day during the 2 days. Each session included a video observation (an 8-minute sequence showing laparoscopic suturing and knot tying performed by expert surgeons), followed by a MI session during the same time (8 minutes). Participants were isolated in a quiet room where they watched the same video on a large screen. During MI, the participants were free to close their eyes or not. A script describing the suturing and knot tying procedure was read aloud by the same investigator.

The BSS group (n = 9) underwent basic surgery skill training. Additionally, all participants had a neutral activity—that is, free discussion with the experimenter

for a duration equivalent to that of the MI sessions. Finally, the CTRL group ($n = 9$) had no activity and was included in the experimental design to control any biased effect caused by test habituation because the pretest and the posttest were separated by 1 day only.

Procedure and Variables

We assessed surgical performance, spatial abilities, and cognitive load 1 day before and 1 day after training in all groups. We used the mental rotation test³⁵ (MRT) and the Spatial Orientation test³⁶ (SO) for assessment of spatial abilities. The MRT consists of 24 items. Each item contains a row of 5 geometrical drawings, including a target figure on the left and 4 response choice figures on the right (2 rotated reproductions of the target and 2 distractors are presented at random³⁷). Participants were requested to indicate which 2 of the 4 response choice figures were rotated reproductions of the target figure. To do this, they had to mentally rotate each response choice figure in 3-dimensional space. The allocated time to answer the test was 6 minutes. The number of correct responses was collected. A correct answer was granted only when the 2 figures matching the target were correctly found. The highest score was thus 24. The SO tests the participants' ability to imagine different perspectives or orientations in space. The SO test consisted of a booklet with a separate page for each of the test items. Each item shows a picture of an array of objects (eg, house, flower, tree, car) and an "arrow circle" with a question about the direction between some of the objects. For the question on each page, participants should imagine themselves standing at one object in the array (eg, the car; the word "car" will be named in the center of the arrow circle) and facing another object (eg, traffic light; the word "traffic light" will be named at the top of the arrow circle). The task was to draw an arrow from the center object (the car) showing the direction to a third object (eg, the stop sign) from this facing orientation. Here is an example of questions: "Imagine you are standing at the car and facing the traffic light. Point to the stop sign." Each participant had to complete 12 different items within a 5-minute period. Physically rotating the booklet was forbidden. The final performance includes the errors (in degrees) between the indicated location and the correct location of the object.

Surgical performance assessment consisted of suturing and tying a knot in a box trainer with the laparoscopic instruments within a 4-minute time period.³¹ Two blinded senior surgeons assessed the procedure and the performance, using a modified version of the Objective Structured Assessment of Technical Skill Scale³⁸ (OSATS). Following previous studies,^{13,39,40} our modification consisted of adapting the content of the items to our specific task but

using the same rating scales. The rating scale assessed 8 components of the surgical suturing and knot tying using 6-point Likert scales (1 was for the worst execution with none of the criteria observed, and 6 was for the best performance, thus respecting all criteria). The highest score was 48. The 8 assessed criteria were (1) participant position, (2) needle handling, (3) needle insertion, (4) needle extraction, (5) knot integrity, (6) tissue respect, (7) handling efficiency, and (8) overall performance. Before starting the experimental phase, the experimenters agreed on how to assess each criterion unambiguously and clarified any potential sources of discrepancy. Each assessor evaluated the same sample of participants 1 day before and 1 day after the training sessions.

After they completed the test, each participant completed the NASA-Task Load Index (TLX).⁴¹ The NASA-TLX evaluates the load associated with the laparoscopic task. It is a 2-part evaluation procedure. First it rates the contribution of the following 6 factors to the laparoscopic task workload: (1) mental demand, (2) physical demand, (3) time constraint, (4) performance, (5) frustration level, and (6) general effort. Each item provides information about the nature of the workload imposed by the laparoscopic task. The second part consisted of rating the relative contribution of each factor to the whole workload by comparing each item to the 5 remaining others. Each participant performed 15 pairwise comparisons, thus selecting the factor contributing the most to the overall workload. The number of times each factor is selected is noted and then tallied; finally, its relative contribution to the whole load is rated with a single coefficient. Thus, the overall estimated workload results from multiplying each single rating by the weight given to each of the 6 factors. This method ensures a reliable internal consistency. The NASA-TLX is considered a valid tool to assess mental workload in laparoscopic surgery.⁴²⁻⁴⁴ It was also highly correlated with high eye-blink frequency.⁴⁵ Figure 1 shows a flowchart summarizing the overall experimental procedure.

