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A Quality Improvement Study on Avoidable Stressors and Countermeasures Affecting Surgical Motor Performance and Learning

Claudius Conrad¹, Yusuf Konuk¹, Paul D. Werner⁴, Caroline G. Cao², Andrew L. Warshaw¹, David W. Rattner¹, Lars Stangenberg¹, Harald C. Ott¹, Daniel B. Jones³, Diane L. Miller⁵, and Denise W. Gee¹

¹Harvard Medical School, Massachusetts General Hospital, Department of Surgery, Boston, MA

²Tufts University, Department of Mechanical Engineering, Medford, MA

³Harvard Medical School, Beth Israel Deaconess Medical Center, Department of Surgery, Boston, MA

⁴Alliant International University, California School of Professional Psychology, San Francisco, CA

⁵Tufts University School of Medicine, Boston, MA

Abstract

OBJECTIVE—To explore how the two most important components of surgical performance - speed and accuracy - are influenced by different forms of stress and what the impact of music on these factors is.

SUMMARY BACKGROUND DATA—Based on a recently published pilot study on surgical experts, we designed an experiment examining the effects of auditory stress, mental stress, and music on surgical performance and learning, and then correlated the data psychometric measures to the role of music in a novice surgeon's life.

METHODS—31 surgeons were recruited for a crossover study. Surgeons were randomized to four simple standardized tasks to be performed on the Surgical SIM VR laparoscopic simulator, allowing exact tracking of speed and accuracy. Tasks were performed under a variety of conditions, including silence, dichotic music (auditory stress), defined classical music (auditory relaxation), and mental loading (mental arithmetic tasks). Tasks were performed twice to test for memory consolidation and to accommodate for baseline variability. Performance was correlated to the Brief Musical Experience Questionnaire (MEQ).

RESULTS—Mental loading influences performance with respect to accuracy, speed, and recall more negatively than does auditory stress. Defined classical music might lead to minimally worse performance initially, but leads to significantly improved memory consolidation. Furthermore, psychologic testing of the volunteers suggests that surgeons with greater musical commitment, measured by the MEQ, perform worse under the mental loading condition.

CONCLUSION—Mental distraction and auditory stress negatively affect specific components of surgical learning and performance. If used appropriately, classical music may positively affect surgical memory consolidation. It also may be possible to predict surgeons' performance and

learning under stress through psychological tests on the role of music in a surgeon's life. Further investigation is necessary to determine the cognitive processes behind these correlations.

Keywords

Surgery; Stress; Music; Mental Loading; Motor Performance; Memory Consolidation

INTRODUCTION

Acoustic stimuli are present throughout the work environment and the same holds true in the operating theatre.¹ A landmark paper by Hodge and Thompson was the first to consider the influence of auditory stimulation on surgical performance.² Since that publication, there has been increasing interest in improving patient safety in the operating room through a better understanding of environmental stimuli and surgical outcome. Unequivocal conclusions have yet to be drawn from the research on the effects of music as a modulator of work environments with respect to performance, concentration, communication, and stress. For example, in a survey by Hawksworth et al., the majority of staff interviewed had a negative opinion of music in the operating theatre.³ Both the flight industry and military have also reported auditory stimuli as a cause of stress impacting performance.⁴⁻⁶ However, the true effects of music and other auditory stimuli are still being investigated.

Studies have shown that music can have a positive, negative, or neutral effect on surgical performance.^{7, 8} McGrath demonstrated that background music can improve task performance.⁹ A questionnaire-based study also showed a correlation between music in the operating room and reduced stress levels of operating staff.¹⁰ However, Miskovic et al. showed that music during training procedures in the operating room may be a distraction to novice surgeons.⁸ Conversely, Moorthy et al. found no effect from auditory stimuli on surgeon task performance, with time to complete tasks as the primary measure.^{11, 12} Hawksworth et al. confirmed this observation in anesthesiologists exposed to a variety of auditory stimuli.³

