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Mental skills training limits the decay in operative technical skill under stressful conditions: Results of a multisite, randomized controlled study

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ABSTRACT

Background: Overwhelming stress in the operating room can lead to decay in operative performance, particularly for residents who lack experience. Mental skills training can minimize deterioration in performance during challenging situations. We hypothesized that residents trained on mental skills would outperform controls under increased stress conditions in the simulated operating room.
Methods: Residents from Indiana University enrolled voluntarily in this institutional review board–approved study. Residents were stratified according to baseline characteristics and randomized into a mental skills and control group. Both groups trained to proficiency in laparoscopic suturing, but only the mental skills group received mental skills training. After training, technical skill transfer was assessed under regular and stressful conditions on a porcine model. Performance was assessed using an objective suturing score. The Test of Performance Strategies was used to assess the use of mental skills. Data were combined and compared with data that had been collected at Carolinas Healthcare System because residents underwent the same protocol.
Results: A total of 38 residents completed all study elements. There were no differences in the effects observed between sites. We observed no group differences at baseline. The groups achieved similar technical performance at baseline, posttest, and transfer test under low-stress conditions, but the mental skills group outperformed the control group during the transfer test under high-stress conditions.
Conclusion: Our comprehensive mental skills curriculum implemented with surgery residents at two institutions was effective at minimizing the deterioration of resident technical performance under stressful conditions compared with controls. These results provide further evidence for the effectiveness of mental skills training to optimize surgery trainees' technical performance during challenging clinical situations.

Background

Elite surgical performance is defined by mastery of individual, interpersonal, and environmental demands, and according to expert surgeons, mental readiness for the operative procedure is the most important factor for excellence in performance.[1] The cognitive demands of an operation, such as managing critically ill patients through quick clinical decision-making, maintaining attention on intricate technical details of an operative procedure under high stress for extended periods of time, ignoring distractions, and shifting attention rapidly between multiple sources of information, are critical for effective operative performance.[2–4] Inexperienced surgeons or trainees who have not developed effective coping strategies, however, can be overwhelmed easily by these increased cognitive demands.[3] Stress results from cognitive demands exceeding one's perceived ability to manage them, which can have substantial negative effects on operative performance.[5,6]

In a survey of the deleterious effects of surgeons' stress in the operating room (OR), 40% of responding surgeons had witnessed an intraoperative complication that was directly the result of the

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primary surgeons' level of stress.[7] Excessive stress, then, has the potential to cause errors that negatively impact patient safety. Accordingly, it is important to aid surgery trainees to develop strategies to manage stress effectively and optimize their performance.

Mental skills or psychologic strategies designed to help performers consistently achieve their optimal mindset for performance enable performers to manage stress effectively and generally enhance performance.[8,9] In a recent literature review, our group identified several mental skills that have been implemented with high performers in various high-stress disciplines other than the discipline of surgery, but to this point, mental imagery is the only skill implemented regularly in surgical education.[10] Accordingly, we sought to ameliorate this dearth in surgical education by developing a novel and comprehensive mental skills curriculum (MSC) and have implemented this curriculum with a diverse set of learners.[11–14]

Initially, our group implemented our MSC with surgery novices in a pilot study of its effectiveness during their laparoscopic skills training.[11] From baseline to posttest, we observed significant increases in novices' use of mental skills (ie, overall use of mental skills in practice and performance settings, attention, and mental imagery) and significantly increased laparoscopic technical performance. We also implemented two stress tests displaying strong evidence of validity to elicit stressful responses with novices during our pilot study, the Trier Social Stress Test (ie, a presentation-type task in front of an expert in the field) and a task of fine-motor control and dexterity in competition with each other.[12] After participation in our MSC, participants displayed significantly less stress and workload at posttest compared with baseline.

