Arthroscopic simulation using a knee model can be used to train speed and gaze strategies in knee arthroscopy.

Vincent VG An[1]

Yusuf Mirza[2]

Evangelos Mazomenos[3]

Francisco Vasconcelos[3]

Danail Stoyanov[3]

Sam Oussedik[2]

1. School of Medicine, University of Sydney, Camperdown NSW 2050, Australia

2. Department of Orthopaedics, University College London Hospitals, London, United Kingdom.

3. Department of Computer Science, University College London, London, United Kingdom.

Correspondence to: Vincent VG An, 93 Arthur St, Strathfield NSW 2135, Australia.

Tel. +61 405 648 186

Emails:

Vincent VG An – vian2424@uni.sydney.edu.au; Yusuf Mirza - mirzyusuf@gmail.com; Evangelos Mazomenos - e.mazomenos@ucl.ac.uk; Francisco Vasconcelos - f.vasconcelos@ucl.ac.uk; Danail Stoyanov - danail.stoyanov@touchsurgery.com; Sam Oussedik - sam.oussedik@gmail.com.

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Author Contributions

VA – Manuscript drafting and editing; data collection and analysis. YM – Manuscript drafting and editing; data collection. EM – Manuscript drafting and editing; data collection and analysis. FV – Manuscript editing; data collection and analysis.
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Abstract

Purpose

This study aimed to determine the effect of a simulation course on the gaze fixation strategies of participants in arthroscopy.

Methods

Participants (n = 16) were recruited from two one-day simulation-based knee arthroscopy courses, and were asked to undergo a task before and after the course which involved identifying a series of arthroscopic landmarks. The gaze fixation of the participants was recorded with a wearable eye-tracking system. The time taken to complete the task and proportion of time participants spent with their gaze fixated on the arthroscopic stack, the knee model and away from the stack or knee model was recorded.

Results

Participants demonstrated a statistically decreased completion time in their second attempts compared to the first ($p = 0.001$). Participants in their second attempt also demonstrated improved gaze fixation strategies, with a significantly increased amount ($p = 0.008$) and proportion of time ($p = 0.003$) spent fixated on the screen vs. knee model.

Conclusion

Simulation improves arthroscopic skills in orthopaedic surgeons, specifically by improving their gaze control strategies as well as decreasing the amount of time taken to identify and mark landmarks in an arthroscopic task.

Level of Evidence: IV, Non-controlled prospective study.

Keywords: Simulation Training, Surgical Education, Arthroscopy.

Introduction

The European Working Time Directive (EWTD) was implemented in 2009 with the aim of protecting the safety of both patients and practitioners by limiting the amount of working hours. The directive has been met with considerable criticism particularly from the Royal College of Surgeons who expressed concerns that the reduction in hours would compromise the quality of surgical training[1].

To counter this, simulation has been proposed as a potential tool to account for the hour reduction in surgical exposure. Simulation offers a safe environment in which trainees are able to hone their skills whilst also avoiding the potential compromise in patient outcomes that accompanies lack of experience and has demonstrated considerable efficacy in the aviation and the military settings. Simulators have also demonstrated efficacy in medicine, with Cochrane reviews demonstrating an improvement in proficiency of inexperienced operators for laparoscopy[2], endoscopy[3], and some improvement in knowledge and proficiency acquisition in ear, nose and throat surgery[4]. Simulation could also serve to offload the current model of surgical training and performance evaluation, revolving around expert supervision, evaluation of procedural logs as well as written and oral exams. Surgical simulators can be also used in combination with various sensing modalities (hand tracking, tool tracking, eye tracking, etc.), which is not possible during actual cases. These could provide a plethora of information about the user-surgeon that is representative of performance and skill level. Ultimately, many heterogeneous datasets can lead to the development of efficient and fully objective skill assessment and performance evaluation methods for minimally invasive operations including arthroscopy.

