Analysis of Head Motion as an Objective Measure of Point-of-Care Ultrasound Procedural Guidance Competency

Carrie D Walsh, MD*
Department of Emergency Medicine
Massachusetts General Hospital
Brigham and Women's Hospital
Boston, MA
cdwalsh@bwh.harvard.edu

Rayan Ebnali Harari, PhD*
Research Scientist
Brigham and Women's Hospital
Boston, MA
mebnali-heidari@bwh.harvard.edu

Rebecca E. Cash, PhD
Department of Emergency Medicine
Massachusetts General Hospital
Boston, MA
RCASH@mgh.harvard.edu

David Lee, MD
Department of Internal Medicine
Brigham and Women's Hospital
Boston, MA
DLEE64@bwh.harvard.edu

Paulo Borges, MD PhD
Department of Emergency Medicine
Brigham and Women's Hospital
Boston, MA
pborges1@bwh.harvard.edu

Phillip D Plevek, MD
Department of Emergency Medicine
Jackson Memorial Hospital
University of Miami
Miami, FL
phillip.plevek@jhsmiami.org

Lindsay V. Walsh, MD
Department of Emergency Medicine
Massachusetts General Hospital
Brigham and Women's Hospital
Boston, MA
lvwalsh@mgb.org

Chanel Fischetti, MD
Department of Emergency Medicine
Brigham and Women's Hospital
Boston, MA
cfischetti@bwh.harvard.edu

Lachlan Driver, MD
Department of Emergency Medicine
Massachusetts General Hospital
Brigham and Women's Hospital
Boston, MA
ldriver@mgh.harvard.edu

Andrew J Goldsmith, MD MBA+
Department of Emergency Medicine
Brigham and Women's Hospital
Boston, MA
ajgoldsmith@bwh.harvard.edu

Roger Dias, MD PhD+
Department of Emergency Medicine
Brigham and Women's Hospital
Boston, MA
rdias@bwh.harvard.edu

Nicole M Duggan, MD+
Department of Emergency Medicine
Brigham and Women's Hospital
Boston, MA
nmduggan@bwh.harvard.edu

Abstract

Background:. *Currently, there is no standardization in ED-based-Ultrasound-guided-nerve-blocks (UGNB) training, credentialing, or procedural quality assurance nation-wide. This study aims to investigate objective measures of procedural competency for UGNB.*

Methods: *Novice and expert users performed UGNB in a simulation-based setting. Participants were fitted with a head-motion tracking headband and their performance graded with a traditional OSCE. Head motion metrics were captured using both accelerometer and gyroscope sensors.*

Results: *11 novices and 7 experts were recruited. OSCE scores demonstrated a statistically significant difference between groups. Significant correlations were observed for accelerometer data in the z-axis and gyroscope data in the y-and z-axes, with positive correlation between accelerometer z-axis RMS values and OSCE scores(r=0.36), and gyroscope z-axis RMS values and OSCE scores(r=0.29).*

Conclusion: *Objective measures of head motion in the z-axis demonstrated significant differences between novice and expert POCUS. Our data suggests that computer-based metrics may be reliable measures of procedural competency.*

Keywords: *objective competency, point-of-care-ultrasound, education, head motion, pain management.*

1. Background

Point-of-care-ultrasound (POCUS) is a critical tool in emergency medicine practice and training. Competency in POCUS is required by the Accreditation Council of Graduate Medical Education for graduation

URI: https://hdl.handle.net/10125/109294
978-0-9981331-8-8

and board certification (ACGME Program Requirements 2020). When applied correctly, POCUS can improve the diagnostic speed of critically ill patients, decrease time-to-operating room, and decrease length-of ED stay (Seif et al., 2012, Goldsmith et al., 2020, Gottlieb et al., 2017, Doniger et al., 2009, Bahl et al., 2022, Makary et al., 2016). When used for procedural-guidance, POCUS can result in more successful first-pass procedural attempts, reduce the rates of complications, and improve patient outcomes. Its use in acute care settings has proven to reduce diagnostic errors and procedural complications, leading to decreased morbidity and mortality, and reduced healthcare-related costs (Brower et al., 2022, Butler et al., 2016). As an example, POCUS-guided peripheral intravenous access in the ED has reduced central line placement in non-critical ill patients by up to 80% (Doniger et al., 2009). Central venous access is associated with deep vein thrombosis, bloodstream infections and iatrogenic errors, therefore the introduction of appropriately performed POCUS can reduce morbidity and mortality and improve the quality of patient care. However, given its high user variability and the speed at which the adoption of POCUS has outpaced critical safety needs, it has also been identified as one of the highest health technology hazards.