The effect of various parameters of music on performance and concentration requires further investigation. These parameters include self-selected music versus experimenter-selected music. Distinctions in the literature have been made between dichotic music (two different type of music in each ear) and classical music, between loud and quiet music and other modulators of acoustic stimuli.¹³ We have shown in a pilot study that auditory conditions and mental loading impact performance of even world-renown experts during laparoscopic surgery.¹⁴ In this experiment, experts were better able to complete tasks in the presence of classical music. Dichotic music and mental loading, however, could negatively impact expert surgeons' performance, although the data was heterogeneous. Other studies report that random background music improves task performance and responsiveness significantly more than continuous noise, broadband sounds, or silence.¹⁵

This crossover study examines the effect of auditory stress (dichotic music) and auditory relaxation (classical music) on laparoscopic motor skill performance in novices and compares these results to the effects of the internal stresses of mental loading (arithmetic tasks). Subjects were asked to perform four standardized tasks on a laparoscopic surgery simulation trainer twice, the second time after a short break between trials, to evaluate their ability to consolidate the memory of the performed task. Performance was evaluated based on time to completion and tip trajectory (path of tip through space). Following conclusion of the tasks, subjects completed the Brief Music Experience Questionnaire (MEQ), a self-report measure of individual differences in reactions to music.¹⁶ The MEQ assesses 6 aspects of music experience that are summarized by two dimensions: Subjective/Physical

Reactions to music (e.g., emotional reactions) and Active Involvement in music (cognitive/behavioral involvement). It was hypothesized, on the basis of pilot studies, that novice surgeons would show improved task performance in the presence of auditory relaxation and decreased performance in the presence of auditory stress or mental loading. The degree of influence on the two major components of surgical performance (speed and accuracy) by the test conditions, as well the effects on surgical learning, was to be determined by this study.

METHODS

(Figure 1) 31 volunteer novices of surgery with no previous laparoscopic training were asked to complete four simple, standardized tasks on the surgical computerized laparoscopy simulator Surgical SIM VR (Medical Education Technologies, Inc[®], Sarasota, FL, USA). No active selection of the volunteers were performed to avoid selection bias. The virtual tasks included (A) Lifting up a structure and cutting below it, (B) targeting objects, (C) feeding a rope and (D) aligning objects. To control for prior knowledge, the tasks were abstract, not requiring surgical knowledge. However, the tasks employed were related to the manual tasks necessary for surgical procedures. Subjects were evaluated on accuracy and time to completion, with accuracy assessed through the measure of tip trajectory (path of tip through space). Permutations of task order were performed in order to avoid a systematic error of a learning effect. For ten minutes after completion of the tasks, each subject was engaged in a simple manual number alignment quiz. The goal of this exam was to distract the subject's mind from the completed task and allow accurate measurement of memory consolidation. After the number alignment quiz, each task was repeated to test memory consolidation of motor performance.

The tasks were completed under four conditions: A) silence, B) dichotic music, C) mental loading, or D) classical music. Dichotic music represented two conflicting genres, "Death Metal" and German Folk, with one type of music presented in each ear simultaneously. The stress level of the dichotic music was amplified through the inclusion of inverse dynamic lines – melodic lines in the left ear complementing those in the right ear during short breaks. It has been demonstrated that the presentation of acoustic stimuli in a dichotic format leads to significant stress with decreased gastric pH and a typical "fight or flight" response.¹⁷ The next condition, "mental loading," was created through simple, standardized arithmetic exercises that had to be performed as quickly as possible while completing the task. Subjects were required to answer questions as quickly as possible, and a silence of greater than 3 seconds and/or incorrect answers prompted repeating the question. The condition of relaxation music was created through exposure of the volunteers to classical music. Classical music was presented as slow movements from Mozart's piano Sonatas, which have been demonstrated to offer soothing compositional elements. In prior experiments in surgical ICU patients, we found that the observed relaxation response may be mediated by the hypothalamic-hypophyseal-pituitary axis, and lead to a decreased interleukin-6 secretion due to a direct action of growth hormone on peripheral blood mononuclear cells.¹⁸ Each test condition was presented to the novices at the initial task performance as well as during the repeat performance. The auditory stimuli were applied in a standardized fashion via headphones. Noise pressure level was standardized for all participants and set at 75% of the maximum allowed noise pressure level for operating room environments [85 dB (A)] at 60 to 65 dB (A).

