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Background. An operating room is a noisy environment. How noise affects performance during robotic surgery remains unknown. We investigated whether noise during training with the da Vinci surgical robot (Intuitive Surgical, Inc., Sunnyvale, CA) would affect the performance of simple operative tasks by the surgeon.
Methods. Twelve medical students performed 3 inanimate operative tasks (bimanual carrying, suture tying, and mesh alignment) on the da Vinci Surgical System with or without the presence of noise. Prerecorded noise from an actual operating room was used. The kinematics of the robotic surgical instrument tips and the muscle activation patterns of the subjects were evaluated.
Results. We found noise effects for all 3 tasks with increases in the time to task completion (23%; P = .046), the total distance traveled (8%; P = .011) of the surgical instrument tips, and the muscle activation volume (87%; P = .015) with the presence of noise. We confirmed that the mesh alignment task was the most difficult task with the greatest time to task completion and the greatest muscle activation volume, whereas the suture tying task and the bimanual carrying could be considered the intermediate and the least difficult task, respectively. The noise effects were significantly greater while performing more difficult tasks.
Conclusion. Our findings demonstrated that noise degraded robotic surgical performance; however, the impact of noise on robotic surgery will depend on the level of difficulty of the task. Subsequent research is required to identify how different types of noise, such as random or rhythmic sounds, affect the performance of operative tasks using robots such as the da Vinci.

Introduction

Many sources, including patient monitors, suction machines, and conversations between individuals, contribute to the noise that is present in the operating room.[1,2] Shapiro and Berland[2] measured the noise levels in the operating room and found them to be as great as 70 dB (eg, crushing paper garbage) to 86 dB (eg, opening package of rubber group), and they are often greater than the recommended standard of 45 dB for a working environment.[3] Especially during neurosurgical and orthopedic procedures, the peak levels of noise can be as great as 100--120 dB,[4] which can interfere seriously with the communication between medical doctors and nurses during an operation. Such a noisy environment in operating rooms could be potentially dangerous to staff and patients,[2] and it could also have a negative impact on the performance of surgeons during operative procedures.[1,5] Thus, several studies have also investigated the effect of noise on the performance of a conventional laparoscopic task.[5-7] Background noise at 80--85 dB impaired operative laparoscopic performance regarding dexterity and increased the incidence of errors.[5] In contrast, another study on the effect of noise and background music on laparoscopic performance showed no changes in performance regarding the time taken to complete a suturing task, the path length of the hand movement, the accuracy of suturing, and the knot quality.[7] These contradictory results showed the need to establish clearly how environmental effects such as background noise impact operative performance. In addition, no such studies have been performed for robot-assisted surgery, where the movements of the robot can produce additional background noise.

In this study, we investigated how noise affects performance of simple operative tasks during robotic surgery. We examined if noise during practicing with the da Vinci Surgical System (dVSS; Intuitive Surgical Inc., Sunnyvale, CA) would affect the performance of simple operative tasks used commonly in robotic laparoscopy. We hypothesized that environmental noise would have a negative impact on robotic operative performance by the surgeon. Furthermore, we have found in our previous research work[8] that operative performance is influenced by the level of difficulty of the tasks used for robotic laparoscopic training. Therefore, we also hypothesized that the impact of noise on robotic operative performance would be related to the level of difficulty of the operative tasks.

MATERIALS AND METHODS

Twelve medical students (aged 27 ± 4 years) volunteered to participate in this study and had only basic surgical knowledge with no prior experience in robotic surgery. All subjects were right handed. This study was approved by the Institutional Review Board of the University of Nebraska Medical Center. The subjects were assigned randomly to 2 groups. Six subjects completed simple operative tasks in a noisy environment, whereas the other 6 completed the same tasks without noise.

