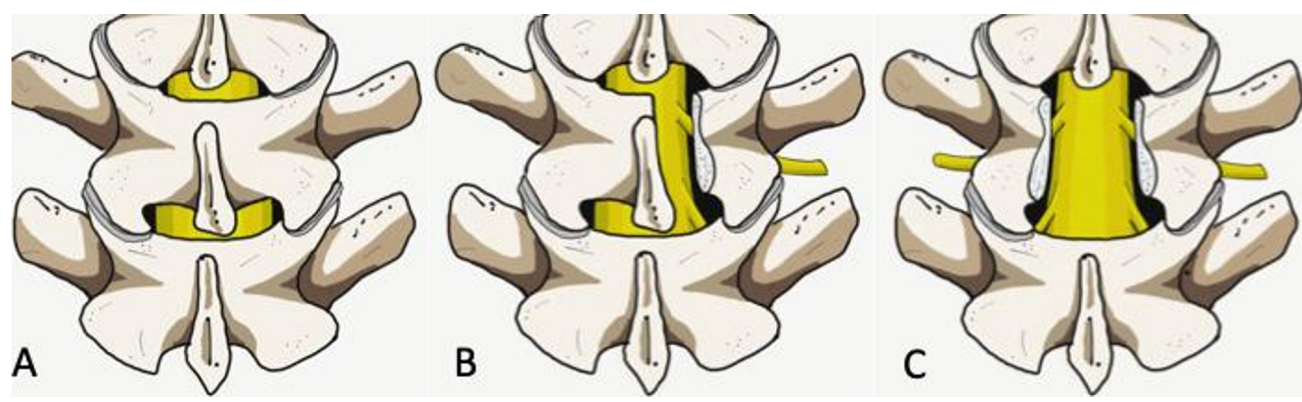


Background

- Decompressive lumbar laminectomy** is a procedure to **treat spinal stenosis** by drilling out portions of the lamina (**left**) [1]
- Limited visualization of critical structures risks **incidental durotomy**
 - 1.6% – 16% incidence rate during lumbar surgery [2]
- Virtual reality** (VR) offers low-risk training environments for surgeons
 - Prior success of VR with haptic device for mastoid drilling (**right**)

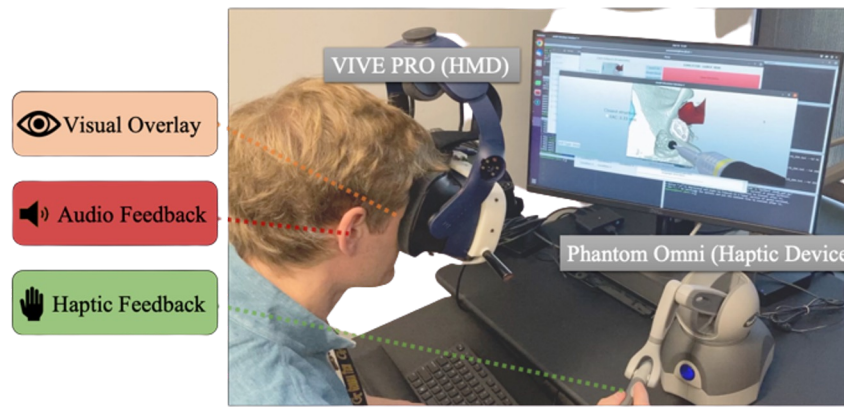
Left: Lamina removal in laminectomy [3]

Right: VOXEL-MAN TempoSurg VR [4]



Motivation

Need: VR drilling simulator for training surgeons on laminectomy



- Prior work: AMBF-based simulator with multi-sensory feedback [5]
- Visual feedback increased cognitive load due to positioning of warnings

