# Real-time workflow detection using webcam video for providing real-time feedback in central venous catheterization training

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## 1. ABSTRACT

**Purpose:** Medical schools are shifting from a time-based approach to a competency-based education approach. A competency-based approach requires continuous observation and evaluation of trainees. The goal of Central Line Tutor is to be able to provide instruction and real-time feedback for trainees learning the procedure of central venous catheterization, without requiring a continuous expert observer. The purpose of this study is to test the accuracy of the workflow detection method of Central Line Tutor. This study also looks at the effectiveness of object recognition from a webcam video for workflow detection. **Methods:** Five trials of the procedure were recorded from Central Line Tutor. Five reviewers were asked to identify the timestamp of the transition points in each recording. Reviewer timestamps were compared to those identified by Central Line Tutor. Differences between these values were used to calculate average transitional delay. **Results:** Central Line Tutor was able to identify 100% of transition points in the procedure with an average transitional delay of -1.46 ± 0.81s. The average transitional delay of EM and webcam tracked steps were -0.35 ± 2.51s and -2.46 ± 3.57s respectively. **Conclusions:** Central line tutor was able to detect completion of all workflow tasks with minimal delay and may be used to provide trainees with real-time feedback. The results also show that object recognition from a webcam video is an effective method for detecting workflow tasks in the procedure of central venous catheterization.

## 2. PURPOSE

Medical schools are moving away from traditional time-based approaches to education in favour of a competency-based approach. Previously, medical students have been deemed competent based solely on the number of hours spent practicing and performing a procedure. Competency based medical education (CBME) places a greater focus on trainee performance as opposed to the amount of time spent training on an educational unit[1].

In order to gain competency in a procedure, students must spend many hours practicing. However, allowing students to practice on live patients poses many risks. In the case of central venous catheterization, novice proceduralists have complication rates as high as 35%[2]. Trainees need access to a safe environment for practicing, where they can gain competency without risking patient safety. Medical simulators and models provide a simple way for trainees to gain competency before transitioning to live patients. With deliberate practice, simulation-based training has been shown to provide better results than traditional methods. A study of 663 students trained using simulators for a variety of skills, including central venous catheterization, showed that students who first trained on a simulator showed better performance and higher confidence than their traditionally trained counterparts[3].

Several modules for training other ultrasound-guided procedures have been developed as part of the Perk Tutor extension (www.perktutor.github.io) of 3D Slicer (www.slicer.org). 3D Slicer is an open sourced software platform designed for medical image informatics. Perk Tutor is an open-sourced training platform for procedures that involve ultrasound-guided needle insertions[4]. These training modules aim to help to further enhance the training experience on simulators and training phantoms by improving visualization during ultrasound-guided procedures. Using electromagnetic (EM) tracking on the ultrasound probe and needle, Perk Tutor is able to provide a 3D representation of their movements in space. A study performed with a training module for ultrasound-guided lumbar puncture showed that students who were trained using Perk Tutor had more consistent outcomes and caused less tissue damage than students who were trained with the simulated model alone[5].

Central Line Tutor goes beyond what has been done in previous Perk Tutor applications by providing learners with instruction and real-time, meaningful feedback. Central Line Tutor does this by incorporating EM tracking and object recognition from a live webcam video to detect the completion of tasks in the workflow. Previous attempts to identify workflow tasks in 3D Slicer used only EM tracking and were not greatly successful[6]. These attempts were limited to only tracking the ultrasound probe and needle. While EM tracking is able to give a more accurate position of the tool, due to the number and nature of the tools used in the procedure, tracking all tools electromagnetically is not feasible. Tools such as the dilator and guide wire, that are used to enable the catheter to be inserted into the vein, cannot perform their function if they must be attached to EM sensors. By performing additional video analysis on a live webcam video, Central Line Tutor hopes to be able to recognize a wider range of tasks.

