A Cyber-Human based Integrated Assessment approach for Orthopedic Surgical Training

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***Abstract*— In this paper, an innovative cyber-human based assessment approach developed for a VR based orthopedic surgical training simulator is presented. The approach is based on three perspectives: knowledge assessment, skills assessment and an assessment of mental composure. Such an approach provides a foundation for a robust and balanced assessment of the Virtual Reality (VR)/Augmented Reality (AR) simulation environment on improving the knowledge and skills of the users involved in the simulation based training. A discussion of the three assessment methods is provided followed by the assessment studies conducted at a medical hospital. The major outcomes of the assessment activities are discussed in the paper which underline the usefulness of such an integrated assessment approach.**

Keywords—virtual reality, orthopedic simulator, integrated assessment

I. Introduction

The use of VR based training in the medical field has increased rapidly. Researchers have developed VR based simulators for various surgical fields such as laparoscopic surgery [1, 10], brain surgery [3], eye surgery [2] among others. This increase is partly due to recent developments in low cost VR technologies such as immersive (HTC Vive, Oculus), haptic (providing a sense of touch) and Augmented and Mixed reality technologies (Microsoft HoloLens). The surgeons have shown their inclination towards such VR/AR based surgical simulators [5, 6]. It is also important to note that accreditation groups such as the American Board of Surgery (ABS) and the American Board of Orthopedic Surgery (ABOS) have approved the use of simulation based approaches for surgical training [7, 8].

In this paper, the focus is on the creation of an integrated VR based training and assessment environment for orthopedic surgical training.

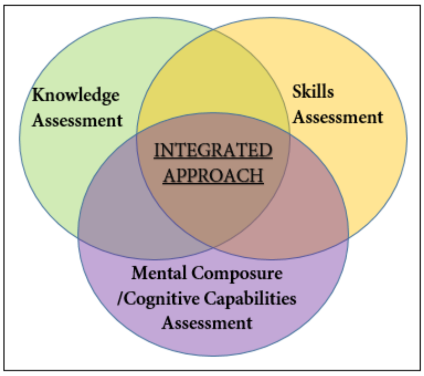

Fig. 1. Integrated Assessment Approach

In the field of orthopedic surgery, researchers have primarily focused on the development of arthroscopic simulators [11-13] and hip surgery [14, 15]. A bone drilling simulator has been experimentally validated in [16]. A bone-sawing process using haptic technology was designed and presented in [17]; other researchers have utilized haptic technologies as well [18]. The attitude of surgeons towards the role of VR-based simulators and their use as training and planning tools in surgeries have been discussed [19].

Recently, the emergence of low-cost Immersive platforms such as Vive and Oculus Rift have been explored to design VR simulators for medical surgical training contexts [20, 21]; however, this number is very less given the recent emergence of these VR platforms. Such low cost emerging platforms provide fully immersive capabilities at a lower cost compared to traditional technologies such as CAVE and PowerWall. In [20], a comparison between non-immersive and immersive Vive laparoscopic simulator has been presented. In [21], residents were tested on scenarios such as appropriate completion of the primary survey, responding to vital cues from the monitor and recognizing fatal situations in a fully immersive VR blunt thoracic trauma simulator.

Comparison studies have been conducted to rate the performances of haptic based simulators and non-haptic based simulators for surgical training [1, 22]. The results show that using the haptic platform, the users made fewer technical errors and were able to complete the task with better precision and speed [1]. For the force-sensitive tasks, visuo-haptic interface served as a better platform [21]. For

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the assessment of the simulators, researchers have compared the impact of learning on VR simulators to other techniques such as video based training [23, 24, 27]. The results from the study suggest that the haptic interface is superior to video based learning as a training tool.

There are various types of assessment techniques to help study the impact of using VR simulators on learning and training. These include (A) Pre and post-tests involving knowledge assessment based on traditional question/answer type of approach (B) In-simulator skills assessment (C) Mental composure/cognitive capabilities assessment.

A. Knowledge Assessment

Few researchers have studied the impact of using VR simulators for medical training by conducting pre and post-tests with participants [24, 25, 26]. A pre and post based method was utilized to measure the subjective experiences of the trainees for VR based endoscopy surgical training in [25]. A low cost VR simulator to train residents increasing surgical oncology capacity and capability was discussed in [24].

