misplacement of the needle in the tissue, driving the needle more than once from one point of the incision to the other. The No Skills group had an average of 5.8 and 6.5 errors. The Limited Skills group had an average of 4.6 and 5.6 errors. The Advanced Skills group had an average of 2.8 and 1.9 errors. The Expert Skills group had an average of 0.6 and 0.4 errors.


Figure 14 Number of errors in completion of the tasks in two trials for all four skills groups.

The Expert Skills group demonstrated very few errors, a statistically significant difference compared to the other groups. Surprisingly, the No Skills and Limited Skills groups' performances suffered on the second trial, yielding more errors than their first attempt. The Advanced Skills group demonstrated learning as they improved from trial 1 to trial 2.

## Discussion

Motion analysis of the hand was performed for four basic surgical skills. Improvement was documented with repetitions of the tasks. Performances of the participants at each level of training were evaluated to determine whether level of training correlated with skill proficiency. Other researchers have performed motion analysis in orthopaedic surgery. Woodrow et al. described a system for measuring wrist movements during spine surgery through electromagnetic trackers and a force plate [18]. That system measures wrist motion, mean forces, peak forces, and task time. For surgeons cannulating a complete set of lumbar pedicles on a synthetic model, a statistically significant difference was seen between experts and novices. A similar study performed by Tashiro et al. analyzed tool motion and force during a simulated arthroscopic procedure [11]. Leong et al. quantified orthopedic skills using experts to subjectively rate performance on video recordings of participants performing tasks on synthetic bone models [19]. Subjective ratings by experts are difficult to assimilate into automated objective quantification systems.

All these studies use tool movements and force profiles as the means of assessing competency of the performer in simulation environments. None of the studies measured hand movement and posture during the task. This is a major limitation of these studies as operator movement and posture are important components of basic motor skills. An algorithm that is based on assessing tool motion and tool forces can objectively analyze proficiency of skills such as drilling; however, it only has limited feedback capacity. Without assessment of hand movements and posture, the determinants of drilling angle and applied force, the feedback will not be as informative to the user. For instance the feedback will describe the incorrect orientation of the tool and which direction/angle it needs to be corrected to for the user to improve the outcome. However, this will not provide the user with precise instructions on how to move their fingers, palm, wrist, or shoulders in order to achieve the desired outcome. Measuring hand movements will allow detailed analysis and feedback, providing corrections for hand, wrist, and shoulder posture and the movements of each to create the desired gestures. Our system is capable of quantifying hand movement and posture in addition to the parameters associated with tool movements which can be estimated by the hand movement profiles.

We capture hand movement data using Immersion CyberGloves®. CyberGloves® have been used to precisely record finger, hand, and forearm position and movement in technical activities ranging from hand gesture computing for the hearing and speech impaired to monitoring and evaluation of virtual bone cement injection [21,22]. Using these gloves, kinematic features of surgeons' hand movements can be analyzed to demonstrate motor proficiency. Previous studies using CyberGloves® gesture recognition have indicated that gesture based analysis of surgical movements may be suitable for analysis of proficiency in general surgery tasks [23]. Gestures are the basic building blocks of tasks. In laparoscopic surgery for example, clockwise rotation and grasping are gesture components of laparoscopic tasks. Complex laparoscopic procedures are segmented into atomic gestures which are then analyzed to reveal proficiency. The overall score in a procedure is the sum of scores for performance of individual gestures and the order in which the gestures are performed. This is a useful method of analysis and is commonly known as task decomposition, as used in OSATS. The advantage is that automatic gesture based analysis of surgical movement including segmenting complex movements into simpler movements can be performed by a computer, eliminating human bias and error.