Exclusion criteria for the study included hearing difficulties, motor deficits, and a self-reported strong dislike of classical music. The criteria to terminate trials prematurely were predefined and included obvious inability to cope with auditory or mental stress. Triple blinding occurred by the following mechanism: Volunteers were unaware of the study design and exact parameters measured to evaluate performance. All volunteers wore

headphones and study personal recording performance parameters were blinded towards whether music, no music or dichotic music was played via headphones. Data analysis and statistics were performed by an independent statistician, blinded towards study design and outcome parameters

Aspects of musical experience were quantified via the reliable and factorally validated Brief Music Experience Questionnaire (MEQ).¹⁹ The MEQ consists of 53 items (questions) that test for six scales: 1. *Commitment to Music* (the centrality of pursuit of musical experiences in the person's life); 2. *Innovative Musical Aptitude* (self-reports of musical performance ability as well as the ability to generate musical themes and works); 3. *Social Uplift* (the experience of being uplifted in a group-oriented manner by music); 4. *Affective Reactions* (affective and spiritual reactions to music); 5. *Positive Psychotropic Effects* (calming, energizing, integrating reactions); 6. *Reactive Musical Behavior* (motile reactions including humming and swaying along with music). Using the principle factors method during the development and subsequent study of the questionnaire, two factors were identified with great eigenvalue. Those factors were Factor 1, *Subjective and Physical Reactions to Music*, and Factor 2, *Active Involvement*. Factor 1 had an eigenvalue of 2.59 and accounted for 43.19% of the variance and Factor 2 had an eigenvalue of 1.44 and accounted for 23.93% of the variance. We tested for those factors independently from the six scales mentioned above. Descriptive statistical analysis was performed using ANOVA with Bonferroni post-test to compare subgroups and paired t-test (SPSS Inc 16.0. and Prism 4.0).

The study was approved by the Institutional Review Board of the Beth Israel Deaconess Medical Center of Harvard Medical School.

RESULTS

SURGICAL SPEED

(Figure 2, Table 1A) Silence was the most conducive condition for task completion. Performance was significantly worse (118%, $p<0.0001$) under mental loading conditions. Dichotic music also worsened performance (115%) with a high degree of variance (Bartlett's test for equal variances $p<0.0001$). Although the surgeons performed the task somewhat more slowly while exposed to classical music, the difference compared to silence was not statistically significant ($p>0.05$).

Speed of task completion was greatest in silence, with an improvement between trials of 39.2% ($p=0.004$). Speed improved 38.1% under dichotic music conditions, however this difference was not statistically significant due to high variance ($p=0.08$). Mental loading conditions resulted in the slowest performance with an improvement between trials of only 7.1% ($p=0.01$). Conversely, performance improved the greatest in classical music conditions (61%, $p=0.0006$). Consequently, classical music condition is as beneficial as silence with regards to task performance and significantly better with regards to improvement upon repetition. We noted a high degree of variance among the novice surgeons, with some performing similarly under dichotic conditions as well as in silence, while others were negatively influenced by this condition (up to 257%). This high variance was unique to the dichotic condition group.

SURGICAL ACCURACY

(Figure 3, Table 1B) An evaluation of accuracy shows a similar pattern, but this pattern is not fully comparable to that found with the measure of surgical speed. When compared to silent conditions, task performance was 64% less accurate in dichotic conditions ($p<0.05$) and 126% less accurate under mental loading conditions ($p<0.001$). In the presence of classical music, task performance was only 9% less accurate ($p>0.05$), which was not

statistically different from silent conditions. Procedural recall of accuracy was 32% ($p=0.0001$) in silence, 39% ($p=0.421$) in dichotic music, only 5% ($p=0.192$) under mental loading conditions, and the greatest at 75% ($p=0.019$) in classical music.

However, there is an inverse relationship within one response domain with regards to the degree of variance of speed and accuracy in silent and dichotic conditions. Novice surgeons demonstrated less variance for initial versus post-test performance of accuracy in silence and more variance under dichotic conditions. This relationship is inverse for speed; for the measure of speed, there is greater variance in silence and less under dichotic conditions.