In a randomized controlled trial with surgical novices, we implemented our MSC with participants concurrently with laparoscopic skills training; whereas the control group only participated in laparoscopic skills training.[13] Participants completed two transfer tests of laparoscopic technical skill, an initial test immediately after training, and a retention test of skill after 2 to 3 months of no training. We observed that MSC-trained novices displayed significantly enhanced retention of operative technical skills compared with controls. Last, our group recently implemented this novel MSC with surgery residents in a randomized controlled trial.[14] MSC group residents engaged in laparoscopic skills training and received mental skills training, and the control group participants only received laparoscopic skills training. In a transfer test of laparoscopic technical skill under low-stress conditions and stressful conditions, we found that, although performance was similar between groups under low stress, the MSC-trained residents better maintained operative technical skills under stressful conditions compared with controls. The goal of the current study was to implement this MSC in a second institution and obtain evidence of external validity to support its effectiveness in enabling general surgery and obstetrics and gynecology residents to maintain their operative technical skills under stress. A secondary aim of the current study was to identify specific mental skills enhanced through our mental skills curriculum and identify areas for curricular refinement.

We hypothesized that, in a stressful, simulated clinical environment, residents who participate in this MSC would perform significantly better than controls who do not participate in the MSC.

Methods

After approval by our Institutional Review Board and Institutional Animal Care and Use Committee (the Indiana University School of Medicine, Indianapolis), 22 general surgery residents provided informed consent to participate voluntarily in this randomized controlled study at the university school of medicine during the 2016 to 2017 academic year. All participants followed the same study protocol (Fig 1) as had been applied at Carolinas Healthcare System (Charlotte, NC).[14] Given that the same protocol was used at both sites, data were combined and compared to assess any differences in findings between sites.

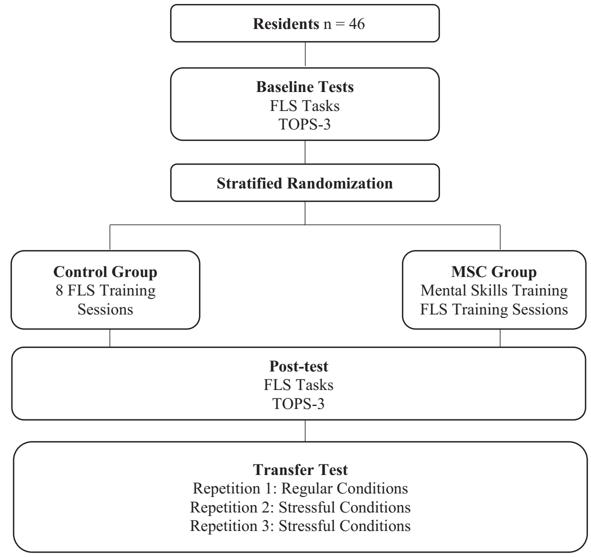

Fig 1. Study algorithm.

Baseline testing

First, participants completed baseline testing that included a demographic questionnaire which asked participants to detail their laparoscopic simulator experience, a mental skills assessment, and one repetition on each of the Fundamentals of Laparoscopic Surgery (FLS) pattern cut, peg transfer, and intracorporeal suturing tasks.[15] Use of mental skills (eg, relaxation skills, goal setting, mental imagery, etc) in performance and practice settings was assessed with the Test of Performance Strategies v 3 (TOPS-3). The TOPS-3 is a reliable, 68-item assessment that asks performers to rate the frequency of their use of mental skills on a 5-point Likert scale and has displayed validity in assessing use of mental skills in practice and performance situations.[16]

Participants were stratified according to TOPS-3 cumulative scores (ie, overall use of mental skills) and FLS performance and then randomized into intervention and control groups. Both groups engaged in 8 weeks of proficiency-based, laparoscopic skills training, and the intervention group also participated in our 8-week MSC.