The participant groups in our study were distinct based on experience in that the No Skills group was neither familiar with the system (Cybergloves, instruments, and individual bone/synthetic skin) nor possessed the task specific motor skills. The Limited Skills group lacked familiarity with the system, yet was familiar with the specific bone site/suturing tools and the task specific motor skills. The Advanced Skills group in Study 2 lacked familiarity with the CyberGloves, yet was familiar with the instruments, suturing material, and possessed the task specific motor skills. The Experts Skills group was fully familiar with the instruments and femoral cortical bone/suturing material, in general, but was not familiar with the CyberGloves® system or the individual bone/synthetic skin they were about to use.

The Expert Skills group had the ability to rapidly adapt the familiar tasks to the experimental bone drilling environment and suturing environment; however, they were more cautious than other groups. Since the experts are already at a very high level of proficiency, one might expect that their group displays the least improvement across the repetitions of the tasks. However, the data demonstrates that the Expert Skills groups improved their speed (as they became less cautious with repetition) and decreased the number of errors made as they adapted to the setup of the system. The setup was different than their typical OR, they were not in the surgical gowns and gloves that they are used to, nor did they have any assistance with tools (such as a scrub tech to hold on to tools not in use) and had to find places for their tools in between uses. Because of these circumstances, it is understandable that they are able to improve more than the other groups as their potential for accuracy and proficiency is much greater than the other groups.

Immersion CyberGloves® can capture objective, quantitative, and continuous performance data from participants performing fundamental orthopaedic tasks as well as gynecologic tasks. The data acquired in these studies was able to objectively distinguish between the skill levels of the participant groups.

Improved performance was detected with increasing task repetitions in all participant groups in Study 1. The Limited Skills group improved the most. This is expected as they begin with a lower baseline score. However, in Study 2, no single group demonstrated superior improvement when assessed across the four metrics. The proportion of system 'familiarization' to motor skills 'learning' was not quantified. Multi-step procedures with decision making were not part of this investigation. Incorporating these considerations into the analysis algorithm will be a component of future work.

When examining the use of time or task duration as an assessment criterion, it is evident that it is weaker in its ability to differentiate between the skill levels. The average time to complete the tasks amongst all groups in the two studies was relatively similar, except for the No Skills group in Study 2. Thus, because this cannot reliably and consistently separate out different skill levels of participants, it has poor construct validity and cannot be used as a stand-alone criterion. It may be possible to develop a system in which the number of errors and the task duration are both utilized in a combined rating system to improve the construct validity.

This gesture proficiency system measures a participant's performance against a theoretical ideal. The main advantage of working with an ideal gesture as the target reference is that the need

# Objective Methodology to Quantify Motor Skills in Basic Orthopaedic and Gynecologic Surgical Tasks

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## Introduction

- Skill level of surgeons is an important metric to capture in a training environment.
  - To date, teaching of skills has been subjective.
- Objective outcome measures in surgery are identified in the literature, and are effective in differentiating levels of expertise in surgical tasks.
  - An experienced surgeon demonstrates expertise through sophisticated motor skills, which are refined, smooth, and very efficient.
  - Comparatively, a novice's performance appears awkward and highly inefficient.
- Fine level detailed analysis in surgical procedures reveals important mechanisms involved in surgical learning.
- There is a need to develop a cross-compatible evaluation system that can be employed with many simulators, skills, and even in the OR.

Hypothesis

Surgical skill levels of individuals with various years of training can be differentiated using data gloves (Immersion CyberGloves ®).

## Materials & Methods

Study 1 – Orthopaedic Drilling

IRB approval through Banner Health and informed consent from all participants. 16 Participants were recruited based on experience:

- No Skills - 6 medical students that had never used a drill
- Limited Skills – 4 junior orthopaedic residents with 6 months – 1 year of exposure
- Expert Skills – 6 practicing orthopaedic surgeons with extensive use of these skills

*Figure 1: Setup orthopaedic drilling*

Task:

Drill a 3.2 mm hole in cadaveric femur, tap threads into the hole using a tap on a T-handle, and insert a 4.5 mm cortical screw into the hole until the head was tight against the near cortex. Repeat 10 times. Real time wrist, hand and finger position was recorded using Immersion CyberGloves® and the Ascension Liberty Tracker®.

