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**Criterion-based Training with Surgical Simulators: Proficiency of Experienced Surgeons**
**5/31/06 DRAFT for TATRC/SLS Committee**

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**Abstract**
OBJECTIVE: The new paradigm in surgical education for basic skills training is using computer-based (manikin, augmented or virtual reality) simulators with embedded criteria to be achieved by students before performing surgery on patients. To establish training criteria, we have assessed the performance of 18 experienced laparoscopic surgeons' basic technical surgical skills of recorded electronically in 26 basic skills modules selected in five commercially available, computer-based simulators.
METHODS/PROCEDURES: Quantitative data produced by the surgeons practicing repetitively during three one-half day sessions on each of five different simulators were collected in a Stanford IRB-approved study. Laparoscopic surgeons ( 8 generalists, six gynecologists, and four urologists) were recruited; eleven were academic surgeons, and fifteen perform ≥ ten laparoscopic surgeries per month. Surgeons were randomly assigned to simulator stations (a total of 15 were provided by vendors) during each session. Each surgeon received a demonstration of the functioning of each module by a trained assistant who also logged the surgeon into and out of modules, using assigned participant numbers to assure anonymity. Demographic and opinion data were obtained to facilitate analysis. We developed proficiency score formulas for each module of the form $b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_k$, where $b_0, b_1, b_2, \ldots, b_k$ are constants (called coefficients) and $X_1, X_2, \ldots, X_k$ are the measures (variables) recorded in the module. Assumptions in the analysis are that the proficiency levels of subjects are ≥ 50%, best performances do not exceed 100%, and proficiency increases with practice.
RESULTS: As expected, early practice attempts demonstrated a sharp learning curve and reduced variability among surgeons' performance. In the third and subsequent practice attempts, performance scores improved little. Median scores and the 10, 25, 50, 75, and 90 percent levels (percentiles) are provided for each module. Construct validity was examined with these data by comparing data for two of the modules from a convenience sample of less-experienced laparoscopic surgeons.
CONCLUSIONS: The mathematical method is simple, easily adjustable, and is applicable to the following simulators for which data are available: Lap Mentor (Simbionix), LapSim (Surgical-Science), LTS2000 ISM60 (RealSim), ProMIS

(Haptica), and Surgical Sim (METI). Based upon this study, proficiency levels for training courses can now be specified objectively (and tentatively) by residency directors and by professional organizations for different levels of training or post-training assessment of technical performance.

## Introduction

The 2000 Institute of Medicine report, *To Err is Human: Building a Safer Healthcare System,* riveted the attention of the medical establishment onto the errors made during patient care. A portion of the errors occurs during the care of surgical patients, and the report made recommendations for mitigation (1). In 1999, the ACGME (American Council on Graduate Medical Education) endorsed six competencies required for resident medical education (2,3,4). Those in *Patient Care* and in *Practice-Based Learning* concern several components of surgical management, one of which is technical competence in conducting surgical procedures. By 2002, training programs were required to implement the ACGME recommendations to achieve program certification. Simultaneously and independently, simulation of laparoscopic surgery has become established as a valid technique for training basic surgical skills. (5,6). Several validation studies indicated that simulator-trained surgeons were more efficient and made fewer errors during subsequent animal or human surgery, compared to those trained using traditional methods (6-9). And as expected, experienced surgeons are more proficient than novices while operating surgical simulators (10). Performances on surgical simulators can be measured electronically, therefore affording objective assessments of technical competency (11). Commercially available surgical simulators have unique outputs of performance variables and errors that are different between systems because standards have not been developed. The metrics found in simulators are of several types including in units that describe distances that instrument tips travel in pursuit of a prescribed target, or an economy measure that relates the distance traveled compared to the direct distance, smoothness of the movement; or the values collected may be the percent of targets touched and transferred, in the number of minor or major errors, etc. The outputs nevertheless provide immediate feedback to users, but some can also be utilized for determining normative performances across a wide range of expertise. This research project has its roots in the need to document these metrics, to establish normative data for guiding the use of simulators in surgical training, and to develop a criterion-based training capability that is useful for residency program directors, vendors, and professional surgical organizations that seek to adopt surgical simulation as a learning and assessment technology.

## Study design

The Surgical Simulation Committee of the Society of Laparoendoscopic Surgeons (SLS) organization (Drs. McDougall, Satava, Hasson, Nezhat, Heinrichs, Youngblood, Wetter) authorized SUMMIT to conduct this research study prior to the 15th Annual Meeting in San Diego, Ca, during September 2005. Committee members and vendors met at SUMMIT on July 25 to review the modules of each simulator, and select the 26 modules to be performed (see Table 1). Eight laparoscopic surgeons in General Surgery, six in Ob/Gyn, and four in Urology were recruited by committee members not conducting the trials, based upon professional reputation of surgical excellence and volume of surgical cases. The 18 subjects included members of the following professional organizations: the AAGL, ACS, AUA, SAGES and SLS. The subjects were paid to join this one and one-half day study group, to demonstrate their performance of surgical skills in an IRB-approved study. The number of systems available from vendors was two *Lap Mentor's* (Symbionix), four *LapSim's* (Surgical-Science AB), four *LTS2000 ISM60's* (RealSim), two *ProMIS's* (Haptica), and three *SurgicalSIM's,* (METI).

Data were collected anonymously, and subjects completed two questionnaires, one providing demographic information and the other a rating scale of subject's opinions of the simulators that was completed immediately after their last performance on each system. Subjects were assigned randomly to complete an individual module on randomly assigned systems. The time allocated for each system during the first session on Day 1 was approximately 35 minutes, and for later sessions, 30 minutes. After a demonstration of the module by a trained assistant, surgeons' questions were answered before the assistant logged the surgeon into system. Surgeons completed the first module at least once, and repeated it if time was available before the time was exhausted and they were signaled to move to another system; performance data were collected on all trials. In the interest of accumulating the maximal number of performances, a flexible schedule allowed subjects to complete a module before moving to their next assigned module/system. After completion of a trial, the assistant's logged subjects out, saved the performance results, and repeated the process for the next assigned surgeon. The mean number of trials per surgeon was 3.5, and the range was 1 to 10.

These procedures were very similar to those developed and used on two previous occasions for collecting data from a 'convenience sample' of attendees at the 2004 annual meetings of the SLS and the AAGL meeting in New York City and San Francisco, respectively. These trials, used in this report as a reference sample of 46 less-experienced surgeons, were limited to the Peg Manipulation module of the LTS 2000 and the Lifting and Grasping module of the LapSim. These trials were not timed and were not repetitive, although some surgeons performed them more than twice.

**Developing proficiency score formulas**

Proficiency formulas were developed in two steps. In the first step we utilized a statistical procedure to create an initial proficiency formula for each module on each simulator of the form:

$$\text{Proficiency} = b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_k, \qquad (1)$$

where $b_0, b_1, b_2, \ldots, b_k$ are constants (called coefficients) and $X_1, X_2, \ldots, X_k$ are the measures (variables) recorded by a particular module. For example, if a particular module records total time and number of errors, one possible proficiency formula of this form would be

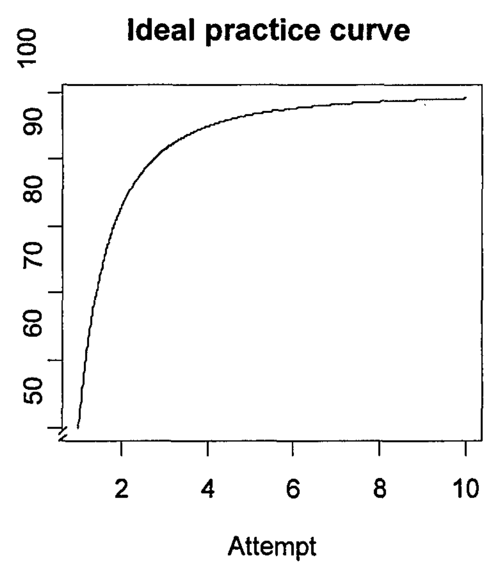
$$\text{Proficiency} = 120 - 2 \times \text{Time} - 4 \times \text{Errors}. \quad (2)$$

The interpretation of the proficiency formula in (2) is as follows:

- A user that records a performance with a total time of zero and zero total errors is given a score of 120.
- Each additional unit of time spent on the task translates into a 2-point *decrease* in proficiency.
- Each additional error on the task translates into a 4-point *decrease* in proficiency.

We will call some variables—such as total time or number of errors—"negative" variables because good performances should correspond to lower values on these variables (e.g., a good performance corresponds to a low total time or a low number of errors). Likewise, we will call other variables—such as efficiency of dessication or economy of movement—"positive" variables because good performances should correspond to higher values on these variables. In the proficiency formula (1), the coefficient $b_i$ should be negative if $X_i$ is a negative variable and should be positive if $X_i$ is a positive variable.

Note that the form of our proficiency score formula in (1) allows a wide range of possible formulas by simply selecting the coefficients $b_0$, $b_1$, $b_2$, . . ., $b_k$ in different ways. For example, we could penalize errors more heavily by modifying the proficiency formula in (2) so that the coefficient for Errors was -8 instead of -4. This would mean that each error would translate into an 8-point (instead of 4-point) decrease in proficiency.




Since the general form (1) allows for an infinite number of possible proficiency formulas for a set of variables $X_1$, $X_2$, . . ., $X_k$, what is the best way to select one of these possibilities? Note that selecting $b_0$, $b_1$, $b_2$, . . ., $b_k$ is all that is necessary to narrow down the general form (1) to a specific proficiency formula such as the one in (2), so the question comes down to selecting the best set of $b_0$, $b_1$, $b_2$, . . ., $b_k$. To do this we first made a number of assumptions about surgeon proficiency in general:

1. We assumed that overall performance on a task increases with the number of attempts, with the most improvement occurring early on. (To test this assumption, we looked at the incremental improvements through attempt 5 on each measure across all simulators. For 49% of the 204

total measures, the greatest improvement was seen between attempts 1 and 2, and for an additional 36% of the measures the greatest improvement was seen between attempts 2 and 3. On only 15% of the measures was the average improvement during attempts 1-5 greatest between attempts 3 and 4 or attempts 4 and 5.)

2. Our expectation was that among a group of experienced surgeons, their performance on the simulator (and subsequent improvement after repeated attempts) should be fairly homogeneous.
3. Finally, we assumed that a typical experienced surgeon's performance would (a) start halfway up a proficiency scale and then (b) approach a perfect score as the number of attempts increased.

These assumptions can be displayed graphically in the figure above, which displays the ideal practice curve—what we consider to be the "typical" performance of an experienced surgeon. This curve is the graph of the function $E(x) = 100(1 - (x - .414)^{-2})$, where $x$ is the attempt number.[1] Assumption 2 is that if we plotted all of the experienced surgeons' practice curves, they would fit tightly around this curve. We can also tabulate our "typical" experienced surgeon performance at each attempt number:

| Attempt $a$ | "Typical" proficiency score $E(a)$ |
|---|---|
| 1 | 50 |
| 2 | 82.84 |
| 3 | 91.42 |
| 4 | 94.87 |
| 5 | 96.59 |
| 6 | 97.57 |
| 7 | 98.18 |
| 8 | 98.59 |
| 9 | 98.87 |
| 10 | 99.08 |

Our method for selecting the coefficients $b_0, b_1, b_2, \ldots, b_k$ was to run an ordinary least-squares regression on the data set consisting of *all* attempts by *all* surgeons for a particular module, with the measures produced by the module, $X_1, X_2, \ldots, X_k$, as the predictor variables and the "typical" proficiency score as the response variable. (The subject number is also placed into the model as a

[1] Our assumptions specified that the function $E(x)$ should be monotone increasing, with $E(1) = 50$ (Assumption 3a), $E(x) \rightarrow 100$ as $x \rightarrow \infty$ (Assumption 3b), and $d^2E/dx^2 < 0$ for $x > 1$ (Assumption 1). The specific function given above is only one of many functions that could satisfy these properties. However, choosing different functions—even those that relaxed Assumptions 1 or 3a (e.g., using a logistic curve instead of the curve we selected) didn't seem to change the main results by much.

covariate, to account for the fact that repeated attempts by the same surgeon are not independent.) In effect, this procedure selects the coefficients of the proficiency formula so that the actual practice curves fall as close to the ideal practice curve as possible.

Sometimes, the initial set of coefficients selected by the regression contains values that are nonsensical because the sign of the coefficient (positive or negative) is not the same as the type of variable (positive or negative). When this occurs, our statistical procedure drops these variables from the proficiency formula by setting the offending coefficients to zero.

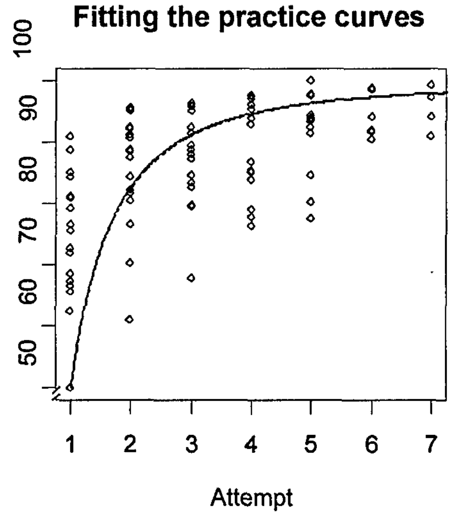
After dropping coefficients from the model, it is sometimes the case that the range of the experienced surgeons' proficiency scores is undesirable. (when calculated from the proficiency formula generated by the procedure thus far) For example, some experienced surgeons' scores may be above 100 or below 0. To remedy this result, we scale the proficiency formula (by multiplying all coefficients by the same constant and changing the coefficient $b_0$) so that the lowest expert score (on any attempt) is 50 and the highest expert score (on any attempt) is 100.

The figure below shows the results of this statistical procedure for the Camera Navigation task in the LapSim simulator. Here, the ideal practice curve is drawn with points that represent individual performances on the module. In this case, the proficiency formula selected by the procedure was

$$\text{Proficiency} = 112.52 - 3.72 \times \text{Path Length} - 0.36 \times \text{Total Time} - 0.10\ \text{Drift} - 1.82 \times \text{Tissue Damage}. \quad (3)$$

In this case, there were two other variables (angular path length and max damage) that were dropped from the proficiency formula before arriving at the formula in (3) because the regression selected positive coefficients for them despite the fact that they are both negative variables.

**Fitting the practice curves**




Thus far we have been discussing what is only the first step of a two-step procedure for finding proficiency score formulas. Although the statistical procedure tries to utilize commonsense rules to arrive at a proficiency formula, it may drop conceptually important variables. Therefore, step two is to review and adjust the coefficients so that they are meaningful in a surgical context. For example, it may be advisable to reintroduce variables that have been automatically dropped by the statistical procedure (recall that positive variables are dropped if their estimated coefficients are not positive, and negative variables are dropped if their estimated coefficients are not negative). Reviewing and adjusting the coefficients is a critical next-step that must be addressed by a team of surgeon-educators.

**Description of Subjects**

The demographic data indicate that the sample of surgeons was heterogeneous, despite efforts to select a group with extensive experience. Table 1 below contains details of each number in each category.

*Table 1. Surgical Experience of Subjects*

| **a. Years Experience** | | **1–10** | **11–20** | **>20** |
|---|---|---|---|---|
| Laparoendoscopic Surgery | | 7 | 8 | 3 |
| **b. Monthly Cases** | **5 – 9** | **10 – 14** | **15 – 19** | **≥ 20** |
| Average No. Cases / Month | 2 | 7 | 4 | 5 |

The data are analyzed by the three clusters of years of experience, and the four clusters of the average number of laparoscopic cases conducted monthly.

The planned experiment was smaller than hoped because some subjects were unable to complete the three half-days due to competing activities and unexpected responsibilities. Also, one vendors' equipment was delayed in US Customs, and three vendors provided fewer than the ideal number of four systems requested for this number of subjects.

**Description of Modules/tasks**

The members of the Simulation Committee selected the modules/tasks during a planning session at Stanford University in July 2005 when the five vendors provided their systems for review. Decisions were made about which modules/tasks would be performed, what level of difficulty (if relevant) would be required, and the overall conduct of the study. Although some systems support partial-procedures, emphasis was placed upon tasks that incorporate basic surgical skills.

*Table 2: Modules/tasks selected for each simulator.*

| System | "Tasks' | System | "Tasks' |
|---|---|---|---|
| *Lap Mentor*<br><br>– Nine 'tasks' | Camera Navigation – 0°<br>Camera Navigation – 30°<br>Eye-hand coordination<br>Grasping and Clipping<br>Clip applying<br>Two-Handed Maneuvers<br>Cutting – dissecting<br>Hook electrodes<br>Translocation of Objects | *LTS2000 ISM60*<br><br>– Five 'tasks' | Peg manipulation,<br>Ring manipulation-rt, lt, hand<br>Intracorporeal knot & Integrity test<br>Circle cutting |
| | | *ProMIS*<br>– Three 'tasks' | Dissection<br>Instrument handling<br>Suturing & knot tying |
| *LapSim*<br>– Five 'tasks'<br>(medium level of difficulty) | Camera navigation,<br>Instrument navigation,<br>Grasping & transfer,<br>Cutting,<br>Grasping & lifting, | *SurgicalSIM*<br><br>– Four 'tasks' | Retract-Dissect,<br>Traverse tube,<br>Place arrow,<br>Dissect gallbladder |

## Results

The dataset for this benchmark study is comprised of 204 measurements for the 26 modules selected. For each measure we collected multiple "attempts" by the surgeons. As expected, first and second practice attempts demonstrate a sharp learning curve and reduced variability thereafter among surgeons' performance. In the third and subsequent practice attempts, performance scores improved little.

