A comparison of evaluation, time pressure, and multitasking as stressors of psychomotor operative performance

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Background. There is gathering interest in determining the typical sources of stress for an operating surgeon and the effect that stressors might have on operative performance. Much of the research in this field, however, has failed to measure stress levels and performance concurrently or has not acknowledged the differential impact of potential stressors. Our aim was to examine empirically the influence of different sources of stress on trained laparoscopic performance.

Methods. A total of 30 medical students were trained to proficiency on the validated Fundamentals of Laparoscopic Surgery peg transfer task, and then were tested under 4 counterbalanced test conditions: control, evaluation threat, multitasking, and time pressure. Performance was assessed via completion time and a process measure reflecting the efficiency of movement (ie, path length). Stress levels in each test condition were measured using a multidimensional approach that included the State-Trait Anxiety Inventory (STAI) and the subject’s heart rate while performing a task.

Results. The time pressure condition caused the only significant increase in stress levels but did not influence completion time or the path length of movement. Only the multitasking condition significantly increased completion time and path length, despite there being no significant increase in stress levels. Overall, the STAI and heart rate measures were not correlated strongly.

Conclusion. Recommended measures of stress levels do not necessarily reflect the demands of an operative task, highlighting the need to understand better the mechanisms that influence performance in surgery. This understanding will help inform the development of training programs that encourage the complete transfer of skills from simulators to the operating room. (Surgery 2011;149:776-82.)

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There has been a tendency to ignore or deny the impact of stress on operative performance,1 despite ample evidence from other high-demand environments (eg, aviation) demonstrating that stress can impact cognitive and psychomotor performance.2,3 Although there has been reluctance to consider the level of stress experienced by an operating surgeon as a contributor to outcome, there is gathering research interest in determining the typical sources of stress and their impact on surgical performance (see the review paper by Arora et al4).

A major limitation of much of this research is the failure to assess concurrently stress and performance. Rather, the influence of stress on the surgeon has been imputed, thus making a link between stress and performance difficult to establish.5 In addition, most research fails to adopt a mechanistic approach to explain how stress might impact operative performance. This limitation is important because different stressors may cause operative performance to break down for different reasons.

Considering stress as a unidimensional construct limits the degree to which underlying mechanisms may be understood and the degree to which an intervention (eg, stress management training4,5) may be successfully matched to a particular source of stress. Sources of stress that have been identified...
in the surgery literature include technical complications,6 time pressure,7,9 distractions,7,9,11 and evaluative threat or performance anxiety.7,12 It has also been suggested that laparoscopic procedures are more stressful than open operations and that novice surgeons are less able to cope with stress than their experienced counterparts.13 Because increased stress has been implicated in the incomplete transfer of technical skills from simulator and bench models to the operating room, the development of technical skills training curricula for novice laparoscopic operators needs to consider the impact of stress on psychomotor performance.12,14

For this type of effective training curricula to be developed, the mechanisms underpinning the relationship between stress and psychomotor performance in novice operators trained to acceptable levels of proficiency need to be better understood. This study sought to address some of the limitations of the current evidence base4 by empirically examining the impact of different sources of stress on trained laparoscopic performance using process tracing measures and objective and subjective measures of stress.

METHODS
A cohort of 34 fourth- and fifth-year undergraduate medical students from the University of Hong Kong volunteered to take part in the research. Of the initial cohort, 4 subjects dropped out after the first training session, leaving 30 subjects to complete the experiment (20 males and 10 females). The students were recruited while on their surgery rotation and had little or no previous laparoscopic experience. Institutional ethical approval was obtained before study commencement, and all participants provided written informed consent and demographic information before testing.

Subjects attended training sessions individually on at least 23 occasions (see below). Throughout the training and testing phases, subjects wore a heart rate monitor (Polar S810; Polar Electro Oy, Finland) and motion tracking sensors on each hand (Isotrak II; Polhemus, VT) to analyze hand motion efficiency using the Imperial College Surgical Assessment Device (ICSAD).