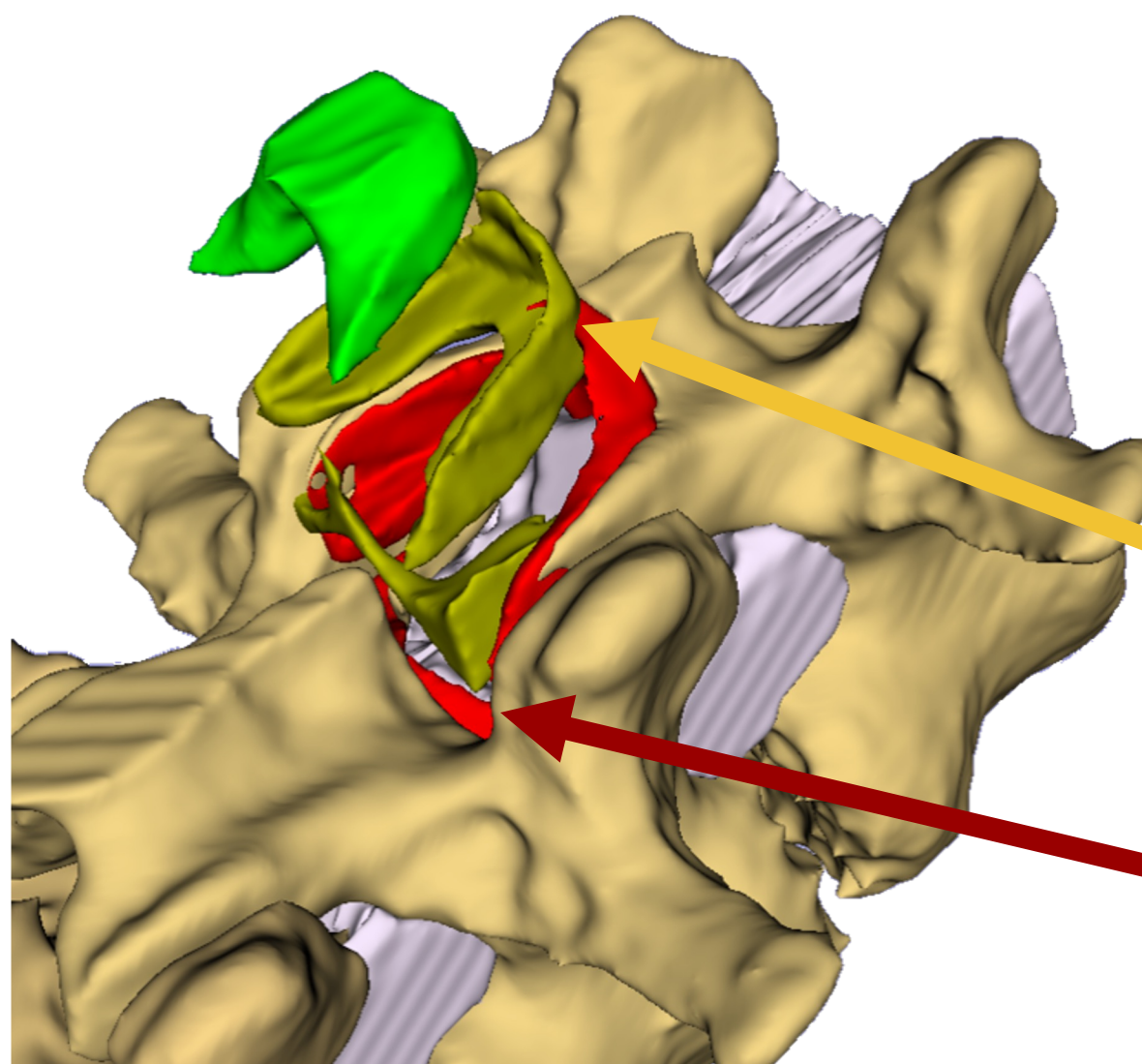
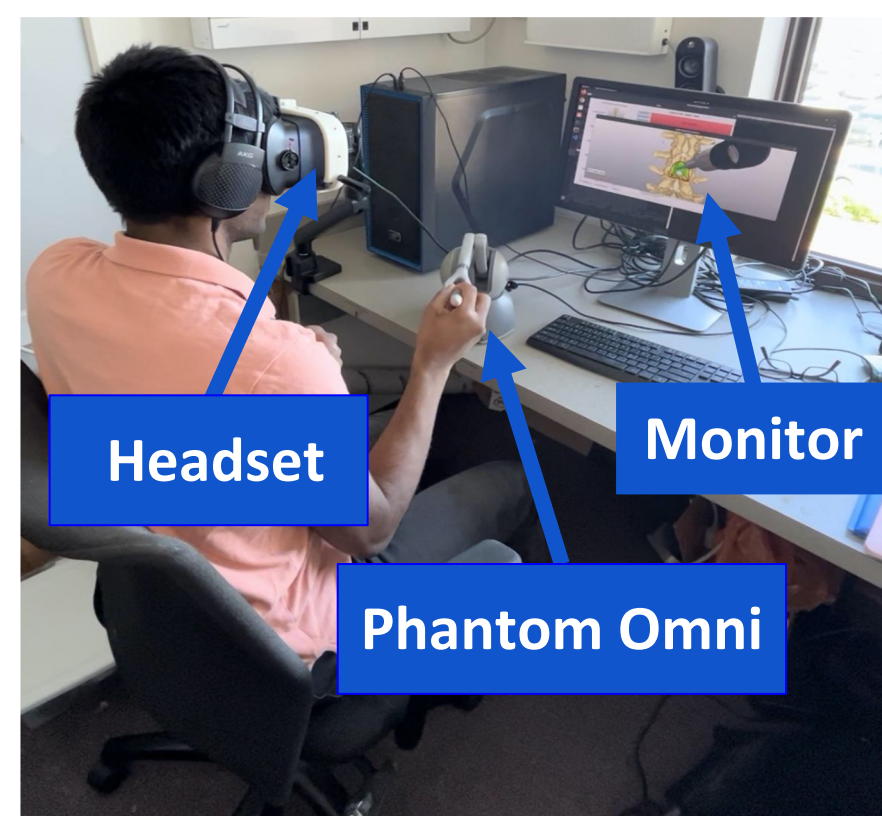
Goal: Improve visual feedback with anatomical color overlay



