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# Surgical Experience Correlates With Performance on a Virtual Reality Simulator for Shoulder Arthroscopy

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**Background:** The traditional process of surgical education is being increasingly challenged by economic constraints and concerns about patient safety. Sophisticated computer-based devices have become available to simulate the surgical experience in a protected environment. As with any new educational tool, these devices have generated controversy about the validity of the training experience.

**Hypothesis:** Performance on a virtual reality simulator correlates with actual surgical experience.

**Study Design:** Controlled laboratory study.

**Methods:** Forty-three test subjects of various experience levels in shoulder arthroscopy were tested on an arthroscopy simulator according to a standardized protocol. Subjects were evaluated for time to completion, distance traveled with the tip of the simulated probe compared with a computer-determined optimal distance, average probe velocity, and number of probe collisions with the tissues.

**Results:** Subjects were grouped according to prior experience with shoulder arthroscopy. Comparing the least experienced with most experienced groups, the average time to completion decreased by 62% from 128.8 seconds to 49.2 seconds; path length and hook collisions were more than halved from 8.2 to 3.8 and 34.1 to 16.8, respectively; and average probe velocity more than doubled from 0.18 to 0.4 cm/second. There were no significant differences for any parameter tested between subjects with video game experience compared to those without.

**Conclusions:** The study demonstrated a close and statistically significant correlation between simulator results and surgical experience, thus confirming the hypothesis. Conversely, experience with video games was not associated with improved simulator performance. This indicates that the skill set tested may be similar to the one developed in the operating room, thus suggesting its use as a potential tool for future evaluation of surgical trainees.

**Clinical Relevance:** The results have implications for the future of orthopaedic surgical training programs, the majority of which have not embraced virtual reality technology for physician education.

**Keywords:** surgical education; shoulder arthroscopy; arthroscopy simulator

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The process of surgical education is largely unchanged from the traditional apprenticeship model proposed by John Halsted in 1904.[1,2,10,14] Although this system has successfully trained generations of surgeons, there are important limitations. First, there are inherently increased risks to the patient based on lesser-skilled surgeons performing procedures.[12,32] Second, there are cost implications, such as prolonged operative time.[7,19,21] Finally, there are educational disadvantages as the current process is unable to

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TABLE 1
Demographic Characteristics of Participants[a]

| Group | Surgical Experience | Video Game Experience (L:X) | Subjects (n) | Gender (male:female) | Handedness (right:left) | Average Age (years) |
|---|---|---|---|---|---|---|
| 1 | None | 5:3 | 8 | 4:4 | 7:1 | 26.9 |
| 2 | PGY-2/3 | 6:5 | 11 | 8:3 | 11:0 | 29.4 |
| 3 | PGY-4/5 | 11:3 | 14 | 12:2 | 13:1 | 32.1 |
| 4 | Fellow/Attending | 10:0 | 10 | 10:0 | 7:3 | 37.3 |

[a] L, limited; X, experienced; PGY, postgraduate year of training.

objectively quantify the skill levels of surgical trainees, while the surgical procedure itself cannot be adjusted to the needs of the individual trainee.[3,6,11,16,18,27,35]

Early attempts to train surgical skills outside the operating room environment used foam or cadaveric models, which were limited by their lack of realism and availability.[20,23] Computerized simulators offer the potential to improve the training process, analogous to pilots training on flight simulators before taking control of an actual plane.[30] Surgical simulators hold great promise to increase surgical skills without risk to patients and without the time and financial constraints of traditional surgical education. These potential benefits may become even more apparent as surgical procedures become increasingly complex and work hour restrictions limit residents' operative experience.[4,13,36] Early computerized simulators were developed for nonorthopaedic applications such as laparoscopy, vascular surgery, and various other fields, where they have since gained considerable clinical acceptance.[5,9,17,24,29,33] Increasingly, studies are being conducted to validate that these simulators are not only able to measure but also improve surgical skills.[15,34]

Within the field of orthopaedic surgery, the teaching of arthroscopic procedures appears to lend itself well to computerized surgical simulators.[19,25,26,31] Arthroscopic interventions have become the most common procedures performed by orthopaedic surgeons.[26] However, unique challenges are created by the technical nature of these procedures. Similar to traditional open procedures, arthroscopy is performed in a 3-dimensional environment, yet surgeons have to rely on a merely 2-dimensional camera image for visual feedback; this imposes challenges not only to the operating surgeon but also to surgical teaching and education. This challenge has generated interest within the orthopaedic community for computer-based simulators that can be designed to address various skill sets and situations. Recognizing the importance of simulator-based learning, the American Board of Orthopaedic Surgery (ABOS) in 1997, and later the American Academy of Orthopaedic Surgeons (AAOS) in 1998, each designated task forces to evaluate available technology in this field.[26]