Arthroscopy is a minimally invasive procedure in which a camera and probe are used to examine and manipulate structures in joints. It combines dexterity with proprioception and hand-eye co-ordination. Specific to arthroscopy, simulators have been shown to effectively improve surgical performance, with trainees demonstrating decreased task time[5], accuracy[6], and subjective competency in the live operating theatre setting[7, 8].

Simulation provides an arena in which the concept of "deliberate practice" can be pursued. Deliberate practice is defined as the engagement of a structured activity, with the aim of improving performance. Feedback can be given on the trainee surgeon's performance. The surgeon can also repeat challenging aspects of the surgery, whilst retrospective video analysis can also provide a further insight into performance aspects which can be improved [9]. The use of a simulator encouraging deliberate practice has demonstrated medical student performance of a coronary anastomosis to be equivalent to that of senior trainees [10].

The mechanism of this improvement remains unclear, and is important to elucidate in order to guide teaching towards developing good surgical habits. Previous papers have shown that in image-guided, minimally invasive surgery such as arthroscopy or laparoscopy, surgeons' gaze patterns change with experience level: relatively inexperienced surgeons are expected to focus swift their focus away from the imaging modality, alternating between their hands and the screen[11, 12]. The concept of gaze control has previously been validated in the domain of arthroscopy[13], but it remains unclear as to whether the simulation in fact improves visual control strategies.

Therefore, the aim of the study was to establish whether an arthroscopic simulation course has a positive effect on the manual dexterity of orthopaedic surgeons. To evaluate this we evaluated operational performance parameters, namely percentage of focus fixation on the arthroscopy screen and time taken to perform the task as an indication of the performance of participants during the simulation course. We hypothesized that trainees would improve their gaze fixation strategies after the completion of an arthroscopic simulation course, proportionally fixating more on the screen.

Materials and Methods

Participants

Participants were recruited from 2, one-day knee arthroscopy courses. The content of the course was directed towards participants at an early stage of orthopaedic training. Participants included those at the onset of surgical training to those in the early stages of advanced surgical training. The format of the course involved lectures on knee arthroscopy and common knee arthroscopy problems interspersed with simulation-based arthroscopic tasks. The age, sex and number of months spent in orthopaedics of participants were recorded. Additionally the participants were asked to designate how many diagnostic arthroscopies each had undertaken.

The study was prefaced by a short presentation inviting the recruits to participate. After obtaining informed consent, each participant received instruction about the sequence of arthroscopic landmarks to highlight.

Equipment

The model of the knee consisted of skin made of plastic encasing a saw bone model of the knee joint. Anatomical structures including the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial and lateral menisci were incorporated within the knee. The arthroscopic equipment used was a Stryker arthroscopic stack (Kalamazoo, Michigan), similar to that used in the operating theatre environment. Two tools, an arthroscope and a probe, were used. The experimental set-up is illustrated in Figure 1.

Eye/gaze tracking

The gaze fixation of the participants was recorded with the Tobii Pro Glasses 2 (Tobii AB, Danderyd, Sweden) wearable eye-tracking system. It consists of a lightweight pair of spectacles with protective lenses equipped with various sensors and a dedicated processing unit that executes image processing algorithms to recover the wearer's eye positions and gaze focus point. A high definition camera (1080p, 25 fps) positioned in the front of the spectacles recorded the viewing scene of the user. The Tobii Pro Glasses 2 system employs an established eye/gaze tracking technique known as pupil centre – corneal reflection (PCCR).Each eye is illuminated with non-collimated infrared (IR) light while miniature cameras, positioned in the back of the spectacles, capture images of the eyes every 20ms (50Hz). IR illumination creates easily identifiable reflections in the cornea (glint) and the pupil of the eye. The reflections can be easily localized, in the captured images, allowing for the vector between the centre of the pupil and the cornea reflection to be extracted. This vector is then used with parameterised 3D physiological models of the eye to calculate the position of the eyes, the gaze direction and the fixation point in the viewing scene (captured by the front camera). Prior to the beginning of a recording, a calibration process takes place to adjust the parameters of the 3D models to the individual user. The protective lenses are detachable and prescription lenses are available in case the user suffers from an eye condition. At the end of each recording, video data of the viewing scene with the fixation points overlaid are recorded for further study. Figure 2 shows the Tobii eye-tracking system used in our study.