- Color-guidance** with OpenGL to display distance from sensitive anatomies
- Conducted **user study** to evaluate its differential impact during laminectomy

VR System Design

- Stereoscopic view** of spine with Phantom Omni haptic stylus, VIVE PRO headset, and OpenGL shading of red/yellow/green
- Pipeline to upload segmented CT scans from **3D Slicer** into AMBF
- Parallel recording of drilling (kinematics, force, time) using **ROSPY**

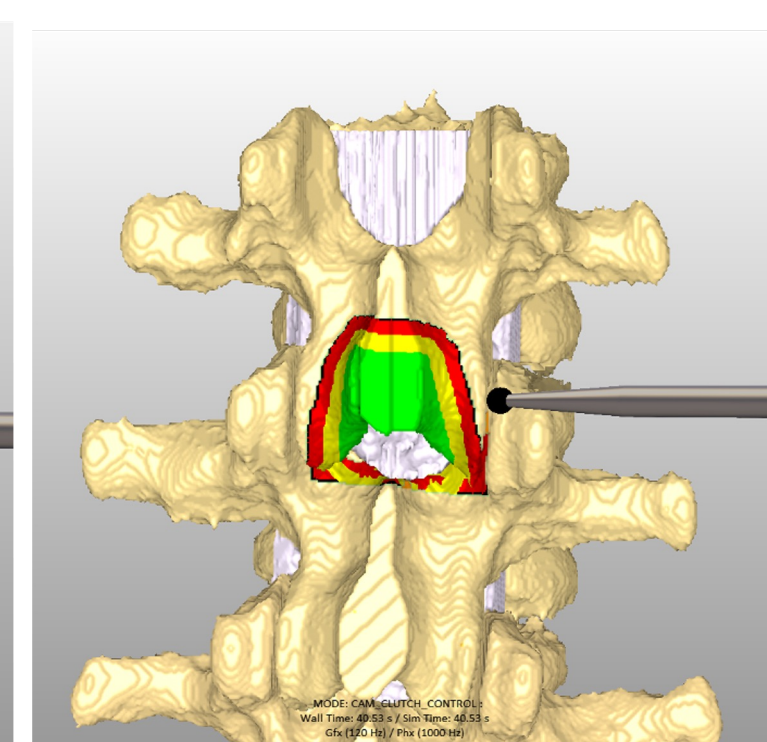
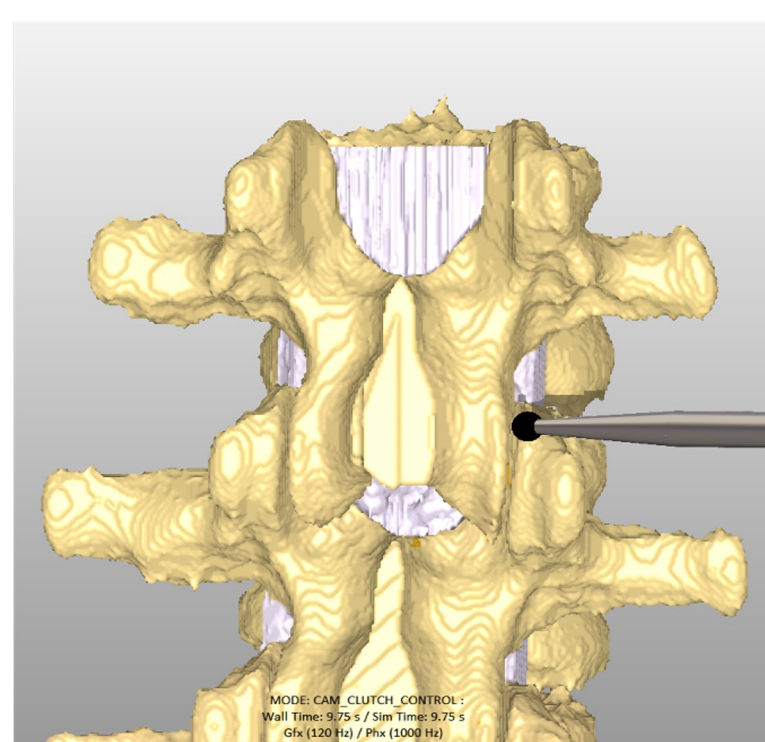