Our group and others believe that a computerized surgical simulator may be useful to evaluate and eventually teach arthroscopy skills.[22] To be suitable for this role, the simulator must measure, or train, the skill set required in the operating room. Some previous investigations of arthroscopic simulators have suggested good correlation of surgical experience with performance on a shoulder simulator[25,32]; however, the orthopaedic community has not embraced this emerging technology. In part, this might be attributed to concerns that these simulators closely resemble video games and, as such, would evaluate experience with games rather than actual surgical skill levels. One prior report indicated improved performance of users experienced with video games when tested on virtual reality laparoscopy simulators[8]; however, while video game aptitude translated to better simulator performance in novice surgeons, additional training on video games did not result in further improvements in simulated laparoscopy skills.[28]

The present study builds on the limited existing data on arthroscopy simulators to further validate their utility in surgical education. It is hypothesized that more experience in surgical arthroscopy will correlate with better performance on a computerized simulator, thus validating its use as an evaluation tool.

## MATERIALS AND METHODS

After approval by the Institutional Review Board, a total of 43 test subjects (Table 1) were recruited from medical students, orthopaedic residents, and attending orthopaedic surgeons at our institution. The participants provided information on their individual experience levels with shoulder arthroscopy as well as demographic data, including age, gender, and handedness (Table 1). Furthermore, participants were questioned on their prior experience with arthroscopy simulators and video games; the latter was quantified as limited (none or remote experience) or experienced (currently playing video games at least once per month).

All subjects were tested according to a standardized testing protocol on the Procedicus arthroscopy simulator (Mentice Corp, Göteborg, Sweden). The setup consists of a computer workstation and monitor to simulate the arthroscopic video display experience (Figure 1), and an arthroscopy station with instruments modeled after a real arthroscopic camera and tools (Figure 2). The computer receives input through transducers on the instruments and camera and is able to provide tactile feedback to the user through motors attached to the instruments. The device simulates shoulder arthroscopy of the right shoulder and can be set to simulate beach chair or lateral positioning.

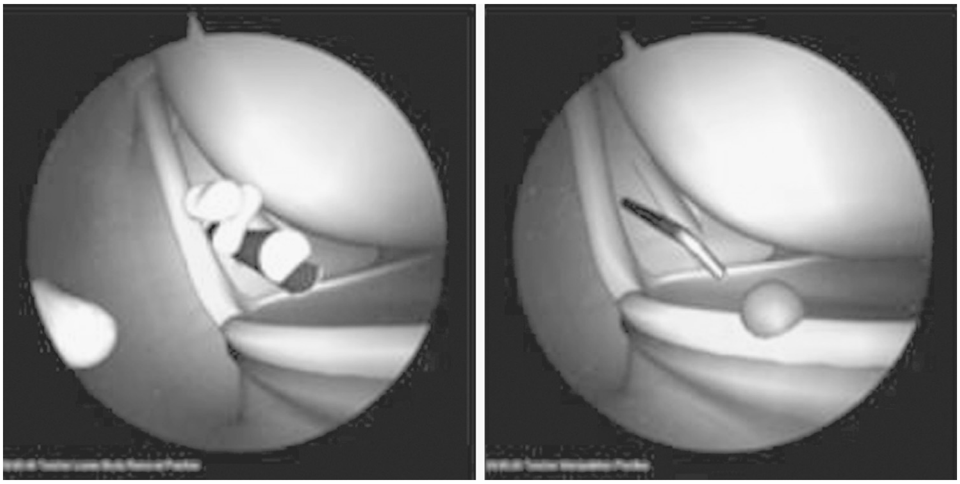

**Figure 1.** Computer-generated images of the shoulder joint as viewed from a posterior portal in the lateral position. A grasper (left) and probe (right) are shown entering from the anterior portal (image by Mentice Corp).

