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Subjective and Objective Quantification of the Effect of Distraction on Physician's Workload and Performance During Simulated Laparoscopic Surgery

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Background: Distracting interference cognitive tasks place undeniable pressure on the minds of people who need high precision and attention during the tasks, such as those tasks performed during surgery; these tasks might affect current surgical procedures. We measured the effect of additional cognitive tasks on the mental load of the physician by measuring the mean change in pupil size, blink rate, and subjective assessment during surgery.



Material/Methods: We recruited 24 participants with different levels of laparoscopic surgery to perform a complete appendectomy using a standardized virtual reality laparoscopic surgery simulator. The participants then performed the cognitive task (arithmetic problem), after that they performed an appendectomy surgery task while completing the cognitive task on the simulator. All participants wore trackers to monitor pupil size and blink rate during surgery and the cognitive task. The National Aeronautics and Space Administration (NASA) Task Load Index (TLX) score also recorded performance parameters during the surgical mission.

Results: The double-task pupil size and the blink rate were significantly increased compared to the single-task observation, and the associated increase in psychological load might have been affected by surgical performance, and the performance parameters were also statistically significant. However, for the aforementioned parameters, experienced surgeons had some differences compared with inexperienced surgeons, but these differences did not reach statistical significance.

Conclusions: Distracted cognitive task stimulation in the operating room can increase the surgeon's psychological burden while also affecting their operational skills, thereby threatening patient safety; reduced cognitive costs might be obtained by improving or managing cognitive deficits.

MeSH Keywords: **Appendectomy • Eye Movements • Laparoscopy • Workload**

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Background

In most cases, surgeons will be distracted during surgery. The degree and frequency of distractions depend on a variety of factors, including the surgeon's own experience, the environment factors in the operating room such as interruptions by phone calls in the operating room at any time. According to previous research, surgeons are interrupted an average of 13.5 times per case during general surgery [1].

Distractions often are cognitive in nature and require immediate attention. Modern surgical practice often requires multi-tasking, and distractions are frequent [2]. These interruptions include alarms in the ward or emergency room or calls, telephones, sounds of operating machines, sounds of opening and closing doors, and personnel in the operating room conversing on matters not related to the surgical case. Chisholm et al. observed that interruptions were necessary to meet the needs of multiple cases, but excessive interruptions might hinder physician performance [3]. This possibility requires the surgeon to perform a dual task because they are required to perform a surgical task (surgery) and also required to respond to cognitive tasks (distractions). So, performing a dual task challenges the ability of the surgeon; both surgery and cognitive tasks are very important and should be quality-responsive.

The secondary task measurement reflects the previous description of the workload, which can be used to compare workloads under different mission conditions. This secondary task should be different from that primary task performed by the surgeon during an actual operation, thus, the choice of a secondary task should be one that is both natural and sensitive to the primary task [4]. Research on the impact of distraction on performance is largely limited to measuring the effects of distraction on purely cognitive tasks (such as memory or reading comprehension tasks) [5,6]. It is unclear how interference affects the performance of a surgery and the extent to which experience or practice might reduce the effects of distraction. However, the experimental psychology literature suggests that mitigating effects on performance exist in most dual-task situations [7]. Such studies have successfully demonstrated cognitive interference; the performance of various cognitive and athletic tasks is degraded. Little is known regarding the impact of distraction on surgical performance and a surgeon's attention, as it is a variable that might be unsafe to test in an actual operating environment.

More research has shown that additional cognitive tasks increase the duration of surgery and might adversely affect the ability to handle surgical and cognitive tasks. Virtual reality simulators have been used extensively in the airline industry to objectively assess the effect of fatigue on pilot performance. It has been reported that a virtual reality simulator

for laparoscopic surgery has been used to evaluate its workload. With the advancement of analogue technology, it is now possible to better assess the potential interference factor of surgery [8].

Most previous studies only used and analyzed performance parameters and subjective data. The purpose of this study was to confirm the impact of cognitive interference on physician cognitive load and surgical performance using a surgeon's virtual reality simulator. To the best of our knowledge, this study is the first to use eye movements to evaluate the effects of cognitive distractions on the ability of laparoscopic physicians to operate using virtual reality simulators in China.

Material and Methods

Participants

We recruited 24 postgraduate students from Huazhong University of Science and Technology Tongji Medical College. The age range of participants was 23–33 years (mean \pm standard deviation was 26.2 \pm 2.2 years of age). To reduce biases caused by gender differences, the study cohort had equal numbers of men and women [9].