Training

Participants in each group completed 8 training sessions during the course of approximately 3 to 4 months. During these sessions, both groups engaged in 45 minutes of proficiency-based, FLS technical training with coaching provided by members of the research team with experience in laparoscopic skills training. These sessions focused on training residents on the following FLS tasks: peg transfer (maximum of 2 sessions), pattern cut (maximum of 2 sessions), and intracorporeal suturing (minimum of 4 sessions). Proficiency at these tasks was determined by defined, expert-derived proficiency levels.[17]

Before each laparoscopic skills training session, the MSC group participants completed 45-minute modules that featured educational videos, applied practice of learned skills (eg, engaging in centered breathing exercises, practicing mindfulness, and mental imagery, etc), and included an accompanying workbook for additional practice using mental skills (eg, developing action plans for laparoscopic surgery, completing concentration grids to engage in techniques of attention management, developing comprehensive refocusing plans, and performance routines). The specific skills featured in our curriculum, which have been described in detail elsewhere,[11,12] included identifying action plans and goals for laparoscopic skills training and performance, arousal regulation skills, attention management and mindfulness, mental imagery, comprehensive refocusing strategies, and developing thorough routines for operative performance. Although skills were taught to residents to generally enhance their operative performance, applied practice during sessions of laparoscopic skills training focused on enabling residents to crystalize these skills as habits for laparoscopic performance. After the training period, participants completed the same testing protocol that was used at baseline (ie, posttest).

Transfer test

After the posttesting, participants completed a transfer test of laparoscopic skill on a live, anesthetized, porcine model. Participants were instructed to perform on a Nissen fundoplication model by placing 3 intracorporeal, gastrogastric sutures under varying conditions. An expert surgeon in minimally invasive techniques prepared the porcine model for testing, which has been detailed elsewhere.[18] Participants connected target stitches on the pig fundus using the same intracorporeal suturing technique they practiced during training, which included a surgeon's knot and 2 square knots per suture. A maximum time limit of 10 minutes was allotted for each suture.

The first suture was placed under normal conditions, with no additional external stressors introduced. The second and third sutures were placed under stressful conditions. The stressors implemented in the second repetition included a shorter tailed suture (ie., 4 inches as opposed to the standard 6-inch suture length), the camera was offset in a side port compared with the traditional placement in the center port, and a nurse confederate entered the simulated operating room to interrupt the participants' performance with a mock page. The third suture repetition included a confederate of the research team taking over camera operating duties for the attending surgeon and flipping the 30° laparoscope upside down to provide suboptimal visualization of the pig fundus and having the attending express dissatisfaction with the residents' performance. All stressors incorporated in this study had been identified to be stressful to surgeons in a systematic review of the literature.[3]

The attending surgeons were blinded as to which training group the residents had been assigned. Laparoscopic suturing performance was evaluated using a published, objective score: 600 (cutoff time) − task completion time − [10 × accuracy error (millimeter away from target stitch)] − [100 × knot security error (secure knot = 0, knot slip = 1, knot failure = 2)].[19,20]

Before, during, and after the transfer test, participants' stress was assessed objectively (ie, average heart rate [HR] and heart rate variability [HRV] [Polar H7 HR monitor, Polar Electro Inc, Lake Success, NY; Elite HRV smart phone application, Elite HRV LLC, Asheville, NC]) and subjectively (ie, perceived stress) with the six-item version of the State-Trait Anxiety Inventory (STAI-6). HR and HRV were used to assess participants' stress objectively because these measures have been identified as effective metrics of stress.[18,21] The STAI-6 is a self-report questionnaire that uses a four-point Likert scale to measure six items related to perceived anxiety in a moment of time.[22] Perceived workload during the suturing repetitions was assessed with the National Aeronautics and Space Administration-Task Load Index (NASA-TLX), which is a six-item measure of perceived workload.[23]

Table I
Baseline group characteristics

	Control group (n = 17)	MSC group (n = 21)	P value
Age (years)	30 ± 4	29 ± 3	.73
Women (%)	53%	43%	.54
Postgraduate year	2 ± 1	2 ± 1	.82
Specialty	76% General surgery	71% General surgery	.70
Baseline FLS suturing score	155 ± 162	161 ± 1,467	.92
TOPS-3 cumulative score	206 ± 21	203 ± 26	.69

Note: Greater FLS suturing score indicates greater laparoscopic suturing performance. Greater TOPS-3 score represents greater use of mental skills.