In the remainder of this paper we tabulate performance data for the surgeons at one particular attempt. Our analysis described above led us to focus on attempt 3, since it is far enough along in surgeons' learning procedure for us to be able to obtain a fairly good picture of the surgeons' abilities (without much interference due to any unfamiliarity with the system). Ideally, we would focus on as late an attempt number as possible, but for later attempt numbers we have less data, as fewer surgeons managed to complete a large number of attempts for a given task. Thus, the tables and graphs generally focus on attempt number 3 for all surgeons. The one exception to this is the Lap Mentor tasks, which took longer to complete, and had only two systems. As a result, no surgeon completed more than 3 attempts on a Lap Mentor task, and many completed fewer than 3 attempts. Thus, for the Lap Mentor tasks we focus on attempt number 2. As an example, Table 3 lists the variables measured in the Lifting & Grasping module of LapSim, and the 10th, 25th, 50th, 75th, and 90th percentiles on each of these variables. (Note that the 50th percentile is equivalent to the median, which is a measure of the middle of the distribution of scores.) Table 3 also lists percentiles of the final composite proficiency score, which for this module was computed using the formula

$$\begin{aligned}\text{Proficiency} = 125.7327 &- 0.0552 \times \text{LeftInstMisses}\\ &- 9.0428 \times \text{LeftInstPathLength} - 0.1861 \times \text{RightInstMisses}\\ &- 0.4068 \times \text{TotalTime} - 0.37 \times \text{TissueDamage}\\ &- 0.0101 \times \text{MaxDamage}.\end{aligned}$$

This formula was derived using the methodology described above. Appendix 1 gives such tables for each of the 26 modules.

*Table 3. 10th, 25th, 50th, 75th and 90th percentiles for variables measured by LapSim Lifting & Grasping and composite LapSim Lifting & Grasping proficiency score (attempt 3)*

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| LeftInstMisses | 0.00 | 0.0 | 0.0 | 0.0 | 19.8 |
| LeftInstPathLength | 1.17 | 1.3 | 1.6 | 1.9 | 2.0 |
| LeftInstAngPath | 303.93 | 318.8 | 354.9 | 406.8 | 438.6 |
| RightInstMisses | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 |
| RightInstPathLength | 1.15 | 1.3 | 1.5 | 1.7 | 1.8 |
| RightInstAngPath | 292.68 | 311.6 | 338.2 | 360.7 | 430.1 |
| TotalTime | 42.23 | 54.4 | 58.8 | 62.3 | 70.3 |
| TissueDamage | 1.00 | 2.0 | 3.0 | 5.0 | 6.6 |
| MaxDamage | 0.52 | 1.3 | 2.5 | 9.9 | 28.7 |
| Proficiency | 74.87 | 82.8 | 87.8 | 90.5 | 95.2 |

Mean values and SDs were calculated but are not described because the distributions of these variables are not necessarily symmetric (making the reporting of means plus or minus some number of SDs potentially misleading).

**Demographic factors of the subjects compared to performance scores**

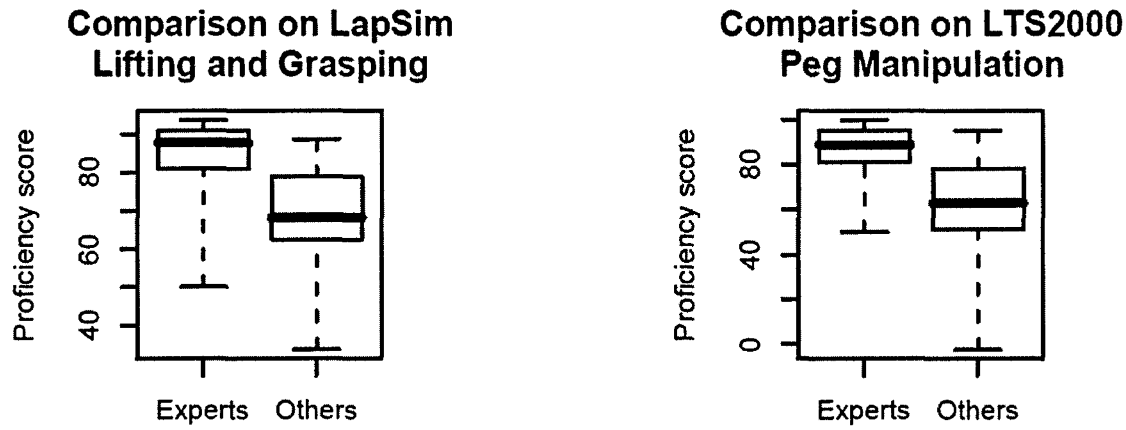
Appendix 2 presents six plots for each of the 26 modules. The first five relate a snapshot of proficiency scores at attempt # 3 to each of five demographic factors (surgical specialty, years of surgical experience, number of laparoscopic procedures per month, number of endoscopic procedures per month, and whether the surgeon was a videogamer – ≥ 6 hours weekly). In these plots, the dark horizontal lines represent medians, the boxes represent the inter-quartile range of the 25th to the 75th percentile, and the brackets represent the full range of the data. The sixth plot represents the practice curves—each dot represents a performance by a particular surgeon on a particular attempt.

Relating proficiency to demographic factors yields a number of important correlations that may nevertheless be different for larger groups of subjects. In this section we illustrate with examples from each simulator.

- "In the Lifting and Grasping module on the LapSim, general surgeons (column #1) and gynecologists (column #2) demonstrated approximately equal proficiency scores, while urologists (column #3) demonstrated slightly lower proficiency scores. Neither years of experience nor the number of endoscopic procedures conducted per month discriminated performance for this task very well."
- In the ProMIS Suturing & Knot Tying module, gynecologists fared more poorly than the two other types of surgeons, and those who performed more surgical procedures per month had higher proficiency scores.
- In the Surgical Sim system on a typically general surgical procedure, dissection of the gall bladder from the liver, the performance of all the surgeons was similar, but remarkably, the number of cases performed monthly was inversely related to expected performance. This module is possibly the most advanced of any of the modules, approaching a portion of a surgical procedure. It incorporates the integrated tasks of grasping, retracting, and dissection with electro-surgery using a foot-pedal.
- Illustrating a result from the LST2000 ISM60, the graphs indicate that proficiency on the suturing and knot integrity task is greatest among surgeons who perform this task most frequently.
- In the LapMentor Clip Applying task, performance generally improved with years of surgical experience.

**Reliability and validity**

We used the "sample of convenience" described earlier to test the construct validity of our proficiency score formulas for two of the tasks (LTS2000 Peg Manipulation and LapSim Lifting & Grasping). We used the proficiency scores developed on our expert sample, comparing that result with scores from the less-experienced surgeons in the "sample of convenience." In both tasks, the experts (our sample) had significantly higher mean proficiency scores than the other surgeons ($p < .001$ for LapSim Lifting & Grasping, $p < .001$ for LTS2000 Peg Manipulation).

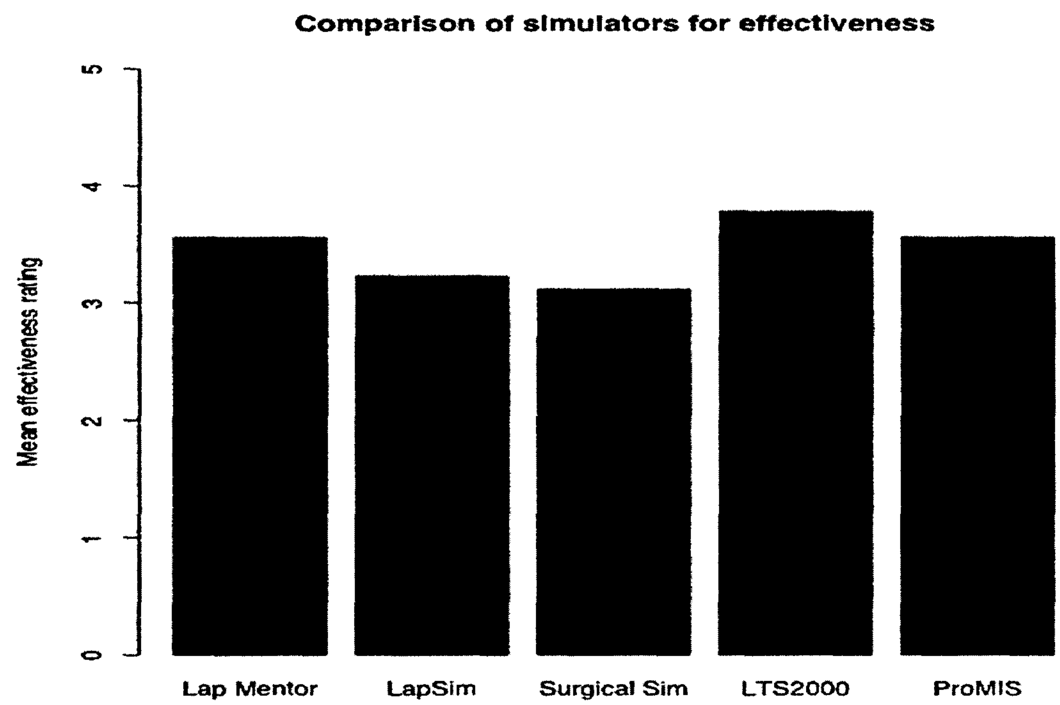



We emphasize that further work is needed to more comprehensively validate the proficiency score formulas that we developed.

One simple way to get a measure of reliability is to compute the correlation between proficiency scores on successive attempts after the learning curve has flattened out. Since for non-Lap Mentor tasks we focused on attempt 3, we computed the correlations between proficiency scores on attempts 3 and 4 on all non-Lap Mentor tasks. The mean correlation was .65, with quite a large range (.14 to .96).

Appendix 3 presents representative data for the LapSim system concerning performances of each surgeon for all of their practice attempts. Total time and Proficiency Scores confirm the reliability of this method of assessment.

Finally, the opinions of the surgeons about the *Effectiveness* of the systems for training (scale 1 – 5) are presented in Fig.4. All rank closely between 3 and 4.




## Discussion

This ground-breaking study provides for the surgical community the first set of simultaneously-generated, performance data for criterion-based training on a group of five surgical simulators by 18 experienced laparoscopic surgeons. Three needs are met: 1) acquiring data simultaneously from a significantly large group of experienced surgeons, 2) providing vendors with objective, validating data for guiding their subsequent development of simulator modules, and 3) providing the surgical community data to begin establishing standards for training and assessment. The findings of this study tentatively will help training program directors to begin to establish competency-based training goals with any of these systems. We say tentatively because future experience with the proficiency scores will provide feedback as to reasonable levels of performance in practice, because none of the simulators were developed as an assessment instrument per se. Also, because future studies are needed to demonstrate transfer of skills mastered on simulators, to performance in surgery, and, ultimately on surgical outcomes.

**Strengths and limitations of the study**

In this study, the researchers intended to use the existing "internal" metrics of five "brands" of commercial-off-the-shelf (COTS) laparoscopic surgical simulators to capture the individual performances of a small group (30) of experienced laparoscopic and endoscopic surgeons. The data collected were the surgeons' scores from their first, second, third and subsequent attempts on specific tasks/modules of each simulator. A strength of the study is that for the first time, we now have objective measures of surgical performance of experienced surgeons, recorded electronically by the simulator, rather than scored subjectively by surgeon educators/observers. (12).

A limitation, however, is that these objective measures are different for each of the five simulators, and even for each module/task within a simulator, as there are no standards for measuring laparoscopic surgical skill in the simulator industry at this time. The measurements that are recorded include such variables as "time", "path length", "tissue damage", and other plausible (logical) indicators of good and poor performance. These are recorded as a set of sub-scores for each task, and there is no overall score for the task. Thus, a significant part of this study was devoted to deriving a standard "proficiency score" for each surgeon's performance of each task (and for each attempt).

Another strength of the study is that the method of deriving these proficiency scores is based on an objective, statistical model, rather than on expert judgment. However, as noted above, it is important for experienced surgeon educators to review these proficiency formulas to ensure that the data contributing to the proficiency score is meaningful for the specific surgical task, and that no important data has been dropped from the equation.

We believe that the performance scores of "expert" or experienced surgeons can provide a benchmark against which trainees may compare their own skill development progress over time during their training program. The statistically significant differences on two modules in the performance of the surgeons in our test group, compared to that of the less-experienced laparoscopic surgeons in the convenience sample (46 surgeons), provides strong evidence of the contruct validity of these modules, which verifies their use as benchmark values. The goal of this study is to help trainees, surgeon educators, and residency program directors better interpret the objective measures that each simulator is capturing.

**Study Sample**

Another limitation of the study is the total number of experienced surgeons who were able to participate in the study, and the number representing each subspecialty. In addition, the sample of surgeons who participated were not recruited by the researchers on the basis of objective criteria, but were nominated by the SLS Simulation Committee members on the basis of the surgeons' years of experience and professional reputation in their field. While the committee sought an equal number of expert surgeons from each specialty area—the final numbers were 8 from general surgery, 6 from obstetrics & gynecology and 4 from urology.

The planned experiment was smaller than hoped because some subjects were unable to complete the three half-days due to competing activities and unexpected responsibilities. Also, one vendors equipment was delayed in US Customs, and three vendors provided fewer than the ideal number of four systems requested for this number of subjects.

The interpretation of these data from only 18 surgeons leaves many questions unanswered. An obvious question is, "How representative are they for the universe of laparoendoscopic surgeons?" And do the wide variances in some modules, indicate real differences in the skills of these subjects, a mis-match between what the simulator module required and what surgeons do during surgery, or that a subject was not representative of their peers? Also, proficiency scores on some modules showed large discrepancies among surgeons related to years of practice, sometimes, demonstrating higher and sometimes lower scores, compared to those with fewer years of practice. Does a lower score ever reflect a subtle, physical deterioration of aging in this group of vigorous surgeons, who compensate by alternate redeeming behaviors? The same observation of discrepancy holds for the number of cases a surgeon performs per month. The two individuals who play videogames frequently, often but not always had higher scores than their peers, but this does not rise to the level of a 'finding', it's only interesting. The opinions of these surgeons about the effectiveness of simulators for training indicate no preference between physical systems and virtual reality systems, although the highest score was for a physical system, and the lowest for a VR system. Is this because the handles used in physical reality systems 'felt-right' to the surgeons because they are like those used during surgery, or did the opinions reflect their disdain for the graphics or the tasks of the VR systems? These are questions needing further study.

The language of metrics used within the surgical community deserves comment. All of the several skills required for performing these tasks are based upon and reflect the inherent *abilities* of each user, including eye-hand coordination, visuo-spatial perception, focus, neuro-muscular stability, etc. (11). The *skills* required for performing the *tasks* listed in the table below require practice to improve performance, and are shared by most of the simulators. Beyond *tasks, procedures* are the product of choreographing multiple *tasks* which when combined, comprise a surgical procedure. Some systems describe tasks by using the names of skills, providing confusion for users. For example, grasping and transfer, or grasping and lifting are individual skills, not tasks, but the combination of two skills has been labeled as a task in the LapSim. Thus nomenclature too, has not been standardized across systems. Delineation of the skills that comprise each task is presented in Table 4 to clarify the nomenclature (12).

*Table 4. Vocabulary for Surgical Skills and Tasks*

| ***Lap Mentor*: 'Tasks':** | ***Skills for completing the tasks:*** |
|---|---|
| Camera Navigation – 0° | Navigate to target, fix on target, activate hand signal of completion |
| Camera Navigation – 30° | Same as for 0° endoscope |
| Eye-hand coordination | Navigate instruments to targets, touch target to signal completion |
| Clip Applying | Navigate instrument to target, apply clip(s) |
| Grasping and Clipping | Select instruments, navigate to target, grasp tube, retract & clip |
| Two-Handed Maneuvers | Select instruments, navigate, retract, grasp, transfer, & place |
| Cutting – dissecting | Select instruments, navigate, grasp, retract, expose, excise |
| Hook electrodes | Navigate, identify & hook (band), expose, desiccate (foot pedal) |
| Translocation of Objects | Navigate, elevate, rotate, orient, transfer, place |
| ***LapSim*: 'Tasks':** | |
| Camera navigation | Navigate camera to target, fix on target, hold |
| Eye-hand Coordination | Navigate instruments to target, touch target |
| Grasping | Navigate, grasp, extract, transfer, insert, place |
| Grasping & cutting | Navigate, grasp, retract, incise, place |
| Lifting & grasping | Navigate, expose, grasp, transfer, place |
| Suturing | Navigate, grasp, penetrate target, rotate, grasp, tie square knot |
| ***LTS2000 ISM60*'Tasks':** | |
| Peg manipulation | Navigate, grasp, transfer, place, release |
| Ring manipulation | Navigate, grasp, rotate, traverse, guide, stretch, place, release |
| Ductal cannulation | Navigate, grasp, push to canulate, grasp, extract |
| Lasso loop formation & cinching | Navigate, grasp suture, loop instrument around, navigate to suture end, grasp and pull; repeat to make lasso, place onto peg, and pull |
| Intracorporeal suturing | Navigate, grasp, penetrate target, rotate, grasp, tie knot, test |
| Tissue 'disc' dissection | Navigate, grasp, incise, rotate, elevate, release |
| ***ProMIS*: 'Tasks':** | |
| Object positioning: Grasp & transfer. | Navigate, grasp, transfer |
| Sharp dissection: Cut out circle | Navigate, grasp, position, incise, rotate, excise repeatedly |
| Knot tying Surgeon's knot | Navigate, grasp suture, loop instrument around, navigate to suture end, grasp and pull; repeat twice |
| ***Surgical SIM 'Tasks'*** | |
| Retract–Dissect | Navigate, grasp, navigate, desiccate, repeat |
| Traverse Tube | Navigate, grasp, navigate, grasp, etc. |
| Place Arrow | Navigate, grasp, navigate, grasp, place, hold, repeat |
| Dissect Gall Bladder | Navigate, grasp, retract, navigate, desiccate, excise |

Similarly, what constitutes an error varies among modules/tasks. For example, in the Peg-transfer module of the LTS2000, dropping a peg is recorded as one error. In the LapSim, touching the target with the shaft of a grasper, or striking the edge of a bounding box with either the target-in-transfer, or the instrument tip, or the shaft, constitutes an error. The LapSim module on Lifting and Grasping, records errors of several types such as touching the cover lying over a target object (surgical needle) with the shaft of a handle, or touching the background (producing a *red-out*), and it records the depth of pressure-distortion of the background. We are unaware of a vocabulary for surgical simulators that characterizes errors (13). However, a standard nomenclature that represents the vocabulary of surgeons is likely to facilitate the development and adoption of surgical simulators as learning tools (15).