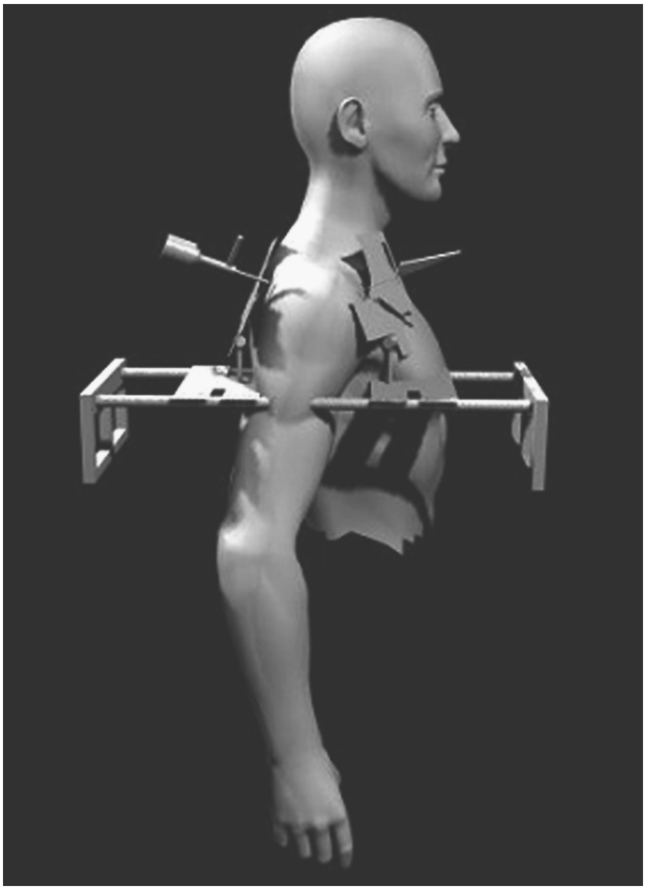

**Figure 2.** Depiction of the arthroscopic workstation and its simulated relation to patient position (image by Mentice Corp).

The protocol consisted of 6 repetitions of the same training module. The module required the participant to first locate an object within the shoulder joint and then touch it with a simulated probe, thus assessing the psychomotor skills of orientation and triangulation. Successful manipulation results in the disappearance of the object, with the simultaneous creation of a new object in a different, random location within the joint. After 11 objects, the module is completed and the computer provides 4 parameters: time to completion of the module; the distance traveled with the tip of the simulated probe compared with a computer-determined optimal distance; the average velocity of probe movement; and the number of probe collisions with the tissues.

For data analysis, the subjects were grouped according to their self-reported experience with shoulder arthroscopy. Subjects were divided into 4 groups: no prior arthroscopic procedures performed (group 1); experience equivalent to residents in their second or third postgraduate year of training (group 2); experience equivalent to residents in their fourth or fifth postgraduate year of training (group 3); and experience level equivalent to a sports medicine-trained specialist such as a sports medicine fellow or attending (group 4).

Averages for each of the recorded parameters and standard deviations were calculated across the 4 groups; group differences in the means were analyzed using single-factor analysis of variance (ANOVA), and when significant group differences were found, pairwise comparisons were made using the Tukey post-hoc test. The level of significance was set at .05.

## RESULTS

There were large differences in performance between the least and most experienced groups. Comparing least with most experienced groups (Table 2), the average time to completion decreased by 62% from 128.8 seconds to 49.2 seconds; path length and hook collisions were more than halved from 8.2 to 3.8 and 34.1 to 16.8, respectively; and average probe velocity more than doubled from 0.18 to 0.4 cm/s (Table 2).

TABLE 2
Results of Simulator Testing[a]

| Group | Time (sec) | Path Length (mult) | Probe Collisions (n) | Velocity (cm/s) |
|---|---|---|---|---|
| 1 | 128.8 ± 39.9 | 8.2 ± 2.2 | 34.1 ± 15.3 | 0.18 ± 0.06 |
| 2 | 72.7 ± 27.4 (P = .003) | 6.0 ± 1.6 (P = .03) | 24.6 ± 9.8 (P = .03) | 0.32 ± 0.16 (P = .000003) |
| 3 | 59.9 ± 14.3 (P = .03) | 4.9 ± 0.9 (P = .03) | 21.2 ± 3.7 (P = .1) | 0.33 ± 0.08 (P = .8) |
| 4 | 49.2 ± 12.9 (P = .01) | 3.8 ± 0.6 (P = .0003) | 16.8 ± 6.3 (P = .005) | 0.40 ± 0.12 (P = .7) |

[a] Average ± standard deviation. Statistical significance is provided in relation to the preceding, less experienced group (statistically significant results are shown in italics).