The nature of CBME requires continuous observation and evaluation in order to monitor how learners are progressing towards competency. The hope is that Central Line Tutor will reduce the need for constant observation by medical experts and make access to training and meaningful feedback more convenient for learners. The goal of this particular study is to validate the accuracy with which the program can detect task completion and to observe the effectiveness of object recognition from a webcam video for the detection of tasks in central venous catheterization.

## 3. METHODS

The experimental setup included an EM tracker, ultrasound machine and webcam connected to a computer which displayed Central Line Tutor's user interface to the learner (Figure 1). EM sensors were placed on the training phantom, the needle and the ultrasound probe.

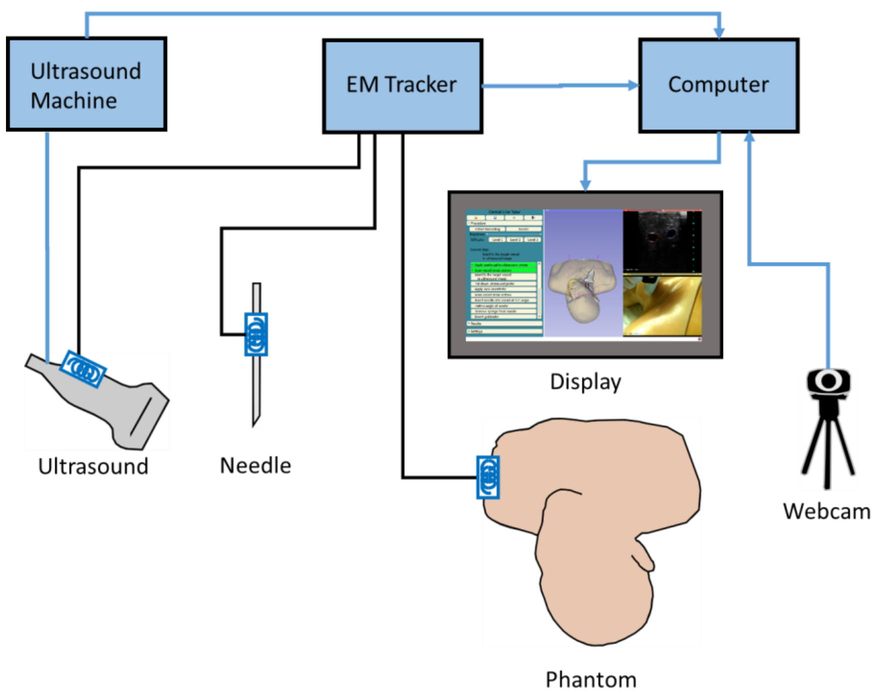


Figure 1. Central Line Tutor experimental setup

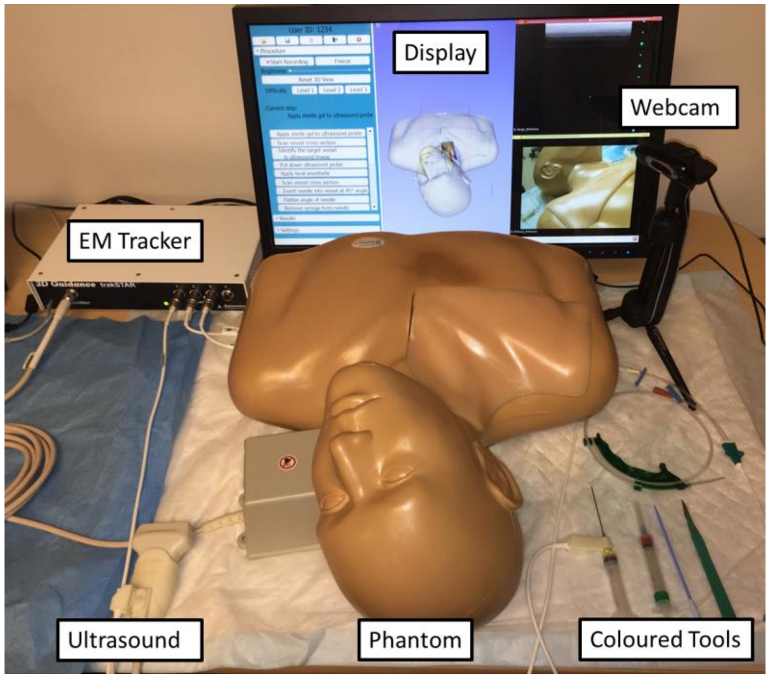


Figure 2. Central Line Tutor setup as seen by learner

The user interface displays the ultrasound and webcam videos to the learner (Figure 2). Central Line Tutor also displays a 3D virtual model of the training phantom, ultrasound probe and needle using input from the EM tracker. Learners are also given a list of instructions for completing the procedure. Central Line Tutor provides