Head Motion Analysis as an Objective Measure of Point-of-Care Ultrasound Image Acquisition Competency

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Abstract

Background: *POCUS education and competency milestones are required for emergency medicine residency graduation. Currently, POCUS competency is assessed using OSCEs. This approach is non-standardized, subjective, and resource intensive. In this pilot study we determine the ability of head motion analysis to differentiate between novice-and-expert-level POCUS performance.*

Methods: *Fifteen emergency medicine physicians, eight novice POCUS users and nine experts, performed cardiac and FAST exams. Head motion was tracked using Muse2-headband with accelerometer and gyroscope sensors. Fellowship-trained experts observed all exams and independently recorded OSCE scores.*

Results: *Experts scored higher in OSCEs than novices in both examinations (p<0.00001). Experts demonstrated less head motion distribution in the X,Y and Z-directions, with significant differences (p<0.001) between expert and novice groups.*

Conclusions: *Head-motion metrics can differentiate novice-and expert-level ultrasonographers, which could offer objective competency assessments for new POCUS learners. Additional studies are needed to identify minimum threshold values for defining competency based on these metrics.*

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1. Background

Point-of-care ultrasound (POCUS) is a critical element of emergency medicine residency training, and its competency has been integrated into the milestones required for graduation and board certification. Assessing competency in POCUS is complex and includes evaluating skills in image acquisition, interpretation, and integration of the information gathered into clinical scenarios. Current standards for measuring ultrasound competency vary nationally and internationally. Competency assessments are currently based on objective structured clinical examinations (OSCEs), expert observation, comparison with expert interpretation, and volume of scans performed.[10,11] These methods are not only subjective, which leads to poor interrater reliability, but they are also time- and resource-intensive. As POCUS use disseminates more broadly across specialties beyond emergency medicine and begins playing a role in non-traditional clinical spaces such as in patients' homes, prehospital, battlefields, or even in space expeditions, objective, scalable competency metrics will be key. Additionally, using POCUS for procedural guidance has exponentially increased the use of ultrasound across specialties as it has been shown to reduce complications and improve patient outcomes. Currently, however, given its high user variability and the speed of POCUS adoption, safety needs, such as standardization in training and credentialing, has been identified as one of the highest health technology hazards.[1,3]

Objective procedural competency metrics such as motion and eye tracking, have been explored for assessing surgical skill proficiency. These metrics can discern novice learners from expert surgeons. Similarly, in ultrasound education, hand motion analysis and gaze tracking have both shown to be correlated with expertise level.[4,5] Here, we assess the metric of head motion tracking to differentiate between levels of competency in POCUS image acquisition. We hypothesize that novice users will demonstrate a greater degree of head motion while performing POCUS compared to experts, and that these differences will correlate with OSCE-based scores in differentiating between levels of expertise.

2. Methods

Study Design and Setting

This was a prospective, observational study conducted at a simulation center at an academic tertiary medical center. The medical center supports a 4-year emergency medicine (EM) residency program with fifteen trainees per year and sees an ED volume of roughly 65,000 patients annually. This work was approved by the local institutional review board.

Participants

Participants were recruited via email advertisement to the local EM residency intern class, as well as to faculty, fellows, and advanced practice providers (APPs) of the local emergency ultrasound fellowship program. All members of these groups were eligible to participate. Novice participants were defined as intern-level trainees with no prior formal experience in performing POCUS. Expert-level participants were defined as fellows or faculty who had completed at least a portion of emergency ultrasound advanced fellowship training, or APPs who had been practicing with the emergency ultrasound faculty for at least three years. After consenting to participate, participants completed recruitment surveys confirming their eligibility to participate and prior POCUS training to identify their level of expertise. Participants who did not meet criteria of either a novice- or expert-level sonographer as described above were excluded from the study.

POCUS Image Acquisition Tasks

Participants were asked to complete two POCUS examinations including a focused assessment with sonography for trauma (FAST); including the right-upper quadrant view, the left-upper quadrant view, the pelvic view [Figure 1], as well as a cardiac examination, which included parasternal long and short axis views, apical four chamber view, and the subxiphoid view [Figure 2]. Participants were positioned in a standardized position along the right side of the model patient with the ultrasound machine positioned in a standardized location in front of participants [Figure 3]. All participants scanned with the POCUS probe in their right hand. Participants had a total of ten minutes to complete both studies on a standardized patient.