Data Analysis

We used R (R Core Team, 2015) and the package *lme4*⁴⁶ to run a linear mixed-effect analysis of MRT, SO, OSATS, and NASA-TLX scores as dependent variables. As fixed effects, we used test (pretest and posttest) and group (CTRL, BSS, and EXP) with an interaction term. As random effects, we had intercepts by participants. Visual inspection of residual plots did not reveal any obvious deviation from homoscedasticity or normality. We measured the effect sizes in terms of the proportion of variance explained by the linear mixed-effects models using the Ω_0^2 method recommended in Xu.⁴⁷ We computed the P values by

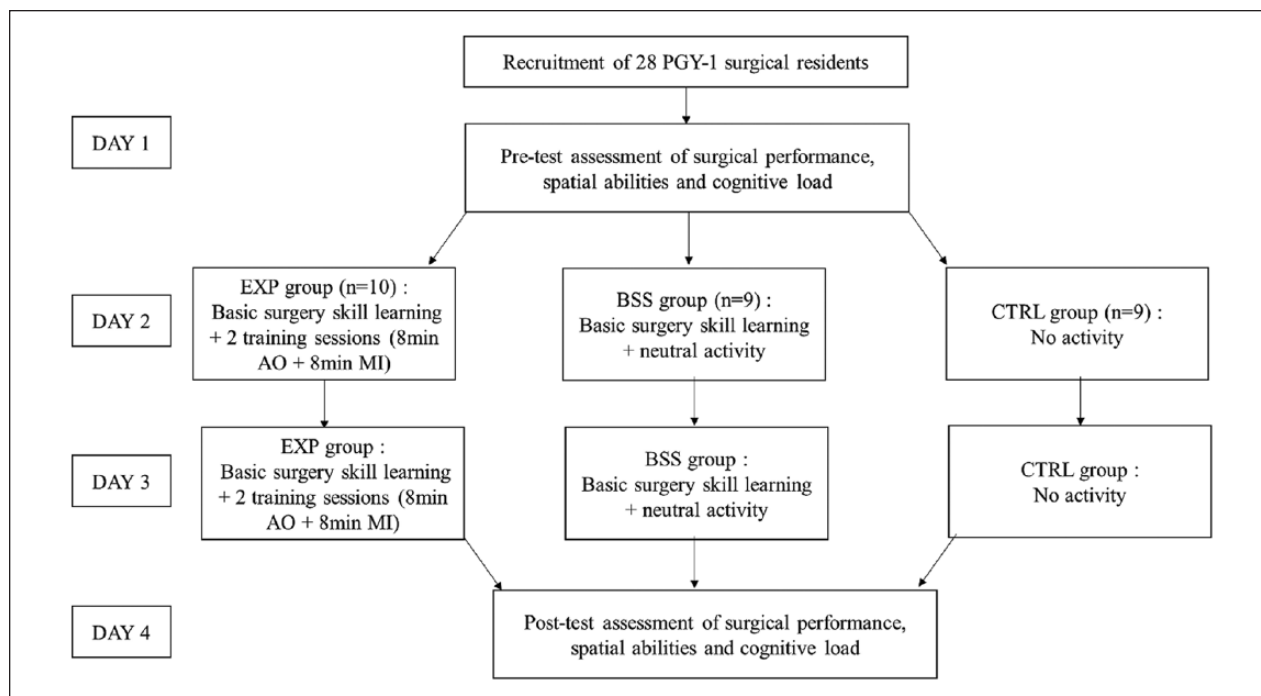


Figure 1. Flowchart of the study process.

Abbreviations: PGY-1, first year postgraduate surgical residents; EXP, experimental group; BSS, basic surgery skill group; CTRL, control group; AO, action observation; MI, motor imagery.

likelihood ratio tests of the full model with the effect in question against that without the effect in question. The statistical significance threshold was set up for a type 1 error rate of 5%. We performed post hoc comparisons using contrast tests of least-mean-square estimates and applied Holms' sequential corrections to control the false discovery rate.⁴⁸

Results

Assessment of Test \times Group Interactions

The linear mixed-effects analysis revealed no Test \times Group interaction [$\chi^2(2) = 0.03$; $P = .98$; $\Omega_0^2 = 0.74$] for the OSATS, whereas the same interaction approached the statistical threshold for the NASA-TLX [$\chi^2(2) = 3.84$; $P = .07$; $\Omega_0^2 = 0.62$], the MRT [$\chi^2(2) = 3.36$; $P = .09$; $\Omega_0^2 = 0.75$], and the OS [$\chi^2(2) = 3.25$; $P = .10$; $\Omega_0^2 = 0.69$].