real-time feedback to learners by highlighting steps as they are completed (Figure 3). Learners are given the opportunity to select from three levels of difficulty that remove visual aids as learners' progress towards competency (Figure 4).

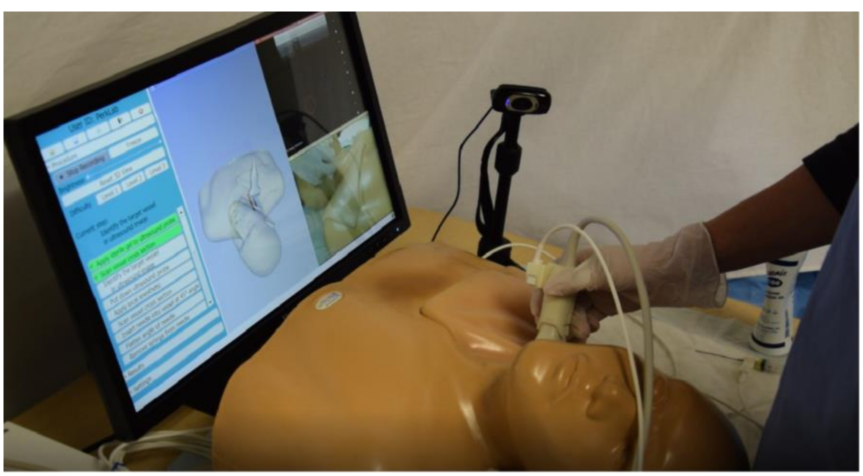

Figure 3. Learner practicing with Central Line Tutor

Central Line Tutor provides learners with real-time instruction and feedback by assessing which task is being completed at a given time. In order to detect which task is being completed at a given time, Central Line Tutor makes use of both EM tracking and a live webcam video to recognize steps in the procedure's workflow. Completion of tasks that involve the ultrasound probe and needle depend on their position and orientation with respect to the training phantom. Tasks where the tool's position relative to the phantom was highly important were tracked using the EM tracker. These tasks included ones such as performing cross-sectional and long-axis scans of the vessel as well as ensuring that the needle has been correctly inserted. As mentioned previously, the data from the EM tracker was used to construct a three-dimensional, virtual model of the motions of the ultrasound probe and needle in relation to the training phantom. The remaining steps were detected through the live webcam video using coloured object recognition.