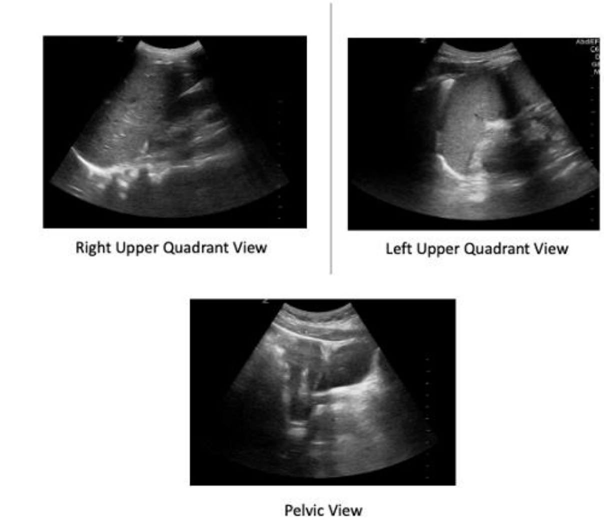

Figure 1. Focused Assessment with Sonography for Trauma (FAST)

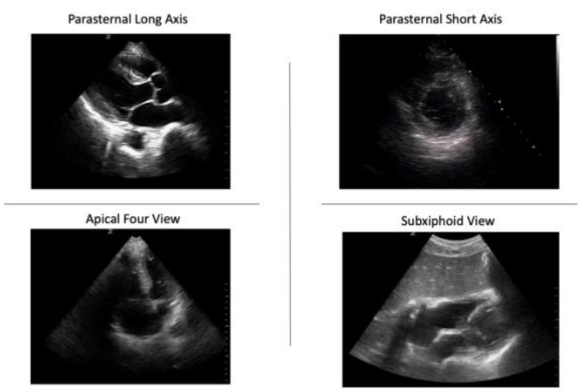

Figure 2. Cardiac POCUS Examination

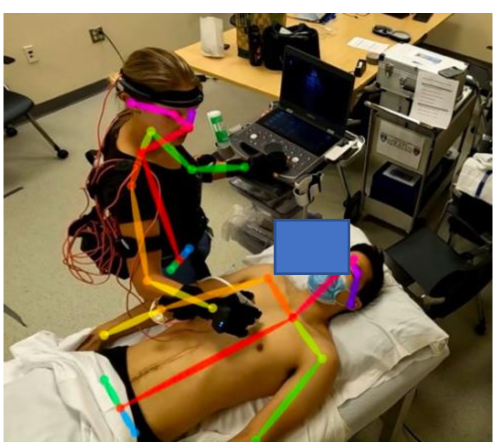

Figure 3. Standardized positioning of participant and model

Head Motion Tracking

For this study, we utilized head motion data (x, y, z) collected by the MUSE2 headband (Figure 4) and the Rokoko motion capture system. The Rokoko system is a wearable technology that incorporates Inertial Measurement Unit (IMU) sensors to track joint movement and motion data. To adhere to COVID-19 guidelines and ensure participant safety, we employed a modified approach. Instead of using the full Rokoko suit, we removed the sensors and cables, affixing them to the participants' bodies with straps. Calibration was performed to ensure accurate tracking of joint movement. During the data collection process, participants performed standardized POCUS tasks while their head motion data was recorded by the Rokoko system.

Figure 4. MUSE2 headband

OSCE evaluation

Two independent POCUS expert reviewers observed each participant complete the POCUS tasks and independently scored each exam using a standardized OSCE checklist. The checklist included observing the participant positioning the patient, selecting the appropriate probe and orientation, obtaining the correct views, and adjusting ultrasound parameters for optimal image quality per ACEP guidelines. Each view was scored from 0-100 with 0 being unable to obtain a view, 50 being partial view obtained, and 100 being correct view obtained. A percentage of the points earned out of the total points possible was assigned as the OSCE score for each examination. Overall OSCE scores for each participant was calculated by averaging the scores from the two expert reviewers for each examination.