The BSS group exhibited lower NASA-TLX scores during the posttest (60.15 ± 24.05) than during the pretest (74.96 ± 10.51 , $P = .01$). Conversely, there was no difference between pretest and posttest scores in the CTRL (pretest: 66.59 ± 12.83 ; posttest: 73.33 ± 15.51) and EXP groups (pretest: 69.50 ± 9.64 ; posttest: 68.93 ± 14.26 ($P > .05$; Figure 2).

We further investigated the NASA-TLX posttest scores by including the dimension factor corresponding

to the NASA-TLX subscores (physical, mental, temporal, and frustration demand) in the linear mixed-effects analysis. This revealed a Group \times Dimension interaction [$\chi^2(6) = 12.71$; $P = .05$; $\Omega_0^2 = 0.32$]. In the CTRL and BSS groups, there was no difference between physical (CTRL: 44.44 ± 26.98 ; BSS: 26.67 ± 22.36), mental (CTRL: 68.33 ± 15.41 ; BSS: 57.22 ± 19.86), temporal (CTRL: 50.00 ± 23.45 ; BSS: 61.67 ± 34.64), and frustration demand (CTRL: 58.89 ± 27.25 ; BSS: 58.33 ± 38.41) subscores of the NASA-TLX (ie, all $P > .05$). Conversely, frustration (80.00 ± 24.04) and mental demand (69.50 ± 23.39) subscores were higher than physical demand (28.50 ± 15.10) subscores in the EXP group (both $P < .01$; Figure 3).

The MRT scores were lower in the EXP ($P < .01$) and CTRL ($P < .001$) groups during the posttest (EXP: 8.10 ± 3.45 ; CTRL: 7.78 ± 4.18) than during the pretest (EXP: 11.40 ± 4.43 ; CTRL: 12.56 ± 4.39). The difference did not reach significance in the BSS group (pretest: 11.00 ± 4.87 ; posttest: 9.44 ± 3.36 ; $P > .05$; see Figure 4).

The BSS group improved the SO test performance between the pretest ($37.16^\circ \pm 32.69^\circ$) and posttest ($23.17^\circ \pm 8.26^\circ$; $P = .04$), whereas the CTRL (pretest: $30.34^\circ \pm 27.17^\circ$; posttest: $23.76^\circ \pm 8.45^\circ$) and EXP groups (pretest: $27.75^\circ \pm 14.46^\circ$; posttest: $29.67^\circ \pm 21.24^\circ$) did not (both $P > .05$; see Figure 5).