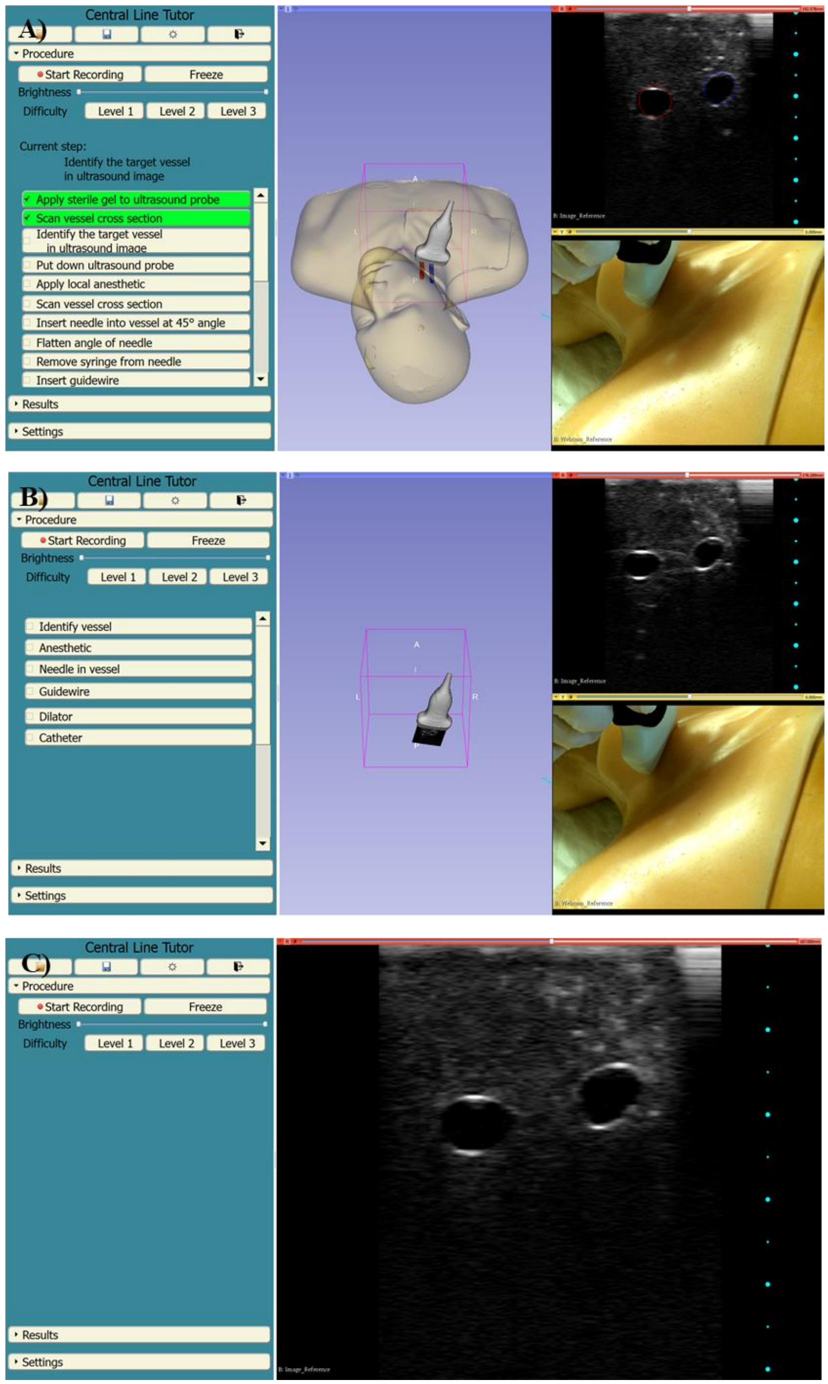


Figure 4. Central Line Tutor interface showing three levels of difficulty. A) Level 1. B) Level 2. C) Level 3.