What is the utility of these data and their analysis? Among their many potential uses, one will be for setting practice criteria to be met by trainees at different levels of surgical education. Perhaps programs with particular systems will seek to 'qualify' their candidates by surveying them for technical performance skills during interviews; a 10 percent performance could be set as a goal. By the end of the first six months in residency, program directors may select a 25 percent performance, perhaps requiring a higher level of proficiency before entry into operating room activities, etc. However, all proposed uses require additional study before establishing such practices. Similarly, hospitals may find useful a requirement that surgeon's whose practices are flagged by Quality Assurance Committees, for excessive technical complication rates, are required to provide objective documentation of performance skills. Similarly, professional surgical organizations such as the American College of Surgery, SAGES, AAGL, SLS, and others, will begin by assessing resident performances for identifying laggard individuals, or screening applicants for membership by requiring a high proficiency level on surgical simulators available to them.

Vendors will be able to respond to program directors and professional organizations by selecting courses that incorporate selected modules/tasks that challenge trainees to perform at designated performance levels. Further, as these companies continue their development plans, we hope that these data will inform further developments.

A host of research questions are generated by these data. They include, but are not limited to:

- How closely do the currently available modules in simulators reflect the fundamental skills of surgery, and what should be measured? An important issue is whether simulators prompt actions that score well in these systems, but are invalid in surgery, thus reinforcing inappropriate behaviors;
- What change in the algorithms is needed to accommodate different levels of training? E.g., is the power curve appropriate for novices whose performances require more practice to reach a plateau, at least in some modules, compared to experienced surgeons? This type of question will require experiments to determine such answers, but a consortium of investigators may be able to pool data to arrive at a first approximation of an answer;
- Given that the current generation of simulators has not been designed for assessing surgical skills, what assessment instruments would be advisable for inclusion?
- Handedness is another topic that academic surgeons must adapt to among their trainees, and similarly, the performance of the approximately

10% of left-handed surgeons (two of 18 in this study) needs, when appropriate, to be facilitated in simulators.

- How much emphasis ought to be given to lesser errors such as 'touching' a surface, contrasted with 'damaging' an object? Of course, if the touch is associated with an activated diathermy electrode, the injury should have a very significant error value;
- In instances when the coefficient is registered for only one of two actions, e.g., right or left handed-action, should a value be generated for the absent coefficient? (This may happen when the performance of one hand, say the distance navigated to the target, changes little over the number of attempts for one hand, but is large for the other hand, because of significant change over the same number of practice attempts.)
- In instances when a coefficient is not generated for some metric, say an error in the number of inadvertent touches of non-target objects, should a value be generated for the absent coefficient? If so, how much emphasis does the missing value receive?

We believe that the current analysis provides a benchmark to guide further assessment of simulation-based training, and simulator development. If these consequences are realized, the effort of the participating surgeons, the research team, and the sponsoring organizations will be satisfied.

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(15)

**Appendix 1:** Percentiles of experienced surgeon performance on individual measures and on composite proficiency score, by simulator and module LapSim System:

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MODULE: LapSim Camera Navigation - Attempt 3

---

Proficiency =
112.5161
- 3.7154 PathLength
- 0.3557 TotalTime
- 0.1014 Drift
- 1.8243 TissueDamage

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| PathLength | 1.4 | 1.5 | 1.7 | 1.9 | 2.2 |
| AngPath | 303.7 | 417.5 | 546.1 | 690.3 | 841.1 |
| TotalTime | 30.4 | 34.3 | 45.8 | 61.5 | 66.2 |
| Drift | 2.7 | 3.3 | 4.6 | 6.4 | 30.3 |
| TissueDamage | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MaxDamage | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Proficiency | 79.6 | 83.2 | 88.5 | 93.1 | 96.0 |

---

MODULE: LapSim Instrument Navigation - Attempt 3

---

Proficiency =
136.4479
- 36.7202 LeftInstPathLength
- 21.4565 RightInstPathLength
- 0.012 RightInstAngPath
- 0.6106 RightInstTime
- 0.2756 TissueDamage
- 0.1563 MaxDamage

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| LeftInstPathLength | 0.60 | 0.65 | 0.72 | 0.77 | 0.81 |
| LeftInstAngPath | 168.37 | 180.38 | 204.47 | 228.95 | 245.88 |
| LeftInstTime | 9.20 | 10.13 | 11.11 | 12.76 | 14.86 |
| RightInstPathLength | 0.58 | 0.62 | 0.70 | 0.74 | 0.81 |
| RightInstAngPath | 131.35 | 142.44 | 155.53 | 180.19 | 194.22 |
| RightInstTime | 9.74 | 11.39 | 14.11 | 15.53 | 17.32 |
| TissueDamage | 0.00 | 0.00 | 1.00 | 1.00 | 4.00 |
| MaxDamage | 0.00 | 0.00 | 0.75 | 1.37 | 5.33 |
| Proficiency | 77.65 | 80.10 | 83.45 | 88.52 | 91.98 |

---

MODULE: LapSim Grasping - Attempt 3

---

Proficiency =
111.5076
- 2.9354 LeftInstPathLength
- 0.0013 LeftInstAngPath
- 0.0632 LeftInstMisses
- 1.2948 RightInstPathLength
- 0.2603 RightInstTime
- 0.1122 RightInstMisses
- 0.1343 MaxDamage

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| LeftInstPathLength | 1.9 | 2.1 | 2.4 | 3.1 | 3.3 |
| LeftInstAngPath | 382.4 | 479.6 | 542.5 | 782.8 | 803.9 |

| | | | | | |
|---|---|---|---|---|---|
| LeftInstTime | 37.4 | 39.7 | 49.9 | 61.5 | 81.2 |
| LeftInstMisses | 0.0 | 0.0 | 0.0 | 4.0 | 24.5 |
| RightInstPathLength | 1.9 | 2.1 | 2.4 | 2.7 | 2.9 |
| RightInstAngPath | 317.2 | 330.4 | 383.2 | 432.1 | 555.4 |
| RightInstTime | 32.1 | 35.7 | 45.5 | 53.9 | 54.6 |
| RightInstMisses | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| TissueDamage | 0.5 | 1.0 | 3.0 | 9.0 | 10.5 |
| MaxDamage | 1.1 | 2.5 | 3.6 | 8.8 | 23.5 |
| Proficiency | 79.0 | 82.5 | 87.4 | 92.2 | 93.5 |

---

MODULE: LapSim Cutting - Attempt 3

---

Proficiency =
120.2763
- 0.0461 CutterAngPath
- 0.4382 TotalTime
- 0.0685 MaxStretchDamage
- 0.1884 RipFailure

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| CutterPathLength | 0.43 | 0.463 | 0.49 | 0.73 | 0.97 |
| CutterAngPath | 107.17 | 120.672 | 139.29 | 204.62 | 256.78 |
| TotalTime | 45.77 | 49.243 | 59.99 | 69.11 | 80.33 |
| MaxStretchDamage | 2.30 | 23.775 | 34.68 | 74.64 | 93.57 |
| TissueDamage | 0.00 | 0.500 | 1.00 | 2.00 | 3.00 |
| MaxDamage | 0.00 | 0.063 | 1.19 | 8.35 | 13.93 |
| RipFailure | 0.00 | 0.000 | 0.00 | 0.00 | 19.80 |
| DropFailure | 0.00 | 0.000 | 0.00 | 16.50 | 33.00 |
| Proficiency | 63.13 | 75.514 | 87.07 | 88.74 | 92.48 |

---

MODULE: LapSim Lifting and Grasping - Attempt 3

---

Proficiency =
132.0551
- 9.7609 LeftInstPathLength
- 0.002 LeftInstAngPath
- 0.098 RightInstMisses
- 1.6881 RightInstPathLength
- 0.4771 TotalTime
- 0.0971 MaxDamage

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| LeftInstMisses | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| LeftInstPathLength | 1.24 | 1.41 | 1.7 | 1.8 | 1.9 |
| LeftInstAngPath | 318.25 | 323.94 | 354.9 | 403.2 | 420.2 |
| RightInstMisses | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| RightInstPathLength | 1.24 | 1.42 | 1.5 | 1.7 | 1.8 |
| RightInstAngPath | 299.95 | 320.13 | 354.1 | 364.2 | 418.3 |
| TotalTime | 47.48 | 54.37 | 58.8 | 62.3 | 76.4 |
| TissueDamage | 1.00 | 1.50 | 2.0 | 3.5 | 5.6 |
| MaxDamage | 0.32 | 0.96 | 1.5 | 7.8 | 28.7 |
| Proficiency | 72.35 | 79.74 | 84.5 | 88.4 | 91.1 |

## Surgical Sim System:

MODULE: Surgical Sim Gall Bladder - Attempt 3

Proficiency =
108.1165
- 0.0306 total_time
- 0.0235 tip_trajectory
- 0.1717 burning_in_air_time

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| total_time | 154.90 | 172.75 | 244.5 | 296.3 | 325 |
| tip_trajectory | 177.28 | 192.28 | 327.4 | 449.7 | 613 |
| burning_in_air_time | 0.61 | 1.09 | 4.7 | 9.0 | 12 |
| tissue_overstretched | 0.00 | 0.25 | 2.5 | 6.5 | 19 |
| dissected_outside_target | 1.30 | 2.00 | 6.0 | 9.0 | 19 |
| Proficiency | 82.32 | 88.15 | 91.5 | 97.4 | 99 |

MODULE: Surgical Sim Place Arrow - Attempt 3

Proficiency =
113.4184
- 1.3418 total_time
- 1.1734 dropped_arrow
- 1.7601 closed_entry_right_tool

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| total_time | 12 | 15 | 17 | 20.75 | 22.00 |
| tip_trajectory | 34 | 35 | 37 | 45.99 | 60.57 |
| dropped_arrow | 0 | 0 | 0 | 0.15 | 0.20 |
| lost_arrow | 0 | 0 | 0 | 0.15 | 0.62 |
| closed_entry_left_tool | 0 | 0 | 0 | 0.15 | 0.34 |
| closed_entry_right_tool | 0 | 0 | 0 | 0.20 | 0.74 |
| Proficiency | 84 | 85 | 90 | 93.90 | 96.67 |

MODULE: Surgical Sim Retract and Dissect - Attempt 3

Proficiency =
105.7729
- 0.2211 total_time
- 0.0121 tip_trajectory
- 0.6981 burning_in_air_right_time
- 5.5962 dissected_outside_target_left
- 7.1573 dissected_outside_target_right
- 0.3437 lost_aligned_pod_left
- 10.9549 lost_aligned_pod_right

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| total_time | 24 | 32.000 | 36.00 | 49.50 | 58.70 |
| tip_trajectory | 60 | 65.497 | 85.62 | 112.00 | 118.89 |
| burning_in_air_left_time | 0 | 0.050 | 0.24 | 0.45 | 1.43 |
| burning_in_air_right_time | 0 | 0.028 | 0.10 | 0.24 | 0.84 |
| tissue_overstretched_left | 0 | 0.063 | 0.25 | 0.69 | 1.10 |
| tissue_overstretched_right | 0 | 0.063 | 0.25 | 0.94 | 1.00 |
| dissected_outside_target_left | 0 | 0.000 | 0.25 | 0.50 | 0.68 |
| dissected_outside_target_right | 0 | 0.250 | 0.25 | 0.69 | 1.00 |
| dissected_pod_not_aligned_left | 0 | 0.000 | 0.00 | 0.25 | 0.50 |
| dissected_pod_not_aligned_right | 0 | 0.000 | 0.00 | 0.19 | 0.50 |
| lost_aligned_pod_left | 0 | 0.000 | 0.00 | 0.25 | 0.25 |
| lost_aligned_pod_right | 0 | 0.000 | 0.00 | 0.25 | 0.43 |
| Proficiency | 77 | 85.762 | 90.08 | 93.11 | 96.65 |

MODULE: Surgical Sim Transverse Tube - Attempt 3

Proficiency =
116.6667
- 1.2821 total_time

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| total_time | 18 | 22.25 | 25.0 | 27.25 | 38.8 |
| tip_trajectory | 66 | 67.14 | 74.4 | 90.76 | 108.1 |
| dropped_tube | 0 | 0.05 | 0.2 | 0.75 | 1.4 |
| wrong_segment | 0 | 0.00 | 0.1 | 0.50 | 0.8 |
| Proficiency | 67 | 81.73 | 84.6 | 88.14 | 93.6 |

## ProMIS System:

MODULE: ProMIS Dissection - Attempt 3

Proficiency =
111.4094
- 0.0649 LeftInstPath
- 0.0097 RightInstPath
- 0.0286 LeftInstSmoothness
- 0.0106 RightInstSmoothness

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| TotalTime | 75 | 77 | 82 | 103 | 148 |
| LeftInstPath | 85 | 89 | 99 | 119 | 190 |
| RightInstPath | 202 | 219 | 260 | 368 | 431 |
| LeftInstSmoothness | 261 | 284 | 329 | 409 | 604 |
| RightInstSmoothness | 282 | 300 | 351 | 413 | 619 |
| Proficiency | 72 | 85 | 89 | 92 | 92 |

MODULE: ProMIS Instrument Handling - Attempt 3

Proficiency =
127.6061
- 0.7341 TotalTime
- 0.09 LeftInstPath
- 0.0171 LeftInstSmoothness
- 0.0149 RightInstSmoothness

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| TotalTime | 29 | 34 | 38 | 49 | 51 |
| LeftInstPath | 103 | 117 | 129 | 137 | 155 |
| RightInstPath | 110 | 117 | 127 | 141 | 175 |
| LeftInstSmoothness | 85 | 97 | 118 | 147 | 164 |
| RightInstSmoothness | 98 | 110 | 141 | 159 | 204 |
| Proficiency | 70 | 73 | 84 | 90 | 92 |

MODULE: ProMIS Suturing & Knot Tying - Attempt 3

Proficiency =
100.1275
- 0.005 LeftInstPath
- 0.013 RightInstSmoothness

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| TotalTime | 88 | 106 | 115 | 289 | 296 |
| LeftInstPath | 244 | 278 | 353 | 744 | 1142 |
| RightInstPath | 325 | 373 | 406 | 861 | 1398 |
| LeftInstSmoothness | 277 | 328 | 397 | 931 | 970 |
| RightInstSmoothness | 303 | 342 | 419 | 1043 | 1049 |
| Proficiency | 81 | 83 | 93 | 94 | 95 |

## Lap Mentor System:

---

MODULE: LM Camera Navigation 0° - Attempt 2

---

Proficiency =
-21.1648
- 0.1244 Total.time
- 0.1357 The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera
+ 0.9976 Accuracy.rate...target.hits....
+ 0.357 Maintaining.the.horizontal.view.while.using.the.0..camera....
+ 0.1245 Average.speed.of.camera.movement..cm.sec.

Percentiles of each variable

| | 10 | 25 |
|---|---|---|
| Total.time | 58.5 | 61.5 |
| Total.no..of.camera.shots | 10.0 | 10.0 |
| The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera | 51.2 | 53.8 |
| Total.path.length.of.camera..cm. | 200.8 | 216.9 |
| No..of.correct.hits | 10.0 | 10.0 |
| Accuracy.rate...target.hits.... | 79.7 | 83.3 |
| Maintaining.the.horizontal.view.while.using.the.0..camera.... | 75.4 | 79.3 |
| Average.speed.of.camera.movement..cm.sec. | 8.9 | 9.2 |
| Proficiency | 71.5 | 75.9 |

| | 50 | 75 | 90 |
|---|---|---|---|
| Total.time | 79 | 83 | 86 |
| Total.no..of.camera.shots | 11 | 12 | 13 |
| The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera | 63 | 70 | 79 |
| Total.path.length.of.camera..cm. | 245 | 267 | 303 |
| No..of.correct.hits | 10 | 10 | 10 |
| Accuracy.rate...target.hits.... | 91 | 100 | 100 |
| Maintaining.the.horizontal.view.while.using.the.0..camera.... | 84 | 94 | 95 |
| Average.speed.of.camera.movement..cm.sec. | 10 | 11 | 11 |
| Proficiency | 82 | 88 | 92 |

---

MODULE: LM Camera Navigation 30° - Attempt 2

---

Proficiency =
82.5559
- 0.1543 Total.time
- 12.7571 Total.no..of.camera.shots
+ 15.4429 No..of.correct.hits

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 61 | 68.0 | 73.0 | 82.3 | 111 |
| Total.no..of.camera.shots | 10 | 10.0 | 10.0 | 11.0 | 11 |
| Total.path.length.of.camera..cm. | 239 | 278.1 | 288.5 | 357.1 | 422 |
| No..of.correct.hits | 10 | 10.0 | 10.0 | 10.0 | 10 |
| Accuracy.rate...target.hits.... | 91 | 90.9 | 100.0 | 100.0 | 100 |
| Average.speed.of.camera.movement..cm.sec. | 8 | 8.1 | 8.4 | 9.3 | 10 |
| Proficiency | 79 | 86.2 | 97.5 | 98.5 | 99 |

---

MODULE: LM Eye-hand Coordination - Attempt 2

---

Proficiency =

```
-158.101
- 0.5331 Total.time
+ 2.5167 Accuracy.rate...touched.targets....
+ 0.0648 Ideal.path.length.of.right.instrument..cm.
+ 0.0094 Ideal.path.length.of.left.instrument..cm.
+ 0.1161 Economy.of.movement...right.instrument....
+ 0.1076 Economy.of.movement...left.instrument....
```

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 28.8 | 33.0 | 39.0 | 46.5 | 47.8 |
| Total.no..of.touched.balls | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| No..of.movements.of.right.instrument | 16.0 | 16.5 | 19.0 | 20.5 | 24.6 |
| No..of.movements.of.left.instrument | 15.4 | 17.0 | 18.0 | 18.5 | 19.4 |
| Total.path.length.of.right.instrument..cm. | 75.1 | 80.8 | 88.4 | 108.1 | 112.2 |
| Total.path.length.of.left.instrument..cm. | 73.9 | 78.2 | 84.8 | 101.6 | 102.7 |
| Relevant.path.length...right.instrument..cm. | 36.1 | 41.1 | 57.5 | 68.0 | 72.0 |
| Relevant.path.length...left.instrument..cm. | 37.7 | 41.5 | 44.1 | 51.1 | 52.1 |
| No..of.correct.hits | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Accuracy.rate...touched.targets.... | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Ideal.path.length.of.right.instrument..cm. | 26.4 | 30.1 | 34.1 | 37.8 | 39.6 |
| Ideal.path.length.of.left.instrument..cm. | 27.1 | 30.4 | 32.7 | 34.1 | 35.9 |
| Economy.of.movement...right.instrument.... | 52.3 | 55.5 | 64.8 | 73.3 | 76.1 |
| Economy.of.movement...left.instrument.... | 63.7 | 65.0 | 70.7 | 75.0 | 80.5 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.6 | 2.9 | 3.2 | 3.3 | 3.3 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.7 | 2.7 | 3.1 | 3.5 | 3.5 |
| Proficiency | 84.7 | 85.6 | 89.6 | 94.1 | 97.7 |