B. In-simulator Skills Assessment

Researchers have also adopted skills based assessment to better understand the impact of using VR based training simulators. They have focused on conducting assessments within the simulator to assess the skills of the users [18, 28]. An in-simulator assessment environment to test the decision making skills pertaining to blunt thoracic trauma was proposed in [28]. A VR based simulator for skills assessment of catheter/guidewire manipulation for cardiovascular interventions was elaborated in [18].

C. Mental composure/Cognitive capabilities Assessment

In surgical contexts, the mental composure of the surgeon has been acknowledged to play a key role in the success of a surgical procedure [40, 41]. Measuring the cognitive responses of surgical residents will provide a preliminary assessment of their ability to perform complex tasks under stress (such as in an operating room). Researchers have investigated measuring cognitive load using various modalities and processes.

Cognitive load refers to the working memory load utilized by a user when performing a particular task. In learning of complex tasks such as flying airplanes and performing surgeries, cognitive load becomes a crucial factor. The working memory is limited and differs from one person to another. If the complexity of a certain task is greater than the working memory of a person, the learning is negatively affected and the person is cognitively overloaded. Learning systems should be designed in a way that provides appropriate levels of cognitive load to its users. Cognitive load theory categorizes cognitive load into two broad types: intrinsic and extraneous load [29]. Intrinsic load refers to the load imposed by the nature of the topic to be learned. Extraneous load refers to the load imposed by the manner in which the information or instructions are provided to the users.

There are different types of methods used to assess the cognitive load on a user during the interaction with a simulator. They are broadly divided into (1) Subjective and (2) Objective Assessment.

1) Subjective Assessment

Researchers have developed and utilized a number of subjective methods to measure the cognitive load. Some of the methods are NASA TLX test [30], Paas Scale [33], among others. The Paas Scale measures the mental load of a person during a task; it consists of Likert chart ranging from 1 (very, very low mental effort) to 9 (very, very high mental effort). The NASA TLX test measures the mental, physical, temporal demand, effort and frustration using a 21 point Likert scale.

2) Objective Assessment

The objective assessment of the cognitive load can be categorized into:

a) Task based Assessment

The cognitive load can be measured objectively by using a test called Dual Task Measures. In this test, it is assumed that when the learning task becomes overloading, the level of performance in the secondary task decreases. The secondary tasks can be tasks such as pressing a button when the user hears a buzzing sound, identifying letters which are displayed on the screen, among others.

In [29], the cognitive load study during traditional cadaveric dissection training and VR simulation training was conducted using secondary task analysis; reaction to a sound stimulus was chosen as the secondary task. The results indicate that VR training leads to lower cognitive load compared to traditional dissection. Secondary task analysis has also been used to measure cognitive load during VR based temporal bone surgery and mastoidectomy training [37, 38].

b) Assessment using Physiological Indices

Cognitive State or mental state can be measured using different modalities such as external physiological indices (pupil dilation, eye movement and gaze, facial expression, etc), central physiological indices (related to the central nervous system such as brain activity) and peripheral physiological indices (related to the peripheral nervous system such as muscle activity, heart rate, among others).

In [42], facial electromyography (EMG) was used to measure facial expressiveness while viewing pictures with positive and negative stimuli in an immersive VR environment. EMG is used to measure muscle activity by detecting tiny electric impulses and then amplifying them. The results indicate that facial expressiveness was measured accurately despite the interference of the head mounted display (HMD) using EMG. Electroencephalography (EEG) was also used to classify facial expressions accurately when wearing an HMD using machine learning algorithm in [43]. EEG is a method to record brain activity by placing electrodes along the scalp.

Some researchers have measured various eye related data to recognize facial expressions, confusion, emotional arousal among others [44-46]. In [44], users wearing HMD were asked to pose with various facial expressions; the images of their eyes were photographed using the eye tracking camera which was later used to classify facial expressions using machine learning algorithm. Eye fixation data coupled with random forest machine learning algorithm was used to classify confusion in [45]. Prior research also suggests that fixation duration can be used to indicate confusion [36]. Pupil dilation was monitored to measure emotional arousal in [46]. The results show that dilation was larger when emotionally arousing pictures were shown to the users.

