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Award Number:

W81XWH-10-1-0870

TITLE:

Advanced Prosthetic Gait Training Tool

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REPORT DATE:

October 2013

TYPE OF REPORT:

Final Option

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT:

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE October 2013		2. REPORT TYPE Final Option		3. DATES COVERED 20September2012-19September2013	
4. TITLE AND SUBTITLE Advanced Prosthetic Gait Training Tool				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81XWH-10-1-0870	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Dr. Karim Abdel-Malek, Professor, University of Iowa email: amalek@engineering.uiowa.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The University of Iowa Iowa City, IA 52242-1316				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool to aid in professional development for clinicians and prosthetists at military treatment facilities providing care for wounded service members. The effort will ultimately provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art gait laboratories. The tool will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans.					
15. SUBJECT TERMS- none provided					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 19	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code)

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Advanced Prosthetic Gait Training Tool

INTRODUCTION

The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool to aid in professional development for clinicians and prosthetists at military treatment facilities providing care for wounded service members. The effort will ultimately provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art gait laboratories. The tool will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans.

Due to the wide variety of injuries suffered by military personnel and the wide range of medical interventions employed to improve the standard of living for patients, it is very challenging to expose medical practitioners to a comprehensive set of human subjects to support their training in gait analysis. Under this effort, an extensive set of archived motion capture data representing gait patterns for wounded service members with varying challenges will be harvested from the Military Performance Laboratory at the Center for the Intrepid at Brooke Army Medical Center in San Antonio.

To ensure confidentiality for these service members, the gait patterns will be imposed on a digital human model, referred to as SantosTM. This computer-based model provides additional benefit to trainees, allowing for the repeated virtual playback of motion capture sequences that can be viewed from any angle. Options will also be provided to allow trainees to view clothed or unclothed avatars, stick figures, or even skeletal models to support their analyses. The system will also allow trainees to isolate specific parts of the anatomical model for detailed analysis. The trainees will enter their assessments of observed gait deviations, which will be scored against standard measures prepared by experts in the field. Based on the accuracy of the trainees' responses, the system will provide remediation. When fully developed, this system will provide a comprehensive training experience, allowing practitioners to benefit from a broad array of patient data previously collected by the US Army, thus bridging a critical gap in current medical training practices. The system will be developed to accommodate additional sequences captured over time, thus offering an extensible, distributable, and sustainable training library.

In Year 1 of the effort, significant work was completed at the University of Iowa Center for Computer-Aided Design (CCAD), the University of Iowa Orthopedic Gait Analysis Laboratory (OGAL), and the Military Performance Laboratory (MPL). A representative set of motion capture sequences was provided by MPL to CCAD and OGAL. CCAD's work focused on imposing these sequences on the Santos digital human avatar. An initial user interface for the training application was also developed. These data were then provided to researchers from OGAL and MPL to support an assessment of the ability of trained clinicians to observe and accurately identify gait deviations in the target environment. Researchers at OGAL also embarked on a program to develop a web-based questionnaire using the Santos software. This questionnaire will be sent to experts in the field of gait analysis. The primary goal of the

questionnaire is to identify the sensitivity of gait experts to detect variations in gait for different severity levels of the patients. In addition, the differences in ability to detect variations in gait conditions for skinned avatar vs. line-skeletal avatar, concurrent (side-by-side) image representation vs. consecutive (one after the other) image representation, and image vs. movie representation was also studied. The information gathered from this approach will be used to identify a set of gait profiles and to develop the training and evaluation questionnaire.

During Year 1 of Phase 2 effort, the initial interface was improved further with feedback from gait experts at OGAL to incorporate tutorial options to best train a new clinical student in gait deviations. For most of Year 1 of phase 2, MPL was responding to queries and waiting for IRB approval to collect the data necessary to go into the software. However, OGAL members created a couple preliminary tutorials using dummy data to try out various ideas in training. These tutorials served as reference for VSR to incorporate the interface changes and develop additional capabilities to enhance learner interaction with the software. In the sections below, these training ideas and the development of the tutorial are discussed.