Managing acute pain is one of the most common challenges faced in the ED. Pain regimens often rely on a combination of topical or oral agents, as well as parenteral options such as nonsteroidal anti-inflammatory drugs, acetaminophen, ketamine, propofol, or antipsychotic medications. Unfortunately, each of these regimens has limitations in indications and efficacy. Opioid analgesics are commonly used as a second-line therapy for treating severe pain in the ED. However, even short courses of opioids used as directed for acute pain are associated with addiction and dependence (Hoppe et al., 2015, Heard et al., 2020, Shah et al., 2017, Hayashi et al., 2022). Thus, limitations in available pain regimens, combined with concerns surrounding opioid prescribing has prompted ED physicians to seek out analgesic alternatives. When performed correctly, ultrasound-guided nerve blocks (UGNB) can provide safe, non-addictive, long-lasting analgesia by delivering local anesthetic to peripheral nerves thereby blocking pain signals distal to the injection. (Fahey et al., 2022, Kring et al., 2022, Gao et al., 2018). In UGNB, a proceduralist uses their dominant hand to direct an echogenic needle towards an anatomical target (often a nerve or a fascial plane) which is identified live on POCUS with their non-dominant hand. In perioperative settings, successful UGNBs decrease opioid use, reduce hospital length-of-stay, and increase patient satisfaction compared to traditional analgesia. UGNBs have been shown beneficial for an array of ED indications, and in 2021 UGNBs were identified as core elements of ED-based analgesia.

Currently, 100% of academic EDs report performing UGNBs, a 16% increased from 2016 (Goldsmith et al., 2022, ACEP, 2016, Nelson et al., 2016, Damewood et al., 2019). From a recent national survey of academic emergency departments only 30% of programs offer training and credentialing pathways in performing UGNB. Furthermore, as of 2021, 21% of programs perform no quality assessment metrics on UGNB performed in their department, and a surprising 72% of departments perform no longitudinal competency assessments on UGNB at all. Despite UGNB being rapidly adopted as an ED-based procedure, there is currently no standardization in UGNB training, education, credentialing, or quality assurance, thus ED-based UGNB demonstrate highly variable rates of safety and efficacy.

Current assessment strategies for education and credentialling for both diagnostic and procedural POCUS rely on observation by trained evaluators in the traditional Objective Structured Clinical Examination (OSCE), which is an assessment that requires high implementation costs and often leads to suboptimal inter-rater reliability (Landon et al., 2003). Feasible, viable, and scalable assessment systems could maximize cost-effectiveness by using validated tools with high reliability and low implementation costs. This study used Computer-based measures (CBM), with a focus on head motion analysis, to give a more objective, accurate, and resource-friendly competency assessments compared to traditional OSCE.

Head motion analysis was chosen as one of our study metrics given anecdotal experience with teaching novices to perform ultrasound-guided procedures. Head position, and therefore gaze, is something that novices struggle with when learning ultrasound procedural guidance. Novices tend to be less direct when changing their gaze between the needle and the ultrasound machine. Additionally, novices tend spend more time looking down at the needle rather than using the ultrasound image to guide their needle tip. Furthermore, head motion can be analyzed by the MUSE2 Headband, a product that is relatively inexpensive and commercially available, which will be important for future use to use in low resource and remote settings.

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 class year, Advanced Practice Providers, 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 and new physician assistant hires, as well as to faculty, fellows, and senior ultrasound-focused residents 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-guided ultrasound nerve blocks. Expert-level participants were defined as fellows or faculty who had completed at least a portion of emergency ultrasound advanced fellowship training, or ultrasound focused senior residents 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 report 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.

Simulation-Based Ultrasound Guided Nerve Blocks

The selected UGNBs used in this study are commonly indicated in ED practice, and included the transgluteal sciatic nerve block, the interscalene nerve block and the fascia iliaca nerve block. The study took place with two, 2-hour, in-person simulation sessions at STRATUS Center for Medical Simulation (STRATUS) at Brigham and Women's Hospital in Boston, Massachusetts. UGNB were performed using block phantom models (Blue Phantom Regional Anesthesia Ultrasound Simulation Models, CAE Healthcare Inc, Sarasota, FL, USA).

Novice participants were given a brief 10-minute recorded PowerPoint lecture on the three UGNBs, which was followed by an online survey that asked basic demographic information, in addition to asking participants to rate confidence levels with a Likert scale where 1=not confident at all and 10=very confident. Expert participants completed the online survey but did not receive the 10-minute recorded PowerPoint lecture.

Mindray ME8 devices (Mindray, Shenzhen, China) owned by STRATUS for education and training purposes were used for ultrasound-guidance and image collection. The Mindray device was positioned beside the block phantom model and set to identical depth and gain settings for each user before each block (depth 4 cm, gain 50%). The high-frequency linear transducer (5-15 MHz) was used for all three UGNB.