MUSICAL EXPERIENCE

Degree of commitment to music and innovative musical aptitude reported in the Brief Musical Experience Questionnaire both had highly significant, inverse, correlations to accuracy and measured memory consolidation of accuracy during the condition of mental loading ($p=0.0001$ and $p=0.032$). Music experience variables did relate to performance in dichotic conditions.

CONCLUSION

The main focus of this study was to enhance surgical performance (measured by speed and accuracy) and learning by focusing on avoidable stressors and identifying potential benefits of music. The relationship between music, surgical performance, and learning were investigated and correlated to the influence of the musical background.

In this study we were able to demonstrate the precise influence of auditory stress and mental stress on the two important measures of surgical motor performance: speed and accuracy. We then contrasted these findings with performance under previously defined “relaxing” music conditions with the goal of determining whether music, as an inexpensive and readily available tool, could improve surgical performance. Our design allowed comparative analysis of the degree of influence of stressful auditory stimuli or mental loading on speed and accuracy, and we found that these distracters decrease speed and accuracy of task performance. A previous study had demonstrated that certain auditory conditions significantly affect the surgical performance of expert surgeons.¹⁴ This study asserted that dichotic music can lead to worse performance with respect to time until task completion, task accuracy, as well as recall of a performed task. In experts, mental loading had a greater effect on time until completion than on accuracy, but did not appear to affect recall as much. In follow up to this study, our current experiment suggests that novice surgeons, too, are affected by the acoustic environment of the operating theatre. While this effect was expected based on the experts’ data, the degree of influence was greater than predicted.

Although speed and accuracy are influenced by all stressful test conditions in a similar way, we determined that dichotic music affects speed more negatively whereas mental loading affects accuracy more negatively. In addition, the degree of influence of dichotic music on performance was variable. Some novice surgeons encountered a significant disadvantage from this stimulus, performing 2.5 times more poorly. Conversely, others operated as well as in silence. We were unable to isolate a factor in the brief music experience questionnaire that would allow us to identify these surgeons through psychometric testing. If such a factor were identified, special training could be developed to improve performance under auditory stress and mental loading stimuli. Follow up studies will focus on preemptively identifying surgeons -- through more extensive psychometric testing -- who will be at risk for performing poorly with auditory and mental stress.

Nevertheless, we were able to identify variables that predict surgical performance under various auditory conditions through correlating outcome to the role of music in a surgeon's life. The highly significant statistical result that surgeons with a particular music background perform worse while mentally loaded was astounding. A possible explanation for this result could be that musicians are trained to focus their thought process on the musical performance only and block out all other thought processes. Clearly this finding warrants further investigation and might offer insight into the thought processes that contribute to higher achievements in music or to variations in surgical performance.

Intentionally, music preference was not taken into account in the design of the experiment. To date, little is known about the phenomenon of musical taste. However, personal preference of musical taste, which is strongly linked to primary personality, sex, age and, interestingly, income, has been shown to impact surgical performance under the influence of music.^{13, 20} The goal of our study design was to use a music selection that would be applicable to an actual operating room environment. Therefore, the selection was designed to encompass the diverse musical tastes of the operating room staff and to negate the need for exploring musical taste prior to employing a music intervention during an operation. Further, our music selection has been shown in previous studies to be relaxing regardless of musical taste.¹⁸

This study is the first to suggest that not only is performance impacted by acoustic stimuli, but learning is as well. Previous studies have shown that music is associated with relaxation, but a clear correlation to surgical learning has not been made. We were able to demonstrate that listening to relaxing music leads to improved learning of a surgical procedure.