Simulation Evaluation Tasks

Prior to recruitment, candidates became acquainted with the arthroscopy stack as well as the sequence of the evaluation. The evaluation test sequence was based on the Orthopaedic Competence Assessment Project arthroscopy based assessment, previously described by Howells et. al[7]. The sequence of the protocol is detailed below in table 1. Two evaluations were carried out, the former at the beginning of the course and latterly toward the end of the day. Each participant wore the Tobii eye-tracker spectacles to record the movements of the eye and were manually timed using a stopwatch. The overall time to completion as well as the time for each individual landmark was recorded. Each participant performed two executions of the arthroscopy protocol. The first one was at the initial stages of the course, after they have gained familiarity with the operation of the arthroscopy stack. The second one took place at the conclusion of the course after the completion of lectures and after having performed another two similar procedures without the eye-tracking or timing.

Gaze focus analysis

Gaze fixation was determined by examining video recordings, with the gaze focus circular track overlaid, captured by the Tobii eye-tracking system. Standard playback software was used. Videos were annotated on a frame-by–frame basis and gaze fixation was classified in one of the categories of interest based on the location of the focus track, through visual assessment. Four categories of gaze fixation were considered for our experiments:

- Arthroscopy screen: defined as when any part of the gaze tracker was located within the Stryker stack monitor (Figure 3)
- Knee model: defined as when any part gaze track was fixed on the knee model (Figure 4)
- Other/Distractor: defined as when gaze deviated from the screen or knee model and was located anywhere else in the surrounding space
- No gaze focus: occasionally the eye-tracking algorithm was not able to produce an estimation of the gaze orientation and location, in which case the frame was discarded

The proportion of frames spent with the gaze fixated in each category is quantified as a ratio over the total number of frames. Given that arthroscopy is an image-guided operation, we designated the arthroscopy screen as the most important of the three gaze fixation categories for the procedure. Subsequently, we hypothesized that better technical dexterity, understanding and confidence would result in improved coordination and, in turn, performance. Thus, a superior practitioners gaze would mostly remain fixated on the arthroscopy stack's screen while performing the experiment. Statistical analysis of recorded parameters (completion time, fixation percentage) took place with the Wilcoxon sign rank test to investigated the differences among the same population between the first and second executions. Differences are deemed significant for p-value < 0.05. Statistical analysis was performed in MATLAB (Mathworks, MA, USA).

Results

Participants

Sixteen participants (male, 14; female, 2) were recruited and performed the diagnostic arthroscopy protocol twice. There was an average of 26.1 months of orthopaedic experience amongst the participants with an average of 10 arthroscopies performed. Figure5 and Figure 6illustrate the completion times, per landmark and for each participant, for the first and second execution respectively.

Time to Completion

In the first execution (see Figure 4a), the task that took the longest overall was identifying the patella (43.6s), while identifying the lateral meniscus (6.3s) was the fastest. In the second execution (see Figure 4b), the medial tibia plateau took longer time to identify (24.6s) and probing of the medial meniscus surface was the fastest (5.5s). Figure 5a shows the differences in completion times between the two attempts. Fourteen participants completed the second execution faster than the first one with an average reduction of 125.2s and only two exhibited a higher completion time in the second attempt.

Gaze Fixation: what were participants looking at?