In [39], multimodal physiological indices along with performance data was used to measure cognitive load in individuals with Autism Spectrum Disorder (ASD) when interacting with a driving simulator. Physicological data included pupil dilation recorded using eye trackers, brain activity recorded using EEG and other peripheral physiological data such as muscle activity using electromyography (EMG), heart rate using electrocardiography (ECG) were recorded. The performance was recorded in terms of driving behavior, use of brake and accelerator during the interaction with the simulator. The results show that multimodal information can be used to measure cognitive load with increased accuracy.

As noted earlier, Knowledge assessment accomplished through pre and post-test questionnaires is different from the assessment of surgical skills. Knowledge assessment does not assess the skill level of the users. Some researchers have also developed skills based assessment for various surgical training processes [12, 13, 29]. In [12, 13], skills based assessment was performed for shoulder arthroscopy surgery in which the users had to locate and probe a simulated target within the shoulder joint using a simulated arthroscope. In [18], a skills based assessment was conducted in which the users inserted catheter and guidewire for cardiovascular interventions. However, such skills based assessments do not evaluate the knowledge gained by the users after learning interactions with a simulator. For this reason, a more integrated assessment approach is needed which is the focus of this paper. A tri-pronged assessment approach is proposed involving assessment of skills and knowledge as well as the mental composure.

Our previous publications provided an elaboration of the design aspects of the condylar plating VR simulator [9]. The focus of the previous publications [31, 32] was only on questionnaire based pre and posttests.

In this paper, an innovative integrated assessment method is proposed which is based on three perspectives: knowledge assessment, skills assessment and an assessment of mental composure. Such an assessment method with integrated perspectives lays the foundation for a robust and balanced assessment of the VR/AR simulation environment on improving knowledge and skills of the users involved in the simulation based training.

The rest of the paper is categorized in the following order. In section II, the design of the training and assessment environments are presented. The integrated assessment approach is also discussed in section II. The results from the integrated assessment activities are elaborated in section III. Discussion and conclusions are presented in section IV.

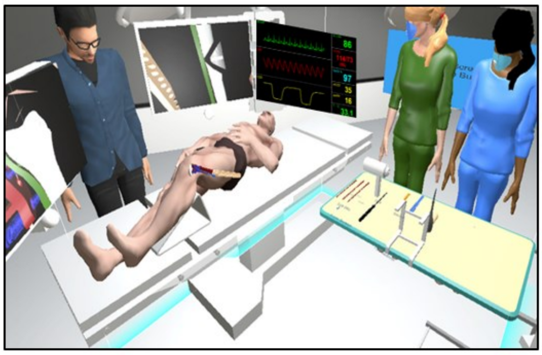
II. Design of Training and Assessment Environments

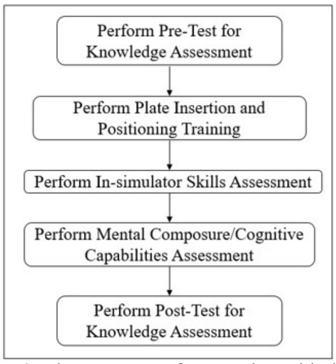
Participatory design approach was used in the design of the VR based training and assessment environments. Participatory design is a method to involve the people who are going to be affected to have their input during the design process [47, 48]. It is a democratic design process for the design of social and technological systems based on the argument that users should be involved in the design and all stakeholders should have input during the design process [49]. Participatory design has been utilized by several researchers in the field of VR [50-53]. Participatory design for the creation of 3D virtual scenes for applications such as virtual museums has been used in [50]. In [51], a study was presented to evaluate the feasibility and the efficacy of participatory design approach to evaluate the usability of virtual product interface for products such as microwave and electric oven. A VR based tool for the participatory design of workplace has been discussed in [52]. The resulting VR tool helped in addressing issues such as interface design and cognition during the design of workspaces. A study has been presented involving civic participation in the design of a public park using VR in [53].