A recent review addressed the problem of stressors impacting performance. These stressors included laparoscopic surgery, bleeding, distractions, time pressure, procedural complexity, and equipment problems.²¹ However, this review did not identify relevant literature on the effect of these stressors on surgical learning. The data on the correlation of auditory and mental stress on surgical performance from this study has positive implications for postgraduate surgical training and potentially offers a relatively simple way to improve learning through avoiding these stressors. Our data suggests that music could be an inexpensive yet effective tool to reverse some of these negative effects on surgical motor learning. The precise mechanism by which this effect might be achieved will be elucidated in further studies. Specifically, our studies will aim to identify the component of the motor learning process that is positively influenced through defined music: apprehension of the task, memory consolidation, or recall of the learned procedure. It has been shown that the interaction between amygdala-driven and hippocampus-driven activities explains how emotion enhances episodic memory recognition.²² The behavioral evidence regarding the emotion-induced enhancement of immediate and delayed episodic memory recognition remains poorly understood in humans. However, this data may offer an explanation of how music-induced improvement of memory in surgical motor performance is mediated in the brain.

References

1. Falk SA, Woods NF. Hospital noise--levels and potential health hazards. *N Engl J Med*. 1973; 289(15):774–81. [PubMed: 4728750]
2. Hodge B, Thompson JF. Noise pollution in the operating theatre. *Lancet*. 1990; 335(8694):891–4. [PubMed: 1969991]
3. Hawksworth CR, Sivalingam P, Asbury AJ. The effect of music on anaesthetists' psychomotor performance. *Anaesthesia*. 1998; 53(2):195–7. [PubMed: 9534648]

4. Sexton JB, Helmreich RL. Analyzing cockpit communications: the links between language, performance, error, and workload. *Hum Perf Extrem Environ*. 2000; 5(1):63–8. [PubMed: 12190082]
5. Sexton JB, Thomas EJ, Helmreich RL. Error, stress, and teamwork in medicine and aviation: cross sectional surveys. *Bmj*. 2000; 320(7237):745–9. [PubMed: 10720356]
6. Wallenius C, Larsson G, Johansson CR. Military Observers' Reactions and Performance When Facing Danger. *Military Psychology*. 2004; 16(4):211–229.
7. Carlson S, Rama P, Artchakov D, Linnankoski I. Effects of music and white noise on working memory performance in monkeys. *Neuroreport*. 1997; 8(13):2853–6. [PubMed: 9376518]
8. Miskovic D, Rosenthal R, Zingg U, et al. Randomized controlled trial investigating the effect of music on the virtual reality laparoscopic learning performance of novice surgeons. *Surg Endosc*. 2008; 22(11):2416–20. [PubMed: 18622551]
9. McGrath JJ. Performance sharing in an audio-visual vigilance task. *Hum Factors*. 1965; 7(2):141–53. [PubMed: 5861125]
10. Ullmann Y, Fodor L, Schwarzberg I, et al. The sounds of music in the operating room. *Injury*. 2008; 39(5):592–7. [PubMed: 16989832]
11. Moorthy K, Munz Y, Dosis A, et al. The effect of stress-inducing conditions on the performance of a laparoscopic task. *Surg Endosc*. 2003; 17(9):1481–4. [PubMed: 12820061]
12. Moorthy K, Munz Y, Undre S, Darzi A. Objective evaluation of the effect of noise on the performance of a complex laparoscopic task. *Surgery*. 2004; 136(1):25–30. discussion 31. [PubMed: 15232535]
13. Allen K, Blascovich J. Effects of music on cardiovascular reactivity among surgeons. *Jama*. 1994; 272(11):882–4. [PubMed: 7811324]
14. Conrad C, Konuk Y, Werner P, et al. The effect of defined auditory conditions versus mental loading on the laparoscopic motor skill performance of experts. *Surg Endosc*. 24(6):1347–52. [PubMed: 20033720]
15. Rudin D, Kiss A, Wetz RV, Sottile VM. Music in the endoscopy suite: a meta-analysis of randomized controlled studies. *Endoscopy*. 2007; 39(6):507–10. [PubMed: 17554644]
16. Werner PD, Swope AJ, Heide FJ. The Music Experience Questionnaire: development and correlates. *J Psychol*. 2006; 140(4):329–45. [PubMed: 16967740]
17. Fass R, Naliboff BD, Fass SS, et al. The effect of auditory stress on perception of intraesophageal acid in patients with gastroesophageal reflux disease. *Gastroenterology*. 2008; 134(3):696–705. [PubMed: 18206149]
18. Conrad C, Niess H, Jauch KW, et al. Overture for growth hormone: Requiem for interleukin-6? *Crit Care Med*. 2007
19. Werner PD, Swope AJ, Heide FJ. Ethnicity, music experience, and depression. *J Music Ther*. 2009; 46(4):339–58. [PubMed: 20394134]
20. North AC. Individual differences in musical taste. *Am J Psychol*. 123(2):199–208. [PubMed: 20518436]
21. Arora S, Sevdalis N, Nestel D, et al. The impact of stress on surgical performance: a systematic review of the literature. *Surgery*. 147(3):318–30. 330, e1–6. [PubMed: 20004924]
22. Kuriyama K, Soshi T, Fujii T, Kim Y. Emotional memory persists longer than event memory. *Learn Mem*. 17(3):130–3. [PubMed: 20189956]