From the eye-tracking recordings, the arthroscopy screen fixation percentage, the amount of frames the gaze focus was fixated on the arthroscopy screen over the overall number of frames, was extracted. From Figure 5b, we observe that the proportion of time fixated on the screen increased in the second execution in 13 participants by an average of 8.07%. Only one participant (Participant number 6) demonstrated a decreased fixation percentage (by 14.9%) in the second attempt, while the remaining two (Participant numbers 12 and 16) had similar percentages in both executions. The ratio of fixation percentage / time to completion was calculated to provide a better indication on the fixation focus as it is normalized over time. Figure 6 illustrates the ratio for both executions and we note the significant increase in the second attempt, which should be attributed to both faster execution and a higher fixation on the arthroscopy screen.

Median values and p-values are listed in Table 2 and for all three parameters significant differences are observed between the first and second execution.

Discussion

The practice of orthopaedic surgery has changed. There is an emphasis on the delivery of care by senior surgeons, with high quality and easily reproducible outcomes for patients. The reduction in training time in the face of the EWTD has further compounded this issue, leaving concerns regarding as to how trainees will acquire surgical skills. Advancements in simulation and minimally invasive surgeries such as arthroscopy have led to the development of high-fidelity systems able to reproduce the surgical environment, leading to the proposal of simulation as an alternative to in-hours training. It is proposed that a proficient arthroscopist would complete tasks faster, whilst spending less time focusing their gaze on their instruments. This paper assessed the efficacy of a simulator in improving arthroscopic proficiency as measured by the proposed screen gaze-fixation percentage and the time to completion in simulation experiments involving standard probing tasks. It was found that immediately after completing a simulation-based arthroscopy course, novice trainees demonstrated a mean improvement in gaze targeting strategy, with less gaze focused on the instrument itself and a lower time overall to complete the task.

Previously, papers investigating simulation in arthroscopy have demonstrated relative efficacy in reducing time to task with good transfer validity to the actual operating theatre setting[8]. This paper builds on the work of Alvand et. al, particularly their described concept of arthroscopic “lookdown” as a validated marker of proficiency in arthroscopy[13], validating whether gaze strategies can indeed be trained with simulation.

Gaze focus is well recognised as a marker of proficiency in several tasks requiring significant hand-eye co-ordination spanning across both medical and non-medical domains. It has been shown with laparoscopic surgery that experts will shift their gaze to the product of their manual activity, whilst novices will generally shift their gaze towards the site of manual activity itself as they will require more visual cues due to a reduced proprioceptive competency[11, 12]. Tien et al performed a systematic review of studies utilising eye tracking for the use of skills assessment and skills training in a number of disciplines, including surgery, medicine, nursing as well as aviation and driving, finding that the use of gaze training in skills training demonstrated benefits in terms of time to completion of task and target locking [14].

In this study, the use of an arthroscopy simulator produced a significant improvement in gaze strategy: that is, subjects spent a greater proportion of time fixated on the screen (the product of manual activity) as opposed to the knee model (the actual site of manual activity itself). The concept of gaze focus could also be applied to future simulation courses. Specifically, these courses could focus on gaze modification training, where subjects are taught to mimic the gaze patterns of expert arthroscopists. Gaze training has been demonstrated to confer enhanced improvement in overall skill and multitasking ability compared to traditional motor-based training in laparoscopy [15]. Gaze training has also been shown to enhance the learning of procedural manual skills under pressure compared to traditional motor learning in sports [16, 17]. Theoretically, this would expedite the transfer of simulation-acquired skills to the high-pressure live surgical environment. Simulation offers a valuable tool via which gaze focus training could be safely undertaken, practiced and refined without compromising patient outcomes.

Others refute the benefits of gaze focus. Plujims et al conducted a study to validate the use of sports cameras, to establish the gaze focus in sailing and determine whether the gaze focus is related to an improvement in performance in upwind sailing. The conclusions did not demonstrate that gaze focus predicts a better performance [18].