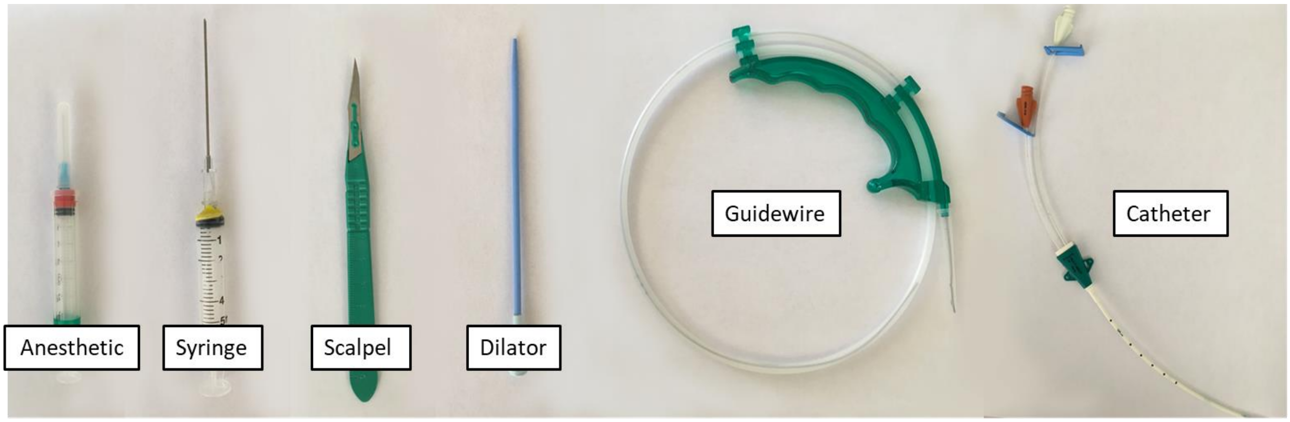


Figure 5. Tools used for central line insertion

Each task that was detected using the webcam video was identified by the tool used to complete that task (Figure 5). Each tool was identified by a range of values for hue, saturation and value (HSV), as well as minimum number of pixels required for identification (Table 1). Most tools had a component with a unique colour that could be used for identification. The exception to this was the syringe used to facilitate the insertion of the needle into the vessel. This syringe had no unique colour to distinguish it from the syringe used to inject the local anaesthetic. To compensate for this problem, we added a matte, yellow sticker for identification purposes. In order to detect tools, Central Line Tutor made use of the OpenCV (www.opencv.org) libraries. OpenCV was used to identify all pixels in the webcam image that fell within a tool's specified HSV range. Next a background subtraction filter was applied. Background subtraction was used to eliminate those pixels whose values were not rapidly changing. This eliminated pixels that represented stationary objects within the scene, such as the training phantom. Following background subtraction, binary thresholding was also applied. These methods were used to minimize the number of pixels that could erroneously be identified as being part of the tool. The number of pixels that fell within the tool's HSV range in the masked image was compared to the tool's minimum size. If the number of pixels within the HSV range was greater, then the tool was marked as found, the task was marked as complete and Central Line Tutor recorded the timestamp when this occurred.

Table 1. HSV ranges and Minimum size for identification of each tool

| **Tool** | **HSV range (low – high)** | **Minimum Size (Pixels)** |
|---|---|---|
| Anesthetic | (10, 190, 88) – (12, 210, 108) | 30 |
| Syringe | (30, 186, 107) – (32, 206, 127) | 5 |
| Scalpel | (76, 190, 69) – (78, 210, 89) | 10 |
| Dilator | (93, 89, 142) – (96, 109, 162) | 50 |
| Guidewire casing | (58, 175, 30) – (61, 195, 50) | 100 |
| Guidewire | (34, 84, 96) – (35, 104, 116) | 10 |
| Catheter | (83, 221, 43) – (85, 241, 63) | 30 |

To test the validity of the workflow detection method, we calculated the percentage of transition points that were correctly identified by Central Line Tutor, as well as the average transitional delay. We define average transitional delay as the average difference between the time when the reviewers and Central Line Tutor identified the transition points. A negative transitional delay indicates that the reviewers identified the transition point earlier than Central Line Tutor. A positive transitional delay indicates that Central Line Tutor was first to identify the transition point. We define transition points as being the point in the workflow where one task is completed and the next task begins (Table 2).