All subjects performed 3 inanimate operative tasks using the dVSS: bimanual carrying, suture tying, and mesh alignment (Fig 1). The bimanual carrying task required simultaneously picking up 2 objects (1 each with left and right graspers) from metal caps (30 mm in diameter) and placing them in 2 other metal caps that were 50 mm away. The caps were arranged in a square configuration such that the left graspers removed pieces from the top left cap and placed them in the bottom left cap. The right grasper removed pieces from the bottom right cap and placed them in the top right cap. The subject repeated the movement 5 times in succession. The suture tying task required tying 2 intracorporeal knots with a suture (100 mm long and 0.5 mm in diameter). Subjects tied 3 knots in each trial. The 3 designated points were marked 150 mm apart. The mesh alignment task required the subject to loosen a rolled mesh and align its designated points accurately onto a material platform's designated points. This task required the subject to manipulate the mesh gently and to align the mesh precisely on the platform. Subjects also had to maneuver and position carefully the flexible material. The subjects performed the tasks by manipulating the dVSS from the surgeon's console. All 3 tasks were designed to mimic the actual laparoscopic tasks that required dexterity and coordination. Based on our previous research,[8] the mesh alignment task is considered the most difficult and the bimanual carrying task the least difficult of the 3 tasks.

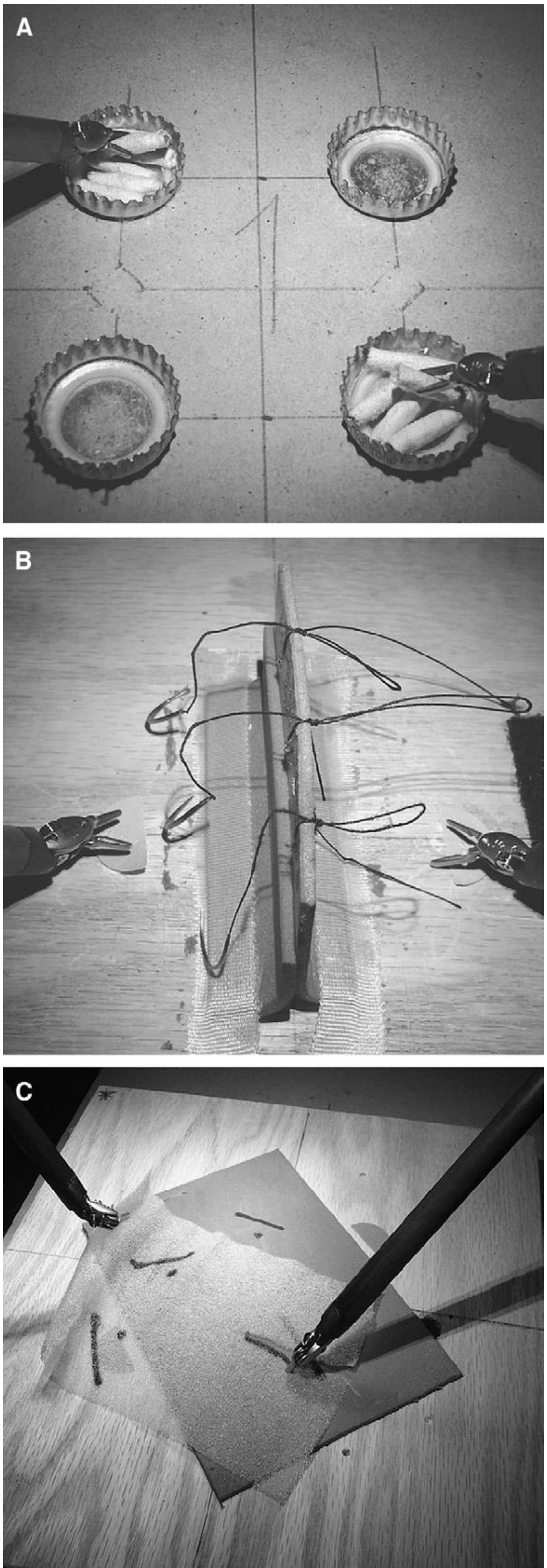

Fig 1. Inanimate operative tasks: (A) bimanual carrying (BC), (B) suture tying (ST), and (C) mesh alignment (MA).