Color thresholding based on **signed-distance fields** [5] that calculate distance from spinal cord and surrounding bone

Yellow outlines 2 mm cautionary boundary

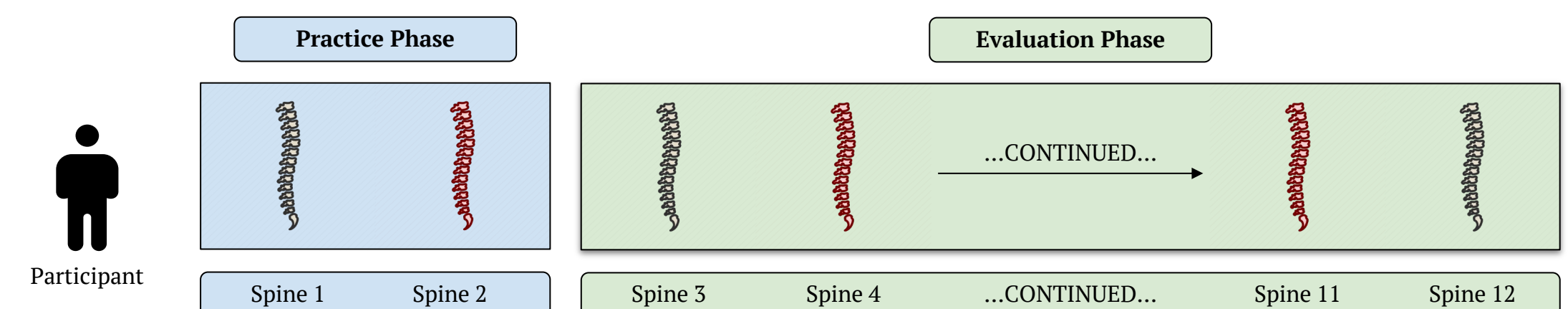
Red indicates sensitive structures to avoid

User Study



Eleven clinical participants (9 resident surgeons, 2 medical students) recruited from the JHMI Department of Orthopaedic Surgery.