The laparoscopic task used in this study was the peg transfer task adopted from the validated Fundamentals of Laparoscopic Surgery (FLS) program developed by The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and endorsed by the American College of Surgeons.15,16 A detailed description of the 5 increasingly difficult tasks that make up the FLS training program, the apparatus used for the tasks, and other information is provided on the FLS Web site.17 In the peg transfer task, 6 plastic objects are grasped, transferred, and then positioned on a pegboard (Fig 1). Specifically, surgeons pick up a triangular object with grasper forceps from a pegboard on their left, transfer the object through space to a grasper in their right hand, and then place the object over a post on the right-hand side of the pegboard. When all 6 objects are transferred from the left to the right, the process is reversed. By this reversal, the surgeon is required to transfer the object from the right hand to the left hand. The exercise is timed, and a penalty score is levied whenever an object is dropped outside the surgeon’s view.

In this study, subjects first watched an introductory video before their training commenced on the peg transfer task. They were required to perform repetitions of the task until they reached proficiency, which was defined as completing the task in less than 54 seconds and without a penalty score on 2 consecutive trials and on 10 additional, nonconsecutive trials. Developers of the FLS skills curriculum16 recommend this criterion for task proficiency to surgery educators based on expert levels of performance.15 Subjects were informed of the criterion level of performance required and were offered feedback on their performance whenever it was requested. They were also instructed to sit down and take a break from training after every 10 trials or, if necessary, more frequently.

The procedure consisted of phases of training and testing. In the training phase, subjects trained on the peg transfer task for up to 90 minutes or until proficiency was reached. If proficiency was not attained in this timeframe, then a second training session was scheduled for the following day. Of the 30 subjects, 16 had to schedule an additional training session to reach the criterion level of proficiency. The testing phase was scheduled for the day after proficiency had been achieved.

In the testing phase, subjects were first reacquainted with the task and then completed repetitions of the task until they attained 2 consecutive, criterion level completions. They then performed 2 trials in each of 4 counterbalanced test conditions designed to manipulate the types of stress that they experienced. The counterbalanced test conditions consisted of a control test, an evaluative condition, a multitasking condition, and a time pressure condition.

In the control test, subjects were simply asked to do their best just as they had been asked to do in training. The multitasking condition was designed
to be distracting and mentally demanding in that subjects were required to perform mental arithmetic while completing the peg transfer task.7,9,18 Specifically, on the first trial, subjects were to start counting back from 737 in increments of 7; on the second trial, they were to start counting from whichever number they reached during the first trial.

The evaluative condition involved a manipulation designed to increase each subject’s ego threat and performance anxiety.7,12 Subjects were informed that their performance would be video-taped, so that it could be viewed by 3 of their course tutors and compared to the performances of trainee surgeons from the U.K. and the U.S. The subjects were made aware of a video camera being turned on and were asked to say their name and year of study for the camera before completing their 2 trials. The final condition was designed to create an element of time pressure.7-9 Subjects were informed that some operations must be completed under time constraints and that they were to try to perform the task more quickly than their best time during the training phase (which they were told). Performance in the peg transfer task was measured by completion time.16

Stress was assessed using 2 of the 3 measures of the Imperial Stress Assessment Tool (ISAT)19, heart rate and a self-report questionnaire (the validated short version of the State-Trait Anxiety Inventory [STAI]).20 It has been suggested that this type of multidimensional approach, which combines objective (eg, heart rate) and subjective (eg, self-report questionnaire) methods to measure stress, is required to help build evidence for validity and reliability of stress measures for use in surgery environments.4 Although the ISAT includes a third measure of stress (eg, analysis of salivary cortisol as a physiologic response to stress), we decided not to adopt it for this experiment. Analysis of cortisol levels appears to be less sensitive than heart rate in differentiating between stressful and nonstressful operative procedures,19 and cortisol levels are sensitive to diurnal variation.

Heart rate was measured with a heart rate monitor (Polar S810; Polar Electro Oy, Finland) set to record each individual heartbeat. The receiver was started at the outset of each trial, and the recording was stopped when the last object was placed. The average heart rate across both trials was used as the dependent variable.12,21 The STAI consists of 6 statements (“I feel calm,” “I feel tense,” “I feel upset,” “I am relaxed,” “I am content,” and “I am worried”). These statements require a Likert scale response (ranging from 1 = “not at all” to 4 = “very much”) and was completed after each pair of trials in each condition. Subjects were asked to complete the questions with reference to how they felt during the previous 2 trials.