However, the measure of a junior surgeon lies beyond operative proficiency. Clinical decision making, clinical skills and overall knowledge are key components of the surgeon's acumen, and are acquired via a combination of formal teaching as well as unstructured, unconscious learning attained simply by spending time in the clinical setting. Simulation may have a role giving trainees an opportunity to repeat procedures, practice difficult parts of an operation and gain familiarity with equipment and instrument handling. Additionally, the simulation takes place with the use of a high fidelity model and in a safe environment, which can provide structured feedback.

Thus the use of simulation outside of working hours can supplement the acquisition of surgical skills in the face of limited working hours, with a focus towards these more abstract and intangible skills[19].

Limitations

Limitations of this study included the lack of a control group to compare the effect of the simulator on gaze focus strategies. However, the application of the simulation course reliably improved gaze control in test subjects. Future studies should employ a control group to elucidate the true effect size of using simulation. Whilst gaze control is a novel outcome investigated in this study, it remains unclear as to how this improvement translates to actual clinical practice and thus surgical outcomes. Future studies should investigate the effect of simulation and gaze control strategies on operating room performance to determine if there is transfer validity to this concept.

Conclusion

Simulation improves arthroscopic skills in orthopaedic surgeons, specifically by improving their gaze control strategies as well as decreasing the amount of time taken to identify and mark landmarks in an arthroscopic task. Simulation could potentially account for decreasing amounts of time in the operating theatre due to shorter working hours, as well as offloading the burden of surgical education on senior clinicians, resulting in improved outcomes for patients. Future studies must investigate the transferability of skills acquired from simulation to the live surgical environment.

Conflicts of Interest

None to declare

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Tables

Table 1. Diagnostic Arthroscopy Protocol

Diagnostic Arthroscopy Protocol
1. Identify trochlea (T)
2. Identify patella –medial (P)
3. Identify medial femoral condyle (MFC)
4.Identify medial tibial plateau (MTP)
5. Identify medial menisci (MM)
6.Identify anterior cruciate ligament (ACL)
7. Identify lateral femoral condyles (LFC)
8. Identify lateral tibial plateau (LTP)
9. Identify lateral meniscus (LM)
10. Probe articular surface of medial femoral condyle (asMFC)
11. Probe articular surface of medial tibial condyle (asMTC)
12. Probe and lift medial meniscal surface (MMs)

Table 2. Median and p-values for the two executions

Feature	First attempt	Second attempt	p-value
Time to completion (sec)	197.5	114.5	0.0013
Arthroscopy screen fixation (%)	86.75	91.75	0.0083
Fixation/Time ratio (% / sec)	0.4513	0.7541	0.0027