Study 2 – Gynecologic Suturing

IRB approval through Banner Health and informed consent from all participants. 20 participants enrolled:

- No Skills – 5 First year residents with minimal to no practice of their suturing skills
- Limited Skills – 5 Second year residents with limited practice of their suturing skills
- Advanced Skills – 5 Upper level residents with ample suturing practice
- Expert Skills – 5 Practicing obstetrician gynecologists with extensive use of suturing as a routine part of their practice

*Figure 2: Layout Study 2 suturing.*

Task:

Place five continuous running sutures across each of the five 10 cm incisions in an artificial silicone skin. Repeat five times. Real time wrist, hand and finger position was recorded bilaterally using Immersion CyberGloves® and the Ascension Liberty Tracker®.

## Discussion

Published studies discuss the use of tool movements and force profiles as the means of assessing competency of the performer in simulation environments. None of the studies measured hand movement and posture during the task, important components of basic motor skills. Measuring hand movements allows detailed analysis and feedback. Our system is capable of quantifying hand movement and posture in addition to the parameters associated with tool movements.

Immersion CyberGloves® can capture objective, quantitative, continuous, performance data from participants performing fundamental orthopaedic tasks such as drilling a hole, tapping threads in a hole, and inserting a screw into the tapped hole; as well as gynecologic tasks like placing the needle in the needle driver, driving the needle into the appropriate layer of tissue repeatedly to bring the edges of the wound together. The data acquired in these studies was able to objectively distinguish between the skill levels of the participant groups.

## Results – Study 1

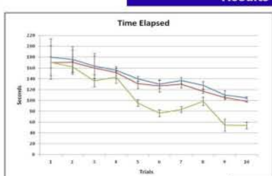


*Figure 3. Time elapsed for trials 1 – 10 for each skills group.*

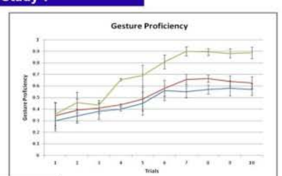


*Figure 4. Gesture Proficiency for trials 1 – 10 for each skills group.*

No Skills
Limited Skills
Expert Skills

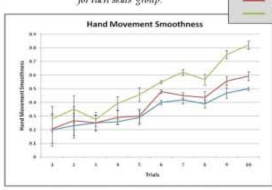


*Figure 5. Hand Movement Smoothness for trials 1 – 10 for each skills group.*

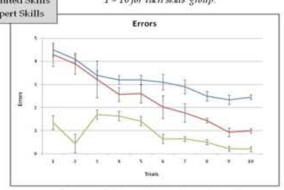


*Figure 6. Number of Errors for trials 1 – 10 for each skills group.*

## Results – Study 2


*Figure 7. Time elapsed to complete the tasks in each trail for the four skills groups.*

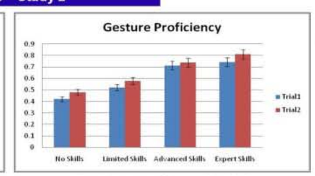


*Figure 8. Gesture Proficiency achieved by the four skills groups in two trials.*

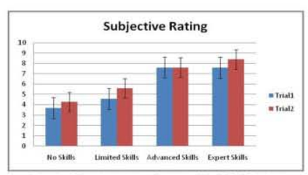


*Figure 9. Subjective rating, as determined by skilled physicians based on video footage, of participants' performance in all four skills groups in two trials.*

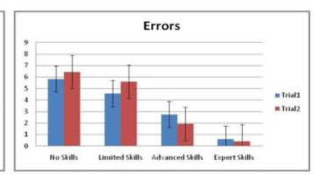


*Figure 10. Number of Errors in completion of the tasks two trails for all four skills groups.*

## Conclusion

In conclusion, hand movement data can be acquired for basic surgical skills required to perform tasks such as suturing, drilling a hole, taping threads in a hole and insertion of a screw. That data can be used to identify motor skills levels and learning across skill levels.

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