Prerecorded noise (50--90 dB) from an actual operating room with the dVSS was used to mimic the noisy environment. This recorded noise contained patient monitors, robot arm movements, suction machines, drill machines, and conversation between surgeons and residents. All participants were asked to perform each task 11 times: 3 pre-exposure trials, 5 exposure trials either with or without noise, and 3 postexposure trials. The order of the 3 operative tasks was randomly presented to each participant. The number of trials was based on our pilot work. Pre-exposure and postexposure trials were given under no noise environment.

The kinematics of the surgical robot and surface electromyography (EMG) of the dominant arm were recorded from all trials. The kinematic-dependent variables used were time to task completion and total distance traveled with respect to the movement of the surgical instrument tips. Both variables were used to differentiate task difficulty in our previous work.[8] They were acquired using the dVSS Application Programmer's Interface provided by Intuitive Surgical, Inc. A custom program using LabView (National Instruments Corp., Austin, TX) was written to interface to the dVSS via an Ethernet connection. Kinematic data were streamed at 100 Hz. All data were postprocessed using MATLAB 6.5 (MathWorks, Inc., Natick, MA).

Surface EMG was used to measure the muscle activation pattern of the flexor carpi radialis and extensor digitorum of the dominant arms of each subject. Although many other types of movements (eg, flexion and extension of the thumb, index, and middle fingers, and forearm pronation and supination) and thus many other muscles are involved, it has been suggested that the contribution of the flexor carpi radialis and extensor digitorum in performance of training tasks such as bimanual carrying are considerably greater than all others.[9,10] Consequently, these 2 muscles were selected for the current study. A Bagnoli-2 (Delsys Inc., Boston, MA) surface EMG system was used to collect data at 1,000 Hz via a custom LabView program. Time domain and frequency domain analyses were performed using MATLAB 6.5 to calculate the total EMG activation volume (EMGv) and median EMG frequency (EMGfm). The total EMG activation is the integration of the normalized EMG output of the entire trial, and it provides an estimate of total muscle activation. The median EMGfm was used as an indicator of muscle fatigue.[11] Increased muscle fatigue was signified as the result of a decrease in median EMGfm.[10] Before the pre-exposure trial, the maximum EMG was recorded for both muscles via isometric contraction for 3 s. The total EMG activation volume was normalized to the maximum isometric EMG and then smoothed using a 150-ms root-mean-square moving window. A complete description of the time and frequency analyses is given in our previous study.[10]

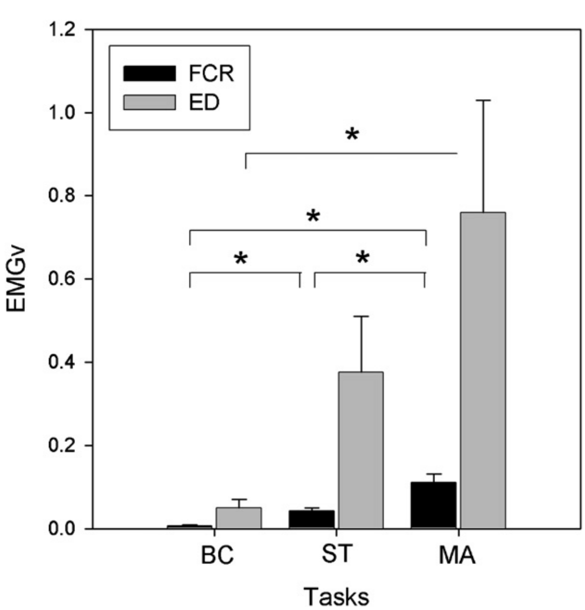

Fig 2. EMGv for both muscles (FCR, flexor carpi radialis; ED, extensor digitorum) in 3 operative tasks (BC, ST, and MA) during the pre-exposure session. A significantly greater EMGv was required to perform the MA and the ST tasks (*P < .05).