Participants were divided into experienced and moderately experienced groups according to their experience in laparoscopic surgery training and clinical practice. Members of the experienced group were medical students who had completed their surgical training courses and had relatively proficient surgical skills. Participants of the moderately experienced group were familiar with well-known surgical procedures that can be performed under the guidance of surgical training.

Before formal experiments, all participants provided signed informed consent and were familiar with the experimental procedures and environments, and all were capable of completing a laparoscopic appendectomy on the experimental platform surgical simulator. All study protocols were approved by the Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology (IORG No. IORG0003571). The experimental environment was designed to simulate an authentic operating room, and appropriate lighting was provided according to the standards of an operating room. Body mass index (BMI) values and elbow heights of participants were recorded before experiments and heights of the experimental platform were adjusted accordingly. Participants with hearing impairments, movement disorders, abnormal vision or corrected vision, and insufficient sleep the night before the experiment were excluded. Participants were not aware of the study design or measurements prior to performing procedures.

Experimental platform and task

Experiments were performed using a virtual laparoscopic surgery simulator (MIS-Laparo Virtual Simulator, misrobot, Suzhou, China), which provides operating performance statistics for tasks, including tip trajectories of surgical instruments, movement speeds, and task completion times. The simulator provides operation similar to a real operating room laparoscope that can be used to perform standardized surgical tasks such as appendectomy, and it can provide the user with an indication of surgical quality, injury after a surgery operation.

Laparoscopic appendectomy is a common laparoscopic surgery involving standard laparoscopic hooks, forceps, and scissors. Surgical resection of the appendix was performed by 1) putting the laparoscope into the abdominal cavity and adjusting the laparoscopic surgery field for the appendix and explorations of other target tissues, 2) ligation at the root of the appendix twice followed by clipping of the appendix at the middle of the 2 ties and electrocoagulation cauterization of the wound, 3) checking for bleeding points and hemostasis, and 4) checking that the surgery is complete prior to submission. The operator is required to complete an appendectomy simulation surgery in the following 3 situations: 1) single task (no interference); 2) cognitive task (answering arithmetic questions of simple difficulty while not operating); 3) dual task (answering arithmetic questions during a surgical task). A mean score was recorded by the platform for the surgical parameters as aforementioned after each surgery operation was completed, and similarly, the total number of questions and incorrect answers per minute were recorded during the procedures that included a cognitive task. The participants were informed that the surgical task and cognitive task were of equal importance [10].

Experiments were performed using a randomized block design, and all participants performed the 3 situations described. Permutations of task order were performed to avoid systematic errors, and all participants filled in the National Aeronautics and Space Administration – Task Load Index (NASA-TLX) scale after each task. All participants had been previously trained to complete the operation surgery tasks on the simulator independently while preventing cumulative load from fatigue caused by multiple exercises.

Mental workload assessments

The NASA-TLX workload self-assessment

The NASA-TLX is among the most commonly used instruments for measuring subjective mental workloads. Previous studies have used it to evaluate the mental load of laparoscopic surgery [11]. The NASA-TLX provides an overall index of mental workload and relative contributions of a 10-point visual

analogue scale with the 6 subscales of mental demand, physical demand, temporal demand, effort, frustration, and performance. NASA-TLX scores range between 0 and 100 (0=totally imprecise to 100=totally precise), and higher scores indicate higher mental loads of subjective perceptions.

Eye-tracking

All links with cognition demonstrated by pupillary response and blink imply that the 2 measures are capable of indicating cognitive load [12]. We sampled binocular eye movements at 50 Hz using a wearable eye tracking system (Tobii Glasses 2.0, Danderyd, Sweden). The device consists of a small recording unit – attached to a belt worn by the participants – and an eye tracking unit mounted on an eyeglasses frame. The eye tracker is connected to the recording unit via a HDMI cable. Recordings are stored in an SD memory card. Prior to experiments, participants were equipped with the eye tracker and were asked to stare at black dots on paper cards to calibrate the instrument. During calibration, physiological parameters of the eye were recorded, and baseline pupil sizes were measured after the calibration. We measured baseline pupil diameter (initial diameter) for each participant [9]. A change in pupil size from baseline was measured as the mean pupil diameter change.

Performance data

The performance parameters including total score, total operation time, clamping times, tip trajectories, and the number of incorrect questions per minute for each task were recorded.

Data analysis

Data were analyzed using SPSS version 20 and GraphPad Prism 6.0. Data tests of normality (Kolmogorov-Smirnov testing) were applied to determine data distribution (single and dual task conditions; experienced and moderately experienced operators) in advance. Paired *t*-test was used for normally distributed data and Wilcoxon signed rank for skewed data. All differences were considered to be significant when $P < 0.05$.