Figure 1. Positioning of participant with block phantom model and ultrasound

The Nerve Blocks

The Fascia iliaca nerve block: The fascia-iliaca nerve block (FIB) is a lower extremity block that anesthetizes both the femoral nerve and lateral femoral cutaneous nerve performed at the location of the inguinal crease. In the ED, this block is used for pain control in proximal femoral fractures. This block has demonstrated efficacy in efficient pain control, increased patient satisfaction, and decreased opioid consumption in patients overall.

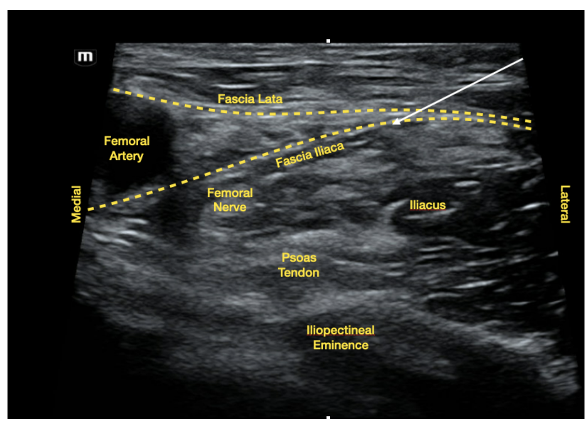

Figure 2. The Fascia Iliaca Nerve Block

The Interscalene brachial plexus block: The interscalene brachial plexus nerve block (IBPNB) targets the brachial plexus at the level of the anterior and middle scalene muscles in the neck. When performed properly, this block achieves anesthesia of the shoulder, clavicle, and lateral arm and is most commonly used for pain control in patients with proximal humerus fractures or for shoulder reductions.

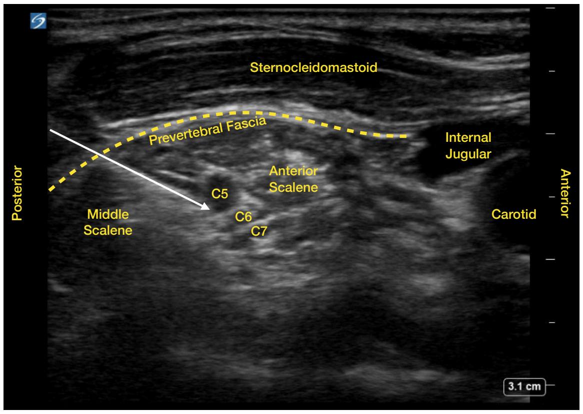

Figure 3. The Interscalene Nerve Block

The Transgluteal Sciatic nerve block: The transgluteal sciatic nerve block (TGSNB) targets the sciatic nerve and is used most commonly for analgesia of acute on chronic sciatic back pain.

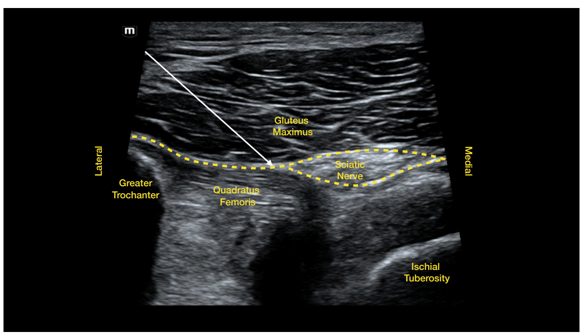

Figure 4. The Transgluteal Sciatic nerve block

Head Motion Tracking

For this study, we utilized head motion data (x, y, z) collected by the MUSE2 headband (Figure 5) and computer-based metrics (CBM), for which data were collected via recording the sessions. Calibration was performed to ensure accurate tracking of head movement between participants. During the data collection process, participants performed UGNBs while their head motion data was recorded by the MUSE2 and CBM system.

Figure 5. The Muse2 Headband

Traditional OSCE Evaluation

Two independent POCUS expert reviewers observed each participant completing the UGNBs and independently scored each exam using a standardized OSCE checklist. The checklist included observing the participant positioning their needle in relation to the probe, obtaining the correct views, and adjusting ultrasound parameters for optimal needle tip visualization per ACEP guidelines. OSCE scores were totaled with a maximum score of 30 for all 3 nerve blocks. Scoring for each nerve block was from 1-10; 1 = unable to correctly reach the target, with incorrect needle orientation and poor image acquisition of the targeted nerves, 5 = reached target with difficulty and with incomplete needle visualization, but with successful visualization of the targeted nerves, 10 = successful nerve block technique with good needle and target visualization throughout the procedure. Overall OSCE scores for each participant was calculated by averaging the scores from the two expert reviewers for each examination.