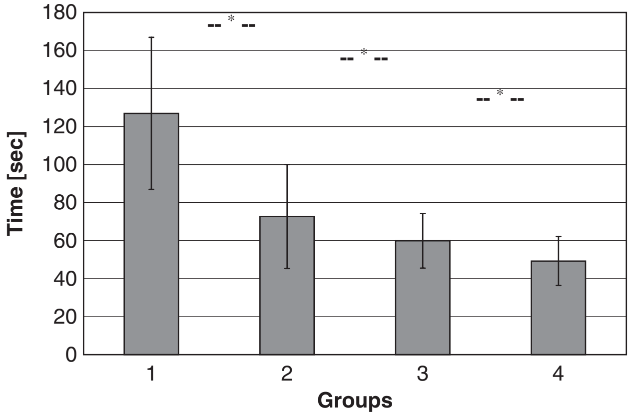

**Figure 3.** Time to completion, in seconds. *denotes significant differences.

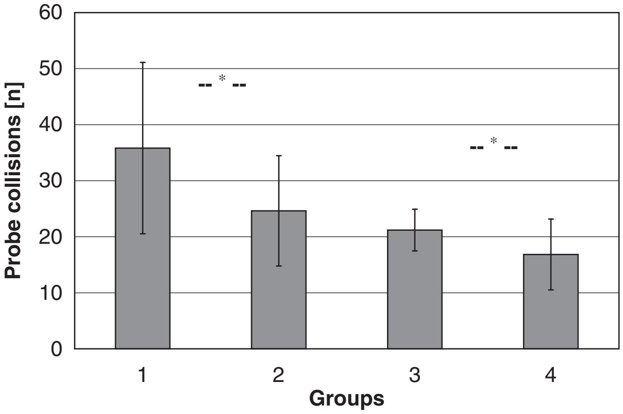

**Figure 5.** Probe collisions, represented as number of collisions (n). *denotes significant differences.

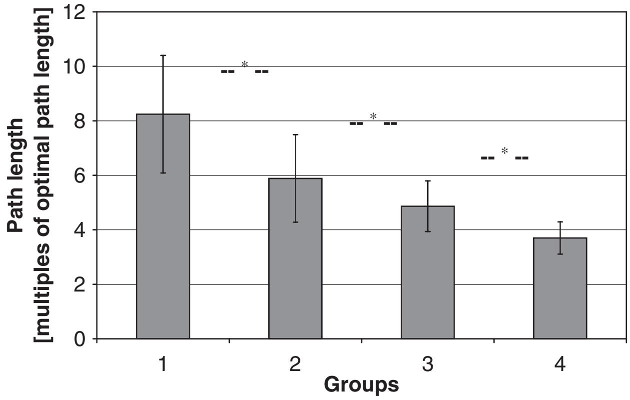

**Figure 4.** Path length, in multiples of the optimal path length. *denotes significant differences.

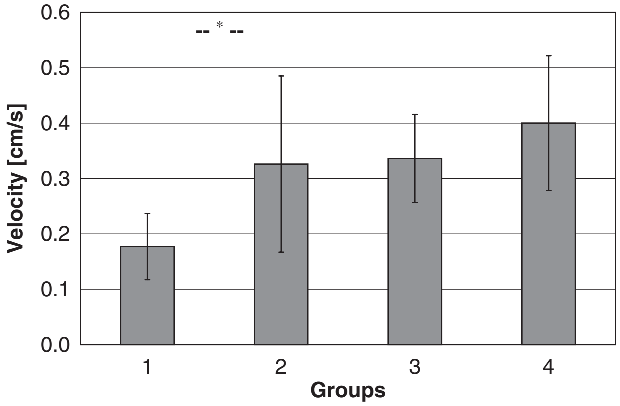

**Figure 6.** Average probe velocity, in centimeters per second. *denotes significant differences.

An ANOVA test detected significant differences across all groups in all parameters. Subsequent pairwise comparisons demonstrated significant differences between each of the groups for time to completion (Figure 3) and path length (Figure 4). The number of probe collisions (Figure 5) was significantly different between all groups except senior and junior residents (*P* = .1). There were significant differences between the inexperienced group (group 1) and each of the more experienced groups (groups 2-4) for velocity (Figure 6); however, there were no significant differences within the experienced groups (groups 2-4) for this category.