In our participatory design approach, three expert surgeons provided input on several design aspects of the VR based environments for condylar plating surgical procedure under the coordination of the lead expert surgeon (who is also a co-author in this paper). The participatory design approach involved first understanding the Condylar plating surgical procedure and especially the plate positioning module through interactions with expert surgeons. Subsequently, the scope of the VR based environments and the assessment methods were finalized. Several design models based on eEML (engineering Enterprise Modeling Language) were created to capture the functional and temporal activities of various design and development activities in this phase. The eEML based design models have been explained in our previous publications [34, 35]. Subsequently, the environments and assessment methods were built following the feedback and suggestions for the expert surgeons during each stage of development.

TABLE I. TRAINING AND ASSESSMENT ENVIRONMENTS

	Skills Assessment	Mental Composure/ Cognitive Capabilities Assessment	Knowledge Assessment
Training	• Plate Insertion and Positioning • Non essential Hand Movement	• Plate Positioning	• Plate Insertion and Positioning
Assessment Scenario	• Inserting the plate inside the patients' leg with minimal deviation from the ideal surgical path • Avoiding the crucial nerves such as Sciatic nerve during the insertion and positioning process • Minimizing the non-essential hand movements during the insertion and positioning process	• Measuring mental composure while positioning the plate using red, yellow and green light indicators	• Measuring knowledge gained during the plate insertion and positioning training
Method	• In-simulator assessment programmed in the VR environment	• Measuring pupil dilation during plate positioning using eye tracking cameras	• Questionnaire based pre and post test method





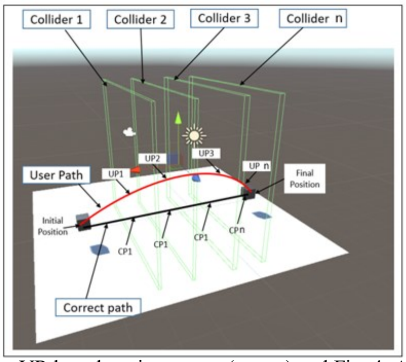


Fig. 2. A view of the Condylar Plating Training Environment; Fig. 3. The sequence of Interaction with the VR based environments (center) and Fig. 4. A conceptual diagram for calculation of deviation from the actual path (right)

The scope of training for the developed simulation environment is a process involving the condylar plating surgery which supports surgical procedures to address fractures of the femur bone. In this paper, the focus is on the development of training and assessment environments for the plate insertion and positioning of the condylar plating surgery in which the users learn to insert and position the plate correctly inside the patient's leg.

The training environments (one of the views of the position training environment is shown in Fig. 2) are developed for the Vive based platform.

The users perform the assessment activities after interacting with the insertion and positioning training environments. The assessment activities involve skills assessment, assessment of mental composure and knowledge assessment. Table I provides the details about three assessment activities which are part of the integrated assessment method. Fig. 3 shows the sequence in which the users interact with the training and assessment environments. The description of the three assessment environments follows.

A. Skills Assessment

This assessment is used to assess the skills of the medical staff in the insertion and positioning of the plate inside the patient's leg. The focus is on proper insertion of the plate following the ideal surgical path and avoiding crucial nerves during the insertion. The assessment also focuses on minimizing the non-essential hand movements during surgery. The skills assessment consists of three scenarios which are integrated within the VR based environment. The discussion of the three scenarios follows.

Scenario 1: Inserting the plate inside the patients' leg with minimal deviation from the ideal surgical path.

The Vive based plate insertion environment provides the necessary information to the residents to determine the appropriate surgical pathway. Deviation from the appropriate pathway leads to inefficient hand movements and possible development of surgical bad habits. In other words, every movement of the hands should have a purpose to achieve a certain goal. HTC Vive is a fully immersive platform in which users can interact with virtual objects using handheld controllers. The process of calculating the deviation for the path taken by the resident (user path) from the path specified by the (instructor / experienced) surgeon (correct path) is discussed in this section.

Fig. 4 shows a conceptual diagram showing the correct path and the user path for the positioning of a virtual part. The initial and final position of the part is also shown in Fig. 4. Collision detection has been utilized to calculate the deviation. As seen in Fig. 4, a number of colliders have been placed in between the initial and final positions of the part. The correct path is shown in black and the user path is shown in red in Fig. 4. Whenever, the part passes through the colliders, the coordinate of the collision point is noted for both the correct and user paths. The distance between the collision point of the user path and the correct path is the preliminary deviation. The total deviation is calculated as the average of deviations from the collision points on each of the colliders. The process of calculation of deviation follows.