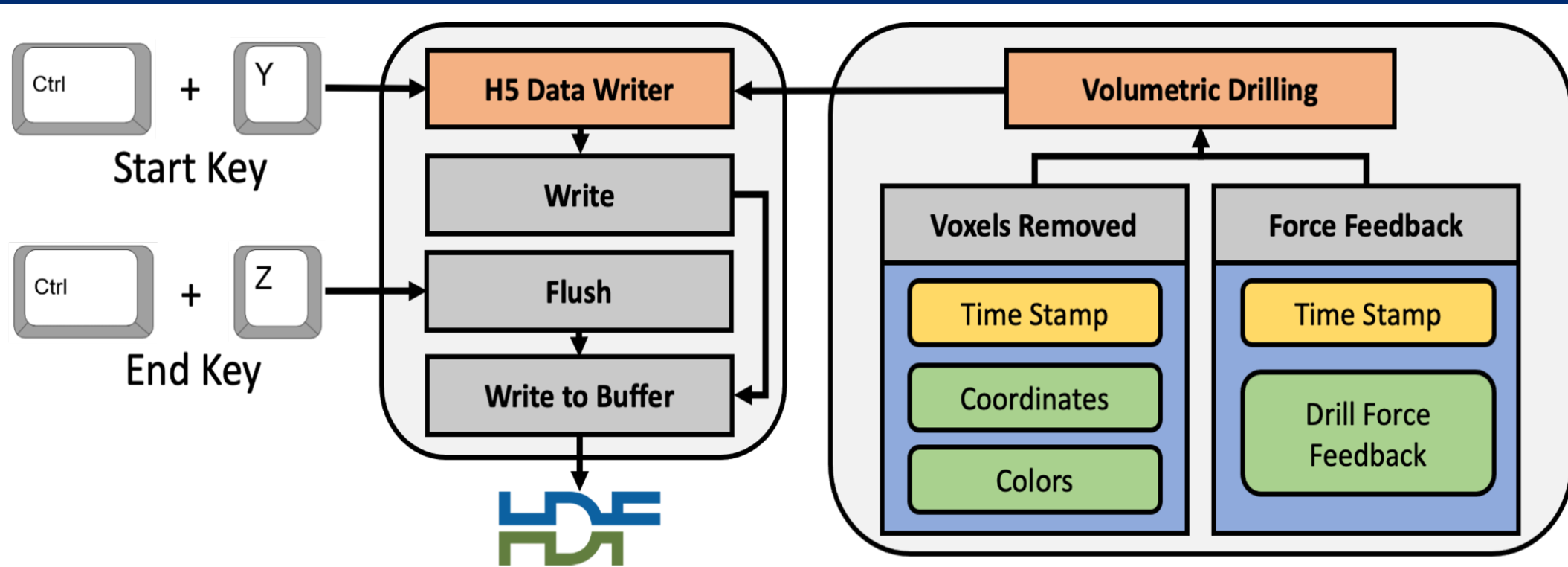
Study Design



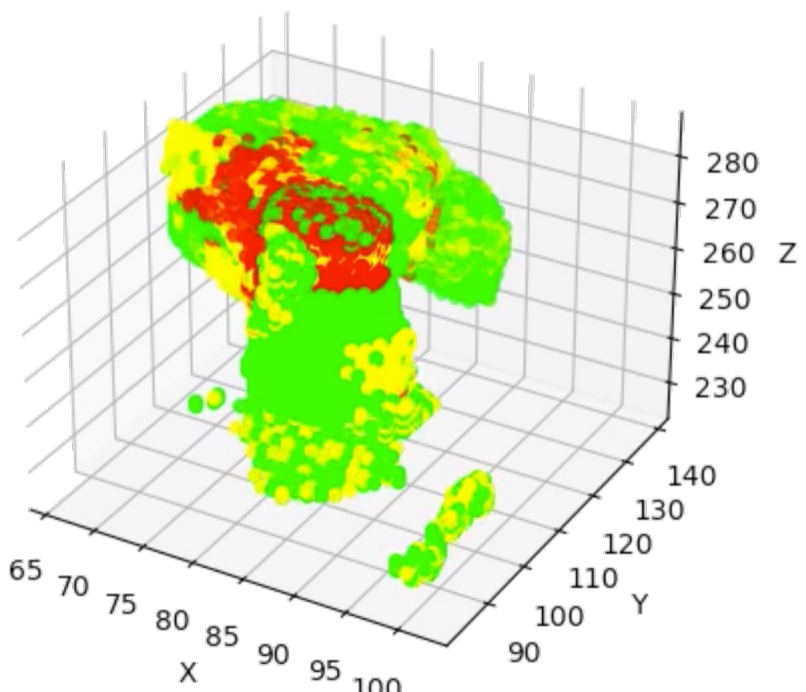
Each session included 12 simulated laminectomies (10 measured, 2 practice; 6 with color-guidance, 6 with only text warnings).