Subjects performed 6 repetitions of the training module. Analyses of trend revealed a slight correlation between participants' number of trials and their score. As expected, the correlation was positive in all groups, that is, the trainees improved with repetition, but low, with correlation coefficients ($r^2$) of 0.28 (group 1), 0.16 (group 2), 0.22 (group 3), and 0.12 (group 4). These modest improvements in performance over time would not materially affect the study results, although it is interesting to note that there was a nonsignificant suggestion of more improvements in performance among those with the least initial surgical training; for example, the highest correlation was observed for group 1.

Within each group, participants with limited video game experience were compared to those reporting current game-playing experience. It was found that subjects who were practiced with such games did not have significantly different performance on any of the parameters tested (all *P* values greater than .2). None of the subjects reported prior experience with an arthroscopic simulator.

## DISCUSSION

The results demonstrate that performance on the computerized shoulder arthroscopy simulator improved with increasing real surgical experience. These improvements in performance were most striking for time to task completion, but were substantial across all 4 measured parameters. The findings are consistent with prior work in this field.[20,25,32]

Interestingly, there appeared to be different learning curves for different parameters in the present study. Time to completion and path length on the simulator steadily and incrementally improved with increasing surgical experience. Probe collisions and average velocity, however, demonstrated the biggest improvement between the inexperienced group and groups with any experience level. These findings suggest that certain arthroscopic skills may be acquired early in training, such as the need to avoid damage to anatomical structures, which was reflected in the sharp decrease in probe collisions once even basic training had been received.

Average probe velocity also showed the clearest improvement early in training, almost doubling between groups 1 and 2, while subsequent increases between the more experienced groups were less and not statistically significant. It is possible that this parameter is less a reflection of the actual speed with which the probe moves once a target has been identified, but rather is a measure of the initial time spent locating the object—a time during which the operator concentrates on the camera and does not move the probe. Thus, the observation that average probe velocity increased significantly with some surgical training may reflect the decreased time spent by participants familiarizing themselves in the shoulder joint and with the controls before locating and manipulating the object.

Each subject repeated the module 6 times. As would be expected from a training tool, average scores improved somewhat with the number of modules completed. The overall correlation was low, with $r^2$ values between 0.12 and 0.28 (0 equals no correlation, 1 a perfect linear correlation), but there was a nonsignificant, inverse relationship, indicating increasing improvements with decreasing surgical experience. This could be interpreted as greater benefits from training among the less experienced groups, while groups with more initial experience gain little beyond their baseline, high level of performance.

The study does have limitations. Because of demographic realities, study groups were dissimilar. More experienced groups were significantly older than less experienced ones. Age has a clear influence on psychomotor skills; however, the relationship is inversely proportional, that is, with advancing age, worse results should be expected. The results showed the reverse, and it is reasonably safe to assume that, at least within the age limits tested in this study, increased experience overpowers any potentially detrimental effects of increased age. A dedicated study would be needed to detect more subtle age-related differences by testing subjects of comparable experience levels but different age. The more experienced groups tended to have fewer women and more left-handed subjects, but with the numbers enrolled, no differences could be detected for gender or handedness. Also, the overall number of subjects reporting video game experience was low, especially in the groups with greater surgical training, limiting the ability to detect potentially subtle differences between the groups according to their video game experience.

Work to date has demonstrated that increased surgical experience results in better performance on the simulator; but this may not necessarily apply to the reverse assumption, that increased experience on the simulator will result in better surgical performance. The logical next step after the present study would be to define an evaluation tool to assess the clinical performance of residents in the operating room and correlate their performance with the extent of prior simulator training. This would allow a clear establishment of whether simulator training not only measures but also directly improves arthroscopic expertise. Additional research opportunities in this field exist, including the comparison of the various simulator models available on the market.

Computerized simulators have potential advantages over traditional intraoperative training on actual patients. In the past, training of arthroscopy outside of the operating room has been limited to comparatively simple foam models or cadaveric specimens. The former, such as the Alex shoulder model, are limited in their realism,[21] while cadaveric specimens offer a more realistic experience but are expensive and have limited availability.[23] Computerized simulators offer the potential to enhance current training by improving patient safety, intraoperative efficiency, and education by allowing surgeons to acquire skills at their own pace and on their own time schedule. Critics have voiced concerns in the past that simulators resemble video games and therefore were more likely to evaluate trainees' experience with such games rather than their arthroscopic skills. However, with the subject numbers tested, no significant differences could be detected between test subjects with and those without prior experience playing video games.

In conclusion, the present results validate those of prior investigations with similar setup and study design.[20,25,32] It is hoped that these additional data will help allay concerns on the validity of simulator technology for the evaluation and, ultimately, training of orthopaedic residents.

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