Figure Legends

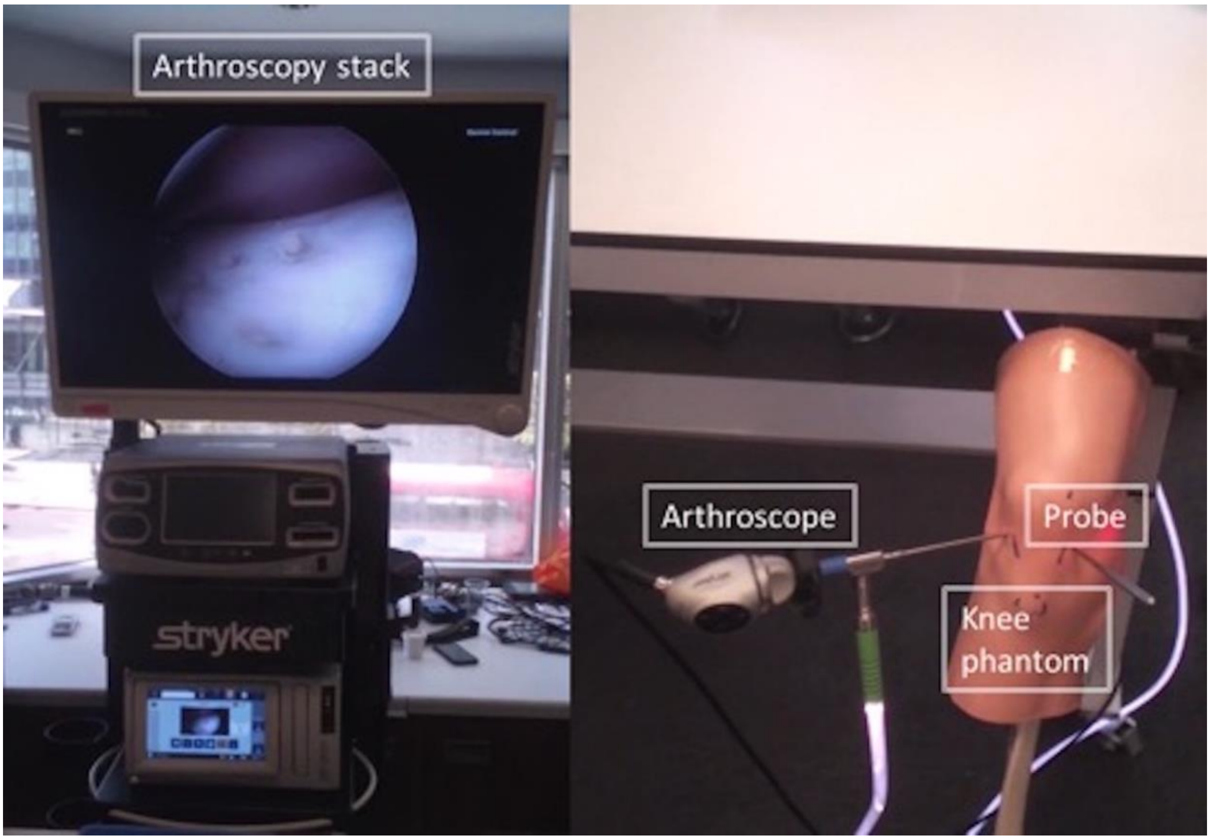

Figure 1. The experimental set-up; (left) - the Stryker arthroscopy stack; (right) - the knee phantom and the tools (arthroscope, probe) used.

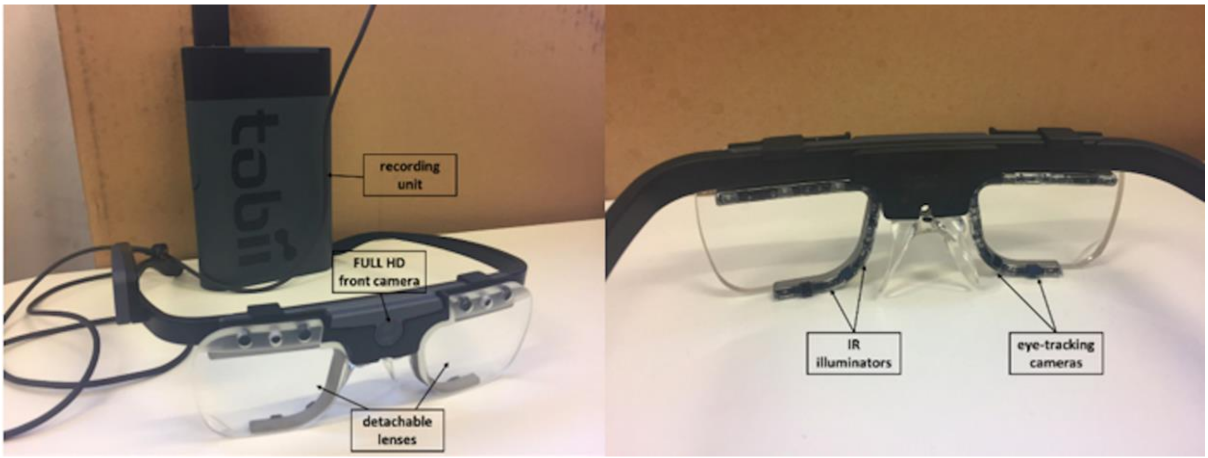

Figure 2. The Tobii eye-tracking system; left – front view showing the scene camera, detachable lenses and recoding unit; right – back view showing the eye-tracking cameras and IR illuminators

Figure 3: a) Example of gaze fixation on the Stryker arthroscopy stack monitor. b) Example of gaze fixation on the knee model itself.