Statistical analyses

Data are presented as means ± standard deviations (SDs). Based on data from a separate study, we performed a power analysis to determine an adequate sample size and originally determined that with an α of 0.05 and a power of 0.8, we needed to recruit a minimum of 12 residents per group to identify a 30% performance difference between groups.[19] We also accounted for 25% participant attrition and sought to recruit a minimum of 15 residents per group across both institutions. Chi-square tests were used to analyze differences in nominal data (eg, sex, specialty, handedness) between groups. Two-sample t tests paired for means were used to assess within-group differences, and two-sample t tests assuming unequal variance were used to analyze between-group and between-site differences for all numerical variables. For all statistical tests, a P value of < .05 was considered significant.

Results

A total of 38 residents across both institutions completed all training and testing elements of the study (Carolinas Healthcare System $n = 23$; Indiana University School of Medicine $n = 15$). At Carolinas Healthcare System, 1 resident withdrew from the study because of a conflict between clinical schedule and transfer testing time. At Indiana University School of Medicine, 8 residents withdrew their study participation because of a lack of adequate time in their schedules to complete training. Otherwise, there were no between-group differences at baseline (Table I).

We observed no significant differences between the groups' laparoscopic suturing performance at posttest (control: 345 ± 102 versus MSC: 364 ± 157, $P = .65$), and we observed borderline differences in the use of mental skills from baseline to posttest for the MSC group compared with controls (controls: +15.8 ± 17.2 versus MSC: +29.6 ± 24.5, $P = .06$). There were no statistically significant differences observed between obstetrics and gynecology (OBGYN) and general surgery residents at baseline (OBGYN: 99 ± 120, general surgery: 167 ± 143, $P = .15$) and men and women (women: 106 ± 128, general surgery: 201 ± 154, $P = 0.06$). At posttest, there were differences in suturing performance between specialties (OBGYN: 269 ± 162, general surgery: 390 ± 98, $P = .05$) and trainee sex (Men: 405 ± 84, Women: 296 ± 150, $P = .01$), but there were no differences in transfer test suturing performance based on specialty or sex. When evaluating the specific differences in mental skills used at posttest compared with baseline, the MSC group reported using goal setting and relaxation strategies significantly more frequently than controls in performance situations (Table II). Control group participants reported being able to control their emotions in performance situations more often than the MSC group.

Table II
Difference in mental skill use in surgical performance from baseline to posttest

	Control group ($n = 17$)	MSC group ($n = 21$)	P value
Self-talk	0.31 ± 0.48	0.72 ± 0.47	.07
Goal setting	0.08 ± 0.62	0.66 ± 1.0	.05
Mental imagery	0.22 ± 0.73	0.66 ± 0.69	.07
Relaxation	0.31 ± 0.73	0.90 ± 0.63	.02
Emotional control	0.31 ± 0.51	−0.09 ± 0.48	.02

Note: Greater scores represent greater use of mental skills in performance situations.

Table III
Differences in transfer test performance between groups

	Control group ($n = 17$)	MSC group ($n = 21$)	P value
Repetition 1: Regular conditions	271.9 ± 98.8	281.1 ± 130.9	.81
Repetition 2: Stressful conditions	26.8 ± 63.3	148.2 ± 150.3	.002
Repetition 3: Stressful conditions	229.4 ± 138.3	211.2 ± 147.6	.70

Note: Greater scores indicate better laparoscopic suturing performance. Repetition 2 featured the following stressors: 4" tail suture, offset position of the camera, and interruption during the case by a nurse confederate. Repetition 3 featured the following stressors: camera being operated by a novice, flipping the 30° laparoscope upside down, and the attending expressing displeasure with the resident's performance.