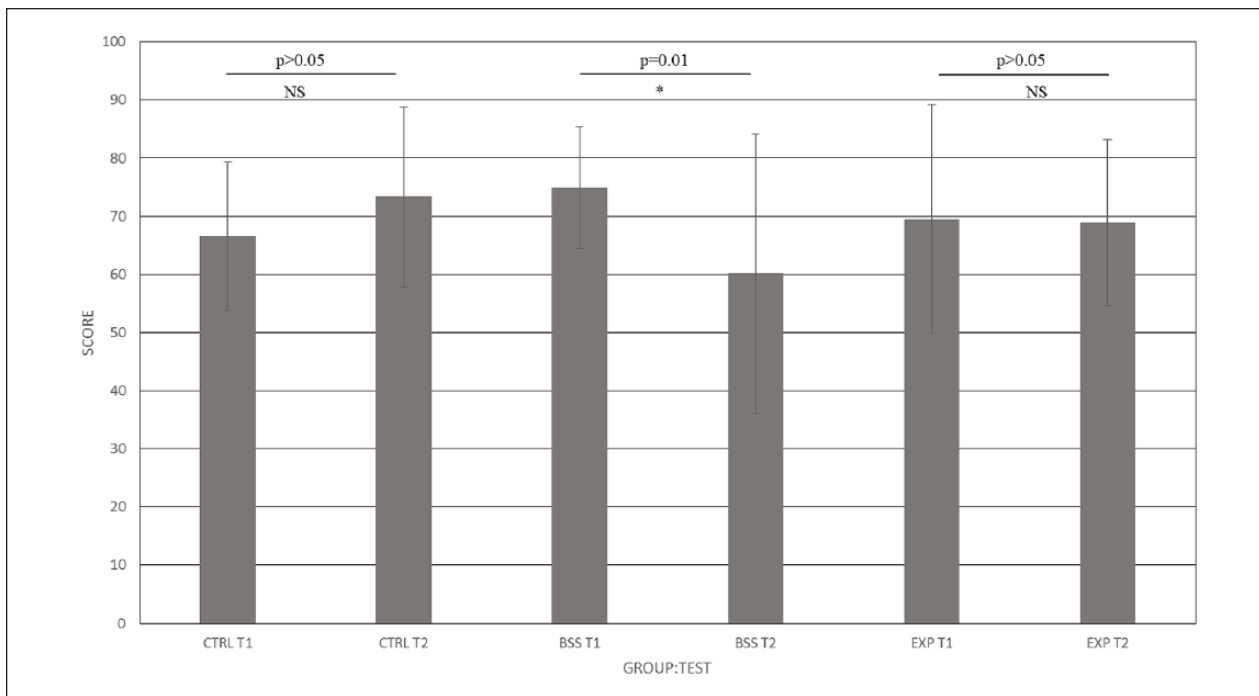


Figure 2. NASA-TLX: evolution of the total mental workload elicited by the task between the pretraining (T1) and posttraining tests (T2) among the 3 groups.^a

Abbreviations: TLX, Task Load Index; NS, statistically nonsignificant; CTRL, control group; BSS, basic surgery skill group; EXP, experimental group.

^a *p < .05; **p < .01; ***p < .001.

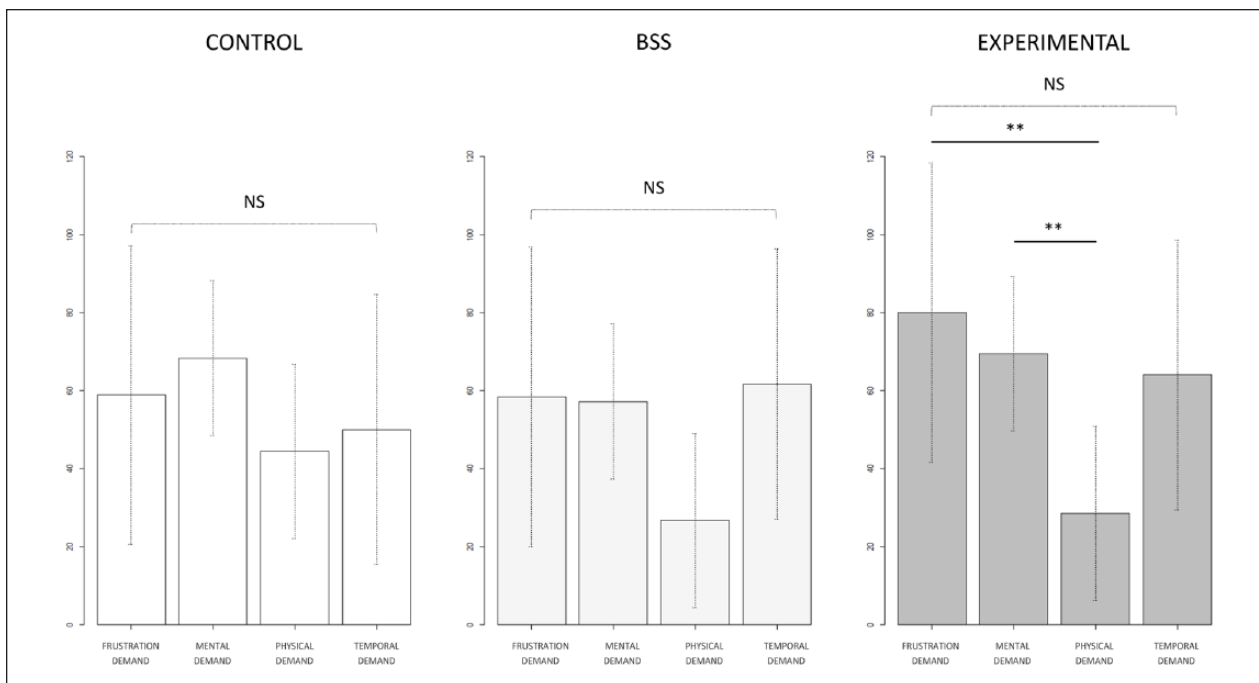


Figure 3. NASA-TLX subscores: frustration, mental, physical, and temporal demand scores on the posttraining test (T2) among the 3 groups.^a

Abbreviations: TLX, Task Load Index; NS, statistically nonsignificant; BSS, basic surgery skill group.

^a *p < .05; **p < .01; ***p < .001.