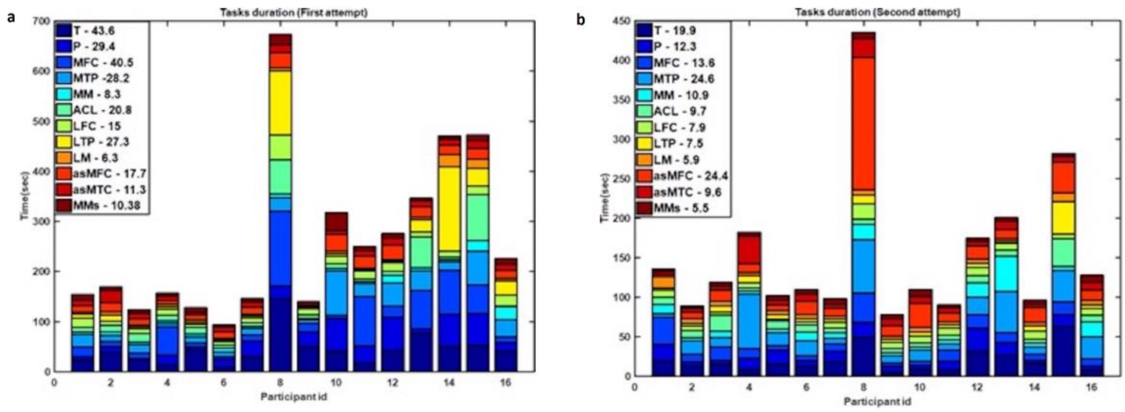

Figure 4: a) Per landmark and overall completion time for the first execution. Average times for each landmark are given in the legend. b) Per landmark and overall completion time for the second execution. Average times for each landmark are given in the legend.

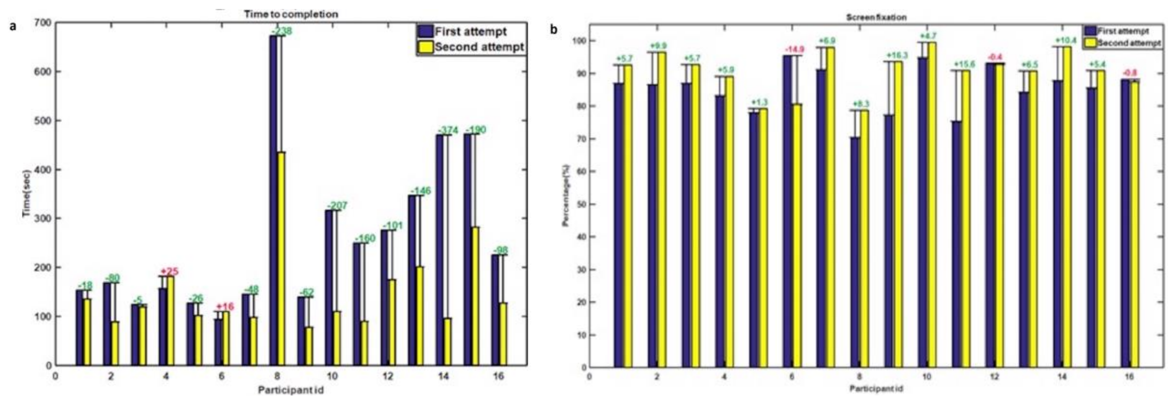

Figure 5: a) Time to completion for first and second attempt with differences. b) Arthroscopy screen fixation percentage for first and second attempts