Results

Figure 1 shows changes in pupil diameters during surgery under the 2 tasks. Pupil dilation was greater under dual tasking conditions than under the single tasking conditions and had a high degree of variance ($P = 0.002$).

Figure 2 shows blink rate during surgery under the 2 tasks. Blink rate was greater under dual tasking conditions than under the single tasking conditions and had a high degree of variance ($P < 0.0001$).

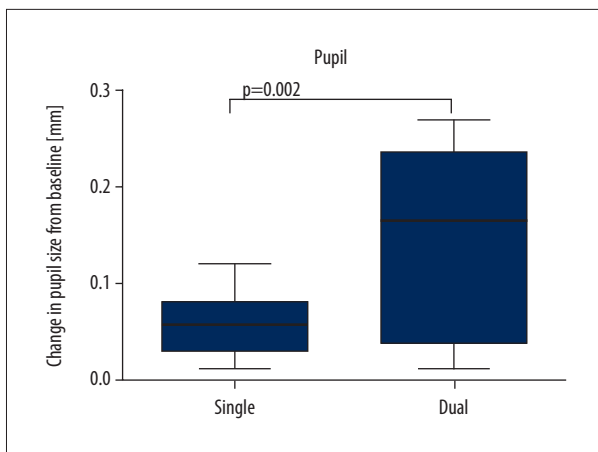


Figure 1. Box plots of changes in pupil sizes from baseline until task completion.

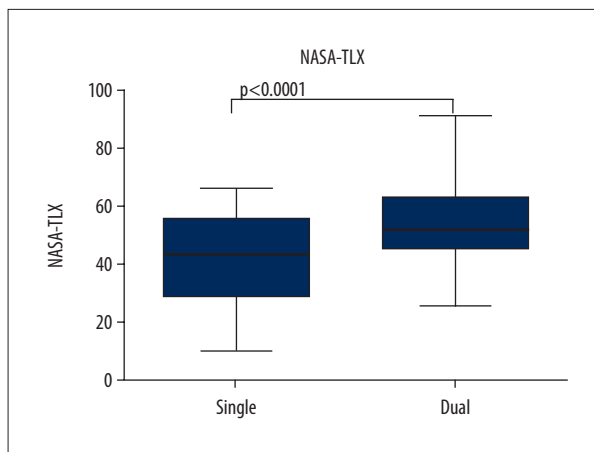


Figure 3. Box plots of NASA-TLX scores.

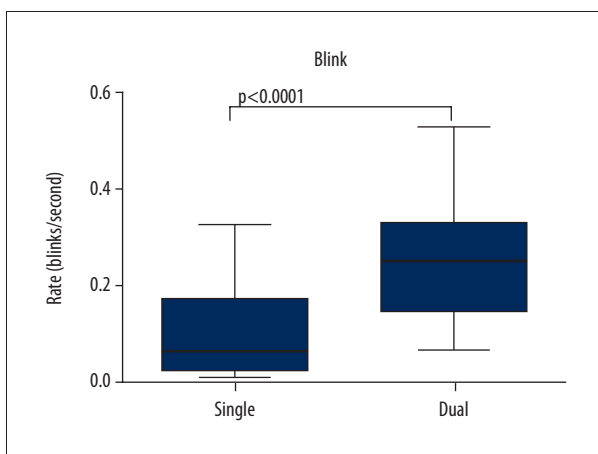


Figure 2. Box plots of blink rate.

Assessments of NASA-TLX scores (Figure 3) showed similar patterns to those of pupil dilation and blink rate, and task scores were higher under dual tasking conditions ($P<0.0001$) than under single tasking conditions.

Table 1 shows results for performance parameters including total scores, total time, clamping times, tip trajectories, correct answers under single tasking (not distracted) and dual tasking (distracted). Dual tasking was significantly longer time than single tasking operations ($P<0.0001$), and the error rate for answering questions was greater ($P<0.0001$). In terms of clamping times, the dual tasking was significantly higher than the single tasking ($P=0.001$), and the tip trajectories of the dual tasking was also larger than that of the single tasking ($P=0.018$). However, no significant difference in total score

Table 1. Results for performance parameters including total scores, total time, clamping times, tip trajectories, correct answers when single tasking (not distracted) and dual tasking (distracted).