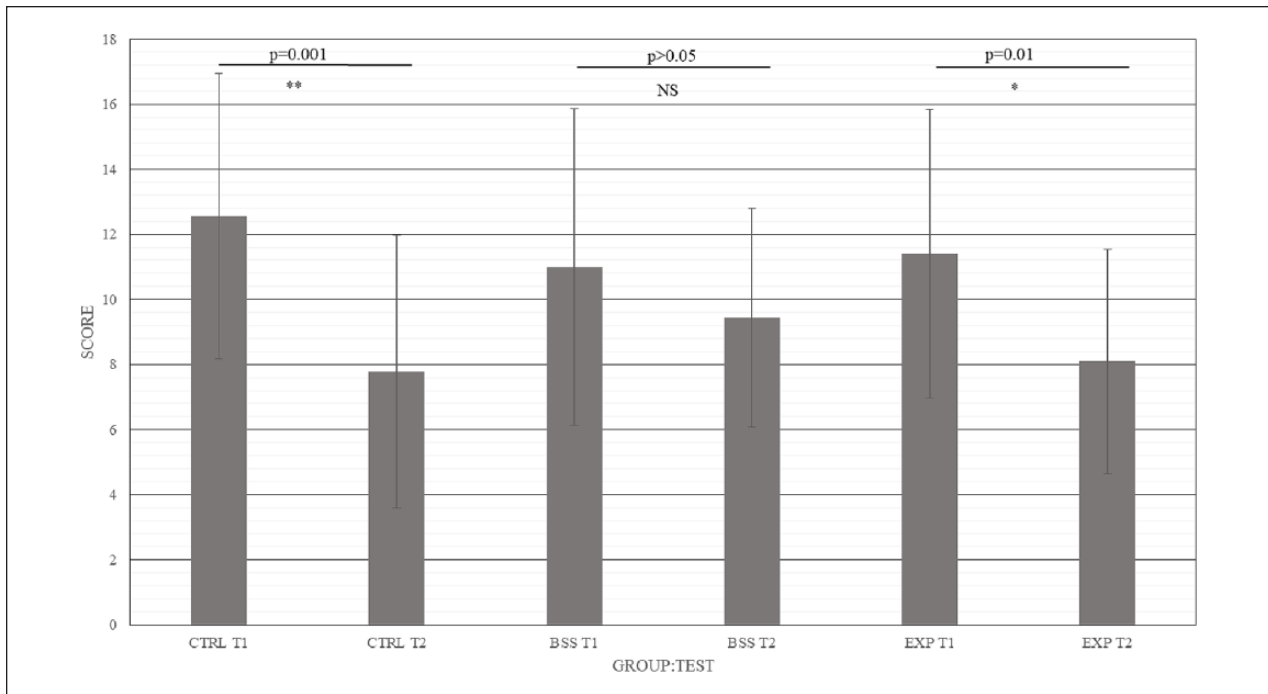


Figure 4. Mental rotation test: evolution of the mental rotation test scores between the pretraining (T1) and posttraining tests (T2) among the 3 groups.^a

Abbreviations: NS, statistically nonsignificant; CTRL, control group; BSS, basic surgery skill group; EXP, experimental group.

^a * $p < .05$; ** $p < .01$; *** $p < .001$.