---

MODULE: LM Clip Applying - Attempt 2

---

```
Proficiency =
63.8809
- 0.0296 No..of.movements.of.right.instrument
- 0.3466 No..of.movements.of.left.instrument
- 0.0292 Total.path.length.of.right.instrument..cm.
- 0.2443 Relevant.path.length...right.instrument..cm.
+ 0.1847 Accuracy.rate...applied.clips....
+ 0.4126 Ideal.path.length.of.right.instrument..cm.
+ 0.4308 Economy.of.movement...left.instrument....
```

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 52.8 | 57.0 | 60.0 | 67.0 | 82.0 |
| No..of.lost.clips | 0.6 | 1.0 | 2.0 | 4.5 | 5.8 |
| Total.no..of.clipping.attempts | 9.6 | 10.0 | 11.0 | 13.5 | 14.8 |
| No..of.movements.of.right.instrument | 28.0 | 31.5 | 38.0 | 48.0 | 64.8 |
| No..of.movements.of.left.instrument | 10.4 | 18.5 | 28.0 | 35.0 | 36.4 |
| Total.path.length.of.right.instrument..cm. | 95.3 | 117.5 | 132.3 | 175.4 | 198.1 |
| Total.path.length.of.left.instrument..cm. | 10.6 | 57.7 | 104.1 | 114.3 | 122.0 |
| Relevant.path.length...right.instrument..cm. | 65.1 | 95.9 | 117.7 | 137.1 | 175.2 |
| Relevant.path.length...left.instrument..cm. | 51.9 | 71.8 | 81.7 | 93.3 | 98.6 |
| Accuracy.rate...applied.clips.... | 61.1 | 66.8 | 81.8 | 90.0 | 94.0 |
| Ideal.path.length.of.right.instrument..cm. | 26.9 | 36.5 | 68.0 | 98.0 | 102.7 |
| Ideal.path.length.of.left.instrument..cm. | 16.7 | 30.7 | 37.9 | 39.9 | 47.8 |
| Economy.of.movement...right.instrument.... | 38.4 | 41.0 | 46.4 | 65.2 | 74.9 |
| Economy.of.movement...left.instrument.... | 23.5 | 30.1 | 42.8 | 52.8 | 60.1 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.7 | 2.8 | 3.1 | 3.5 | 3.8 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.2 | 2.7 | 2.7 | 3.2 | 3.2 |
| Proficiency | 72.2 | 73.0 | 73.6 | 85.5 | 87.5 |

---

MODULE: LM Grasping and Clipping - Attempt 2

---

```
Proficiency =
148.3501
- 0.0013 No..of.lost.clips
```

- 0.1516 Total.path.length.of.clipper..cm.
- 0.1514 Total.path.length.of.grasper..cm.
- 1e-04 Relevant.path.length...clipper.cm.
+ 3e-04 Ideal.path.length.of.clipper..cm.
+ 0.0017 Economy.of.movement...right.instrument....
+ 0.0015 Economy.of.movement...left.instrument....
+ 0.0067 Average.speed.of.right.instrument.movement..cm.sec.

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 70.6 | 83.0 | 101.0 | 109.5 | 125.4 |
| No..of.lost.clips | 0.6 | 1.0 | 1.0 | 2.0 | 2.0 |
| Total.no..of.clipping.attempts | 9.6 | 10.0 | 10.0 | 11.0 | 11.0 |
| No..of.movements.of.right.instrument | 35.6 | 43.0 | 53.0 | 58.5 | 66.0 |
| No..of.movements.of.left.instrument | 45.4 | 51.0 | 64.0 | 74.0 | 82.2 |
| Total.path.length.of.right.instrument..cm. | 170.5 | 174.7 | 185.6 | 207.3 | 222.2 |
| Total.path.length.of.left.instrument..cm. | 174.7 | 211.8 | 232.2 | 260.9 | 267.1 |
| Total.path.length.of.clipper..cm. | 157.1 | 169.5 | 206.0 | 219.1 | 244.0 |
| Total.path.length.of.grasper..cm. | 181.4 | 189.8 | 232.2 | 249.5 | 261.4 |
| Relevant.path.length...right.instrument..cm. | 161.7 | 165.8 | 177.3 | 202.3 | 215.9 |
| Relevant.path.length...left.instrument..cm. | 166.2 | 200.7 | 221.1 | 252.4 | 258.9 |
| Relevant.path.length...clipper.cm. | 148.7 | 161.6 | 200.1 | 212.8 | 234.9 |
| Relevant.path.length...grasper..cm. | 172.4 | 181.6 | 215.5 | 241.1 | 255.1 |
| Accuracy.rate...applied.clips.... | 81.8 | 81.8 | 90.0 | 90.0 | 94.0 |
| Ideal.path.length.of.clipper..cm. | 93.0 | 99.8 | 108.5 | 124.2 | 132.2 |
| Ideal.path.length.of.grasper..cm. | 105.6 | 106.7 | 111.4 | 113.5 | 115.5 |
| Economy.of.movement...right.instrument.... | 50.9 | 56.6 | 60.4 | 62.5 | 69.8 |
| Economy.of.movement...left.instrument.... | 40.6 | 44.3 | 54.1 | 56.6 | 63.4 |
| Economy.of.movement...clipper.... | 46.9 | 54.5 | 60.2 | 67.2 | 75.4 |
| Economy.of.movement..grasper.... | 44.6 | 46.9 | 54.1 | 58.8 | 61.5 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.5 | 2.6 | 2.8 | 3.1 | 3.3 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.9 | 3.0 | 3.2 | 3.6 | 4.1 |
| Proficiency | 74.5 | 77.3 | 85.6 | 90.6 | 95.7 |

---

MODULE: LM Two-handed Maneuvers - Attempt 2

---

Proficiency =
109.7534
- 6.7467 No..of.lost.balls.which.miss.the.basket
- 0.2845 No..of.movements.of.left.instrument
- 0.0225 Total.path.length.of.right.instrument..cm.
- 0.0043 Total.path.length.of.left.instrument..cm.
+ 0.128 Economy.of.movement...right.instrument....

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 50.2 | 73.5 | 84.0 | 112.0 | 178.0 |
| No..of.lost.balls.which.miss.the.basket | 0.0 | 0.0 | 0.0 | 1.0 | 4.2 |
| No..of.movements.of.right.instrument | 26.6 | 42.0 | 49.0 | 92.0 | 119.2 |
| No..of.movements.of.left.instrument | 24.4 | 45.0 | 53.0 | 82.0 | 122.0 |
| Total.path.length.of.right.instrument..cm. | 95.8 | 169.8 | 224.2 | 331.1 | 455.8 |
| Total.path.length.of.left.instrument..cm. | 85.6 | 151.7 | 228.7 | 288.6 | 398.8 |
| Relevant.path.length...right.instrument..cm. | 61.8 | 80.1 | 148.7 | 207.2 | 253.0 |
| Relevant.path.length...left.instrument..cm. | 79.3 | 128.4 | 135.1 | 200.2 | 267.5 |
| No..of.exposed.green.balls.that.are.collected | 4.2 | 7.5 | 9.0 | 9.0 | 9.0 |
| Ideal.path.length.of.right.instrument..cm. | 33.2 | 47.2 | 59.8 | 85.4 | 91.8 |
| Ideal.path.length.of.left.instrument..cm. | 24.6 | 29.0 | 30.9 | 57.8 | 67.2 |
| Economy.of.movement...right.instrument.... | 31.4 | 32.3 | 37.8 | 49.5 | 62.7 |
| Economy.of.movement...left.instrument.... | 15.0 | 22.6 | 36.7 | 42.8 | 45.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 3.4 | 3.6 | 3.9 | 3.9 | 3.9 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.8 | 3.0 | 3.2 | 3.5 | 3.9 |
| Proficiency | 58.6 | 73.5 | 93.0 | 97.5 | 99.4 |

---

MODULE: LM Cutting - Dissecting - Attempt 2

---

Proficiency =
102.2321
- 0.1514 Total.no..of.cutting.maneuvers
- 0.0313 Total.path.length.of.right.instrument..cm.
- 0.0859 Total.path.length.of.left.instrument..cm.
+ 0.2849 Average.speed.of.right.instrument.movement..cm.sec.
+ 3.7835 Average.speed.of.left.instrument.movement..cm.sec.

Percentiles of each variable

| | 10 | 25 | 50 |
|---|---|---|---|
| Total.time | 65.4 | 74.5 | 90.0 |
| Total.no..of.cutting.maneuvers | 24.4 | 29.5 | 34.0 |
| Total.no..of.retraction.operations | 1.0 | 1.5 | 4.0 |
| No..of.movements.of.right.instrument | 64.6 | 81.5 | 99.0 |
| No..of.movements.of.left.instrument | 22.0 | 26.5 | 34.0 |
| Total.path.length.of.right.instrument..cm. | 161.8 | 184.5 | 251.3 |
| Total.path.length.of.left.instrument..cm. | 52.7 | 71.1 | 83.3 |
| No..of.cutting.maneuvers.performed.without.causing.injury | 24.4 | 29.5 | 34.0 |
| No..of.retraction.operations.without.overstretch.injuries.to.tissue | 1.0 | 1.0 | 1.0 |
| Safe.retraction...overstretch.... | 40.0 | 50.0 | 75.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.4 | 2.7 | 3.1 |
| Average.speed.of.left.instrument.movement..cm.sec. | 1.9 | 2.1 | 2.6 |
| Proficiency | 83.4 | 87.7 | 93.4 |

| | 75 | 90 |
|---|---|---|
| Total.time | 136.0 | 175.2 |
| Total.no..of.cutting.maneuvers | 37.0 | 37.4 |
| Total.no..of.retraction.operations | 4.5 | 5.4 |
| No..of.movements.of.right.instrument | 125.0 | 151.6 |
| No..of.movements.of.left.instrument | 40.5 | 53.0 |
| Total.path.length.of.right.instrument..cm. | 297.6 | 386.9 |
| Total.path.length.of.left.instrument..cm. | 95.4 | 130.2 |
| No..of.cutting.maneuvers.performed.without.causing.injury | 37.0 | 37.4 |
| No..of.retraction.operations.without.overstretch.injuries.to.tissue | 3.0 | 3.8 |
| Safe.retraction...overstretch.... | 100.0 | 100.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 4.0 | 5.6 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.8 | 2.8 |
| Proficiency | 96.2 | 98.2 |

---

MODULE: LM Scarification - Hook Electrodes - Attempt 2

---

Proficiency =
-172.9318
- 0.0024 Total.time
- 0.004 Total.cautery.time
- 0.0788 Time.cautery.is.applied.on.non.highlighted.bands
- 0.0076 No..of.movements.of.right.instrument
- 9e-04 Total.path.length.of.right.instrument..cm.
- 0.0075 Total.path.length.of.left.instrument..cm.
+ 0.1777 Efficiency.of.cautery....
+ 2.5832 Accuracy.rate...highlighted.bands....
+ 0.2105 Average.speed.of.left.instrument.movement..cm.sec.

Percentiles of each variable

| | 10 | 25 | 50 |
|---|---|---|---|
| Total.time | 145.6 | 151.0 | 155.0 |
| The.time.cautery.is.applied.without.appropriate.contact.with.bands | 2.2 | 3.0 | 5.0 |
| Total.cautery.time | 41.6 | 42.5 | 45.0 |
| Time.cautery.is.applied.on.non.highlighted.bands | 2.8 | 4.5 | 6.0 |
| No..of.non.highlighted.bands.that.were.cut | 0.0 | 0.0 | 0.0 |
| No..of.movements.of.right.instrument | 66.4 | 77.5 | 93.0 |
| No..of.movements.of.left.instrument | 60.0 | 67.5 | 72.0 |
| Total.path.length.of.right.instrument..cm. | 175.1 | 197.8 | 202.8 |
| Total.path.length.of.left.instrument..cm. | 127.5 | 162.6 | 190.9 |
| Efficiency.of.cautery.... | 77.7 | 83.2 | 89.9 |
| No..of.highlighted.bands.that.were.cut | 20.2 | 21.0 | 21.0 |
| Accuracy.rate...highlighted.bands.... | 96.2 | 100.0 | 100.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 1.9 | 2.0 | 2.2 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.0 | 2.2 | 2.2 |

| | | | |
|---|---|---|---|
| Proficiency | 86.9 | 96.1 | 97.3 |

| | 75 | 90 |
|---|---|---|
| Total.time | 176.5 | 221.2 |
| The.time.cautery.is.applied.without.appropriate.contact.with.bands | 7.5 | 10.6 |
| Total.cautery.time | 48.5 | 52.6 |
| Time.cautery.is.applied.on.non.highlighted.bands | 6.0 | 6.8 |
| No..of.non.highlighted.bands.that.were.cut | 0.0 | 0.8 |
| No..of.movements.of.right.instrument | 106.5 | 137.4 |
| No..of.movements.of.left.instrument | 75.5 | 102.4 |
| Total.path.length.of.right.instrument..cm. | 275.0 | 346.3 |
| Total.path.length.of.left.instrument..cm. | 201.4 | 266.2 |
| Efficiency.of.cautery.... | 93.0 | 94.1 |
| No..of.highlighted.bands.that.were.cut | 21.0 | 21.0 |
| Accuracy.rate...highlighted.bands.... | 100.0 | 100.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.3 | 2.4 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.5 | 2.5 |
| Proficiency | 99.0 | 99.6 |

---

MODULE: LM Translocation of Objects - Attempt 2

---

Proficiency =
85.2375
- 0.0611 Total.time
- 0.0793 No..of.dropped.objects
- 0.0038 Total.path.length.of.left.instrument..cm.
+ 2.5957 No..of.properly.placed.objects
+ 0.0178 Efficiency.of.translocations....
+ 3.4605 Average.speed.of.left.instrument.movement..cm.sec.

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Total.time | 168.0 | 243.3 | 346.5 | 392.8 | 460.0 |
| Average.no..of.translocations.per.object | 3.4 | 4.5 | 6.6 | 8.9 | 10.6 |
| No..of.dropped.objects | 10.0 | 11.8 | 17.0 | 31.3 | 38.0 |
| No..of.movements.of.right.instrument | 245.0 | 328.5 | 438.0 | 633.0 | 797.0 |
| No..of.movements.of.left.instrument | 240.0 | 313.0 | 375.0 | 482.0 | 708.0 |
| Total.path.length.of.right.instrument..cm. | 753.4 | 935.8 | 1073.1 | 1816.8 | 2253.6 |
| Total.path.length.of.left.instrument..cm. | 659.0 | 826.6 | 996.4 | 1130.6 | 1624.9 |
| No..of.properly.placed.objects | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| No..of.translocations | 17.0 | 22.3 | 33.0 | 44.5 | 53.0 |
| Efficiency.of.translocations.... | 45.9 | 54.6 | 73.8 | 95.7 | 100.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.5 | 2.6 | 2.8 | 3.1 | 3.2 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.3 | 2.4 | 2.5 | 2.6 | 2.8 |
| Proficiency | 70.4 | 76.6 | 81.8 | 89.4 | 95.2 |

---

MODULE: LTS Peg Manipulation - Attempt 3

---

Proficiency =
104.319
- 0.1309 Time
- 2.5093 Errors

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Time | 57 | 65 | 98 | 135 | 171 |
| Errors | 0 | 0 | 1 | 2 | 2 |
| Proficiency | 78 | 84 | 86 | 96 | 97 |

**LTS2000 ISM60 System:**

---

MODULE: LTS Ring Manipulation D - Attempt 3

---

Proficiency =
103.0973
- 0.4425 Time

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Time | 8.2 | 12 | 19 | 22 | 32.8 |
| Errors | 0.4 | 1 | 1 | 2 | 2.6 |
| Proficiency | 88.6 | 94 | 95 | 98 | 99.5 |

---

MODULE: LTS Ring Manipulation ND - Attempt 3

---

Proficiency =
100.4142
- 0.1381 Time
- 11.282 Errors

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Time | 11 | 13 | 15 | 25 | 36 |
| Errors | 1 | 1 | 1 | 3 | 3 |
| Proficiency | 62 | 64 | 85 | 87 | 88 |

---

MODULE: LTS Knot Integrity - Attempt 3

---

Proficiency =
106.8519
- 0.1852 Time

Percentiles of each variable

| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Time | 53 | 60 | 71 | 134 | 166 |
| Proficiency | 76 | 82 | 94 | 96 | 97 |

---

MODULE: LTS Circle Cutting - Attempt 3

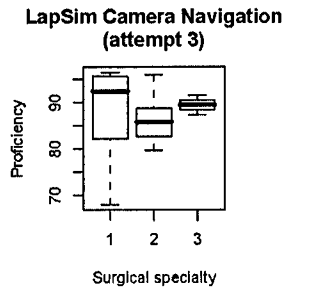
---

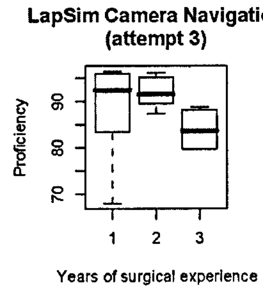
Proficiency =
116.7375
- 0.172 Time
- 1.1435 Errors

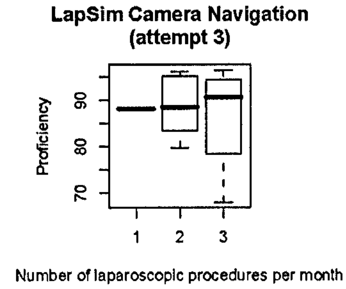
Percentiles of each variable

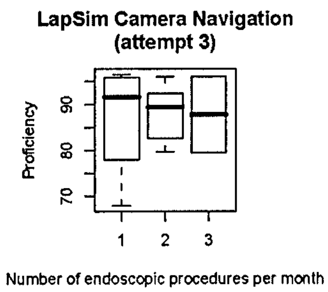
| | 10 | 25 | 50 | 75 | 90 |
|---|---|---|---|---|---|
| Time | 110 | 117 | 163 | 193.5 | 207 |
| Errors | 0 | 1 | 2 | 3.5 | 5 |
| Proficiency | 77 | 80 | 86 | 93.2 | 97 |