Parameter	Single tasking	Dual tasking	P value
Total score			
Mean \pm SD	91.88 \pm 3.3	83.75 \pm 4.74	0.053
95% CI	85.06, 98.69	73.94, 93.56	
Total time(s)			
Mean \pm SD	333.96 \pm 24.92	541.08 \pm 46.38	<0.0001
95% CI	282.4, 385.51	445.14, 637.03	
Clamping times			
Mean \pm SD	36.9 \pm 4.41	54.604 \pm 5.19	0.001
95% CI	27.77, 46.02	43.86, 65.35	
Tip trajectories (cm)			
Mean \pm SD	432.08 \pm 33.56	548.96 \pm 54.12	0.018
95% CI	362.65, 501.52	437.01, 660.91	
Incorrect answers (per min)			
Mean \pm SD	1.03 \pm 0.11	3.03 \pm 0.27	<0.0001
95% CI	0.8, 1.27	2.47, 3.58	

SD – standard deviation; CI – confidence interval.

was identified between dual and single tasking conditions. The aforementioned parameters also show the impact of experience on the task, and there are no significant differences between highly experienced operators and moderately experienced operators ($P>0.05$).

Discussion

In this study, we comprehensively assessed the impact of cognitive interference on the psychology of the surgeon using subjective and objective methods of workload and performance. Our results suggest that additional cognitive disturbances other than surgery increase the surgeon's mental stress and influence their motor skills. To the best of our knowledge, this is the first article to assess the effect of cognitive interference on a surgeon using changes in pupil sizes from baseline and blink rate. A previous study focused only on gaze entropy in surgical task load or did not use eye movements which are a very effective tool to reflect the cognitive load impact of surgeons during interference [13].

In a real operation, the surgeon should ensure that their operating room is not distracting, and that effective response of a certain quality are also provided for additional cognitive tasks. For example, the operator might remember the problem while observing the operation and then respond at the end of the operation, as their answers might not be ideal as they continue to operate. In addition, cognitive tasks that surgeons might obtain from other sources, such as those related to emergency situations in other patients who require treatment or organizational problems, should be treated after the current surgery; if an emergency requires timely treatment, it should be handled by others. It is unlikely that all interferences will be removed from the operating room, so our findings indicate that professional surgeons can maintain a high quality of surgery without interference. However, this study also reflects the reduced ability of surgeons to respond to cognitive tasks during surgery, proving that clinicians should strive to control interference in the operating rooms so that they can be more focused on surgery, and surgeons should be trained to resist distraction.

Eye-tracking assessments of pupil dilation are a useful proxy for mental workload during laparoscopic surgery [14]. However, because pupil sizes vary between individuals, direct comparisons of the ensuing data can be hampered by variance. In this study, for the first time, we compared mean changes in pupil diameters to represent mental workloads, as was used in previous studies, that demonstrated that noise has a stressful effect on surgeons [15]. Accordingly, changes in pupil sizes during the surgical tasks indicated that the surgeon's mental loads were closely related to degrees of pupil dilation. Because pupil

sizes can also be affected by lighting, intelligence, emotion, and exertion, we performed experiments under the most relaxed conditions possible to ensure study participants were in good mental states and to ensure standard operating room lighting levels for all participants. Pupil diameter can index cognitive load only in the situation of low perceptual load and we are the first to provide empirical support for the cognitive control aspect of the load theory of attention in the context of cognitive load measurement [16].

Distraction reduced the surgeon's surgical performance on the laparoscopic simulator, and this might be related to the degree of surgical experience. In this study, the eye movement parameters of the cognitive tasks in the non-expert hands, the subjective scale and performance for the single and double tasks, were greater than the experts. However, these results did not reach statistical significance. In laparoscopic surgery, experienced operators have lower stress levels than inexperienced operators. Experienced operators can perform additional cognitive tasks while ensuring that the program is completed, while inexperienced people can perform only limited additional cognitive tasks while maintaining the quality of these operations.

This study had several limitations. Because the entire course of the experiment was conducted in our hospital, the limited number of surgeons in our hospital resulted in a small sample size.

Furthermore, a similar simulator is only available in a limited number of hospitals across the country to provide larger samples through multi-center collaboration. In past studies, we found that this simulator is very effective for surgical training [17]. This study also showed that this simulator has application value in similar research, as these studies are impossible in real life. The cost associated with purchasing a simulator is high for many organizations. In terms of the current market, the basic cost of a laparoscopic simulator is about several hundred thousand, which requires approximately 3 years of maintenance and system upgrades. The high cost makes this effective technology not widely available. The reason for the difference in total scores is that the simulator's scoring system is relatively simple and does not consider the fact that each operational index only considers bleeding points. Therefore, advances in surgical simulation techniques and more accurate future simulations of actual surgery are urgently expected.