Metrics

For this study, head motion metrics were captured using both accelerometer and gyroscope sensors. These sensors measured root mean square (RMS) values across three axes (X, Y, and Z) for both accelerometers and gyroscopes. The accelerometer RMS values provide a measure of the magnitude of head movements, while the gyroscope RMS values capture the angular velocity of these movements. RMS was used because it effectively quantifies the overall magnitude of motion, providing a robust measure that accounts for variability and directionality in the data. This metric is particularly useful in capturing the intensity of movements, which is critical for distinguishing between different levels of procedural expertise. The accelerometer RMS values (Accelerometer_X_RMS, Accelerometer_Y_RMS, Accelerometer_Z_RMS) and gyroscope RMS values (Gyro_X_RMS, Gyro_Y_RMS, Gyro_Z_RMS) were extracted and used as predictor variables in our analyses.

Additionally, the number of prior procedures performed by each participant was recorded and included as a predictor to account for varying levels of experience. This comprehensive set of metrics allowed for a detailed analysis of the relationship between head motion and procedural performance, providing insights into the factors that differentiate novice and expert practitioners.

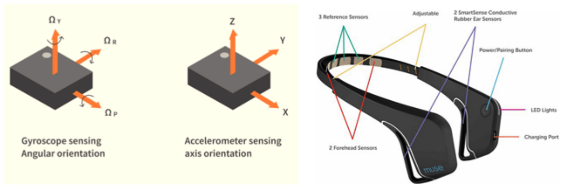

Figure 6. Gyroscope and accelerometer sensing axes (left) and the Muse headband setup (right) used to capture head motion data during ultrasound-guided nerve block procedures.

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 was utilized for group comparisons. Group comparison statistics are reported as the square root of the mean +/- standard deviation (SD) unless otherwise noted. Spearman correlation analysis was performed to assess relationships between each head motion metric (Accelerometer_X_RMS, Accelerometer_Y_RMS, Accelerometer_Z_RMS, Gyro_X_RMS, Gyro_Y_RMS, Gyro_Z_RMS) and OSCE scores due to the non-normal distribution of the data. A multiple linear regression analysis was conducted to examine the combined effects of head motion metrics and the number of prior procedures on OSCE scores. Missing values were removed, and predictors were centered and scaled as needed. The analysis was conducted using the statemodels package in Python. Model diagnostics, including residual plots and Q-Q plots, were examined to ensure assumptions of linearity, homoscedasticity, and normality of residuals. The significance level was set at $p < 0.05$.

3. Results

OSCE and Demographics

In total, eleven novices and seven experts were recruited. 55% of novices completed a POCUS clinical rotation as residents, with the remaining 45% only having completed a POCUS rotation as medical students. The average number (+/- SD) of nerve blocks performed by novices prior to data collection was 3.45 +/- 6.18 and ranking of confidence levels on the Likert Scale averaged at a score of 3.27 +/- 2.79. 71% of the experts recruited were Fellowship trained, with two of the experts being senior residents going into a clinical ultrasound fellowship. Experts had an average of 80.14 +/- 78.01 nerve blocks performed prior to data collection, with an average score of 8.71 +/- 1.03 for confidence level on the Likert scale. Novice participants earned an average overall OSCE score of 15.6 (+/- 7.9), with expert participants scoring 28.5 (+/- 2.44, $p < 0.001$), demonstrating a statistically significant difference between groups.

Computer-based Metrics for Objective Competency

Figure 7 shows the accelerometer data comparing head motion between novice and expert groups across the x-, y-, and z-axes. Significant differences were observed in the z-axis, where experts demonstrated higher RMS values, indicative of more pronounced head nodding movements. This increased motion likely reflects the experts' frequent checks of the ultrasound screen and needle positioning. In contrast, no significant differences were observed between the two groups in the x- (lateral) and y-(vertical) -axes, indicating similar head motion patterns in these dimensions.

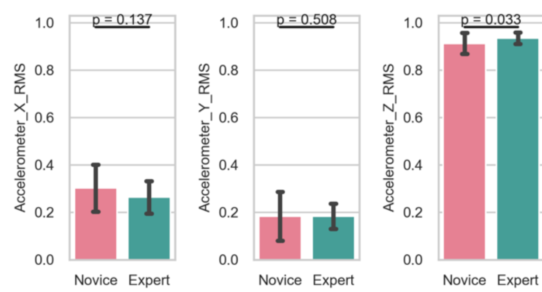

Figure 7 Comparing accelerometer values between novices and experts in the x-, y- and x-axis

Figure 8 presents the gyroscope data comparing head motion between novice and expert groups across the x-, y-, and z-axes. Significant differences were observed in the y- and z-axes. In the y-axis, experts exhibited higher RMS values, indicating greater head movement along this axis. Similarly, in the z-axis, experts demonstrated significantly higher RMS values, reflecting more pronounced head movements in this dimension. No significant differences were found between the two groups in the x-axis.