Analysis of hand movements during trial completion (using ICSAD) was adopted as a process tracking measure of how stress might impact performance. Motion tracking sensors (Isotrak II; Polhemus, VT) were attached to the dorsum of both hands; positional data were filtered and converted into path length and number of movements data using proprietary software.22,23 Path length (the combined total path traversed by each hand in x, y, and z coordinates) was calculated for each trial, as previous research has suggested that this measure is sensitive to stress.9

Descriptive statistics relating to the achievement of proficiency during the training period were calculated (ie, trials to reach proficiency and fastest completion time). A mean value for each dependent variable of interest was calculated from the 2 trials performed in each of the 4 conditions of the test phase (control, multitasking, evaluation, time pressure) and subjected to one-way analysis of variance. Significant main effects were followed with Bonferroni-adjusted, paired sample t tests.
and effect sizes were reported as partial eta-squared ($\eta^2_p$). The 2 measures of stress were correlated against each other in each condition using the Pearson correlation coefficient.\textsuperscript{21} Significance levels were set as $P < .05$ for all analyses.

**RESULTS**

Subjects took, on average, 59 trials (standard error of the mean [SEM] = 4) to reach proficiency (range, 26–95 trials) during the training phase of the study. The mean fastest completion time during the training phase was 42 seconds (SEM = 1). Although the FLS instructions suggest that trainees should move on to the next task if they have not reached proficiency within 80 trials, we allowed subjects to continue training until proficiency was reached. A total of 2 subjects required more than 80 trials to reach proficiency.

Analysis of variance of the STAI data revealed a significant main effect for condition as follows: $F(3,87) = 5.09, P < .005, \eta^2_p = .15$. Follow-up, paired sample $t$ tests demonstrated that the time pressure condition was considered to be significantly more stressful than either the control ($P < .001$) or evaluation condition ($P < .05$). No other significant differences between conditions were found (Fig 2, *upper panel*). Analysis of the average heart rate data revealed no significant main effect for condition as follows: $F(3,81) = 2.04, P = .13, \eta^2_p = .07$. The heart rate data were available for only 28 participants due to an error in data retrieval (Fig 2, *lower panel*).

Correlation analyses revealed that the 2 measures of stress adopted were not strongly correlated. Only in the multitasking condition was there a significant, but weak, correlation between STAI and average heart rate ($R = .38, P < .05$). In this condition, both measures still only predicted 14% of shared variance.

Analysis of variance of the completion time data revealed a significant main effect for condition as follows: $F(3,87) = 15.46, P < .001, \eta^2_p = .35$. Follow-up, paired sample $t$ tests demonstrated that the multitasking condition had slower completion times than all other conditions ($P < .005$; Fig 3, *upper panel*). Analysis of the path length data also revealed a significant main effect for condition as follows: $F(3,87) = 9.21, P < .001, \eta^2_p = .24$. Path lengths were longer in the multitasking condition than all other conditions ($P < .005$; Fig 3, *lower panel*).

**DISCUSSION**

The aim of this research was to quantify 3 stressors that can be present during operative tasks and to examine whether the stressors have differential impacts on the technical operative performance of trained laparoscopic operators. To this end, 3 different manipulations of stress were developed to enable a comparison of stress responses and performance effects among the stress conditions and compared to a control condition. A multidimensional approach including objective and subjective measurements of stress was adopted as recommended in the contemporary surgery literature.\textsuperscript{4}

Most striking was the finding that high stress scores were not associated with poorer performance. Subjects reported the greatest STAI values under time pressure and yet performed best in this condition (although performance was not significantly better than in the control condition). Conversely, subjects performed significantly worse in the multitasking condition despite reporting similar levels of stress in the control condition. Path lengths were also significantly longer in the multitasking condition compared to all other...
conditions, supporting the validity of this process measure of performance.