Data Analysis

Descriptive statistics were used to summarize participant demographics. For the head motion data (x, y, and z dimensions), which were not normally distributed, median values along with the first and third quartiles were employed. The Mann-Whitney U test, were utilized for group comparisons. The significance level was set at $p < 0.05$. Group comparison statistics are reported as mean +/- standard deviation (SD) unless otherwise noted.

3. Results

Participant Demographics

In total, eight novices and nine experts were recruited. Novices had an average age (+/- SD) of 26.8 +/- 1.6 years, 100% were right-hand dominant, and 88% completed a POCUS clinical rotation in medical school as their highest level of POCUS training prior to the study. Experts were 38.9 +/- 9.9 years old, 77.8% were right-hand dominant, and 77.8% had completed some or all of an emergency POCUS fellowship as their highest level of POCUS training. Novices reported completing an average of 14.2 +/- 11.3 echocardiogram studies and 14.9 +/- 10.1 FAST studies prior to participation. Experts reported performing an average of 1255.6 +/- 1341.7 echocardiogram studies and 1122.2 +/- 1124.5 FAST studies prior to participation.

OSCE scores

Novice participants earned overall OSCE scores of 66.19 (+/- 19.68). In comparison, expert participants earned overall OSCE scores of 98.39 (+/- 3.37, $p < 0.00001$). When broken down into individual exams, for FAST exams novice vs expert users earned OSCE scores of 68.93 (+/- 21.47) and 99.11 (+/-2.22), respectively ($p < 0.00001$). For cardiac exams, novice vs expert users earned OSCE scores of 63.43 (+/- 17.99) and 97.66 (+/- 4.17), respectively ($p < 0.00001$).

Head motion

The Mann-Whitney U test revealed significant differences ($p < 0.001$) between the senior and junior groups in both the X, Y, and Z positions of their heads. For the X position, the median was -0.060 (-0.198, 0.071) for juniors and 0.028 (-0.175, 0.110) for seniors. In terms of the Y position, the median was 1.727 m (1.678, 1.737) for juniors and 1.712 m (1.651, 1.729) for seniors. For the Z position, juniors had a median of 0.001 m (-0.078, 0.083), while seniors had a median of 0.192 (-0.017, 0.304). These findings indicate significant differences in head positions between the two groups in all three dimensions. The observed p-value of $p < 0.001$ suggests a highly significant statistical difference. [Figure 5]

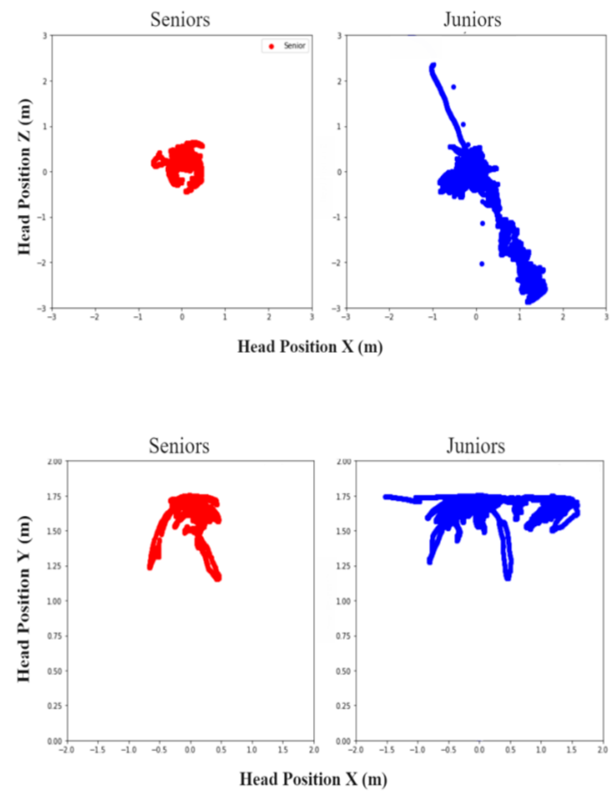

Figure 5. Head positions between the senior and novice groups in all three dimensions

4. Discussion

Prior research in assessment of objective competency measures in the surgical literature has been shown to be translatable to ultrasound education. As POCUS expands across specialties within medicine, both nationally and internationally, it will be imperative to achieve a standardized and objective measure of competency, which is affordable and not resource intensive.