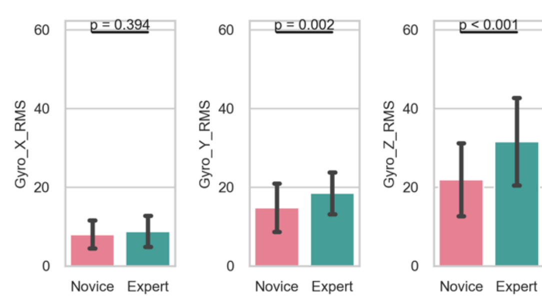

Figure 8. Comparing gyroscope values between novices and experts in the x-, y- and x-axis

Figure 9 shows the correlation between accelerometer and gyroscope RMS values across the x-, y-, and z-axes with OSCE scores. Significant correlations were observed for accelerometer data in the z-axis and gyroscope data in the y- and z-axes. Specifically, a significant positive correlation was found between accelerometer z-axis RMS values and OSCE scores (r = 0.36), as well as between gyroscope z-axis RMS values and OSCE scores (r = 0.29). Gyroscope y-axis RMS values also showed a positive correlation with OSCE scores (r = 0.21), although this was not statistically significant. No significant correlations were observed for the x- and y-axes accelerometer data or for the x-axis gyroscope data, indicating that these dimensions of motion were not predictive of OSCE performance.

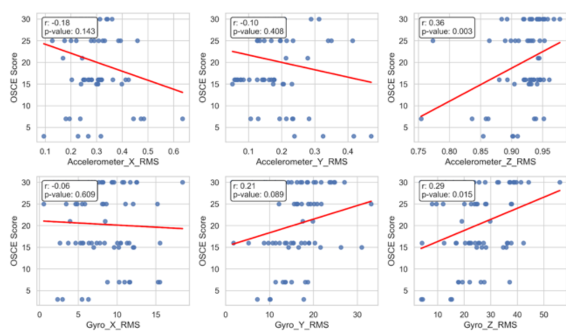

Figure 9. Correlation between head motion metrics (RMS values) and OSCE scores

Multiple Linear Regression:

The multiple regression analysis was conducted to examine the effect of accelerometer and gyroscope RMS values, along with the number of prior procedures, on OSCE scores. The detailed results are shown in Table 1. The overall model was statistically significant, $F(7, 60) = 5.103$, $p < 0.001$, and explained approximately 37.3% of the variance in OSCE scores ($R^2 = 0.373$, Adj. $R^2 = 0.300$). Among the predictors, Gyro_Z_RMS ($\beta = 0.283$, $p = 0.041$) and the number of prior procedures ($\beta = 0.059$, $p = 0.002$) were significantly associated with OSCE scores, indicating that higher values in these variables were related to higher OSCE scores. The coefficients for Accelerometer_X_RMS, Accelerometer_Y_RMS, Accelerometer_Z_RMS, Gyro_X_RMS, and Gyro_Y_RMS were not statistically significant. Figure 10. illustrates the predicted versus actual OSCE scores.

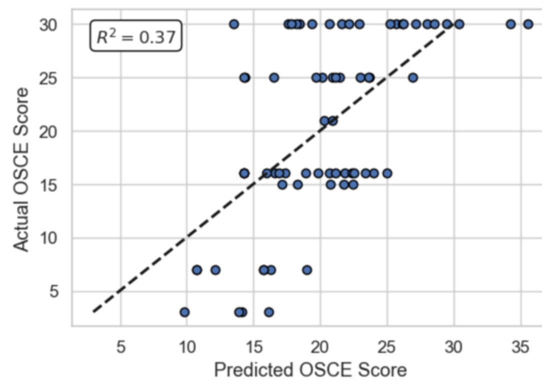

Figure 10. Predicted vs. actual OSCE scores based on multiple linear regression analysis.

4. Discussion

UGNB have become a mainstay for acute pain management in the ED, including use for femoral fractures, rib fractures and acute sciatic radiculopathy. UGNBs offer long-acting analgesia, with benefits including reduction in opioid use as well as decreasing hospital length-of-stay. However, despite their increasing use, there remains a gap in the standardization of education and training for UGNBs in the ED setting. Current assessment strategies for diagnostic and procedural POCUS rely on observation by trained evaluators (OSCE evaluations), which are the current gold standard for assessing competency in medical education. However, the traditional OSCE has high implementation costs and suboptimal inter-rater reliability. Prior research in assessment of objective competency measures in the surgical literature has been shown to be translatable to ultrasound education (Berk et al., 2023, Dias et al., 2019, Lee et al., 2021). 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.