Trainees could deal with the stress imposed by having to rush a procedure, but they could not multitask without a disruption in their operative performance. Given that the correlation analyses revealed only weak relationships between STAI and heart rate, different mechanisms seem to underpin the stress response and mediate these performance effects. Perhaps, a wider conceptualization of what stress means to a laparoscopic operator is required. Stress is experienced when perceived resources are outweighed by demands.24,25 The extent that subjective measures of anxiety (eg, STAI) and physiologic arousal (eg, heart rate) address this demand component of stress is questionable. For example, performance was most disrupted in the multitasking condition despite control levels of experienced stress. This finding suggests that the concept of demand should be taken into account in the assessment of stress.

In line with recent studies of mental demand (workload) and performance in aviation and industrial ergonomics,26 the results of our study support the view of Andreatta et al12 in that volume and complexity of work can lead to cognitive overload of new trainees. If the attentional demands of a task are high, then having to divide attention between various tasks (or components of the same task) will likely result in performance impairment, even if the participants do not report increased anxiety.

The results of this study provide clear implications for operative training. Being able to operate effectively under stress-inducing conditions is a hallmark of expertise, and developing such skill should form part of any curriculum for training in surgery.4 Experienced surgeons may have learned to manage the emotional, cognitive, and physical demands of stress through years of practice and acquired desensitization to associated stressful stimuli,12 but how can effective training help novices cheat some of this experience?

One important point raised by the results of our study is that trained operators were unable to cope with the additional load of mental arithmetic while performing a task. Despite reaching a validated measure of proficiency in a task,15,16 they had not reached a degree of automaticity in their basic technical skills that allowed them to free up cognitive resources for a concurrent task (ie, mental arithmetic). Recent research14 has demonstrated that novices who achieve expert performance on a simulator after proficiency-based training cannot perform at that same level in the operating room. Changes may be necessary to even proficiency-related training programs, if they are to prepare novice surgeons effectively for the stressors inherent in the operating room.27,28

As well as simply asking trainee surgeons to spend more time practicing their basic skills, other adjustments to operative training have been recommended.12,29 For example, training for exposure to stress (stress inoculation training) has been shown to help performers deal with anxiety when stressors are present.30-32 Implicit motor learning has also been shown to help performers maintain stable performance in the face of a variety of stressors.33,34 Implicit motor learning refers to the acquisition of a skill in a nonverbal manner, with little conscious awareness of what is learned. By generating movement control that makes lesser demands on the already taxed cognitive resources of the surgeon, implicit motor learning develops skills that are more stable in conditions of psychological stress, fatigue, and multitasking.18,35 For example,
noise surgeons who learned a suturing task in an implicit fashion via observational learning maintained better performance when multitasking than trainees who learned in an explicit manner.18

Future work needs to examine further the multidimensional approaches to the stress—psychomotor performance relationship in surgery and develop and validate training programs informed by a concise understanding of this relationship.36 Future research also needs to consider individual differences in response to stressors during operations.4 For example, the theory of reinvestment postulated by Masters et al37,38 proposes that people with a propensity to consciously monitor and control their movements are more likely to perform poorly under pressure. Whether factors such as reinvestment moderate operative training and performance in the face of stress remains to be seen.

In this experiment, newly trained laparoscopic operators could perform competently in the presence of evaluation and time pressure stressors that have been shown previously to disrupt operative performance (eg, the studies by Moorthy et al19 and Andreatta et al12). The manipulations used imitated stressors but likely fall short of replicating the levels of stress experienced by trainees when they transfer to the operating room. More powerful and ecologically valid manipulations, such as attendance by an authoritative figure or presence of a countdown clock, may have increased anxiety to the extent that operative performance was disrupted.

Furthermore, the differential impact of the 3 stressors on performance may also change with experience. For example, automatic control over technical procedures enables experienced surgeons to manage concurrently other aspects of the surgical environment, such as team communication or decision-making. For this reason, the performance of experts is less affected in multitasking situations.39,40 The findings we have presented, therefore, are likely to relate only to trainees at the early stages of training in surgery.

In conclusion, high stress levels are not necessarily associated with poorer performance of trained laparoscopic operators. The demands of the operating environment may not be reflected in the stress response evaluated by current recommended measures. A broader consideration of the demands placed on surgeons will advance understanding of the mechanisms that underlie poor operative performances. Training curricula can then be better tailored to lessen the impact of intraoperative stressors.

REFERENCES