Previous laparoscopic simulations have found that after noise and music disturbances, the performance of the surgery experiences an adverse effect [18]. Various types of sound interference can have different effects on the surgeon. Based on previous studies of laparoscopic surgeons' mental load, cognitive tasks in the form of arithmetic problems might have an adverse effect on ongoing surgery resulting in a poor impact on the surgeon's mental load. We choose to evaluate cognitive forms of

arithmetic as a cognitive task because the arithmetic problem is treated as an additional cognitive task which is similar to the challenges that surgeons might face in the operating room, such as querying problems associated with other patients. The cognitive impairment is similar to the cognitive load of the doctor. In summary, an additional cognitive task that is not associated with surgery will reduce the surgeon's ability to handle cognitive tasks. We conclude that this is very important for the safety of patients undergoing daily surgery. Further research on the impact of external cognitive load on the operating room environment can optimize the working environment and organizational management of medical staff. Many factors influence surgical process and outcomes, including human factors, such as noise, ergonomics, telephone, conversation, and fatigue. Although these parameters alone might not have a significant impact, joint optimization might improve the surgeon's performance and might ultimately affect the patient's treatment.

Conclusions

Current subjective and objective assessments indicate that external cognitive load affects a surgeon's mental load during

References:

1. Healey AN, Sevдалис N, Vincent CA: Measuring intra-operative interference from distraction and interruption observed in the operating theatre. *Ergonomics*, 2006; 49(5-6): 589-604
2. Hsu KE, Man FY, Gizicki RA et al: Experienced surgeons can do more than one thing at a time: Effect of distraction on performance of a simple laparoscopic and cognitive task by experienced and novice surgeons. *Surg Endosc*, 2008; 22(1): 196-201
3. Chisholm CD, Collison EK, Nelson DR et al: Emergency department workplace interruptions are emergency physicians "interrupt-driven" and "multitasking"? *Acad Emerg Med*, 2000; 7(11): 1239-43
4. Carswell CM, Clarke D, Seales WB: Assessing mental workload during laparoscopic surgery. *Surg Innov*, 2005; 12(1): 80-90
5. Graydon J, Eysenck MW: Distraction and cognitive performance. *Eur J Cognit Psychol*, 1989; 1(2): 161-79
6. Goodell KH, Cao CG, Schwaitzberg SD: Effects of cognitive distraction on performance of laparoscopic surgical tasks. *J Laparoendosc Adv Surg Tech A*, 2006; 16(2): 94-98
7. Van Selst M, Ruthruff E, Johnston JC: Can practice eliminate the psychological refractory period effect? *J Exp Psychol Hum Percept Perform*, 1999; 25(5): 1268-83
8. Waqar S, Park J, Kersey T et al: Assessment of fatigue in intraocular surgery: Analysis using a virtual reality simulator. *Graefes Arch Clin Exp Ophthalmol*, 2011; 249(1): 77-81
9. Jiang M, Liu S, Feng Q et al: Usability study of the user-interface of intensive care ventilators based on user test and eye-tracking signals. *Med Sci Monit*, 2018; 24: 6617-29
10. Park J, Waqar S, Kersey T et al: Effect of distraction on simulated anterior segment surgical performance. *J Cataract Refract Surg*, 2011; 37(8): 1517-22
11. Yurko YY, Scerbo MW, Prabhu AS et al: Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. *Simul Healthc*, 2010; 5(5): 267-71
12. Chen S, Epps J: Using task-induced pupil diameter and blink rate to infer cognitive load. *Hum Comput Interact*, 2014; 29(4): 390-413
13. Di Stasi LL, Diazpiedra C, Rieiro H et al: Gaze entropy reflects surgical task load. *Surg Endosc*, 2016; 30(11): 5034-43
14. Zhang JY, Liu SL, Feng QM et al: Ergonomic assessment of the mental workload confronted by surgeons during laparoscopic surgery. *Am Surg*, 2018; 84(9): 1538-43
15. Jansen RJ, Sawyer BD, van Egmond R et al: Hysteresis in mental workload and task performance: The influence of demand transitions and task prioritization. *Hum Factors*, 2016; 58(8): 1143-57
16. Mazur LM, Mosaly PR, Hoyle LM et al: Subjective and objective quantification of physician's workload and performance during radiation therapy planning tasks. *Pract Radiat Oncol*, 2013; 3(4): e171-77
17. Walsh TM: The role of simulation to train gynecology residents in minimal-invasive surgery. *Current Women's Health Reviews*, 2018; 14(1): 11-17
18. Conrad C, Konuk Y, Werner PD et al: A quality improvement study on avoidable stressors and countermeasures affecting surgical motor performance and learning. *Ann Surg*, 2012; 255(6): 1190-94

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Conflicts of interests

None.