Our team has successfully performed a related study comparing hand- and head-motion analysis in novice and expert users for diagnostic eFAST and cardiac POCUS image acquisition (Walsh et al 2024). In this study, head motion was tracked with the MUSE 2 headbands, which was mimicked in this procedural ultrasound pilot study. In our diagnostic ultrasound study analysis, experts demonstrated statistically significant less head motion distribution in the Y and Z directions compared to novices (Fig. 11).

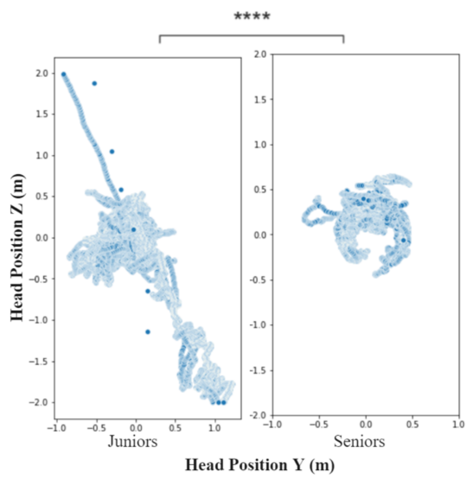

Figure 11. Comparing head motion between novices and experts in diagnostic ultrasound

In comparison to this pilot study for procedural objective competency measures, there was statistically significant differences between novices and experts with acceleration on the z-axis, but without statistically significant differences on the x- and y-axis. (Figure 7) Given that the z-axis is that of a nodding head motion, where the head moves forwards and backwards. This finding becomes procedurally significant as a novice user will spend more time looking downwards to check their probe and needle positioning on the model rather than focusing on the ultrasound screen to find their needle tip. This was also echoed in the gyroscope values, which is a marker of velocity. (Figure 8) In this analysis there were statistically significant differences between our novice and expert groups in the y- and z-axis. The y-axis corresponds to the up-down head motion, and the z-axis as the forward-backwards axis. Experts are faster and more efficient at moving their focus from the key areas on the nerve block model to the important areas of interest on the ultrasound machine, with more time spent with focus on the ultrasound screen to direct their needle tip to the relevant target. This difference was apparent when re-watching the video clips of experts vs novices, and comparing their motion kinetics.

This study demonstrated that when head motion analysis was compared to the gold standard traditional OSCE it could differentiate between novice and expert users with acceleration in the z-axis and with gyroscope values in the y- and z-axis. Most importantly these are metrics that can be clinically correlated and explained when observing novice and expert proceduralists. We hope that these findings will allow for a shift from the subjective, and time and resource intensive OSCE, to computer-based, and more objective metrics in ultrasound education.

Additionally, current 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, with computer-based metrics able to provide immediate feedback to the learner. Future research in this field will be needed to establish set benchmarks in these metrics of objective competency, with the goal that these could be applied to the wide scope of procedures performed by emergency medicine providers in the ED.

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 and new graduates of physician assistant school, which were the providers with the least experience in emergency POCUS at our tertiary academic institution. Given that nerve blocks are more of an advanced skill, we provided a short introduction video to the three nerve blocks performed, but some novice users required some guidance with the procedure itself to be able to perform each of the three nerve blocks. Along those lines, each novice participant will have had different levels of POCUS exposure with their medical training, and therefore this would have introduced some bias to our novice group.

5. Conclusion:

The objective measures of head motion demonstrated significant differences between novice and expert POCUS users. This correlated with differences in OSCE scores, which are the current standard of care in measuring POCUS competency, demonstrating that these computer-based metrics are reliable as a competency tool. This pilot study suggests 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.

6. References

Accreditation Council for Graduate Medical Education. (2020). *ACGME Programs Requirements for Graduate Medical Education in Emergency Medicine.* https://www.acgme.org/globalassets/PFAssets/ProgramRequirements/110_EmergencyMedicine_2020.pdf?ver=2020-06-26-125701-320%26ver=2020-06-26-125701-320

American College of Emergency Physicians. (2016). *Ultrasound Guidelines: Emergency, Point-of-care, and Clinical Ultrasound Guidelines in Medicine.* https://www.acep.org/globalassets/new-pdfs/policy-statements/ultrasound-guidelines---emergency-point-of-care-and-clinical-ultrasound-guidelines-in-medicine.pdf

Amini, R., Kartchner, J. Z., Nagdev, A., & Adhikari, S. (2016). Ultrasound-guided nerve blocks in emergency medicine practice. *Journal of Ultrasound in Medicine*, 35(4), 731-736. https://doi.org/10.7863/ultra.15.05095