To verify the level of difficulty among the 3 operative tasks, the pre-exposure session data was used, and a 1-way analysis of variance (ANOVA) was performed for both the kinematics and the EMG measures. Furthermore, to test the 2 hypotheses that (1) environmental noise would have a negative impact on robotic operative performance; and (2) the impact of noise on robotic surgical performance would be related to the level of difficulty of the operative tasks, a 2-way ANOVA with noise (exposure with noise and without noise) as the between-subject factor and tasks (bimanual carrying, suture tying, and mesh alignment) as the within-subject factor was used to test the differences in both the kinematics and the EMG measures. Last, a second 2-way ANOVA with the same factors was used to test the differences in the total EMGv and median EMGfm during the exposure trials. Post-hoc pair-wise comparison with Bonferroni corrections were performed when factors were significant. The significance level was set at α = .05. All data are presented as mean ± standard errors.

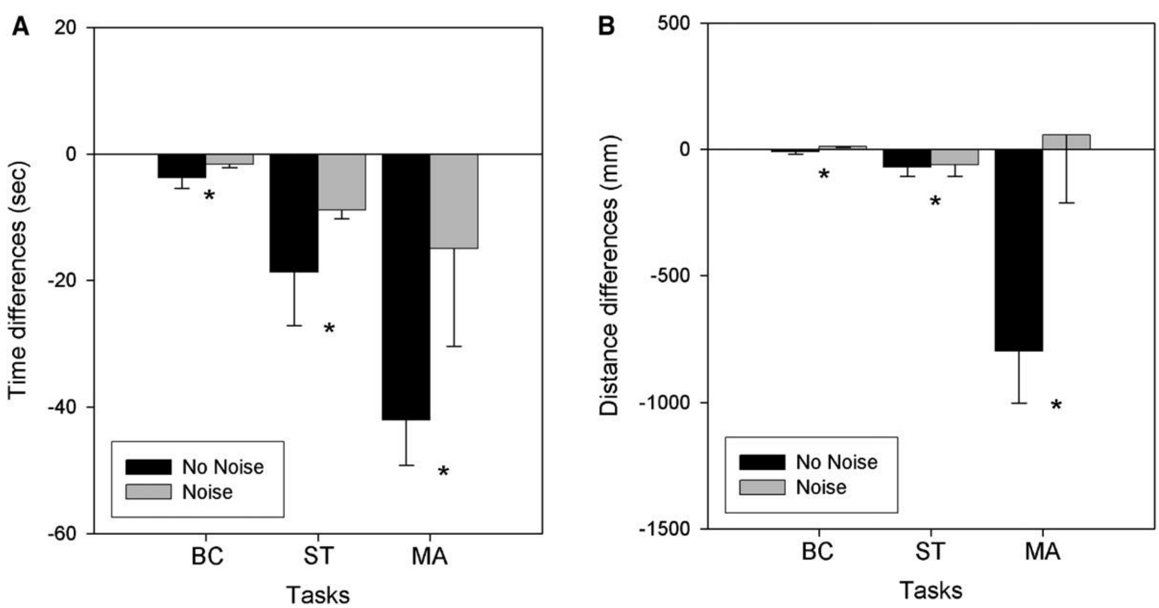

Fig 3. (A) Time to task completion differences and (B) total distance traveled differences between postexposure and pre-exposure trials in 3 operative tasks (BC, ST, and MA). A significant noise effect was found indicating a lesser difference while practicing operative tasks in the noisy environment (*P < .05).