- Quantitative measurements:** number of unintended breaches (i.e., user drilled a red voxel), drilling time, force feedback
- Qualitative measurements:** prior surgical drilling experience, color/no-color preferences, NASA-TLX assessment

Technical Developments

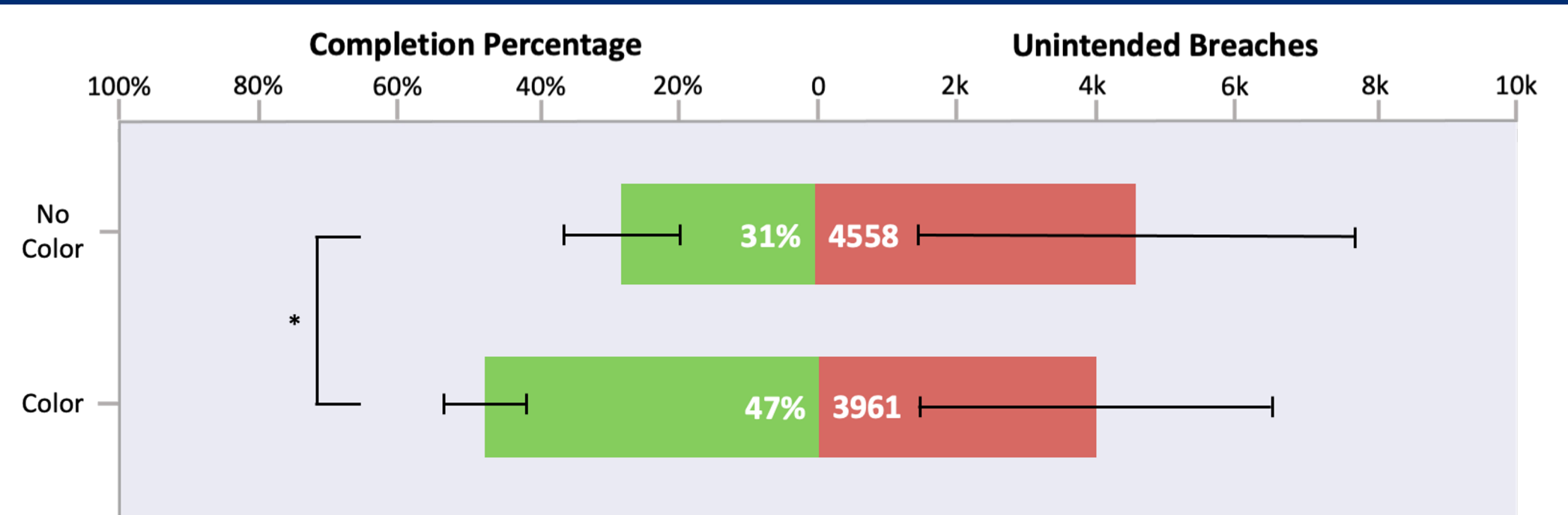


Proposed a C++ plugin for **synchronous data collection** of removed voxels from AMBF. Currently being implemented and unit tested.