Bahl, A., Millard, M., Hijazi, M., & Chen, N. W. (2022). Predictors of ultrasound-guided peripheral intravenous catheter failure: A secondary analysis of existing trial data. *Journal of Vascular Access*. https://doi.org/10.1177/11297298221122118

Berk, B., Ebnali-Heidari, M., Miccile, C., Dias, R., & Wollin, D. (2023). MP68-06 motion capture system for objective assessment of technical skills during ureteroscopy. *Journal of Urology,* 209(Supplement 4). https://doi.org/10.1097/ju.0000000000003331.06

Brower, C. H., Baugh, C. W., Shokoohi, H., Liteplo, A. S., Duggan, N., Havens, J., Askari, R., Rehani, M. M., Kapur, T., & Goldsmith, A. J. (2022). Point-of-care ultrasound-first for the evaluation of small bowel obstruction: National cost savings, length of stay reduction, and preventable radiation exposure. *Academic Emergency Medicine*, 29(7), 824-834. https://doi.org/10.1111/acem.14464

Butler, M. M., Ancona, R. M., & Beauchamp, G. A. (2016). Emergency department prescription opioids as an initial exposure preceding addiction. *Annals of Emergency Medicine*, 68(2), 202-208. https://doi.org/10.1016/j.annemergmed.2015.11.033

Damewood, S. C., Leo, M., Bailitz, J., Gottlieb, M., Liu, R., Hoffmann, B., & Gaspari, R. J. (2019). Tools for measuring clinical ultrasound competency: Recommendations from the ultrasound competency work group. *AEM Education and Training*, 4(Suppl 1), S106-S112. https://doi.org/10.1002/aet2.10368

Dias, R. D., Gupta, A., & Yule, S. J. (2019). Using machine learning to assess physician competence: A systematic review. *Academic Medicine*, 94(3), 427-439. https://doi.org/10.1097/ACM.0000000000002414

Doniger, S. J., Ishimine, P., Fox, J. C., & Kanegaye, J. T. (2009). Randomized controlled trial of ultrasound-guided peripheral intravenous catheter placement versus traditional techniques in difficult-access pediatric patients. *Pediatric Emergency Care*, 25(3), 154-159. https://doi.org/10.1097/PEC.0b013e31819a8946

Fahey, A., Cripps, E., Ng, A., Sweeny, A., & Snelling, P. J. (2022). Pericapsular nerve group block for hip fracture is feasible, safe and effective in the emergency department: A prospective observational comparative cohort study. *Emergency Medicine Australasia*. https://doi.org/10.1111/1742-6723.14013

Gao, Y., Tan, H., Sun, R., et al. (2019). Fascia iliaca compartment block reduces pain and opioid consumption after total hip arthroplasty: A systematic review and meta-analysis. *International Journal of Surgery*, 65, 70-79.

Goldsmith, A. J., Brown, J., Duggan, N. M., Finkelberg, T., Jowkar, N., Stegeman, J., Riscinti, M., Nagdev, A., & Amini, R. (2024). Ultrasound-guided nerve blocks in emergency medicine practice: 2022 updates. *American Journal of Emergency Medicine*, 78, 112-119. https://doi.org/10.1016/j.ajem.2023.12.043

Goldsmith, A. J., Shokoohi, H., Loesche, M., Patel, R. C., Kimberly, H., & Liteplo, A. (2020). Point-of-care ultrasound in morbidity and mortality cases in emergency medicine: Who benefits the most? *Western Journal of Emergency Medicine*, 21(6), 172-178. https://doi.org/10.5811/westjem.2020.7.47486

Gottlieb, M., Sundaram, T., Holladay, D., & Nakitende, D. (2017). Ultrasound-guided peripheral intravenous line placement: A narrative review of evidence-based best practices. *Western Journal of Emergency Medicine*, 18(6), 1047-1054. https://doi.org/10.5811/westjem.2017.7.34610

Hayashi, M., Kano, K., Kuroda, N., Yamamoto, N., Shiroshita, A., & Kataoka, Y. (2022). Comparative efficacy of sedation or analgesia methods for reduction of anterior shoulder dislocation: A systematic review and network meta-analysis. *Academic Emergency Medicine*. https://doi.org/10.1111/acem.14568

Heard, K., Ledbetter, C. M., & Hoppe, J. A. (2020). Association of emergency department opioid administration with ongoing opioid use: A retrospective cohort study of patients with back pain. *Academic Emergency Medicine*. https://doi.org/10.1111/acem.14071

Hoppe, J. A., Kim, H., & Heard, K. (2015). Association of emergency department opioid initiation with recurrent opioid use. *Annals of Emergency Medicine*, 65(5), 493-499. https://doi.org/10.1016/j.annemergmed.2014.11.015

Kim, Y. M., Kang, C., J, Y. B., et al. (2019). The role of ultrasound-guided single-shot femoral and sciatic nerve blocks on pain management after total knee arthroplasty. *Knee*, 26(4), 881-888.