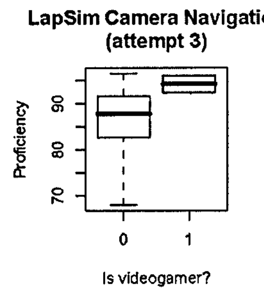
**Appendix 2:** Demographic comparisons and practice curves, by simulator
Surgical specialty: 1 – general, 2 – gynecology, 3 – urology; Years of surgical experience, number of procedures per month: 1 – low, 2 – medium, 3 – high; Is videogamer?: 0 – no, 1 – yes

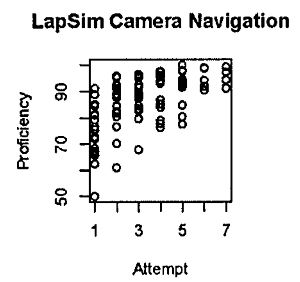


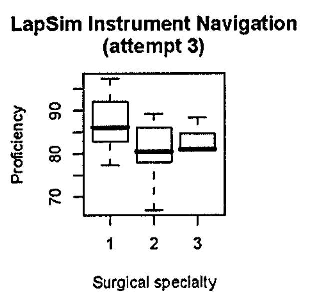



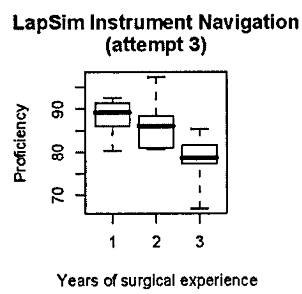



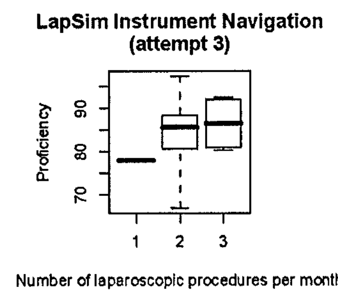



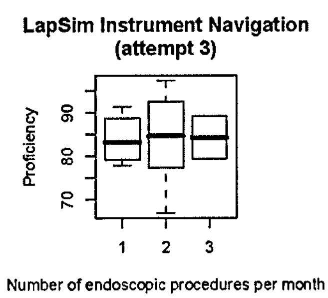



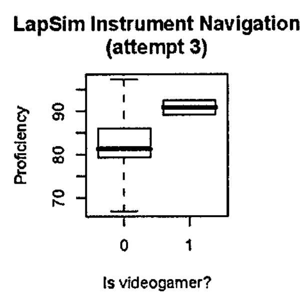



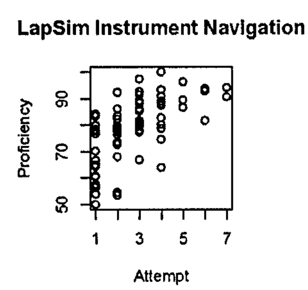



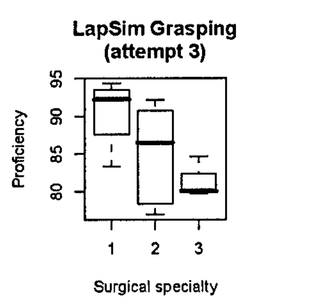



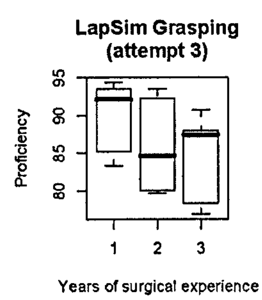



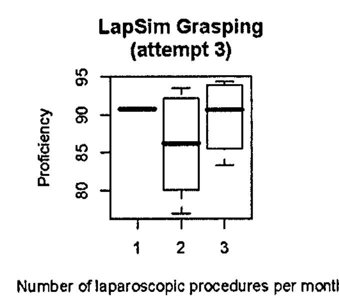



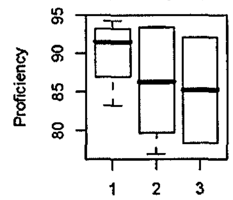



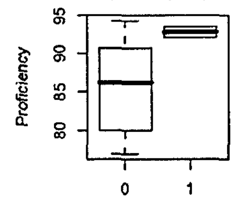



**LapSim Grasping (attempt 3)**



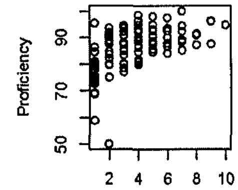

Number of endoscopic procedures per month

**LapSim Grasping (attempt 3)**




Is videogamer?

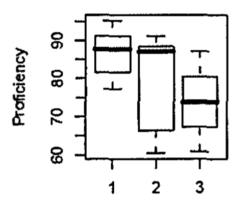
**LapSim Grasping**




Attempt

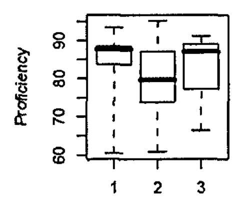
---

**LapSim Cutting (attempt 3)**



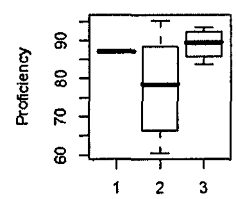

Surgical specialty

**LapSim Cutting (attempt 3)**



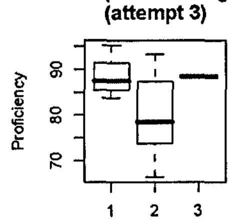

Years of surgical experience

**LapSim Cutting (attempt 3)**



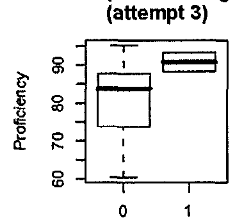

Number of laparoscopic procedures per month

**LapSim Cutting (attempt 3)**



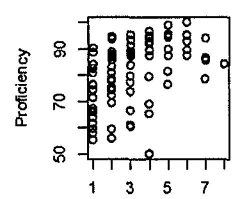

Number of endoscopic procedures per month

**LapSim Cutting (attempt 3)**




Is videogamer?

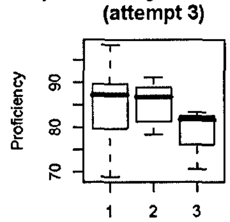
**LapSim Cutting**




Attempt

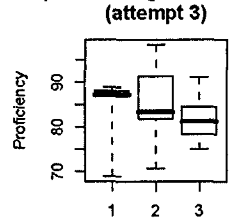
---

**LapSim Lifting and Grasping (attempt 3)**



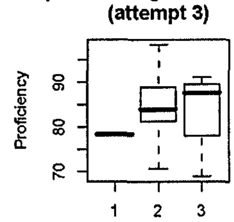

Surgical specialty

**LapSim Lifting and Grasping (attempt 3)**



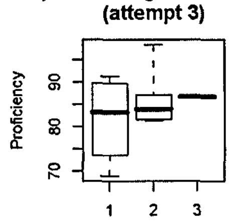

Years of surgical experience

**LapSim Lifting and Grasping (attempt 3)**



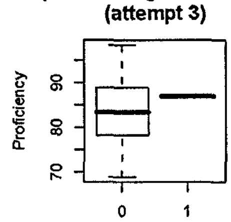

Number of laparoscopic procedures per month

**LapSim Lifting and Grasping (attempt 3)**



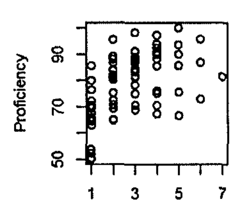

Number of endoscopic procedures per month

**LapSim Lifting and Grasping (attempt 3)**



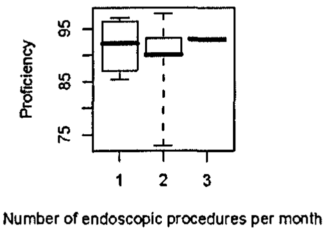

Is videogamer?

**LapSim Lifting and Grasping**

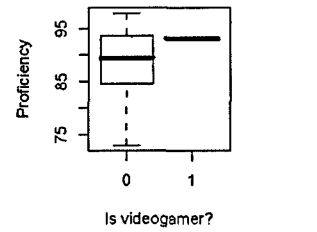



Attempt

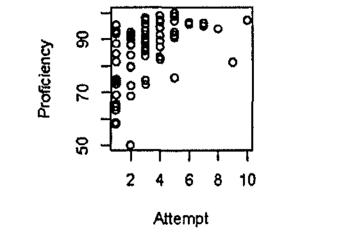
**Surgical Sim Retract and Dissect (attempt 3)**



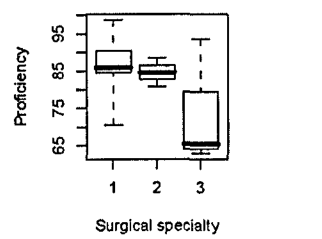

**Surgical Sim Retract and Dissect (attempt 3)**



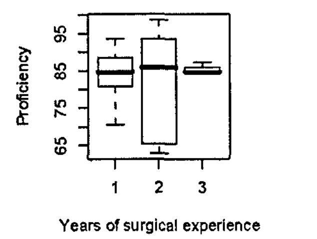

**Surgical Sim Retract and Dissect**



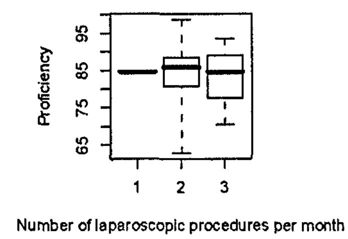

**Surgical Sim Transverse Tube (attempt 3)**



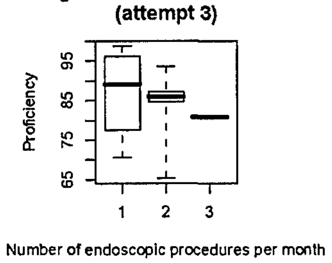

**Surgical Sim Transverse Tube (attempt 3)**



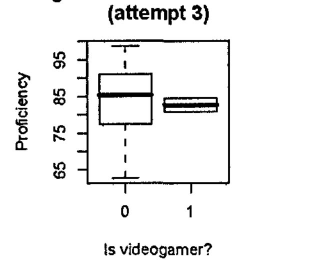

**Surgical Sim Transverse Tube (attempt 3)**



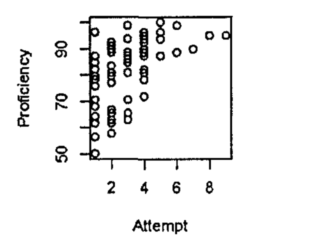

**Surgical Sim Transverse Tube (attempt 3)**



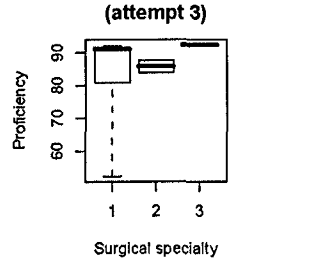

**Surgical Sim Transverse Tube (attempt 3)**




**Surgical Sim Transverse Tube**




**ProMIS Dissection (attempt 3)**

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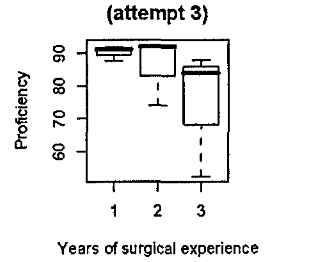


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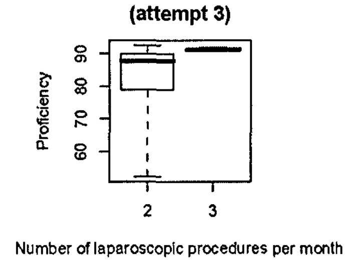
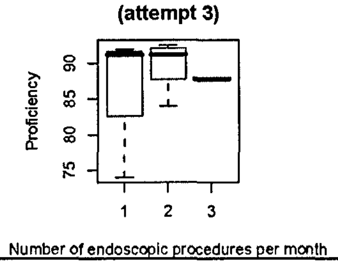
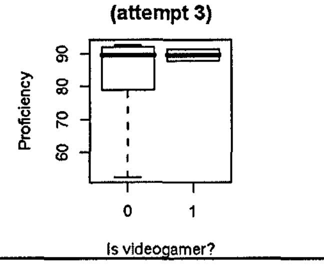


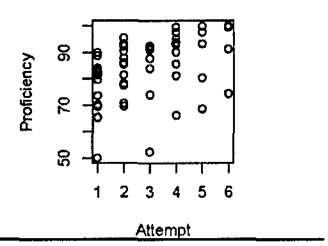

**ProMIS Dissection (attempt 3)**

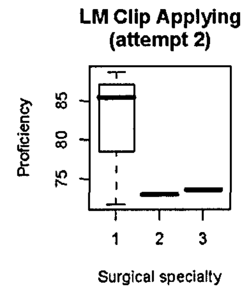


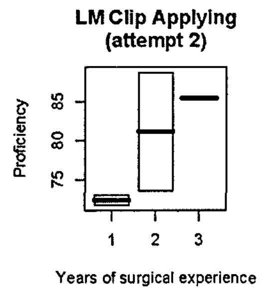

**ProMIS Dissection (attempt 3)**

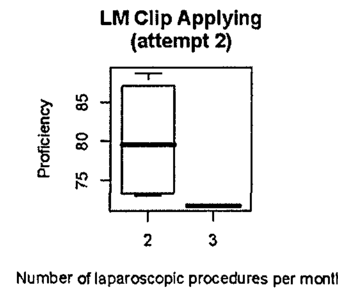


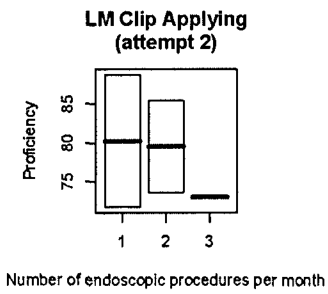

**ProMIS Dissection**

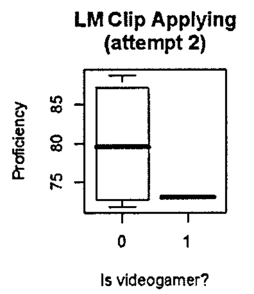


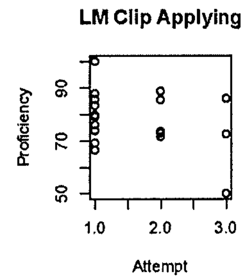

LM Clip Applying
(attempt 2)
Proficiency
75 80 85
1 2 3
Surgical specialty

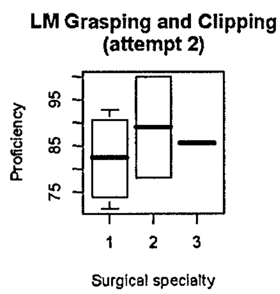

LM Clip Applying
(attempt 2)
Proficiency
75 80 85
1 2 3
Years of surgical experience

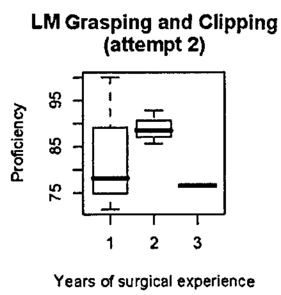

LM Clip Applying
(attempt 2)
Proficiency
75 80 85
2 3
Number of laparoscopic procedures per month

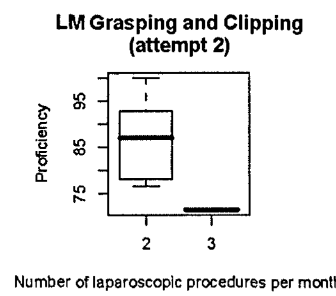

LM Clip Applying
(attempt 2)
Proficiency
75 80 85
1 2 3
Number of endoscopic procedures per month

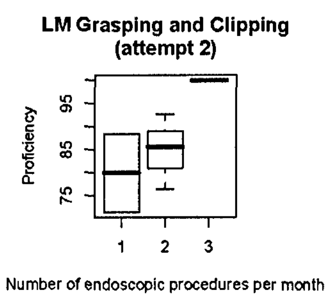

LM Clip Applying
(attempt 2)
Proficiency
75 80 85
0 1
Is videogamer?

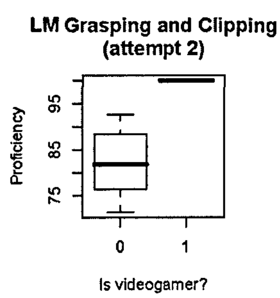

LM Clip Applying
Proficiency
50 70 90
1.0 2.0 3.0
Attempt

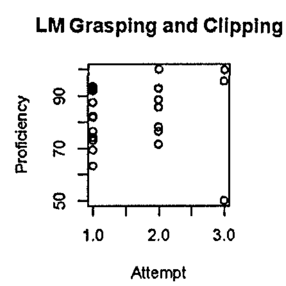

LM Grasping and Clipping
(attempt 2)
Proficiency
75 85 95
1 2 3
Surgical specialty

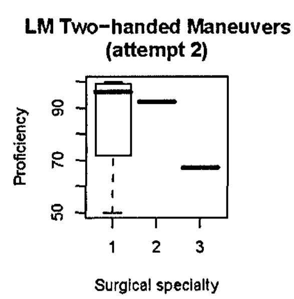

LM Grasping and Clipping
(attempt 2)
Proficiency
75 85 95
1 2 3
Years of surgical experience

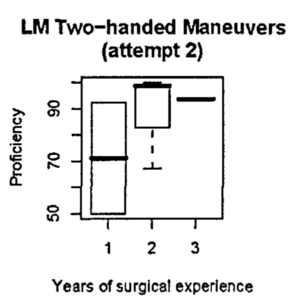

LM Grasping and Clipping
(attempt 2)
Proficiency
75 85 95
2 3
Number of laparoscopic procedures per month

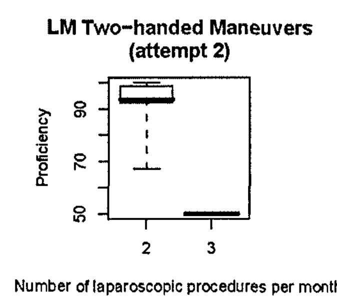

LM Grasping and Clipping
(attempt 2)
Proficiency
75 85 95
1 2 3
Number of endoscopic procedures per month

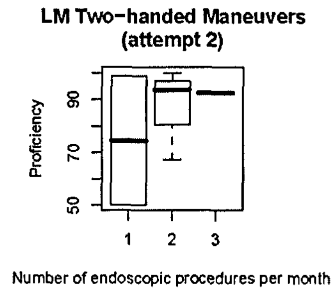

LM Grasping and Clipping
(attempt 2)
Proficiency
75 85 95
0 1
Is videogamer?