We observed no meaningful differences between groups during the first repetition of the transfer test (ie, under regular conditions; Table III). In contrast, when stressors were introduced during repetition 2, MSC-trained participants were able to maintain their suturing performance significantly better than controls. For repetition 3, there were no between-group differences in suturing performance.

For both groups, there was an increase in perceived stress from repetition 1 to both repetitions 2 and 3 (repetition 1 to 2 STAI-6 scores: 13.2 ± 3.1 to 16.1 ± 3.6, $P < .001$ for controls and 13.3 ± 2.4 to 16.2 ± 4.7, $P < .001$ for MSC; repetition 1 to 3 STAI-6 scores: 13.2 ± 3.1 to 14.7 ± 4.3, $P = .06$ for controls and 13.3 ± 2.4 to 14.6 ± 3.7, $P = .04$ for MSC), and there was a decrease in stress for both groups from repetition 2 to 3 (repetition 2 to 3 STAI-6 scores: 16.1 ± 3.6 to 14.7 ± 4.3, $P = .03$ for controls and 16.2 ± 4.7 to 14.6 ± 3.7, $P = .04$ for MSC; Fig 2). Likewise, there was an increase in perceived workload (ie, NASA-TLX scores) from repetition 1 to repetitions 2 and 3 for both groups (repetition 1 to 2 NASA-TLX scores: 74.7 ± 15.4 to 93.8 ± 14.3, $P < .001$ for controls and 73.6 ± 19.3 to 90.1 ± 21.2, $P < .001$ for MSC; repetition 1 to 3 NASA-TLX scores: 74.7 ±15.4 to 85.4 ± 19.4, $P = .006$ for controls and 73.6 ± 19.3 to 80.7 ± 28.1, $P = .09$ for MSC), and there was a decrease from repetition 2 to 3 for both groups (controls: 93.8 ± 14.3 to 85.4 ± 19.4, $P = .04$; MSC: 90.1 ± 21.2 to 80.7 ± 28.1, $P = .02$) (Fig 3). We observed no appreciable differences in HRV between groups for any of the repetitions, and we observed only an increase in HR from repetition 1 to repetition 3 for the control group (103.1 ± 14.2 to 110.2 ± 17.3, $P = .008$). Of note, there were no differences in the effects observed between study sites.

A total of 20 of the 21 participants in the MSC group reported that participation in this project was worth their time and effort, and 18 (86%) believed that the training offered in this study was helpful or very helpful. Some participants remarked:

- "Mental skills are quite valuable for surgical trainees in high-stress environments. They build on existing strategies and increase mindfulness about their existence, helping you feel like you have more control over yourself/emotions/performance."
- "Learned a great deal and cultivated skills that I will use throughout my career."

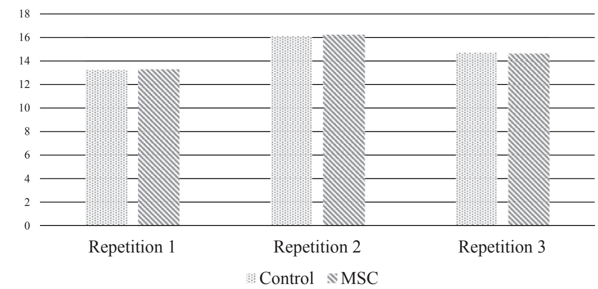

Fig 2. Differences in perceived stress between transfer test repetitions. Greater STAI-6 scores represent greater perceived stress.

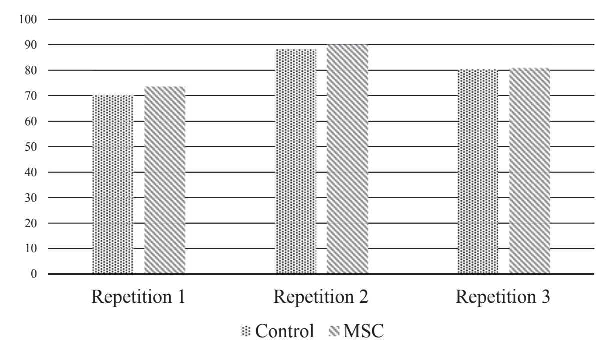

Fig 3. Differences in perceived workload between transfer test repetitions. Greater NASA-TLX scores reflect greater perceived workload.