RESULTS

Our results confirmed that the 3 tasks were different from each other during the pre-exposure session in both kinematic variables (*P* = .000). The mesh alignment task presented the greatest time to complete, whereas the bimanual task presented the least time to complete. The total distance traveled of the instrument tips was also the longest when subjects performed the mesh alignment task. Our data also indicated that the mesh alignment task had a greater EMGv for the flexor carpi radialis muscle when compared with the bimanual carrying task (*P* = .001) and the suturing task (*P* = .019), and the suturing task had a greater EMGv than the bimanual carrying task (*P* = .004). In addition, the mesh alignment task also had a greater EMGv for the extensor digitorum muscle when compared with the bimanual carrying task (*P* = .024; Fig 2).

No differences were found in the median EMGfm between tasks.

Noise effects caused the time to task completion to increase by 23% (P = .046; Fig 3, A) and the total distance traveled to increase by 8% (*P* = .011; Fig 3, B) on the average for all 3 tasks, when the differences between the pre-exposure and the postexposure sessions were compared. These differences were less while performing the operative tasks with the presence of noise. Task effects also caused the time of task completion to increase by 37% (*P* = .012; Fig 3, A) and the total distance traveled to increase by 14% (*P* = .035; Fig 3, B) on average for all 3 tasks. The differences were greater when performing more difficult tasks (ie, mesh alignment). An interaction was found only for the total distance traveled (*P* = .004; Fig 3, B), which indicates that the greatest difference was found when the most difficult task (mesh alignment) was performed without noise. The differences in the muscle activation volume and median frequency, however, were not different between the pre-exposure and the postexposure sessions.

Our results from the exposure trials showed a greater noise effect for the EMGv of all 3 tasks performed by the extensor digitorum muscle (*P* = .015; Fig 4, A), which indicates that more muscle activation volume by 87% was exerted while practicing in the environment with noise. The greater noise effect was shown in the most difficult task (mesh alignment) in the EMG activation volume (Fig 4, A). No significant noise effect (*P* = .066) was revealed for the flexor carpi radialis muscle. Task effects were found for both the extensor digitorum muscle (*P* = .018) and the flexor carpi radialis muscle (*P* = .000), which indicates that muscle activation volume increased with task difficulty. No interactions were found for both muscles in the muscle activation volume. A decrease in median EMGfm of the flexor carpi radialis muscle by 19% (*P* = .033; Fig 4, B) was revealed when the operative tasks were practiced with noise; however, neither a task effect nor an interaction was found in the flexor carpi radialis muscle. No differences were found in the extensor digitorum muscle for the median EMGfm.