In Fig. 4,

CP1, CP2, CP3,… CPn = correct path point; the point where the part hits the collider when it is moving in the correct path

UP1, UP2, UP3,… UPn = user path point; the point where the part hits the collider when the user is moving the part

Deviation n (Δn) = Distance between UPn and CPn

Hence,

$$\text{Total Deviation } (\Delta) = \sum_{i=1}^{n} \frac{D_i}{n}$$

α1 is the initial score of the user

The final score (τ1) is calculated as

$$\tau 1 = (\alpha 1 - \Delta) * 100 \qquad (1)$$

where α1 was set to 1 after discussions with the expert surgeons.

Scenario 2: Avoiding the crucial neurovascular structures such as Sciatic nerve during the insertion and positioning process

The sciatic nerve is the largest nerve in the body. It is formed by the union of five nerve roots from the lower spine. It is a crucial nerve that connects the spinal cord with thigh, leg, and foot. It goes through the back of the knee and can be harmed while performing surgery in the region of the knee including condylar plating of the distal femur if proper care is not taken. The position training environment consists of a virtual sciatic nerve which is placed below the femur bone of the virtual patient. A yellow/red light indicator is placed in the virtual environment as well. When the user is close to the sciatic nerve, the yellow light flashes; which is a warning provided to the user to change the trajectory of the condylar plate so that it does not hit the sciatic nerve. However, if the user hits the sciatic nerve, the red light flashes and the user has to restart the insertion and positioning procedure from the beginning. The environment also records the number of times the user went close to the sciatic nerve during the insertion and positioning procedure. The user's score is based on the number of times he/she went close to the sciatic nerve. The score is calculated as follows

$\alpha 2$ is the initial score of the user

$\beta 2$ is the number of times the user goes close to the sciatic nerve

The final score ($\tau 2$) is calculated as

$\tau 2 = \alpha 2 - \beta 2$ (2)

where $\alpha 2$ was set to 100 after discussions with the expert surgeons.

This scenario initiates when the user has completed the insertion of the assembled plate inside the patient's leg. In this scenario, the user holds the plate using the Vive controller and tries to position the plate correctly without going too close to the sciatic nerve.

Scenario 3: Minimizing the non-essential hand movements during the insertion and positioning process

The correct positioning of the condylar plate on the femur is the most critical step of the condylar plating surgical procedure. The surgeons need to be precise and accurate while inserting the condylar plate on the distal lateral side of the femur. Non-essential hand movements (NEHM) such as handshaking and wobbliness affect the surgeon's ability to precisely and accurately insert the condylar plate. We have introduced a training module which helps the residents reduce the non-essential hand movements. The entire insertion region for the condylar plate is divided into three zones which are green, yellow and red zones.

The green zone is the acceptable region for the insertion. The user needs to move the cube in the green region from left to right. The yellow region and the red region are the regions the user should avoid. The users who tend to have non-essential hand movements are more likely to go to the yellow and red region moving the cube over the green zone. A real-time textual prompt-based training system is introduced so that the condylar plate remains in the green zone.

Here,

$\alpha 3$ is the initial score of the user (time spent by the user in the green zone)

$\beta 3$ is the time spent by the user in the yellow zone

σ is the penalty for spending time in the yellow zone

$\gamma 3$ is the time spent by the user in the red zone

ω is the penalty for spending time in the red zone

The final score ($\tau 3$) is calculated as

$\tau 3 = (\alpha 3 - \beta 3 * \sigma - \gamma 3 * \omega) * 100 / \alpha 3$ (3)

where σ and ω were set to 25 and 50 respectively after discussions with the expert surgeons.

The total score (cumulative score) for the Training environment is based on the following calculations:After the calculation of the total scores ($\tau 1$, $\tau 2$ and $\tau 3$) as shown in (1), (2) and (3) for each of the three scenarios, the expert surgeons rated each scenario based on the impact it has on the training procedure.