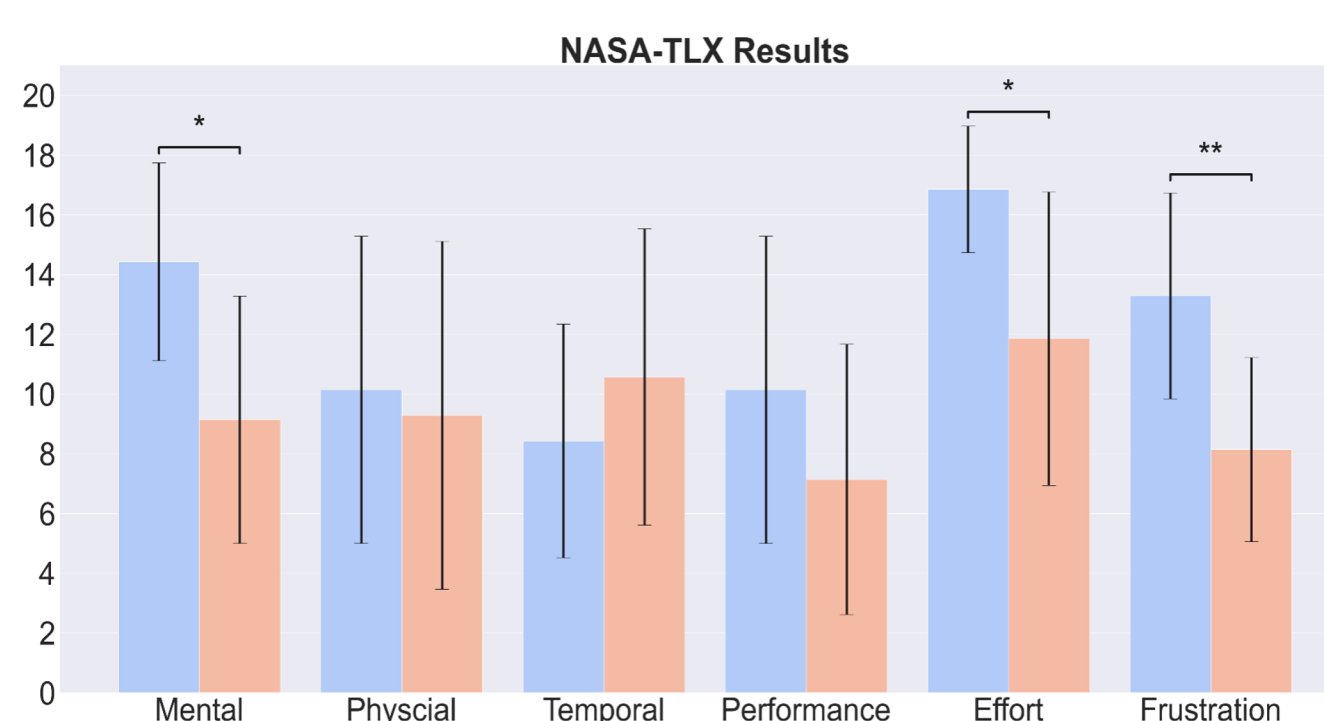


Created GUI to "replay" collected data. Users can see **time-lapse of drilling procedure**, plots of removed voxels by color, and total drilling time.

Results and Discussion



Surgeons had a **significantly higher completion percentage** under color-guidance while on average making less unintended breaches.



NASA-TLX results indicated that color-guidance **significantly reduced cognitive load**.

Challenges Faced

- User studies required careful planning of schedules and logistics
- Simulation lagged for extended drills due to asynchronous recording
- Haptic device required recalibration after every session

Next Steps

- Submit color-guidance technical approach and user study results to *IEEE Transactions on Medical Robotics and Bionics*
- Finish C++ plugin for synchronized data extraction into HDF5 files

References

- [1] K. Phan and R. J. Mobbs, "Minimally Invasive Versus Open Laminectomy for Lumbar Stenosis: A Systematic Review and Meta-Analysis," *Spine*, vol. 41, no. 2, p. E91, Jan. 2016, doi: 10.1097/BRS.0000000000001161.
- [2] H. Ishikura et al., "Risk factors for incidental durotomy during posterior open spine surgery for degenerative diseases in adults: A multicenter observational study," *PLoS One*, vol. 12, no. 11, p. e0188038, Nov. 2017, doi: 10.1371/journal.pone.0188038.
- [3] M. Estefan, S. Munakomi, and G. O. Camino Willhuber, "Laminectomy," in *StatPearls*, Treasure Island (FL): StatPearls Publishing, 2023. Accessed: May 06, 2023. [Online]. Available: <http://www.ncbi.nlm.nih.gov/books/NBK542274/>
- [4] R. Leuwer et al., "VOXEL-MAN TempoSurg A Virtual Reality Temporal Bone Surgery Simulator," *JOURNAL OF JAPAN SOCIETY FOR HEAD AND NECK SURGERY*, vol. 17, pp. 203–207, Jan. 2007, doi: 10.5106/jjshns.17.203.
- [5] H. Ishida et al., "Improving Surgical Situational Awareness with Signed Distance Field: A Pilot Study in Virtual Reality." *arXiv*, Mar. 03, 2023. Accessed: May 06, 2023. [Online]. Available: <http://arxiv.org/abs/2303.01733>