Current literature includes both eye and hand motion tracking as previously studied objective measures of competency.[2,4] Lee et al. studied "areas of interest" (AOI), which were used as a metric for eye tracking, with certain areas of the ultrasound image designated more sensitive or specific to clinical findings, in which participants were assessed on fixation over these AOI. In this study, experts demonstrated significantly longer and faster gaze fixation than novices.[8]

Hand motion analysis has been used in the surgical literature to assess metrics such as path length, and number of hand movements taken to complete a procedure. These hand motion metrics have been translated into the ultrasound literature by Ziesmann et al. who utilized the trakSTAR 3D electromagnetic motion-tracking device. This study included the metrics of (1) time of examination, (2) number of movements, and (3) path length. While the time of examination was not shown to be different between novices and experts, the total path length of travel was shorter, and the number of discrete movements was less in the expert cohort when compared to novices.[12]

This pilot study uses the metric of head movement, which has not been used as a tool to assess objective competency previously. Head movement was chosen because it incorporates precision, focus and efficiency. Assessing competency in ultrasound is multivariable and involves image acquisition, interpretation, and integration of that interpretation into the clinical scenario. Additionally, we wanted our metric to be a tool that is commercially available, easy to use, and cost effective.

The Rokoko motion capture system with the MUSE2 headband was used to plot head motion on the X, Y and Z axis. Statistically significant differences were observed between the novice and expert groups with p-values < 0.001. This finding is visualized in Figure 5, and suggests experts are more efficient and focused with their head movements.

When head motion analysis was directly compared to the gold standard traditional OSCE, it illustrated that head motion analysis can be a reliable and resource friendly tool to differentiate between novice and expert users, with the hope that it can be used in conjunction with other objective measures, such as hand motion and gaze tracking to develop objective competency in the next generation of ultrasound users.

Ultimately these findings would allow for a shift from the subjective, and time and resource intensive OSCE, to computer-based metrics in ultrasound education. Currently, assessment of ultrasound skill is performed in a simulation setting, outside of the clinical setting. Standardization of objective competency using metrics such as head motion with the MUSE2 headband would permit assessment of new learners of ultrasound, whether that be medical students, junior residents, or faculty who did not train in the era of POCUS, within the clinical setting. Additionally, computer-based metrics would provide immediate feedback to the learner and allow for progress to be monitored at each level of training.

Future research in this field will be to establish benchmarks in objective competency. Additionally, as procedural ultrasound becomes more prevalent within Emergency Medicine, it will be vital to extend objective competency measures from diagnostic ultrasound to procedural ultrasound. Currently, like diagnostic ultrasound, ED-based procedural competency is assessed via subjective, time-consuming, and non-validated methods such as direct observation and structured clinical examinations. It is hoped that by extending our findings of objective competency measures from diagnostic ultrasound to include ultrasound guided procedures, we will further reduce malpractice risk by defining objective measures for ultrasound guided procedural competency.

Limitations

While our study demonstrates promising results, the number of participants who were enrolled was small, which was sufficient in this pilot study, but in subsequent work we would want to recruit a larger sample size. Additionally, novices were chosen from the incoming intern class, which were the residents with the least experience in emergency POCUS within the residency program at our tertiary academic institution. However, each intern will have had different levels of POCUS exposure with their medical school training, and therefore this would have introduced some bias to our novice group.

5. Conclusions

The objective measure of head motion demonstrated significant differences between novice and expert POCUS users in all metrics. This correlated with differences in OSCE scores, which are the current standard of care in measuring POCUS competency and therefore reliable as a competency tool. Objective competency measures will be the future of medical education and can be translated into both diagnostic and procedural ultrasound. Developing these computer-based objective tools will be vital as POCUS disseminates more broadly across specialties beyond emergency medicine, playing a role in non-traditional clinical spaces such as in patients' homes, prehospital, battlefields, and even in future space expeditions.

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