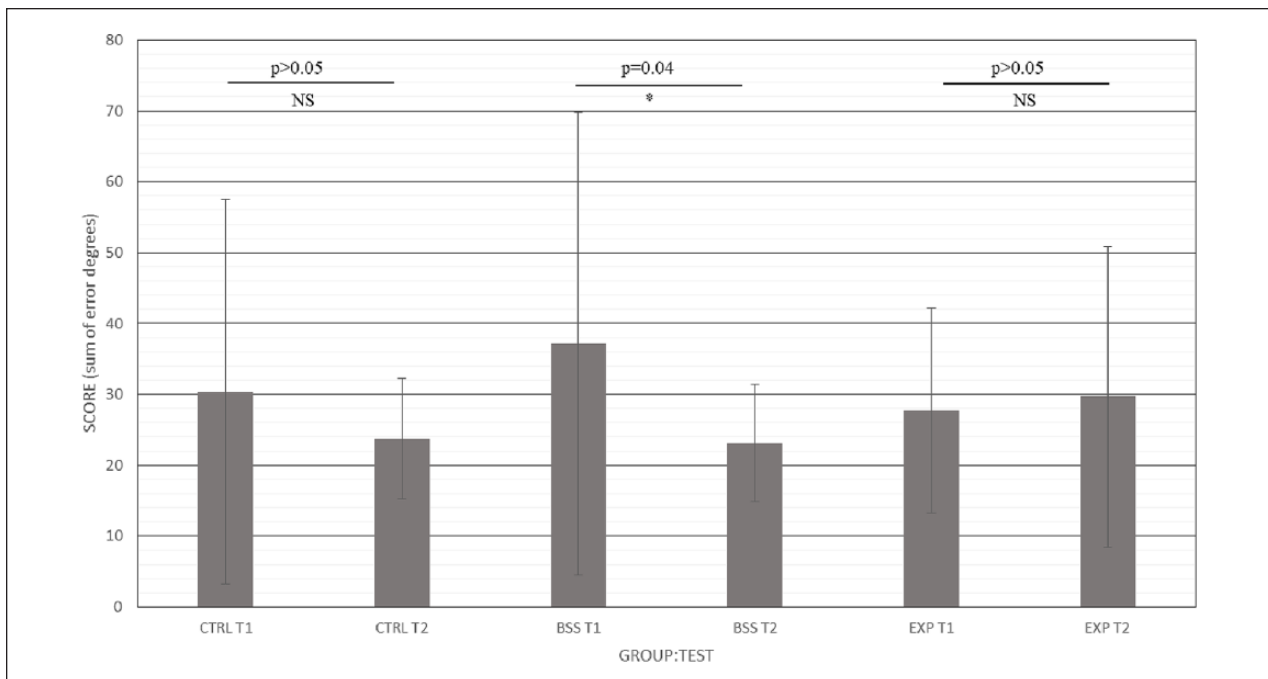


Figure 5. Spatial orientation: evolution of the spatial orientation test scores (sum of error degrees) between the pretraining (T1) and posttraining tests (T2) among the 3 groups.^a

Abbreviations: NS, statistically nonsignificant; CTRL, control group; BSS, basic surgery skill group; EXP, experimental group.

^a * $p < .05$; ** $p < .01$; *** $p < .001$.

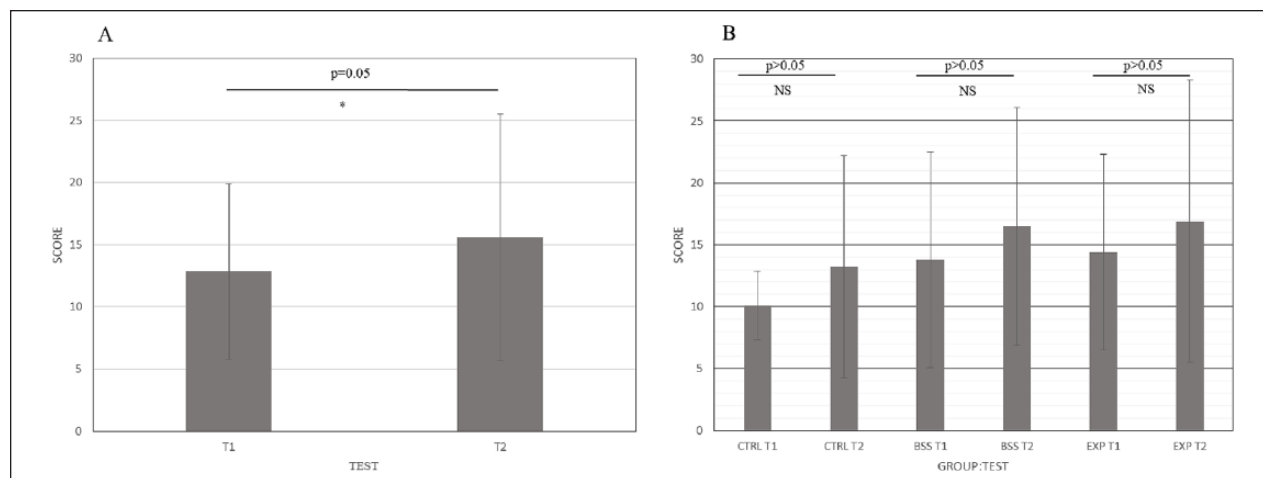


Figure 6. Surgical performance (OSATS): evolution of suturing and knot tying performance scores through the OSATS scale between the pretraining (T1) and posttraining tests (T2) within the whole population (A) and among the 3 groups (B).^a

Abbreviations: OSATS, Objective Structured Assessment of Technical Skill Scale; NS, statistically nonsignificant; CTRL, control group; BSS, basic surgery skill group; EXP, experimental group.

^a * $P < .05$; ** $P < .01$; *** $P < .001$.

Assessment of Main Test and Group Effect

The linear mixed-effect analysis yielded a main test effect for OSATS [$\chi^2(1) = 3.66$; $P = .05$] attesting increased performance from the pretest (12.86 ± 7.07) to the posttest (15.61 ± 9.92) within the whole population. There was, however, no main group effect ($P > .05$; Figure 6).

Discussion

The aim of our study was to test whether implementing cognitive training during a 2-day training session affected basic surgical skill performance (ie, laparoscopic suturing and knot tying). To do this, we integrated script-based MI and AO simultaneously with classical learning based on actual execution. We also had a control group to prevent any biased effect caused by test habituation because the pretest and posttest were separated by only 1 day.