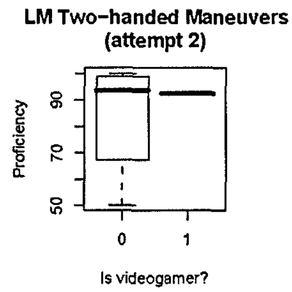

LM Grasping and Clipping
Proficiency
50 70 90
1.0 2.0 3.0
Attempt

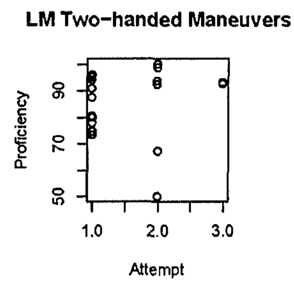

LM Two-handed Maneuvers
(attempt 2)
Proficiency
50 70 90
1 2 3
Surgical specialty

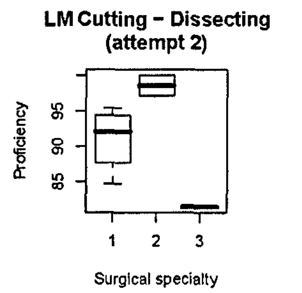

LM Two-handed Maneuvers
(attempt 2)
Proficiency
50 70 90
1 2 3
Years of surgical experience

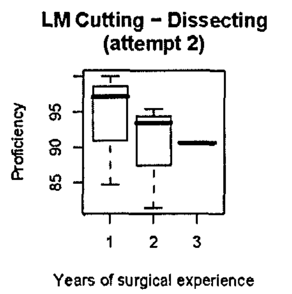

LM Two-handed Maneuvers
(attempt 2)
Proficiency
50 70 90
2 3
Number of laparoscopic procedures per month

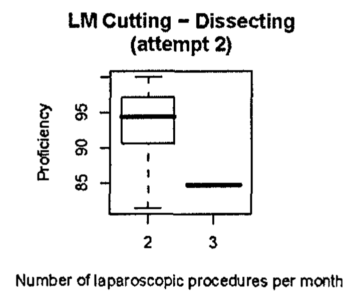

LM Two-handed Maneuvers
(attempt 2)
Proficiency
50
70
90
1
2
3
Number of endoscopic procedures per month

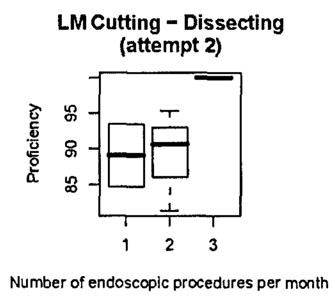

LM Two-handed Maneuvers
(attempt 2)
Proficiency
50
70
90
0
1
Is videogamer?

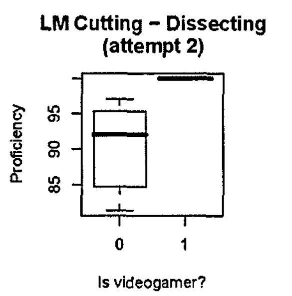

LM Two-handed Maneuvers
Proficiency
50
70
90
1.0
2.0
3.0
Attempt

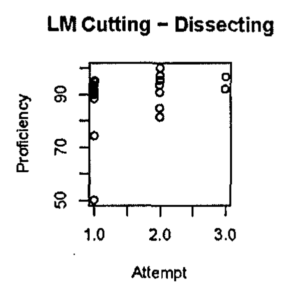

LM Cutting - Dissecting
(attempt 2)
Proficiency
85
90
95
1
2
3
Surgical specialty

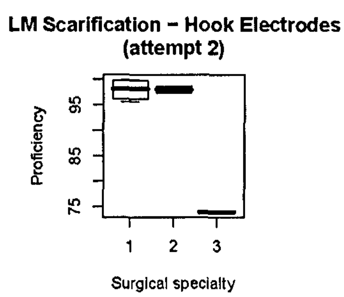

LM Cutting - Dissecting
(attempt 2)
Proficiency
85
90
95
1
2
3
Years of surgical experience

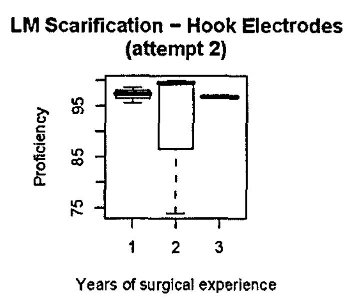

LM Cutting - Dissecting
(attempt 2)
Proficiency
85
90
95
2
3
Number of laparoscopic procedures per month

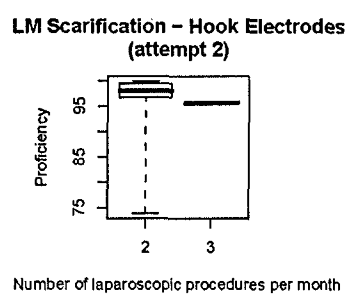

LM Cutting - Dissecting
(attempt 2)
Proficiency
85
90
95
1
2
3
Number of endoscopic procedures per month

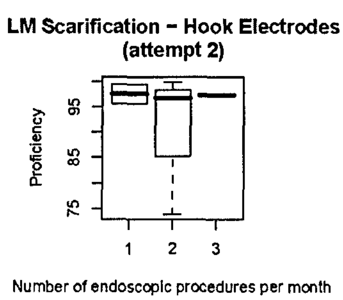

LM Cutting - Dissecting
(attempt 2)
Proficiency
85
90
95
0
1
Is videogamer?

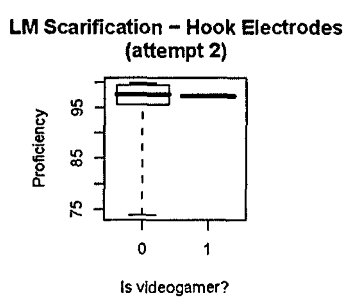

LM Cutting - Dissecting
Proficiency
50
70
90
1.0
2.0
3.0
Attempt

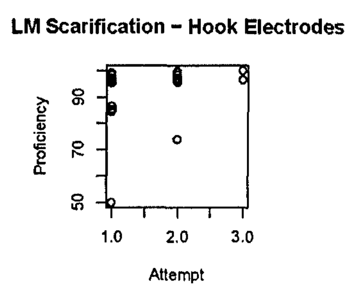

LM Scarification - Hook Electrodes
(attempt 2)
Proficiency
75
85
95
1
2
3
Surgical specialty


LM Scarification - Hook Electrodes
(attempt 2)
Proficiency
75
85
95
1
2
3
Years of surgical experience

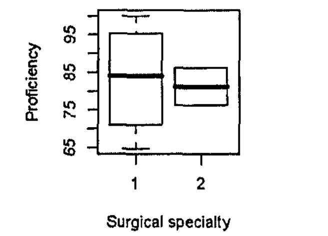

LM Scarification - Hook Electrodes
(attempt 2)
Proficiency
75
85
95
2
3
Number of laparoscopic procedures per month


LM Scarification - Hook Electrodes
(attempt 2)
Proficiency
75
85
95
1
2
3
Number of endoscopic procedures per month

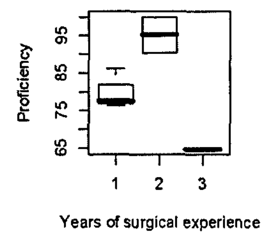

LM Scarification - Hook Electrodes
(attempt 2)
Proficiency
75
85
95
0
1
Is videogamer?


LM Scarification - Hook Electrodes
Proficiency
50
70
90
1.0
2.0
3.0
Attempt

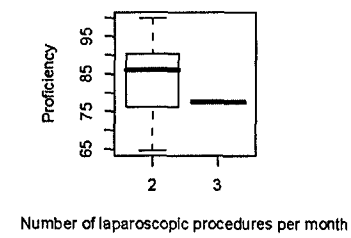
**LM Translocation of Objects (attempt 2)**



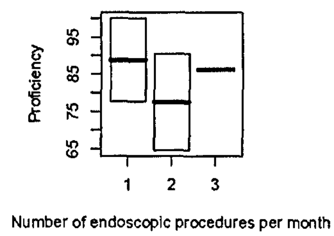

**LM Translocation of Objects (attempt 2)**



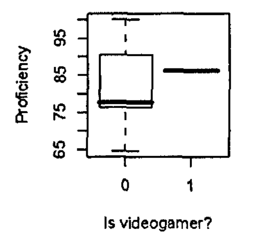

**LM Translocation of Objects (attempt 2)**



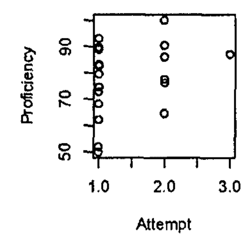

**LM Translocation of Objects (attempt 2)**



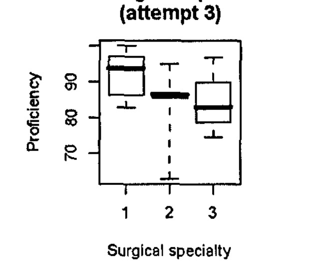

**LM Translocation of Objects (attempt 2)**



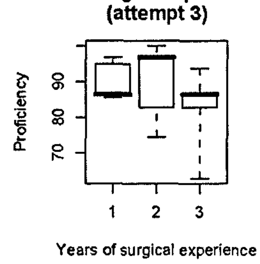

**LM Translocation of Objects**



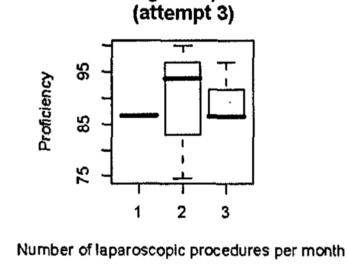

**LTS Peg Manipulation (attempt 3)**



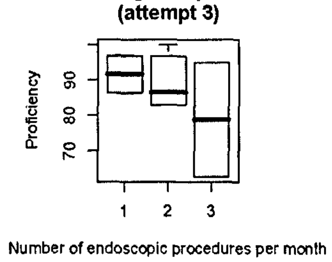

**LTS Peg Manipulation (attempt 3)**



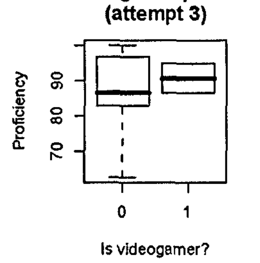

**LTS Peg Manipulation (attempt 3)**



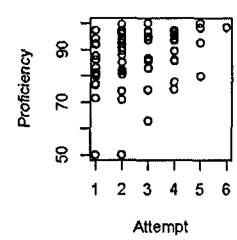

**LTS Peg Manipulation (attempt 3)**



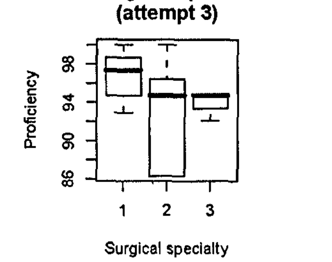

**LTS Peg Manipulation (attempt 3)**



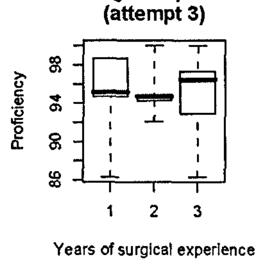

**LTS Peg Manipulation**



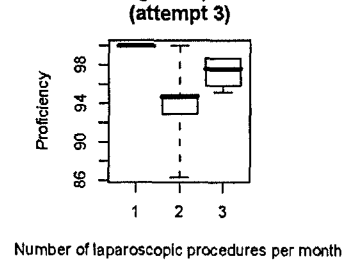

**LTS Ring Manipulation D (attempt 3)**



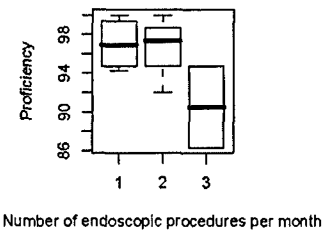

**LTS Ring Manipulation D (attempt 3)**



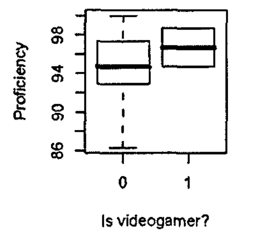

**LTS Ring Manipulation D (attempt 3)**



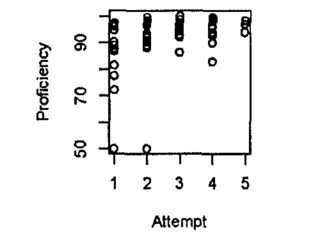
**LTS Ring Manipulation D (attempt 3)**



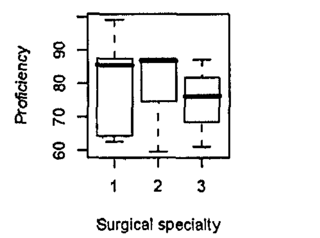

**LTS Ring Manipulation D (attempt 3)**



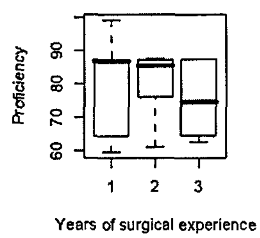

**LTS Ring Manipulation D**



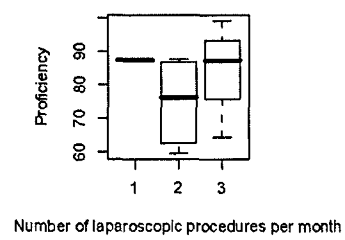

**LTS Ring Manipulation ND (attempt 3)**



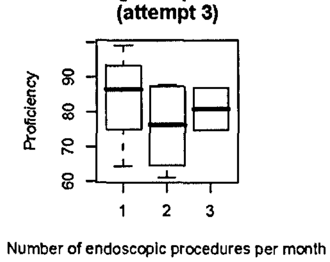

**LTS Ring Manipulation ND (attempt 3)**



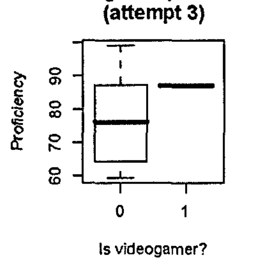

**LTS Ring Manipulation ND (attempt 3)**



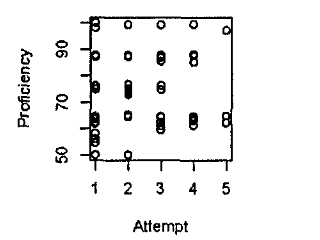

**LTS Ring Manipulation ND (attempt 3)**



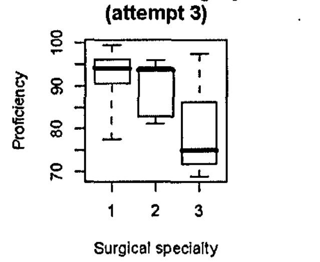

**LTS Ring Manipulation ND (attempt 3)**



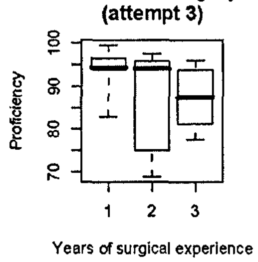

**LTS Ring Manipulation ND**



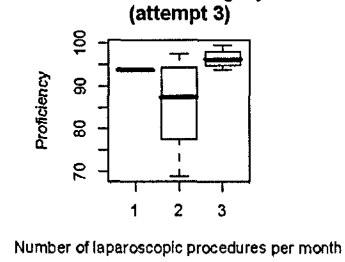

**LTS Knot Integrity (attempt 3)**



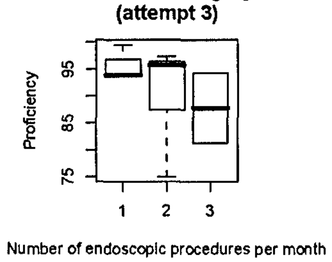

**LTS Knot Integrity (attempt 3)**



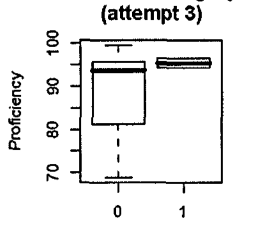

**LTS Knot Integrity (attempt 3)**



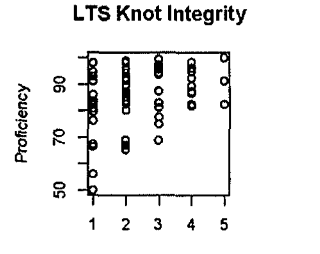

**LTS Knot Integrity (attempt 3)**




**LTS Knot Integrity (attempt 3)**

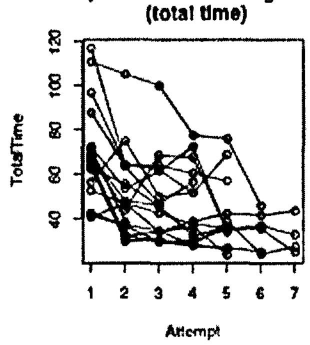



**LTS Knot Integrity**

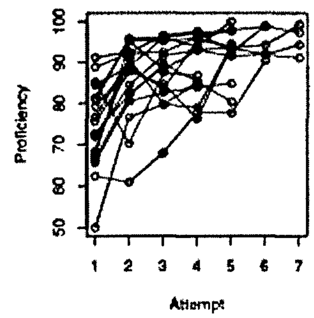


**Appendix 3:** Display of line-graphs with markers displayed at each attempt for each of the surgeon's performance with attempts 1-6 on the X axis, and the Total Time on the Y-axis – Example: LapSim

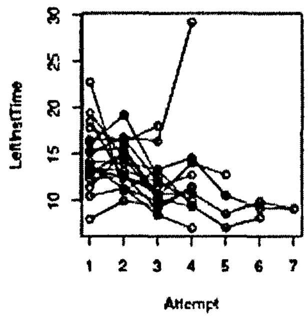
**LapSim Camera Navigation (total time)**