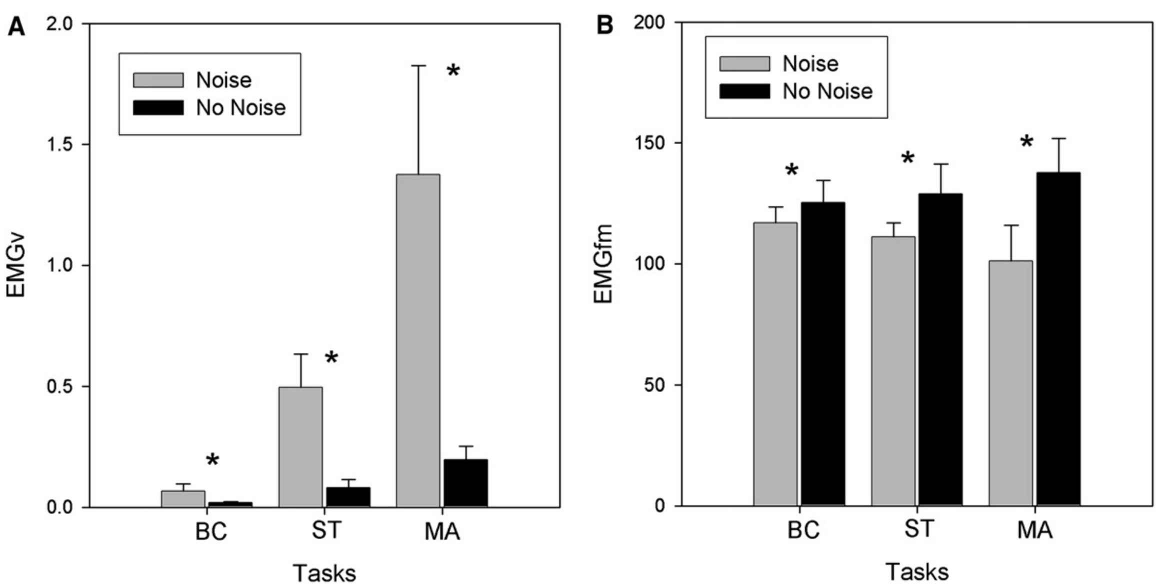

Fig 4. (A) EMGv of extensor muscles for the 2 environments (noise and no noise) in the 3 operative tasks (BC, ST, and MA) during exposure session. A significantly greater EMGv was required to perform all training tasks in the noisy environment (**P* < .05). (B) Median EMGfm of extensor muscles for 2 environments (noise and no noise) in 3 operative tasks (BC, ST, and MA) during exposure session. Overall, a significantly lesser EMGfm was found to perform operative tasks in the noisy environment (**P* < .05)

DISCUSSION

The purpose of this study was to investigate how noise affects the performance of simple operative tasks in medical students during robotic surgery. We examined whether noise presented while using the da Vinci Surgical System can affect the performance of simple operative tasks commonly used during robotic laparoscopy. We hypothesized that environmental noise would have a negative impact on robotic operative performance both in terms of the movements of the surgical instrument tips and the muscular efforts exerted by the subjects. More- over, we hypothesized that this impact would be related to the level of difficulty of the operative tasks.

Our results supported our first hypothesis that prerecorded noise from an operating room affects the performance of simple operative tasks during robotic surgery. All subjects performed the operative tasks with no improvement in both the time to task completion and total distance traveled of the instrument tips after practicing while being exposed to noise. These results are in line with others who found noise to be a psychologic stress to the surgeons that impairs their operative performance in the operating room.[5] The level of prerecorded noise used in our study was as high as 90 dB. Such a level of noise has been found to have a negative impact in the operating room when surgeons performed neurosurgery or other operations requiring noisy equipment, such as electric drills.[4] A previous study has also shown that noise could induce additional stress on surgeons and increase errors when performing a laparoscopic transfer task.[5] Our work also supported these previous findings and indicated that this is also the case for robot-assisted laparoscopy. Our data revealed an increase in muscle activation volume and a decrease in median muscle frequency during the exposure to noise. These EMG results indicated that participants required more muscle effort that led to increased muscle fatigue when they performed robotic laparoscopic training tasks during exposure to noise. Muscle fatigue has been associated with operative performance[12]; increased fatigue could lead to poor performance in laparoscopic surgery.

The above results disagree with those from Moorthy et al,[7] who found that laparoscopic operative performance was not affected by either noise or music. It is possible that their method, using a subjective scale to rate video to assess performance, was not sensitive enough to detect differences. Moreover, it is likely that the surgeons who participated in the study of Moorthy et al[7] had varied laparoscopic operative skills. In our study, all subjects had no prior experience in robotic surgery that could avoid the influential effect of operative experience on the result. Despite the inconsistent findings between our study and Moorthy et al,[7] the conventional laparoscopic surgery is also distinctively different than the robot-assisted surgery.[13,14] Robotic surgery may actually produce an environment in which there is more susceptibility to noise because of the additional movements of the surgical instrument arms or an occasional alarm from the system.