The main result of our experiment is that cognitive training through MI and AO did not yield evidence of significant improvement of laparoscopic suturing and knot tying quality, as assessed by the OSATS. Our result contradicts many previous publications on this topic.^{14,30} However, the outcomes provide some valuable information about the design and implementation of cognitive training sessions in the basic surgical skills course.

This result does not match those previously described in the scientific literature either in professional skills,^{14,30,49,50} sport activities,⁵¹⁻⁵⁴ or both⁵⁵ or even in people with motor disability.⁵⁶⁻⁵⁸ Focusing on the possible different efficacies of MI and AO, Gonzalez-Roja et al⁵⁹ compared these cognitive tools in promoting early

learning of a complex 4-limb, hand-foot coordination task. On the basis of electroencephalogram pattern analysis, they reported that AO was more effective than MI in promoting early learning of a new coordination task.

As far as our results are concerned, data revealed a slight improvement in laparoscopic suturing and knot tying performance for all groups without better improvement in favor of the EXP group (see Figure 6). MI associated with AO was, thus, not as efficient as expected in the learning of a surgical skill by novice surgeons during a 2-day condensed course. Yet Arora et al³⁰ had previously reported how mental practice may enhance surgical technical skills, specifically for laparoscopic surgery (see also Arora et al¹⁴ for a comparison between experienced and novice surgeons).^{14,30} We must, therefore, explain why we did not confirm previous results in the particular case of learning suturing and knot tying through laparoscopy. We must then refer to the effective rules of mental practice, so that mental training may be integrated in the learning process of surgical techniques, as recommended by Arora et al.³⁰

First, let us go back to the experimental design of Arora et al.³⁰ Actually, each participant performed 1 laparoscopic intervention per day on a full procedural simulator for 5 days (sessions). Before each session, the experimental group received mental practice training for 30 minutes, whereas the control group did not. The training sessions were spread over 5 days, whereas these were condensed to only 2 days in our experiment. Learning theory suggests that distributed learning may better facilitate long-term maintenance of behavior change, particularly during the early learning stages.⁶⁰ At a more practical

level, it is generally advised to distribute training sessions across time to better favor learning and retention in novice learners.⁶¹ Massed practice schedules very short rest periods between practice sessions or trials, whereas in distributed practice, the amount of rest between practice sessions or trials is relatively long. According to Ferrari et al,⁶² distributed repetition may facilitate later memory performance because of spontaneous retrieval of prior representations. This was confirmed by Bradley et al,⁶³ who reported that distributed repetition prompts spontaneous retrieval of prior occurrences. In parallel, massed repetition prompts short-term maintenance of the episodic representation because of contiguous presentations. Both studies clearly showed different correlates of learning procedures in brain potentials and oscillatory activity⁶² as well as in fMRI activity.⁶³ Although the optimal gap between the restudy sessions remains unclear, a systematic review clearly evidenced that spacing training sessions improves long-term surgical skills retention when compared with massed practice.⁶⁴ We could, thus, suggest that massed practice is a potential factor that prevented significant progress in learning surgical suturing and knot tying in our experiment. Other features should, nevertheless, be considered, including many other interfering factors during learning: for example, duration of each training session, number of MI trials during each training session, or total time of MI practice. Indeed, while the question of maintenance training has already been posed by Van Bruwaene et al⁶⁵ in a useful review, there are still remaining concerns about the best learning and training procedures for laparoscopic suturing. The questions raised in this review mainly aimed to elucidate the ideal timing and frequency of maintenance training (including 1 massed and 2 distributed training groups). Although the authors underlined the existence of training programs for acquiring the skills required in laparoscopic suturing, the question of whether complementary training procedures with MI and AO would be more efficient was not addressed. In a very thorough review, Schuster et al³² examined publications that integrate MI into skills learning sessions from 5 different disciplines (medicine, education, psychology, music, and sport). The main rules extracted from the selected literature led to the mention of several features—for example, average study intervention lasted 34 days, with participants practicing MI on average 3 times per week for a mean time of 17 minutes, with 34 MI trials. The average total MI time was 178 minutes, including 13 MI training sessions. Although these data provide useful knowledge about MI training, there is considerable variability around the mean—that is, very marked differences among these disciplines, whereas the same abilities are often required. We must, therefore, acknowledge that mental procedures accompanying actual training are not entirely and accurately determined.