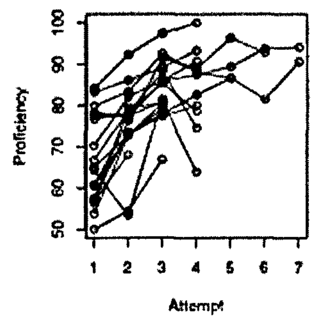

**LapSim Camera Navigation (proficiency score)**



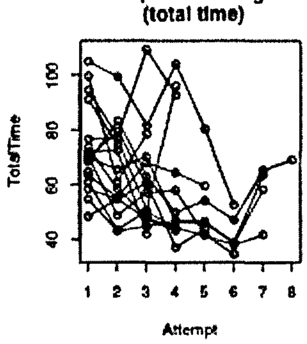

**LapSim Instrument Navigation (left instrument time)**



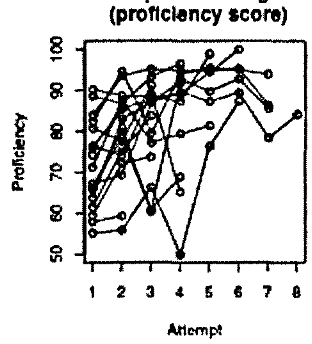

**LapSim Instrument Navigation (proficiency score)**



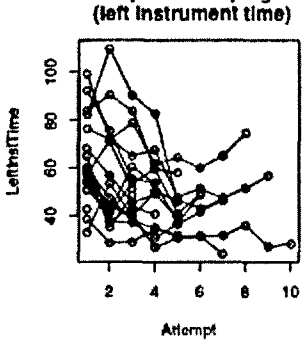

**LapSim Cutting (total time)**



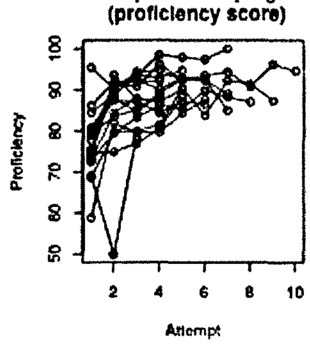

**LapSim Cutting (proficiency score)**




**LapSim Grasping (left instrument time)**




**LapSim Grasping (proficiency score)**



SLS Criterion Study - Means +/-SDs

---

MODULE: LapSim Camera Navigation - Attempt 4

---

Proficiency =
112.5161
- 3.7154 PathLength
- 0.3557 TotalTime
- 0.1014 Drift
- 1.8243 TissueDamage

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| PathLength | 1.0 | 1.2 | 1.7 | 2.2 | 2.4 |
| AngPath | 80.3 | 251.7 | 594.5 | 937.2 | 1108.6 |
| TotalTime | 20.8 | 29.4 | 46.5 | 63.7 | 72.2 |
| Drift | 2.5 | 3.4 | 5.2 | 7.1 | 8.0 |
| TissueDamage | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MaxDamage | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Proficiency | 77.9 | 81.6 | 89.1 | 96.6 | 100.4 |

---

MODULE: LapSim Instrument Navigation - Attempt 4

---

Proficiency =
136.4479
- 36.7202 LeftInstPathLength
- 21.4565 RightInstPathLength
- 0.012 RightInstAngPath
- 0.6106 RightInstTime
- 0.2756 TissueDamage
- 0.1563 MaxDamage

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| LeftInstPathLength | 0.54 | 0.600 | 0.71 | 0.82 | 0.87 |
| LeftInstAngPath | 126.57 | 150.634 | 198.75 | 246.87 | 270.93 |
| LeftInstTime | 3.88 | 6.829 | 12.72 | 18.62 | 21.57 |
| RightInstPathLength | 0.49 | 0.551 | 0.67 | 0.79 | 0.85 |
| RightInstAngPath | 102.53 | 120.756 | 157.20 | 193.65 | 211.87 |
| RightInstTime | 3.42 | 7.201 | 14.76 | 22.33 | 26.11 |
| TissueDamage | -0.72 | 0.038 | 1.55 | 3.05 | 3.81 |
| MaxDamage | -1.42 | -0.290 | 1.97 | 4.23 | 5.36 |
| Proficiency | 69.61 | 74.549 | 84.42 | 94.30 | 99.23 |

---

MODULE: LapSim Grasping - Attempt 4

---

Proficiency =
111.5076
- 2.9354 LeftInstPathLength
- 0.0013 LeftInstAngPath
- 0.0632 LeftInstMisses
- 1.2948 RightInstPathLength
- 0.2603 RightInstTime
- 0.1122 RightInstMisses
- 0.1343 MaxDamage

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| LeftInstPathLength | 1.37 | 1.689 | 2.3 | 3.0 | 3.3 |
| LeftInstAngPath | 315.69 | 382.294 | 515.5 | 648.7 | 715.3 |
| LeftInstTime | 27.04 | 34.855 | 50.5 | 66.1 | 73.9 |
| LeftInstMisses | -6.43 | -3.524 | 2.3 | 8.1 | 11.0 |
| RightInstPathLength | 1.51 | 1.727 | 2.2 | 2.6 | 2.8 |
| RightInstAngPath | 238.46 | 281.731 | 368.3 | 454.8 | 498.1 |
| RightInstTime | 24.83 | 31.098 | 43.6 | 56.2 | 62.4 |
| RightInstMisses | -6.43 | -3.524 | 2.3 | 8.1 | 11.0 |
| TissueDamage | -2.42 | 0.054 | 5.0 | 9.9 | 12.4 |
| MaxDamage | -0.44 | 1.557 | 5.5 | 9.5 | 11.5 |
| Proficiency | 79.91 | 82.833 | 88.7 | 94.5 | 97.5 |

---

MODULE: LapSim Cutting - Attempt 4

---

Proficiency =
120.2763
- 0.0461 CutterAngPath
- 0.4382 TotalTime
- 0.0685 MaxStretchDamage
- 0.1884 RipFailure

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| CutterPathLength | 0.15 | 0.3 | 0.58 | 0.87 | 1.0 |
| CutterAngPath | 18.15 | 61.4 | 147.75 | 234.14 | 277.3 |
| TotalTime | 25.18 | 37.0 | 60.51 | 84.07 | 95.8 |
| MaxStretchDamage | -4.90 | 11.8 | 45.28 | 78.74 | 95.5 |
| TissueDamage | -2.33 | -1.0 | 1.58 | 4.19 | 5.5 |
| MaxDamage | -8.89 | -4.2 | 5.29 | 14.75 | 19.5 |
| RipFailure | -11.54 | -6.8 | 2.75 | 12.28 | 17.0 |
| DropFailure | 0.00 | 0.0 | 0.00 | 0.00 | 0.0 |
| Proficiency | 61.49 | 68.8 | 83.33 | 97.89 | 105.2 |

---

MODULE: LapSim Lifting and Grasping - Attempt 4

---

Proficiency =
132.0551
- 9.7609 LeftInstPathLength
- 0.002 LeftInstAngPath
- 0.098 RightInstMisses
- 1.6881 RightInstPathLength
- 0.4771 TotalTime
- 0.0971 MaxDamage

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| LeftInstMisses | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| LeftInstPathLength | 1.08 | 1.22 | 1.5 | 1.8 | 1.9 |
| LeftInstAngPath | 259.01 | 294.54 | 365.6 | 436.6 | 472.2 |
| RightInstMisses | -14.02 | -7.35 | 6.0 | 19.3 | 26.0 |
| RightInstPathLength | 1.15 | 1.28 | 1.5 | 1.8 | 1.9 |
| RightInstAngPath | 241.43 | 279.34 | 355.2 | 431.0 | 468.9 |
| TotalTime | 36.14 | 43.18 | 57.3 | 71.4 | 78.4 |
| TissueDamage | -0.73 | 0.27 | 2.3 | 4.3 | 5.3 |

```
MaxDamage           -5.78   3.01  20.6  38.1  46.9
Proficiency         68.92  74.03  84.3  94.5  99.6

------------------------------------------------------------------------------------
MODULE: Surgical Sim Gall Bladder - Attempt 4
------------------------------------------------------------------------------------

Proficiency =
108.1165
- 0.0306 total_time
- 0.0235 tip_trajectory
- 0.1717 burning_in_air_time

Means +/- various numbers of SDs for each variable
                          -1.5    -1     0    1 1.5
total_time               111.0 162.2 264.5 367 418
tip_trajectory             4.2 138.1 405.8 674 807
burning_in_air_time      -10.2  -3.9   8.6  21  27
tissue_overstretched     -10.1  -4.5   6.6  18  23
dissected_outside_target  -2.8   1.7  10.5  19  24
Proficiency               72.2  77.8  89.0 100 106

------------------------------------------------------------------------------------
MODULE: Surgical Sim Place Arrow - Attempt 4
------------------------------------------------------------------------------------

Proficiency =
113.4184
- 1.3418 total_time
- 1.1734 dropped_arrow
- 1.7601 closed_entry_right_tool

Means +/- various numbers of SDs for each variable
                          -1.5      -1     0     1    1.5
total_time               8.713 11.6656 17.57 23.48  26.43
tip_trajectory          24.700 30.4520 41.96 53.46  59.21
dropped_arrow           -0.088 -0.0015  0.17  0.34   0.43
lost_arrow              -0.196 -0.0878  0.13  0.34   0.45
closed_entry_left_tool  -0.182 -0.0881  0.10  0.29   0.38
closed_entry_right_tool -0.267 -0.1206  0.17  0.46   0.61
Proficiency             77.293 81.3078 89.34 97.37 101.38

------------------------------------------------------------------------------------
MODULE: Surgical Sim Retract and Dissect - Attempt 4
------------------------------------------------------------------------------------

Proficiency =
105.7729
- 0.2211 total_time
- 0.0121 tip_trajectory
- 0.6981 burning_in_air_right_time
- 5.5962 dissected_outside_target_left
- 7.1573 dissected_outside_target_right
- 0.3437 lost_aligned_pod_left
- 10.9549 lost_aligned_pod_right

Means +/- various numbers of SDs for each variable
                                -1.5     -1      0      1    1.5
total_time                     15.19 21.948 35.462  48.97  55.73
tip_trajectory                 47.20 59.383 83.754 108.13 120.31
burning_in_air_left_time       -0.19 -0.014  0.342   0.70   0.88
```

| | | | | | |
|---|---|---|---|---|---|
| burning_in_air_right_time | -0.26 | -0.073 | 0.293 | 0.66 | 0.84 |
| tissue_overstretched_left | -0.24 | -0.104 | 0.173 | 0.45 | 0.59 |
| tissue_overstretched_right | -0.35 | -0.062 | 0.519 | 1.10 | 1.39 |
| dissected_outside_target_left | -0.40 | -0.149 | 0.346 | 0.84 | 1.09 |
| dissected_outside_target_right | -0.18 | -0.039 | 0.250 | 0.54 | 0.68 |
| dissected_pod_not_aligned_left | -0.13 | -0.038 | 0.154 | 0.35 | 0.44 |
| dissected_pod_not_aligned_right | -0.12 | -0.016 | 0.192 | 0.40 | 0.50 |
| lost_aligned_pod_left | -0.19 | -0.085 | 0.135 | 0.35 | 0.46 |
| lost_aligned_pod_right | -0.23 | -0.121 | 0.096 | 0.31 | 0.42 |
| Proficiency | 83.90 | 86.565 | 91.889 | 97.21 | 99.88 |

---

MODULE: Surgical Sim Transverse Tube - Attempt 4

---

Proficiency =
116.6667
- 1.2821 total_time

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| total_time | 14.220 | 17.198 | 23.15 | 29.11 | 32.09 |
| tip_trajectory | 54.989 | 61.679 | 75.06 | 88.44 | 95.13 |
| dropped_tube | -0.245 | -0.035 | 0.38 | 0.80 | 1.01 |
| wrong_segment | -0.011 | 0.085 | 0.28 | 0.47 | 0.57 |
| Proficiency | 75.528 | 79.346 | 86.98 | 94.62 | 98.44 |

---

MODULE: ProMIS Dissection - Attempt 4

---

Proficiency =
111.4094
- 0.0649 LeftInstPath
- 0.0097 RightInstPath
- 0.0286 LeftInstSmoothness
- 0.0106 RightInstSmoothness

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| TotalTime | 33 | 49 | 80 | 112 | 128 |
| LeftInstPath | 11 | 43 | 105 | 168 | 199 |
| RightInstPath | 87 | 146 | 262 | 379 | 437 |
| LeftInstSmoothness | 134 | 195 | 316 | 438 | 499 |
| RightInstSmoothness | 77 | 160 | 326 | 492 | 576 |
| Proficiency | 75 | 80 | 90 | 99 | 104 |

---

MODULE: ProMIS Instrument Handling - Attempt 4

---

Proficiency =
127.6061
- 0.7341 TotalTime
- 0.09 LeftInstPath
- 0.0171 LeftInstSmoothness
- 0.0149 RightInstSmoothness

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| TotalTime | 24 | 27 | 33 | 38 | 41 |

| | | | | | |
|---|---|---|---|---|---|
| LeftInstPath | 88 | 96 | 110 | 125 | 133 |
| RightInstPath | 92 | 97 | 108 | 118 | 124 |
| LeftInstSmoothness | 67 | 75 | 93 | 111 | 120 |
| RightInstSmoothness | 76 | 87 | 110 | 133 | 145 |
| Proficiency | 82 | 85 | 91 | 96 | 99 |

---

MODULE: ProMIS Suturing & Knot Tying - Attempt 4

---

Proficiency =
100.1275
- 0.005 LeftInstPath
- 0.013 RightInstSmoothness

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| TotalTime | 5.1 | 62 | 177 | 292 | 349 |
| LeftInstPath | 30.5 | 180 | 479 | 778 | 928 |
| RightInstPath | 18.1 | 201 | 567 | 933 | 1116 |
| LeftInstSmoothness | -40.5 | 168 | 584 | 999 | 1207 |
| RightInstSmoothness | -4.8 | 213 | 648 | 1082 | 1300 |
| Proficiency | 78.7 | 82 | 89 | 96 | 100 |

---

MODULE: LM Camera Navigation 0° - Attempt 2

---

Proficiency =
-21.1648
- 0.1244 Total.time
- 0.1357 The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera
+ 0.9976 Accuracy.rate...target.hits....
+ 0.357 Maintaining.the.horizontal.view.while.using.the.0..camera....
+ 0.1245 Average.speed.of.camera.movement..cm.sec.

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 |
|---|---|---|
| Total.time | 54.3 | 60.8 |
| Total.no..of.camera.shots | 9.2 | 9.9 |
| The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera | 45.0 | 51.1 |
| Total.path.length.of.camera..cm. | 168.8 | 196.7 |
| No..of.correct.hits | 10.0 | 10.0 |
| Accuracy.rate...target.hits.... | 74.6 | 79.7 |
| Maintaining.the.horizontal.view.while.using.the.0..camera.... | 71.0 | 75.7 |
| Average.speed.of.camera.movement..cm.sec. | 8.7 | 9.1 |
| Proficiency | 67.5 | 72.5 |

| | 0 | 1 | 1.5 |
|---|---|---|---|
| Total.time | 74 | 87 | 93 |
| Total.no..of.camera.shots | 11 | 13 | 13 |
| The.time.the.horizontal.view.is.maintained...15...while.using.the.0..camera | 63 | 75 | 81 |
| Total.path.length.of.camera..cm. | 252 | 308 | 336 |
| No..of.correct.hits | 10 | 10 | 10 |
| Accuracy.rate...target.hits.... | 90 | 100 | 105 |
| Maintaining.the.horizontal.view.while.using.the.0..camera.... | 85 | 94 | 99 |
| Average.speed.of.camera.movement..cm.sec. | 10 | 11 | 11 |
| Proficiency | 82 | 92 | 97 |

---

MODULE: LM Camera Navigation 30° - Attempt 2

---

Proficiency =
82.5559
- 0.1543 Total.time
- 12.7571 Total.no..of.camera.shots
+ 15.4429 No..of.correct.hits

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | 36.5 | 52.0 | 83.1 | 114.2 | 130 |
| Total.no..of.camera.shots | 9.6 | 9.9 | 10.4 | 10.9 | 11 |
| Total.path.length.of.camera..cm. | 149.2 | 206.7 | 321.7 | 436.7 | 494 |
| No..of.correct.hits | 10.0 | 10.0 | 10.0 | 10.0 | 10 |
| Accuracy.rate...target.hits.... | 89.5 | 91.9 | 96.6 | 101.3 | 104 |
| Average.speed.of.camera.movement..cm.sec. | 7.4 | 7.9 | 8.8 | 9.6 | 10 |
| Proficiency | 76.8 | 81.8 | 91.8 | 101.8 | 107 |

---

MODULE: LM Eye-hand Coordination - Attempt 2

---

Proficiency =
-158.101
- 0.5331 Total.time
+ 2.5167 Accuracy.rate...touched.targets....
+ 0.0648 Ideal.path.length.of.right.instrument..cm.
+ 0.0094 Ideal.path.length.of.left.instrument..cm.
+ 0.1161 Economy.of.movement...right.instrument....
+ 0.1076 Economy.of.movement...left.instrument....