Figure 1. Flow chart explaining the study design

Novice surgeons were randomized to complete simple surgical tasks on a laparoscopy simulator while exposed to four conditions: 1. Silence, 2. Dichotic Music, 3. Mental Loading, and 4. Classical Music. Permutations of the task were created to account for a learning effect. Each task was performed twice to test after a break for a learning effect. The data was correlated to the Brief Music Experience Questionnaire.

Figure 2. Data for Time until Task completion (Speed)

The data for time is depicted for the 4 conditions silence, dichotic music, mental loading and classical music. 1 and 2 on the x-axis behind the various conditions represent completion of the task for the first time (1) and then for second time (2) following a short break.

Figure 3. Data for Tip Trajectory of the Surgical Instrument (Accuracy)

The data for accuracy is depicted for the 4 conditions silence, dichotic music, mental loading and classical music. 1 and 2 on the x-axis behind the various conditions represent completion of the task for the first time (1) and then for second time (2) following a short break

Figure 4. Relative improvement for time depicted as change from baseline for the four conditions

Notice that the greatest relative improvement occurs while listening to relaxing classical music

Figure 5. Relative improvement for accuracy depicted as change from baseline for the four conditions

Again, notice that the greatest relative improvement occurs while listening to relaxing classical music

Table 1

Data for speed under the four conditions

The first column demonstrates the relative improvement to silence and the correlating statistical test (2nd column), when the task is performed the first time. Then the relative improvement to silence (3rd column) and the correlating statistical test (4th column) is shown for when the task is performed the second time. The last two columns (5th and 6th column) demonstrate the relative improvement between the first trial and the second trial of task performance, as well as the correlating statistical test.

	Difference vs silence (pre)	Bonferroni test (ANOVA P< 0.0001)	Difference vs silence (post)	Bonferroni test (ANOVA P< 0.0001)	Pre/Post difference	T-test (p value)
Silence					32.02%	0.0001
Dichotic	115.81%	P < 0.001	120.10%	P < 0.01	28.06%	0.838
Mental	118.46%	P < 0.001	234.01%	P < 0.001	7.14%	0.017
Classic	63.08%	P > 0.05	3.95%	P > 0.05	61.29%	0.006

Table 2

Relevant data for accuracy

The first column looks at the relative improvement to silence and the correlating statistical test (2nd column), when the task is performed the first time. Then the relative improvement to silence (3rd column) and the correlating statistical test (4th column) is shown for when the task is performed the second time. The last two columns (5th and 6th column) demonstrate the relative improvement between the first trial and the second trial of task performance, as well as the correlating statistical test.

	Difference vs silence (pre)	Bonferroni test (ANOVA P< 0.0001)	Difference vs silence (post)	Bonferroni test (ANOVA P< 0.0001)	Pre/Post difference	T-test (p value)
Silence					39.27%	0.0041
Dichotic	63.50%	P < 0.05	45.32%	P > 0.05	39.58%	0.0421
Mental	125.68%	P < 0.001	215.94%	P < 0.001	4.82%	0.192
Classic	9.19%	P > 0.05	-30.92%	P > 0.05	57.00%	0.0188