Here,w1 is the weight for scenario1 (Minimum deviation from the surgical pathway)

w2 is the weight for scenario 2 (proximity to the sciatic nerve)

w3 is the weight for scenario 3 (non-essential hand movement)

The cumulative score (weighted average) is

Cumulative Score (τ)

$$= ((\tau 1 * w1 + \tau 2 * w2 + \tau 3 * w3)/(w1 + w2 + w3)) \quad (4)$$

TABLE II . AVERAGE WEIGHTED SCORES FOR EACH SCENARIO

Scenarios	S1	S2	S3	S4	AWS
Inserting the plate inside the patients' leg with minimal deviation from the ideal surgical path.	30	50	35	15	32.5 (w1)
Avoiding the crucial nerves such as Sciatic nerve during the insertion and positioning process	50	30	35	60	43.75 (w2)
Minimizing the non-essential hand movements during the insertion and positioning process	20	20	30	25	23.75 (w3)

B. Mental Composure/Cognitive Capabilities Assessment

The measurement of cognitive responses of surgical residents provides a preliminary assessment of their ability to perform complex tasks under stress. After the consultations and discussions with three expert surgeons, the condylar plate insertion task was chosen as the task in the surgery which the mental composure and cognitive capabilities are tested the most. Condylar plating insertion is the process of inserting the plate inside the patient's leg correctly. During the assessment, the users have to properly place the plate inside the patient's leg following the red, yellow and green colored indicators located at the proximal and distal end. The users have to keep adjusting the plate until both the colored indicators turn green. In order to measure the cognitive load or mental stress, the pupil dilation of the user is measured. It has been asserted that the increase in cognitive load or mental stress increases the dilation of pupil of the user.

The pupil dilation is measured by using the eye tracker attached in the Vive Pro Eye immersive headset. A view of the Vive Pro showing the eye trackers is provided in Fig. 5. If a user is cognitively overloaded or mentally stressed, the pupil gets dilated and the pupil diameter increases to 5-7 mm. If the average dilation is greater than the threshold pupil dilation (5-7 mm), changes will be made in the VR environment such as providing extra cues, improving the environment, using colors and lighting which can be useful in lowering the cognitive load or mental stress.

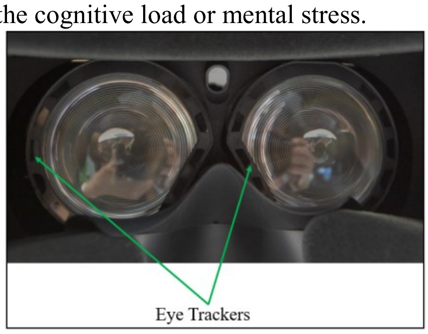


Fig. 5. Eye trackers in the Vive Pro Eye headset

C. Knowledge Assessment

Questionnaire based pre and posttest method was used to assess the knowledge gained by the users after the interactions with the VR based environment. In this method, the users first take a pre-test in which their knowledge regarding the condylar plate insertion task is assessed through a set of questions. Subsequently, they interact with the VR based simulator performing the training activities. Finally, the users take the post-test in which the same set of questions asked in the pre-test is asked again. The knowledge gained is calculated by the difference in the score of post-test and pre-test. The process of knowledge assessment and how it is inter-related with other assessment methods is shown in Fig. 3.

III. Results of the Assessment Studies

The impact of using the VR based training environments for plate insertion and positioning training was assessed through interactions with surgeons and surgical staff at a medical hospital. One of the co-authors of the paper and an expert orthopedic surgeon helped in conducting the assessment activities. Before the assessment activities, the co-author and two other expert surgeons reviewed the training and assessment environments to ensure their correctness. They provided detailed feedback and a list of changes to be incorporated to create effective and user-friendly training and assessment environments. After these changes were implemented and verified, the immersive simulator-based assessment involving medical personnel was undertaken.

A total of nine participants interacted with the VR based simulator as part of the immersive simulator-based assessment studies. Out of the nine participants, four were Surgery Coordinators, three were Physician Assistants and two were Medical Assistants The demographics of the participants are shown in Table III.