Our results also supported our second hypothesis that the effect of noise on robotic surgery may be driven by the difficulty of the operative task. We found that the mesh alignment and the suture tying tasks had greater extensor digitorum and flexor carpi radialis muscle activation volume than bimanual carrying (Fig 3). It has been suggested that mesh alignment and suture tying tasks were more difficult than bimanual carrying task.[8] Our results showed that the mesh alignment task was the most difficult task with increased time to task completion and increased total distance traveled of the robotic surgical instrument tips. Thus, suture tying and bimanual carrying were ranked as an intermediate and easy level, respectively. Based on these rankings from our results, more challenging and complex tasks, such as suture tying and mesh alignment, should show a larger negative effect of noise on operative performance (Fig 3, A and B, Fig 4, A and B). It is possible that those medical students who had no experience in operating the dVSS may be more easily distracted when noise is present. As a result, additional muscle effort may be required to complete the more difficult task. These findings suggest that the task difficulty could play an important role in modulating the levels of difficulty of robotic operative training program in the future. In addition, the findings also suggest that the impact of noise could increase when more challenging and difficult robotic operative procedures are performed.

Compared with experienced surgeons, medical students may require more attention (cognitive capacity) to learn an operative task.[12,15] Performing a difficult operative task in a noisy environment becomes challenging for these new medical students who still lack specific concentration abilities. Therefore, it is essential to investigate how medical students can accomplish a high level of operative task when noise is present. Operative training with noise may provide a better environment for trainees to learn how to focus their attention and use less cognitive resources or become more ''automatic'' like experienced surgeons15 to complete an operative task. Eventually, this training will allow surgeons to be more accustomed to the noisy operating room.

One limitation of this study is that the experiment was not performed at the actual operating theater. Another limitation is that the participants recruited in this study were medical students, which may not represent surgeons in training (surgery residents) or fully trained surgeons. Subsequent investigations are required to examine whether performance in residents or practicing surgeons will be affected by noise during robotic surgery. Nonetheless, this work examines the effect of noise on robot-assisted laparoscopic surgery. It provides the foundation for future studies to investigate the relationship between training and background noise during robot-assisted laparoscopic surgery. More investigations are required to confirm which levels of noise will affect robotic operative performance the most and whether other types of noise, such as random or rhythmic sounds, will impact the performance more substantially. Training in a noisy environment may also influence the skill acquisitions and tissue handling in robot-assisted laparoscopic surgery. More studies are necessary to confirm this hypothesis and possibly incorporate noise into robotic operative training.

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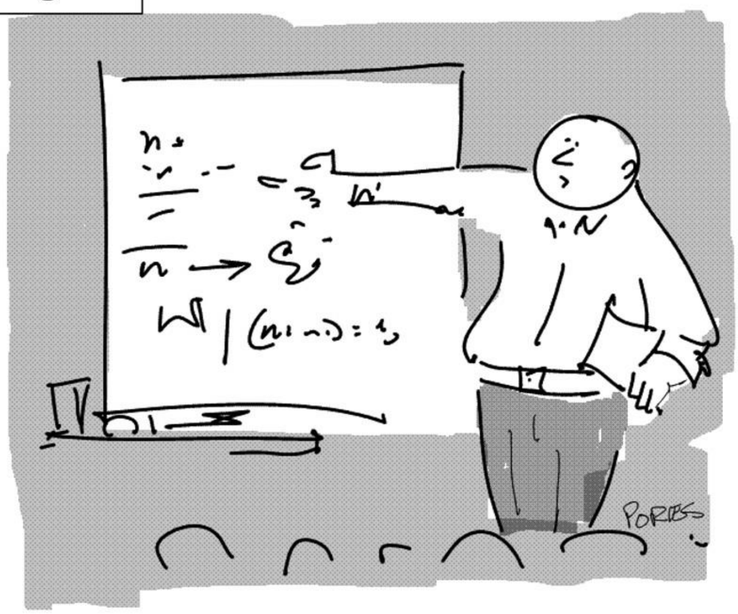

"No, you still don't get it. We have to keep the 'n' small. We're trying to prove our drug is as good as theirs. If we don't reach statistical power, we can conclude there is no difference."