Table 2. Transition points identified in central line insertion procedure

| Transition Point | Name | Detection Method |
|---|---|---|
| 1 | Apply sterile gel | EM |
| 2 | Scan vessel cross section | EM |
| 3 | Put down ultrasound probe | EM |
| 4 | Local anaesthetic found | Webcam |
| 5 | Scan vessel cross section (2) | EM |
| 6 | Insert needle into vessel | EM |
| 7 | Flatten angle of needle | EM |
| 8 | Syringe found | Webcam |
| 9 | Syringe removed | Webcam |
| 10 | Guidewire found | Webcam |
| 11 | Needle removed from vessel | EM |
| 12 | Scan vessel cross section (3) | EM |
| 13 | Scan vessel long axis | EM |
| 14 | Scalpel found | Webcam |
| 15 | Scalpel removed | Webcam |
| 16 | Dilator found | Webcam |
| 17 | Dilator removed | Webcam |
| 18 | Catheter found | Webcam |
| 19 | Guidewire removed | Webcam |

Five trials of the procedure were recorded. Recordings captured the webcam video, the ultrasound video and the movements of the ultrasound probe and needle. Central Line Tutor also logged the timestamp of the transition points in real-time while the videos were being recorded. Trials were recorded in a windowless room with artificial, white light in order to keep lighting conditions consistent. Five reviewers were given the recordings and a list of the transition points. They were then asked to identify the timestamps of the transition points. The reviewers were able to view the movements of the 3D models, the ultrasound video and the webcam video as seen by the user when performing the procedure (Figure 6). To minimize bias, reviewers were not able to see the timestamps that were recorded by Central Line Tutor, or the real-time feedback that was given to the user.

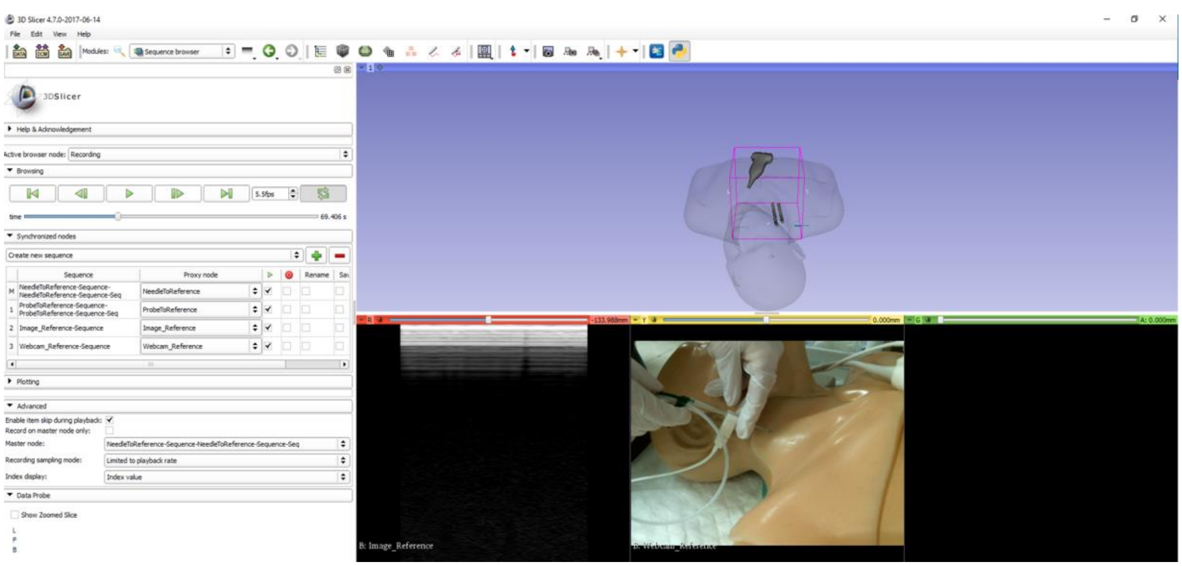

Figure 6. Recordings as viewed by reviewers

## 4. RESULTS

Central Line Tutor was successfully able to detect all transition points in the procedure with an average transitional delay of -1.46 ± 0.81s (Figure 7). Furthermore, 10 of 19 (52.6%) transition points had an average transitional delay of less than one second. The average transitional delay of EM and webcam tracked steps were -0.35 ± 2.51s and -2.46 ± 3.57s respectively. Further work is being done to investigate the effect of different light conditions on the robustness of the webcam object recognition.