- "Overall more calm and less tense, identify when need to pause and refocus when frustrated."

Discussion

In this randomized, controlled, multisite study, we aimed to externally validate the effectiveness of a novel and comprehensive MSC to enable surgery residents to maintain laparoscopic performance better than controls under high-stress conditions. This study builds on our earlier work by offering additional evidence of the effectiveness of our curriculum to enhance the ability of surgery residents to perform under conditions of increased stress. We found that, in spite of a decrease in performance during the transfer test from repetition 1 to 2 (ie, when additional stressors were introduced), the MSC group outperformed controls under increased stress as indicated by both groups' self-reported increase in perceived stress and workload from repetition 1 to 2 as observed elsewhere.[14] Thus, it seems that MSC-trained residents are able to better preserve their clinical performance when faced with increased stress (ie, as evidenced by increased perceived stress and workload during repetition 2 for both groups). Building on our earlier work, our present study also provides insight into what specific mental skills taught through our curriculum were enhanced effectively through the dedicated training. The increased use of mental skills in the MSC group from baseline to posttest, specifically goal setting and relaxation strategies in performance settings, likely allowed them to cope better with their increased stress during repetition 2 and outperform controls.

Both groups experienced a remediation of suturing performance during the third transfer test repetition, which indicates this repetition was less stressful and cognitively demanding than the second repetition. This hypothesis was supported when both groups reported decreases in perceived stress and workload from repetitions 2 to 3. It is possible that the unexpected nature of stressors introduced during repetition 2 had the greatest impact on performance because residents likely expected stressors to be present when they performed repetition 3, and thus, were better prepared to manage them. The literature suggests that unexpected events can cause performers to cognitively reframe perceptions about a situation from routine to unique experience.[24] Increased cognitive demands and stress coincide with this shift in perception, which may explain why resident performance in the current study was less during repetition 2 than in repetition 3. Alternatively, the stressors introduced in repetition 2, primarily an offset placement of the camera, may have presented a more substantial technical challenge than any stressors introduced during repetition 3. Other research suggests that shifting a laparoscope to an offset position can increase a surgeon's cognitive demand and lead to decreased performance.[25] Participants in both groups reported that repetition 2 had the greatest workload, so it is likely that the increased technical demand led to increased workload, which contributed to participants' stress and poor performance. Regardless of the cause however, MSC-trained residents were better able to manage the demands of the increased stress and workload during repetition 2, which led to significantly better preserved suturing performance than controls. The comments submitted by the MSC participants after training support this conclusion.

There were observed differences in suturing performance at post-test regarding specialty and sex of the participant; general surgery residents outperformed OBGYN residents, and men outperformed women. We suspect that the familiarity of the general surgery residents with the FLS tasks (i.e., general surgery residents had been introduced to FLS skills ahead of testing, whereas OBGYN residents had not engaged in FLS skills training before the study), which was illustrated in the performance differences between specialties at baseline, led the general surgery residents ultimately to display increased performance at post-test owing to a decrease in their learning curve on these tasks. There were also differences in suturing performance between men and women at baseline and post-test as well; this observation may be due to the greater number of women being OBGYN residents than general surgery residents (11 vs 7, respectively), and accordingly, not having exposure to FLS before the study. Importantly though, both control and MSC groups were evenly represented in terms of specialty and sex, and there were no differences in performance on the transfer test based on these factors, which indicates these factors ultimately had little effect on simulated clinical performance.