TABLE III. Participants Demographics

Experience (in years)	High: 23 Low: 2 Mean: 12.25
Prior experience with VR Technology	Yes: 1 No: 8
Prior understanding of the surgical procedure	Yes: 3 No: 6

A. *Results of the In-Simulator Skills Assessment*

The participants first completed VR based training in inserting the plate inside the patient's leg. Subsequently, they were assessed based on scenario 1 (inserting the plate inside the patients' leg with minimal deviation from the ideal surgical path). After the insertion, the participants trained in positioning the plate correctly inside the patient's leg which led to the assessment activity based on scenario 2 (avoiding the crucial nerves such as Sciatic nerve during the insertion and positioning process). Further, they also trained in minimizing the non-essential hand movements during the surgical procedure. Finally, they were assessed based on scenario 3 (minimizing the non-essential hand movements during the insertion and positioning process).

Each participant was allowed a total of sixty minutes to complete the training and assessment activities. The participants were allowed to complete the training as many times as needed before they started the assessment activities. The lead expert surgeon categorized the cumulative scores of the participants into four ratings or groups: Highly Skilled, Competent, Marginal and Unskilled. The scores for these ratings are shown below:

Rating	Score
Highly Skilled	65 points or more
Competent	55 to 65 points
Marginal	45 to 55 points
Unskilled	Less than 45 points

The same categories for the ratings were also used for individual scenarios. For assessment scenario 1, two participants were found to be highly skilled, three were competent and four were marginal. For assessment scenario 2, five participants were highly skilled, three were competent and one participant was marginal. For assessment scenario 3, nine out of the nine participants were in the highly skilled category.

The cumulative scores (based on equation 4) from the assessment activities are shown in Fig. 6. Among the nine participants, two were in the highly skilled category, six were in the competent category and one was in a marginally competent category. The scores indicate that the VR based environment can serve as a useful skill training tool.

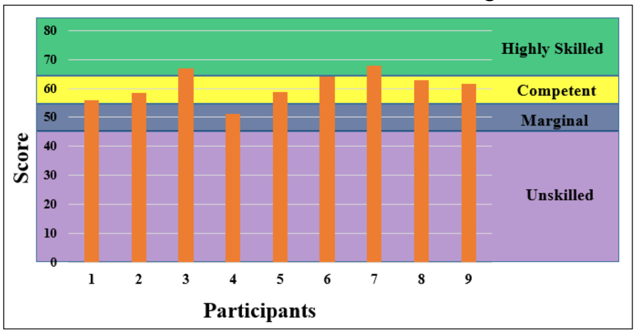


Fig. 6. Results from the in-simulator skills assessment activities

B. *Results of the Mental composure/Cognitive capabilities Assessment*

After the completion of the skills based assessment, the participants performed the mental composure/cognitive capabilities assessment. In order to assess the cognitive load, the users interacted with the Condylar Insertion environment in which their pupil dilation was tracked. The pupil dilation was tracked every frame (60 times per second) during their interaction with the condylar insertion environment. Apart from measuring the pupil dilation, NASA TLX Test was also conducted to verify the objective pupil diameter based mental composure/cognitive capabilities assessment.

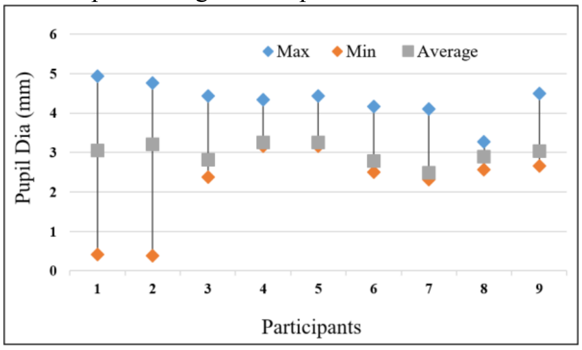


Fig. 7. Results from the eye tracker based mental composure/cognitive capabilities assessment