Kring, R. M., Mackenzie, D. C., Wilson, C. N., Rappold, J. F., Strout, T. D., & Croft, P. E. (2022). Ultrasound-guided serratus anterior plane block (SAPB) improves pain control in patients with rib fractures. *Journal of Ultrasound in Medicine*. https://doi.org/10.1002/jum.15953

Landon, B. E., Normand, S. L., Blumenthal, D., & Daley, J. (2003). Physician clinical performance assessment: Prospects and barriers. *JAMA*, 290(9), 1183-1189. https://doi.org/10.1001/jama.290.9.1183

Leape, L. L., Brennan, T. A., Laird, N., Lawthers, A. G., Localio, A. R., Barnes, B. A., Hebert, L., Newhouse, J. P., Weiler, P. C., & Hiatt, H. (1991). The nature of adverse events in hospitalized patients: Results of the

Harvard Medical Practice Study II. *New England Journal of Medicine*, 324(6), 377-384. https://doi.org/10.1056/NEJM199102073240605

Lee, W. F., & Chenkin, J. (2021). Exploring eye-tracking technology as an assessment tool for point-of-care ultrasound training. *AEM Education and Training*, 5(2). https://doi.org/10.1002/aet2.10508

Makary, M. A., & Daniel, M. (2016). Medical error—the third leading cause of death in the US. *BMJ*, 353, i2139. https://doi.org/10.1136/bmj.i2139

Nelson, M., Abdi, A., Adhikari, S., Boniface, M., Bramante, R. M., Egan, D. J., Matthew Fields, J., Leo, M. M., Liteplo, A. S., Liu, R., Nomura, J. T., Pigott, D. C., Raio, C. C., Ruskis, J., Strony, R., & Lewiss, R. E. (2016). Goal-directed focused ultrasound milestones revised: A multiorganizational consensus. *Academic Emergency Medicine,* 23(11), 1274-1279. https://doi.org/10.1111/acem.13069

Newman-Toker, D. E., & Pronovost, P. J. (2009). Diagnostic errors—the next frontier for patient safety. *JAMA*, 301(10), 1060-1062. https://doi.org/10.1001/jama.2009.249

Park, M. H., Kim, J. A., & Ahn, H. J. (2018). A randomized trial of serratus anterior plane block for analgesia after thoracoscopic surgery. *Anaesthesia*, 73(10), 1260-1264.

Seif, D., Perera, P., Mailhot, T., Riley, D., & Mandavia, D. (2012). Bedside ultrasound in resuscitation and the rapid ultrasound in shock protocol. *Critical Care Research and Practice*, 2012, 503254. https://doi.org/10.1155/2012/503254

Shah, A., Hayes, C. J., & Martin, B. C. (2017). Characteristics of initial prescription episodes and likelihood of long-term opioid use—United States 2006–2015. *MMWR Morbidity and Mortality Weekly Report,* 66(10), 265-296. https://doi.org/10.15585/mmwr.mm6610a1

Shokoohi, H., Loesche, M. A., Duggan, N. M., Liteplo, A. S., Huang, C., Al Saud, A. A., McEvoy, D., Liu, S. W., & Dutta, S. (2020). Difficult intravenous access as an independent predictor of delayed care and prolonged length of stay in the emergency department. *Journal of the American College of Emergency Physicians Open*, 1(6), 1660-1668. https://doi.org/10.1002/emp2.12222

Sidhu, H. S., Olubaniyi, B. O., Bhatnagar, G., Shuen, V., & Dubbins, P. (2012). Role of simulation-based education in ultrasound practice training. *Journal of Ultrasound in Medicine*, 31(5), 785-791. https://doi.org/10.7863/jum.2012.31.5.785

Walsh, C. D., Ebnali, M., Selame, L., Schwid, M., Fischetti, C., Stegeman, J., Plevek, P. D., Bernier, D., Driver, L., Goldsmith, A. J., Dias, R., & Duggan, N. M. (2024). Head motion analysis as an objective measure of point-of-care ultrasound image acquisition competency. *Hawaii International Conference on System Sciences (HICSS).*

Winters, B., Custer, J., Galvagno, S. M. Jr, Colantuoni, E., Kapoor, S. G., Lee, H., Goode, V., Robinson, K., Nakhasi, A., Pronovost, P., & Newman-Toker, D. (2012). Diagnostic errors in the intensive care unit: A systematic review of autopsy studies. *BMJ Quality & Safety*, 21(11), 894-902. https://doi.org/10.1136/bmjqs-2012-0803