The present study had limitations. Logistic constraints limited the duration of overall training of the participants to eight sessions, which did not afford all participants adequate time to achieve proficiency on all FLS tasks. In the event that participants were unable to reach proficiency on peg transfer or pattern cut in two sessions, they were transitioned automatically to the next task. Ultimately, this training paradigm may have led to lower suturing performance during the transfer test compared with what has been reported elsewhere.[19] It is also possible that the intense nature of proficiency-based training that ensures the acquisition of robust surgical skill by trainees by requiring that they engage in deliberate and repetitive practice with ample opportunities for performance feedback may have had a stronger effect on performance than the mental skill strategies the MSC group received. The use of this training paradigm might explain the lack of differences between groups observed after training. Only when stress levels increased substantially (ie, in repetition 2 of this study) did any performance differences between groups became noticeable. Also, our MSC was delivered during eight sessions, which may not be an adequate time to stabilize these skills as habits for their future operative skills. This limitation may have been evidenced by the decrease in performance of the MSC group in repetition 2, the lack of a significant difference in use of overall mental skills from baseline to posttest, and the lack of differences in performance between the MSC and control groups at posttest and repetition 1 of the transfer test. The control group also increased their use of emotional control skills in a performance setting; whereas the MSC group did not, which may be due to our curriculum not featuring a module on emotional control. Our MSC may need to be revised to incorporate additional applied practice opportunities during surgical skills training, and we should develop additional training modules of mental skills, such as emotional control skills, which may offer further benefits to surgical performance. Nevertheless, there was still a practical difference in the use of mental skills from baseline to posttest between groups, which may have contributed to the MSC group outperforming the controls during the increased stress of repetition 2 during the transfer test.

Another limitation with the present study is that there was a lack of an active control condition (ie, 45 minutes spent on a task that was unrelated to laparoscopy or mental skills training) used with control group participants to ensure that equivalent time was spent for both groups on study-related activities to avoid any potential Hawthorne effect.[26] Our group attempted to have residents engage in 45 minutes of team training after their laparoscopic skills training sessions, but engagement was very low and, eventually, this component of the study was removed because of the lack of compliance. Because control group participants did not engage in an active control, it is unclear whether the differences between groups can be attributed to the mental skills curriculum alone or simply the increased time thinking about laparoscopic surgery during the sessions of mental skills training. But, because there were no observed effects between study groups in suturing performance at posttest or repetition 1 of the transfer test and the only observed effects between groups were under increased stress, we are confident that performance differences were attributable to the learned strategies of coping with stress taught during our MSC. Our group plans to develop an engaging, active control condition for future studies in this area to ensure that the time spent completing study-related activities is equal between groups to avoid any potential confounds.

Last, we did not observe any meaningful differences between groups in their physiologic stress, perceived stress, or perceived workload. The stressors included in repetition 2 were clearly very stressful for all participants. We believe that, in spite of the perceived workload and stress, participants in the MSC group were able to cope more effectively than the controls because of their learned mental skills, which was reflected in the better maintenance of suturing performance for the MSC group. Qualitative study of the use of mental skills by residents to cope with intraoperative stress is justified because this approach may allow for further insights to be gleaned and incorporated in future MSC revisions. Furthermore, based on the differences in specific mental skills used for the MSC group from baseline to posttest compared with the controls (ie, a greater use of goal setting and relaxation techniques for MSC group participants than controls and a lower use of emotional control use), it may be necessary to revise our curriculum to incorporate additional focused practice of mental skills that were not comparably enhanced from baseline to posttest.

The results from this multisite, randomized controlled study suggest that our comprehensive MSC is effective at enabling surgery residents to better maintain their performance under stressful conditions compared with controls. For surgery trainees who may be particularly susceptible to surgical error–causing stress, which can decrease patient safety, our MSC may offer skills to help them better manage stressors in the clinical environment. These findings provide additional evidence of the effectiveness of this curriculum with surgical trainees. Based on these findings, additional study on the implementation of our MSC with other health care providers who may be susceptible to intraoperative stress (eg, practicing surgeons, nurses, anesthesiologists, etc) is warranted.

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Conflict of interest

The authors have indicated that they have no conflicts of interest regarding the content of this article.

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