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | 26.2 | 30.5 | 39.1 | 47.8 | 52.1 |
| Total.no..of.touched.balls | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| No..of.movements.of.right.instrument | 12.5 | 15.0 | 19.9 | 24.7 | 27.2 |
| No..of.movements.of.left.instrument | 14.1 | 15.2 | 17.4 | 19.7 | 20.8 |
| Total.path.length.of.right.instrument..cm. | 68.3 | 76.8 | 93.6 | 110.4 | 118.9 |
| Total.path.length.of.left.instrument..cm. | 67.1 | 74.2 | 88.3 | 102.4 | 109.4 |
| Relevant.path.length...right.instrument..cm. | 28.0 | 36.9 | 54.6 | 72.3 | 81.1 |
| Relevant.path.length...left.instrument..cm. | 34.5 | 38.0 | 45.1 | 52.1 | 55.6 |
| No..of.correct.hits | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Accuracy.rate...touched.targets.... | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Ideal.path.length.of.right.instrument..cm. | 23.8 | 27.0 | 33.4 | 39.9 | 43.1 |
| Ideal.path.length.of.left.instrument..cm. | 25.9 | 27.9 | 32.0 | 36.1 | 38.2 |
| Economy.of.movement...right.instrument.... | 47.8 | 53.2 | 64.2 | 75.1 | 80.5 |
| Economy.of.movement...left.instrument.... | 58.7 | 63.1 | 71.7 | 80.4 | 84.8 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.5 | 2.7 | 3.0 | 3.4 | 3.6 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.5 | 2.7 | 3.1 | 3.5 | 3.7 |
| Proficiency | 81.4 | 84.4 | 90.3 | 96.3 | 99.2 |

---

MODULE: LM Clip Applying - Attempt 2

---

Proficiency =
63.8809
- 0.0296 No..of.movements.of.right.instrument
- 0.3466 No..of.movements.of.left.instrument
- 0.0292 Total.path.length.of.right.instrument..cm.
- 0.2443 Relevant.path.length...right.instrument..cm.
+ 0.1847 Accuracy.rate...applied.clips....

+ 0.4126 Ideal.path.length.of.right.instrument..cm.
+ 0.4308 Economy.of.movement...left.instrument....

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | 39.92 | 48.61 | 66.0 | 83.4 | 92.1 |
| No..of.lost.clips | -0.96 | 0.31 | 2.9 | 5.4 | 6.7 |
| Total.no..of.clipping.attempts | 8.04 | 9.31 | 11.9 | 14.4 | 15.7 |
| No..of.movements.of.right.instrument | 16.78 | 25.47 | 42.9 | 60.2 | 68.9 |
| No..of.movements.of.left.instrument | 5.68 | 12.07 | 24.9 | 37.6 | 44.0 |
| Total.path.length.of.right.instrument..cm. | 75.14 | 98.71 | 145.9 | 193.0 | 216.6 |
| Total.path.length.of.left.instrument..cm. | 5.58 | 31.23 | 82.5 | 133.9 | 159.5 |
| Relevant.path.length...right.instrument..cm. | 40.83 | 67.32 | 120.3 | 173.3 | 199.8 |
| Relevant.path.length...left.instrument..cm. | 40.68 | 52.97 | 77.5 | 102.1 | 114.4 |
| Accuracy.rate...applied.clips.... | 54.94 | 62.89 | 78.8 | 94.7 | 102.7 |
| Ideal.path.length.of.right.instrument..cm. | 11.85 | 30.01 | 66.3 | 102.7 | 120.8 |
| Ideal.path.length.of.left.instrument..cm. | 8.55 | 16.97 | 33.8 | 50.6 | 59.0 |
| Economy.of.movement...right.instrument.... | 28.13 | 36.51 | 53.3 | 70.0 | 78.4 |
| Economy.of.movement...left.instrument.... | 14.79 | 23.85 | 42.0 | 60.1 | 69.1 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.42 | 2.66 | 3.1 | 3.6 | 3.9 |
| Average.speed.of.left.instrument.movement..cm.sec. | 1.81 | 2.12 | 2.7 | 3.4 | 3.7 |
| Proficiency | 66.51 | 70.51 | 78.5 | 86.5 | 90.5 |

---

MODULE: LM Grasping and Clipping - Attempt 2

---

Proficiency =
148.3501
- 0.0013 No..of.lost.clips
- 0.1516 Total.path.length.of.clipper..cm.
- 0.1514 Total.path.length.of.grasper..cm.
- 1e-04 Relevant.path.length...clipper.cm.
+ 3e-04 Ideal.path.length.of.clipper..cm.
+ 0.0017 Economy.of.movement...right.instrument....
+ 0.0015 Economy.of.movement...left.instrument....
+ 0.0067 Average.speed.of.right.instrument.movement..cm.sec.

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | 61.47 | 74.03 | 99.1 | 124.3 | 136.8 |
| No..of.lost.clips | 0.15 | 0.53 | 1.3 | 2.0 | 2.4 |
| Total.no..of.clipping.attempts | 9.15 | 9.53 | 10.3 | 11.0 | 11.4 |
| No..of.movements.of.right.instrument | 31.36 | 38.34 | 52.3 | 66.2 | 73.2 |
| No..of.movements.of.left.instrument | 37.80 | 46.20 | 63.0 | 79.8 | 88.2 |
| Total.path.length.of.right.instrument..cm. | 153.16 | 166.72 | 193.8 | 221.0 | 234.5 |
| Total.path.length.of.left.instrument..cm. | 160.87 | 183.09 | 227.5 | 272.0 | 294.2 |
| Total.path.length.of.clipper..cm. | 137.59 | 158.13 | 199.2 | 240.3 | 260.8 |
| Total.path.length.of.grasper..cm. | 166.49 | 185.04 | 222.2 | 259.3 | 277.8 |
| Relevant.path.length...right.instrument..cm. | 145.08 | 158.77 | 186.1 | 213.5 | 227.2 |
| Relevant.path.length...left.instrument..cm. | 150.74 | 173.25 | 218.3 | 263.3 | 285.8 |
| Relevant.path.length...clipper.cm. | 130.16 | 150.64 | 191.6 | 232.6 | 253.0 |
| Relevant.path.length...grasper..cm. | 155.93 | 174.89 | 212.8 | 250.7 | 269.7 |
| Accuracy.rate...applied.clips.... | 77.83 | 81.19 | 87.9 | 94.6 | 98.0 |
| Ideal.path.length.of.clipper..cm. | 81.94 | 91.92 | 111.9 | 131.9 | 141.8 |
| Ideal.path.length.of.grasper..cm. | 103.48 | 105.79 | 110.4 | 115.0 | 117.3 |
| Economy.of.movement...right.instrument.... | 45.94 | 50.92 | 60.9 | 70.8 | 75.8 |
| Economy.of.movement...left.instrument.... | 35.04 | 40.80 | 52.3 | 63.8 | 69.6 |
| Economy.of.movement...clipper.... | 39.78 | 46.57 | 60.1 | 73.7 | 80.5 |
| Economy.of.movement..grasper.... | 41.35 | 45.25 | 53.0 | 60.8 | 64.7 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.33 | 2.51 | 2.9 | 3.2 | 3.4 |

| | | | | | |
|---|---|---|---|---|---|
| Average.speed.of.left.instrument.movement..cm.sec. | 2.44 | 2.77 | 3.4 | 4.1 | 4.4 |
| Proficiency | 69.74 | 74.73 | 84.7 | 94.7 | 99.7 |

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MODULE: LM Two-handed Maneuvers - Attempt 2

---

Proficiency =
109.7534
- 6.7467 No..of.lost.balls.which.miss.the.basket
- 0.2845 No..of.movements.of.left.instrument
- 0.0225 Total.path.length.of.right.instrument..cm.
- 0.0043 Total.path.length.of.left.instrument..cm.
+ 0.128 Economy.of.movement...right.instrument....

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | -5.1 | 30.6 | 102.1 | 173.6 | 209.4 |
| No..of.lost.balls.which.miss.the.basket | -3.4 | -1.7 | 1.6 | 4.9 | 6.5 |
| No..of.movements.of.right.instrument | 2.2 | 23.0 | 64.6 | 106.1 | 126.9 |
| No..of.movements.of.left.instrument | -5.5 | 18.4 | 66.1 | 113.9 | 137.8 |
| Total.path.length.of.right.instrument..cm. | 9.3 | 91.3 | 255.2 | 419.1 | 501.1 |
| Total.path.length.of.left.instrument..cm. | 4.0 | 79.8 | 231.2 | 382.6 | 458.3 |
| Relevant.path.length...right.instrument..cm. | 21.6 | 65.9 | 154.5 | 243.1 | 287.4 |
| Relevant.path.length...left.instrument..cm. | 16.1 | 65.5 | 164.5 | 263.5 | 313.0 |
| No..of.exposed.green.balls.that.are.collected | 2.3 | 4.0 | 7.3 | 10.6 | 12.2 |
| Ideal.path.length.of.right.instrument..cm. | 19.5 | 33.5 | 61.6 | 89.7 | 103.7 |
| Ideal.path.length.of.left.instrument..cm. | 9.5 | 20.5 | 42.5 | 64.6 | 75.6 |
| Economy.of.movement...right.instrument.... | 19.2 | 27.4 | 43.9 | 60.4 | 68.7 |
| Economy.of.movement...left.instrument.... | 8.9 | 16.5 | 31.7 | 46.9 | 54.5 |
| Average.speed.of.right.instrument.movement..cm.sec. | 3.3 | 3.5 | 3.7 | 4.0 | 4.1 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.6 | 2.8 | 3.3 | 3.8 | 4.0 |
| Proficiency | 53.1 | 63.3 | 83.7 | 104.0 | 114.2 |

---

MODULE: LM Cutting - Dissecting - Attempt 2

---

Proficiency =
102.2321
- 0.1514 Total.no..of.cutting.maneuvers
- 0.0313 Total.path.length.of.right.instrument..cm.
- 0.0859 Total.path.length.of.left.instrument..cm.
+ 0.2849 Average.speed.of.right.instrument.movement..cm.sec.
+ 3.7835 Average.speed.of.left.instrument.movement..cm.sec.

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 |
|---|---|---|---|
| Total.time | 34.13 | 58.66 | 107.7 |
| Total.no..of.cutting.maneuvers | 23.23 | 26.30 | 32.4 |
| Total.no..of.retraction.operations | 0.32 | 1.31 | 3.3 |
| No..of.movements.of.right.instrument | 50.16 | 68.20 | 104.3 |
| No..of.movements.of.left.instrument | 13.20 | 21.08 | 36.9 |
| Total.path.length.of.right.instrument..cm. | 93.11 | 148.05 | 257.9 |
| Total.path.length.of.left.instrument..cm. | 28.68 | 48.90 | 89.4 |
| No..of.cutting.maneuvers.performed.without.causing.injury | 23.23 | 26.30 | 32.4 |
| No..of.retraction.operations.without.overstretch.injuries.to.tissue | -0.22 | 0.57 | 2.1 |
| Safe.retraction...overstretch.... | 25.87 | 41.05 | 71.4 |
| Average.speed.of.right.instrument.movement..cm.sec. | 1.04 | 1.95 | 3.8 |
| Average.speed.of.left.instrument.movement..cm.sec. | 1.77 | 1.98 | 2.4 |
| Proficiency | 81.72 | 85.08 | 91.8 |

| | 1 | 1.5 |
|---|---|---|
| Total.time | 156.8 | 181.3 |
| Total.no..of.cutting.maneuvers | 38.6 | 41.6 |
| Total.no..of.retraction.operations | 5.3 | 6.2 |
| No..of.movements.of.right.instrument | 140.4 | 158.4 |
| No..of.movements.of.left.instrument | 52.6 | 60.5 |
| Total.path.length.of.right.instrument..cm. | 367.8 | 422.8 |
| Total.path.length.of.left.instrument..cm. | 129.8 | 150.0 |
| No..of.cutting.maneuvers.performed.without.causing.injury | 38.6 | 41.6 |
| No..of.retraction.operations.without.overstretch.injuries.to.tissue | 3.7 | 4.5 |
| Safe.retraction...overstretch.... | 101.8 | 117.0 |
| Average.speed.of.right.instrument.movement..cm.sec. | 5.6 | 6.5 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.8 | 3.1 |
| Proficiency | 98.5 | 101.9 |

---

MODULE: LM Scarification - Hook Electrodes - Attempt 2

---

Proficiency =
-172.9318
- 0.0024 Total.time
- 0.004 Total.cautery.time
- 0.0788 Time.cautery.is.applied.on.non.highlighted.bands
- 0.0076 No..of.movements.of.right.instrument
- 9e-04 Total.path.length.of.right.instrument..cm.
- 0.0075 Total.path.length.of.left.instrument..cm.
+ 0.1777 Efficiency.of.cautery....
+ 2.5832 Accuracy.rate...highlighted.bands....
+ 0.2105 Average.speed.of.left.instrument.movement..cm.sec.

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 |
|---|---|---|---|
| Total.time | 106.28 | 129.24 | 175.14 |
| The.time.cautery.is.applied.without.appropriate.contact.with.bands | -0.45 | 1.60 | 5.71 |
| Total.cautery.time | 38.47 | 41.03 | 46.14 |
| Time.cautery.is.applied.on.non.highlighted.bands | 1.85 | 2.95 | 5.14 |
| No..of.non.highlighted.bands.that.were.cut | -0.85 | -0.47 | 0.29 |
| No..of.movements.of.right.instrument | 38.36 | 58.86 | 99.86 |
| No..of.movements.of.left.instrument | 36.15 | 50.19 | 78.29 |
| Total.path.length.of.right.instrument..cm. | 114.91 | 156.46 | 239.56 |
| Total.path.length.of.left.instrument..cm. | 79.33 | 118.56 | 197.01 |
| Efficiency.of.cautery.... | 76.19 | 79.98 | 87.56 |
| No..of.highlighted.bands.that.were.cut | 19.58 | 19.96 | 20.71 |
| Accuracy.rate...highlighted.bands.... | 93.26 | 95.05 | 98.64 |
| Average.speed.of.right.instrument.movement..cm.sec. | 1.83 | 1.94 | 2.17 |
| Average.speed.of.left.instrument.movement..cm.sec. | 1.90 | 2.03 | 2.29 |
| Proficiency | 80.64 | 85.24 | 94.45 |

| | 1 | 1.5 |
|---|---|---|
| Total.time | 221.1 | 244.0 |
| The.time.cautery.is.applied.without.appropriate.contact.with.bands | 9.8 | 11.9 |
| Total.cautery.time | 51.3 | 53.8 |
| Time.cautery.is.applied.on.non.highlighted.bands | 7.3 | 8.4 |
| No..of.non.highlighted.bands.that.were.cut | 1.0 | 1.4 |
| No..of.movements.of.right.instrument | 140.9 | 161.4 |
| No..of.movements.of.left.instrument | 106.4 | 120.4 |
| Total.path.length.of.right.instrument..cm. | 322.7 | 364.2 |
| Total.path.length.of.left.instrument..cm. | 275.5 | 314.7 |
| Efficiency.of.cautery.... | 95.1 | 98.9 |
| No..of.highlighted.bands.that.were.cut | 21.5 | 21.8 |
| Accuracy.rate...highlighted.bands.... | 102.2 | 104.0 |

| | | |
|---|---|---|
| Average.speed.of.right.instrument.movement..cm.sec. | 2.4 | 2.5 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.5 | 2.7 |
| Proficiency | 103.7 | 108.3 |

---

MODULE: LM Translocation of Objects - Attempt 2

---

Proficiency =
85.2375
- 0.0611 Total.time
- 0.0793 No..of.dropped.objects
- 0.0038 Total.path.length.of.left.instrument..cm.
+ 2.5957 No..of.properly.placed.objects
+ 0.0178 Efficiency.of.translocations....
+ 3.4605 Average.speed.of.left.instrument.movement..cm.sec.

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Total.time | 106.4 | 179.2 | 324.8 | 470.5 | 543.3 |
| Average.no..of.translocations.per.object | 1.8 | 3.5 | 6.9 | 10.2 | 11.9 |
| No..of.dropped.objects | 1.7 | 8.3 | 21.7 | 35.0 | 41.6 |
| No..of.movements.of.right.instrument | 93.3 | 226.7 | 493.3 | 760.0 | 893.3 |
| No..of.movements.of.left.instrument | 55.3 | 183.9 | 441.0 | 698.1 | 826.7 |
| Total.path.length.of.right.instrument..cm. | 259.2 | 626.1 | 1360.0 | 2093.9 | 2460.9 |
| Total.path.length.of.left.instrument..cm. | 301.1 | 565.2 | 1093.4 | 1621.6 | 1885.7 |
| No..of.properly.placed.objects | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| No..of.translocations | 9.0 | 17.5 | 34.3 | 51.2 | 59.6 |
| Efficiency.of.translocations.... | 35.6 | 48.2 | 73.3 | 98.3 | 110.9 |
| Average.speed.of.right.instrument.movement..cm.sec. | 2.4 | 2.5 | 2.9 | 3.2 | 3.3 |
| Average.speed.of.left.instrument.movement..cm.sec. | 2.2 | 2.3 | 2.5 | 2.8 | 2.9 |
| Proficiency | 63.9 | 70.1 | 82.5 | 94.9 | 101.1 |

---

MODULE: LTS Peg Manipulation - Attempt 4

---

Proficiency =
104.319
- 0.1309 Time
- 2.5093 Errors

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Time | 29.2 | 50.62 | 93 | 136.3 | 157.7 |
| Errors | -1.4 | -0.61 | 1 | 2.6 | 3.4 |
| Proficiency | 77.9 | 81.79 | 90 | 97.4 | 101.3 |

---

MODULE: LTS Ring Manipulation D - Attempt 4

---

Proficiency =
103.0973
- 0.4425 Time

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Time | 2.63 | 8.06 | 18.9 | 29.8 | 35.2 |
| Errors | -0.13 | 0.41 | 1.5 | 2.6 | 3.1 |
| Proficiency | 87.52 | 89.92 | 94.7 | 99.5 | 101.9 |

---

MODULE: LTS Ring Manipulation ND - Attempt 4

---

Proficiency =
100.4142
- 0.1381 Time
- 11.282 Errors

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Time | -21.700 | -6.22 | 24.8 | 55.7 | 71.2 |
| Errors | 0.057 | 0.59 | 1.7 | 2.7 | 3.3 |
| Proficiency | 57.515 | 64.41 | 78.2 | 92.0 | 98.9 |

---

MODULE: LTS Knot Integrity - Attempt 4

---

Proficiency =
106.8519
- 0.1852 Time

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Time | 52 | 69 | 102 | 135 | 151 |
| Proficiency | 79 | 82 | 88 | 94 | 97 |

---

MODULE: LTS Circle Cutting - Attempt 4

---

Proficiency =
116.7375
- 0.172 Time
- 1.1435 Errors

Means +/- various numbers of SDs for each variable

| | -1.5 | -1 | 0 | 1 | 1.5 |
|---|---|---|---|---|---|
| Time | 94.3 | 118.8 | 167.9 | 217.0 | 241.5 |
| Errors | -1.3 | 0.2 | 3.3 | 6.3 | 7.8 |
| Proficiency | 72.2 | 76.2 | 84.1 | 92.1 | 96.1 |