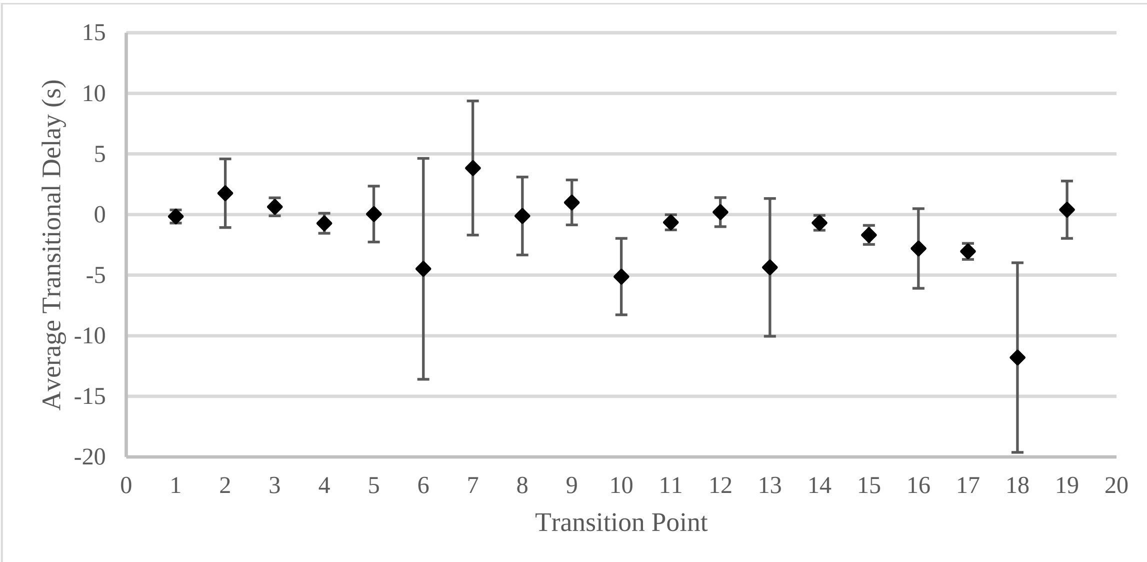


Figure 7. Average transitional delay between Central Line Tutor and reviewers for each transition point

## 5. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

Central Line Tutor is a training module for teaching medical residents the procedure of central venous catheterization. Central Line Tutor implements coloured object recognition from a live webcam video in addition to EM tracking to give trainees real-time feedback and instruction. This study shows that Central Line Tutor is able to detect workflow tasks in central venous catheterization. We also demonstrate the effectiveness of object recognition from a live webcam video for detecting task completion.

## 6. CONCLUSIONS

The workflow detection method in Central Line Tutor was able to successfully detect all transition points in the procedure with minimal delay. This suggests that Central Line Tutor is able to detect all tasks in the procedure and can be used to give trainees real-time feedback and instruction. The minimal difference in the average transitional delay between EM tracking and webcam video detection indicates that webcam video is effective for detecting task completion for central venous catheterization. The methods used for this study were very simple as this was a test to see whether the combination of EM tracking and live video analysis could be used to detect all tasks in the procedure. This was used to show that Central Line Tutor could be used as a valid teaching tool. As such, the trials recorded for this study were performed under ideal conditions. All trials were performed by a single person in a windowless room, under constant artificial lighting conditions. Further research is being done into advanced methods of object recognition that are more robust under a variety of conditions. With more advanced techniques Central Line Tutor will become a more useable training tool that can be used in a more realistic training environment.

## 7. ACKNOWLEDGMENTS

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