Another confounding factor that could have worked against improvement in the EXP group is the difficulty to manage total workload under substantial time constraints. Participants of the EXP group had to manage actual execution associated with mental practice based on both MI and AO. Therefore, they must have probably experienced high strain conditions. In the 2 consecutive days of training laparoscopic suturing and knot tying, it was not possible to adapt actual training sessions to mental practice. We only had the opportunity to test whether MI and AO would improve learning by adding enough amount of mental practice to expect a significant effect. Unfortunately, massed practice associated with substantial time constraints in order to coordinate mental and actual training probably elicited a high workload, thus preventing learning. Indeed, as shown by the NASA-TLX scores, the EXP group had total workload unchanged after training, whereas the BSS group had significantly lowered the perceived total workload because of the automation process (Figures 2 and 3). Further investigations on NASA-TLX scores revealed that our EXP group experienced particularly high levels of frustration and mental load compared with the physical demand during the post-test. No such differences were present in the CTRL and BSS groups. It is, thus, suggested that implementing mental training to enhance laparoscopic suturing and knot tying into a condensed surgical course elicited an overload by increasing the overall cognitive demand of the course. Laparoscopic suturing can be considered a complex skill for novice surgeons because it requires the combination of spatial and motor abilities (ie, interlimb coordination). Actually, learning a new motor sequence is believed to activate both the spatial and motor networks.⁶⁶ Thus, sharing attentional resources on the motor and perceptive aspects of laparoscopic suturing through MI and AO may have exceeded available mental resources, thus preventing learning and then automation. Automated behavior is known to require less mental resources because it is improved—that is, it is a faster and more accurate execution. This likely explains the absence of performance improvement in the spatial tests by the EXP group (see Figures 4 and 5). On the other hand, the BSS group enhanced spatial orientation abilities and maintained mental rotation performance at the same level probably because the participants did not train under overload conditions (Figures 2-5). The latter result confirms that surgical skill learning requires spatial abilities.^{18,21,22} As stated by Uttal et al,⁶⁷ even a limited amount of practice involving spatial reasoning improves spatial abilities.

Our conclusions are more or less similar to those reported by Andersen et al,⁶⁸ where the authors underlined that distributed practice decreased cognitive load more consistently than in massed practice. They suggest that training should be organized as time distributed

rather than as massed blocks of practice, which is common in surgery skills training courses. The main benefit would be consolidation of skills and memory over time—both changes that we did not observe in our EXP group, as we nevertheless previously hypothesized.

Finally, and more surprisingly, the CTRL group, which did not attend the basic surgical skill course had similar outcomes as the 2 other groups during the OSATS retention test. The absence of significant improvement for the BSS group confirmed that classical learning methods need to be updated to improve minimally invasive surgery learning.⁸ This last observation also leads to several limitations by considering 3 complementary hypotheses: (1) the memory consolidation hypothesis, needing the processing of time, in particular by studying retention duration and potential transfer as dependent variables; (2) deepening the potential cognitive overload as a negative effect on attention and, thus, learning abilities; and (3) the fatigue hypothesis by following perceived exertion along the course because fatigue has a strong negative influence on learning.

Conclusion

Two main results may be underlined: first, MI associated with AO may be inefficient in learning new surgical skills when appropriate conditions of learning are not provided. To be more efficient, we could assume that MI and AO should be used as follows: First, (1) cognitive training should not be implemented into a condensed training program—for example, the basic surgical skill course—especially for complex tasks such as laparoscopic suturing and knot tying and when the learners are novices; this would require much more time to assimilate additional mental workload brought by MI and AO; and (2) cognitive training should be more adapted for intermediate to advanced surgeons to strengthen already acquired and memorized techniques (in particular, those related to spatial abilities). Second, without questioning the effectiveness of MI in learning surgical techniques, we can nevertheless assume that the studies that have been carried out on this topic without bringing any probative effect have not been published. We, therefore, do not have any information about the conditions under which the effects of MI have not been proven. Collaboration between surgeons and cognitive neuroscientists specialized in motor learning is one of the main means to complete data and results that are already available. Finally, several upgrades could be added to future investigations. To enable a learning curve, surgical performance should be evaluated on more trials (at least 3 while keeping the median performance) and over a longer training period. Interrater and intrarater reliability measures would provide more accuracy, and a demographic questionnaire

about habits (use of video games) of the participants would complete the understanding of spatial abilities.

Author Contributions

Study concept and design: Benjamin De Witte, Xavier Martin, Christian Collet, and Nady Hoyek

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Analysis and interpretation: Benjamin De Witte, Franck Di Rienzo, Christian Collet, and Nady Hoyek

Study supervision: Christian Collet and Nady Hoyek

Authors' Note

The last 2 authors are both principal investigators and supervisors of the doctoral dissertation.

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