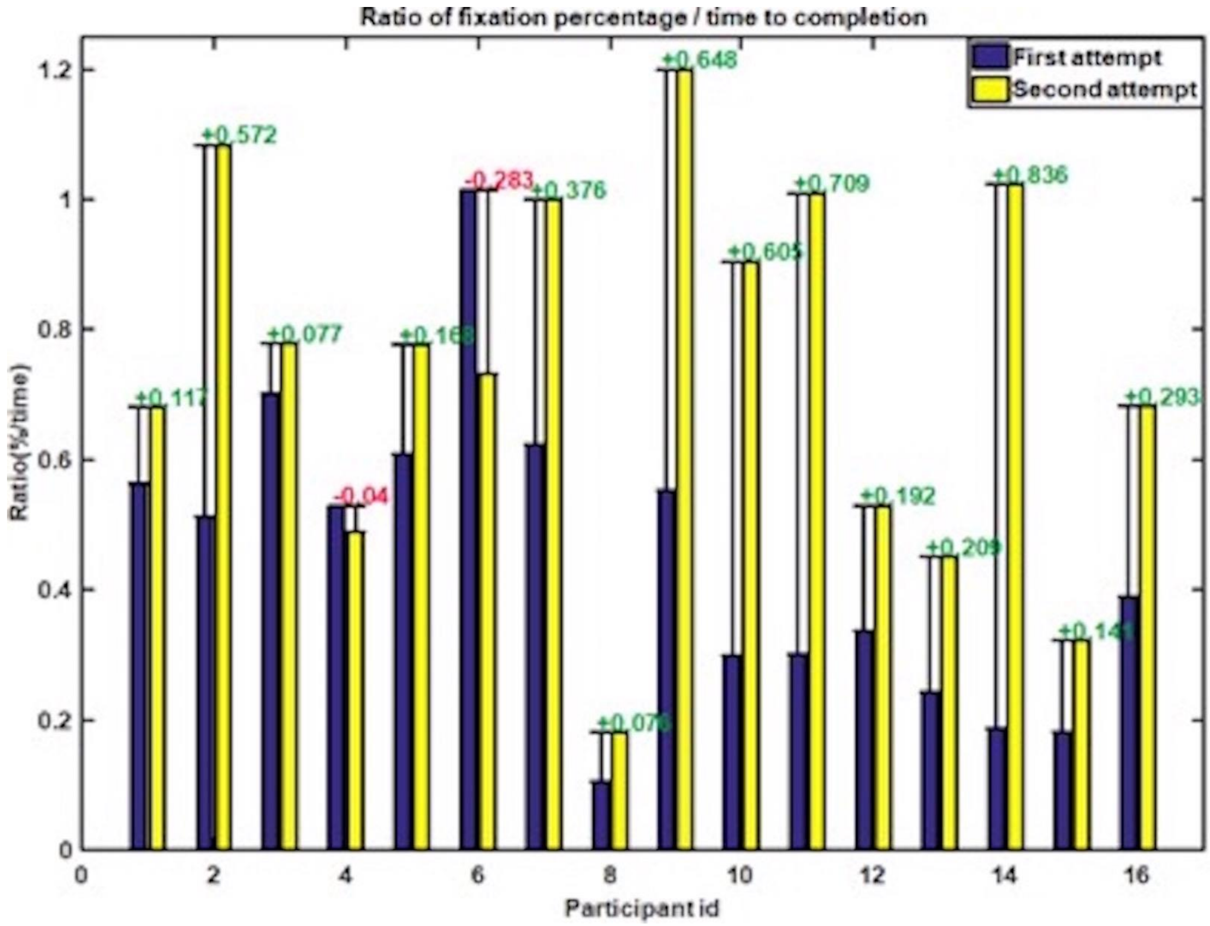

Figure 6: Ratio of fixation percentage over time to completion