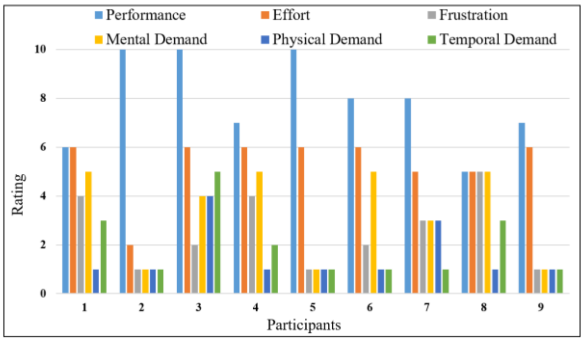


Fig. 8. Results from the NASA TLX test based cognitive assessment

The results from the mental composure/cognitive capabilities assessment are shown in Fig. 7 and Fig. 8. The maximum, the minimum and the average pupil diameter for each participant during the assessment can be seen in Fig. 7. The average pupil diameter for each participant during the training is steady at around 3 mm. This indicates that the participants are not being mentally stressed or cognitively overloaded during the condylar plate insertion task. The results from the pupil dilation based assessment was corroborated with the NASA TLX based assessment. As seen in Fig. 8, the users have indicated that the frustration, mental, physical, and temporal demand were low.

C. *Results of the Knowledge Assessment*

A pre and post-test method based knowledge assessment study was conducted to understand the usefulness of the VR based simulator as a teaching tool. As explained in the previous section, the nine participants first performed a pre-test; subsequently, they interacted with the condylar plate positioning and insertion training environments. Finally, they performed a post-test after the VR interactions. The improvement was measured as a difference between the score in the post-test and pre-test.

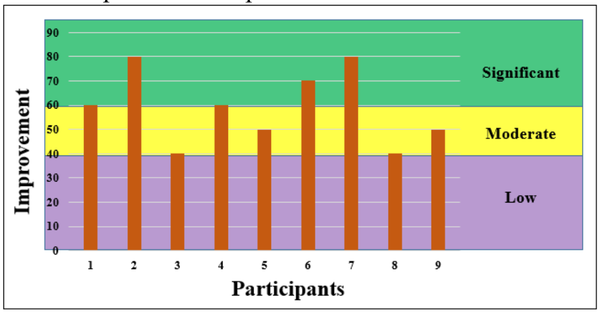


Fig. 9. Results from the pre and post-test based knowledge assessment

The results of the knowledge assessment are shown in Fig. 9. Expert surgeons categorized the improvement into three categories. An improvement of over 60 points was considered to be significant. An improvement between 40 to 60 points was considered to be moderate and an improvement of less than 40 points was considered to be low. As seen in Fig. 9, five out of nine participants showed significant improvement and four showed moderate improvement. This indicates that the VR based environment can serve not only as a skills training tool but also as a useful tool to teach the concepts of condylar plating surgery. The preliminary results from the in-simulator skill assessment activities indicate that such simulators can benefit training of healthcare professionals. The results from the mental composure/cognitive capabilities assessment provided better understanding about the mental composure of the participants; additional work is needed to create more realistic simulation environments which can induce elements of stress, which can affect nurses and others with lesser experience in participating in physical surgical procedures in hospitals. The feedback received from the participants through the NASA TLX test also provided more insights. The results from the pre- and post-test activities provided an in-depth assessment of the knowledge acquired by the participants after using the simulation based environments. An important aspect is the recognition of the importance of the surgeons and medical staff in sharing their knowledge and understanding of the complex surgical procedures; this served as a foundation to understand, design and implement the core simulation environments as well as other introduce the metrics discussed in this study.

IV. Conclusion

An innovative integrated assessment framework was proposed in this paper which was based on three perspectives: knowledge assessment, skills assessment and an assessment of cognitive aspects including mental composure.

In this paper, the focus of discussion was on a broader foundation to support a robust and balanced assessment of the impact of VR/AR simulation environments to improve knowledge and skills of the users. Measures to support the three assessment methods was also discussed. The results of assessment activities conducted involving health care professionals at a hospital were also presented. These preliminary results highlight the potential of adopting such an integrated assessment framework for training healthcare professionals including nurses.

Future activities include incorporation of additional measures to support further assessment of cognitive/mental composure/response attributes of participants as well as conducting assessment activities including a larger population of participants from a wide range of demographics including medical students, residents, budding surgeons and other ancillary medical and health care professionals. Cyber-Human issues such as affordance, cognitive load and other aspects can also be studied as part of a broader assessment approach.

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