The current base effort built upon the Phase 1 demonstration of the feasibility of developing a curriculum centered around motion-capture data collected at MPL within the Santos software. The three main components of the project are: 1) motion capture investigations; 2) gait deviation ratings; and 3) software design. The team was able to progress on two of these three main components: the gait deviation ratings and the software design.

Gait Deviation Ratings

We have developed an assessment to examine general issues related to the ability of the user to observe differences in the walking pattern. We have created a module to assess Visual Sensitivity - Module 1. We have also generated two modules to train individuals to distinguish gait deviations: Observational Gait Analysis : Module 1 - Trunk Motion and Observational Gait Analysis : Module 2 - Lower Limb Motion.

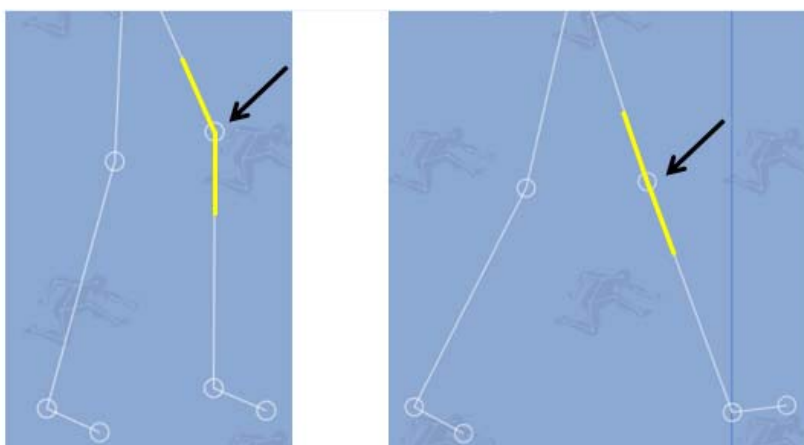
Visual Sensitivity (VS) – Module 1

[Link to the module: https://uiowa.qualtrics.com/SE/?SID=SV_eR5vVCSaSKMASax]

The goal of the first VS Module is to assess the sensitivity of observers in visually detecting differences in static images of the knee joint, represented at various times during the walking cycle. To accomplish this, two images of the knee are presented with approximately 0, 5, or 10 degrees of difference. A secondary goal of this module is to determine if the ability to detect differences was affected by the image presentation. To accomplish this, both stick figure representations and avatar representations were used. Figure 1 below shows an example of the images.



Avatar Form



Stick Figure Form

Figure 1: Examples of the type of visual comparisons that the observer was asked to judge.

The users were asked to rate their confidence in judging the differences between the two modules (Figure 2).

☐	1- Definitely no difference
☐	2- Probably no difference
☐	3- Unsure of a difference
☐	4- Probably a difference
☐	5- Definitely a difference

Figure 2: Scoring system used by observers to represent their ability to detect differences between the two images.

Data from 20 practicing physical therapist has been collected and is currently being analyzed.

Observational Gait Analysis Modules – Phase I

A series of OGA Modules for Phase I are being generated with the goal of honing the observational skills of the users. Modules in this phase will focus on the ability of the user to discriminate between a more ideal walking pattern and non-specific gait deviation. The approach taken is to segment the process by focusing attention on the motion of the trunk and the motion of one lower limb before trying to examine total body motion. The body representations for these initial modules are stick figures.

Observational Gait Analysis (OGA) Module 1: - Trunk Module

[Link to this module: https://uiowa.qualtrics.com/SE/?SID=SV_7P0WyWVTIILSHwF]

This module is focused on distinguishing deviations in movements of the head and trunk during walking. The observer is asked to consider stick figure representations of motions of the head, arms, and trunk (HAT) when viewed from the front (frontal plane) and the side (sagittal plane) relative to what is considered a more ideal pattern of motion (Figure 3).

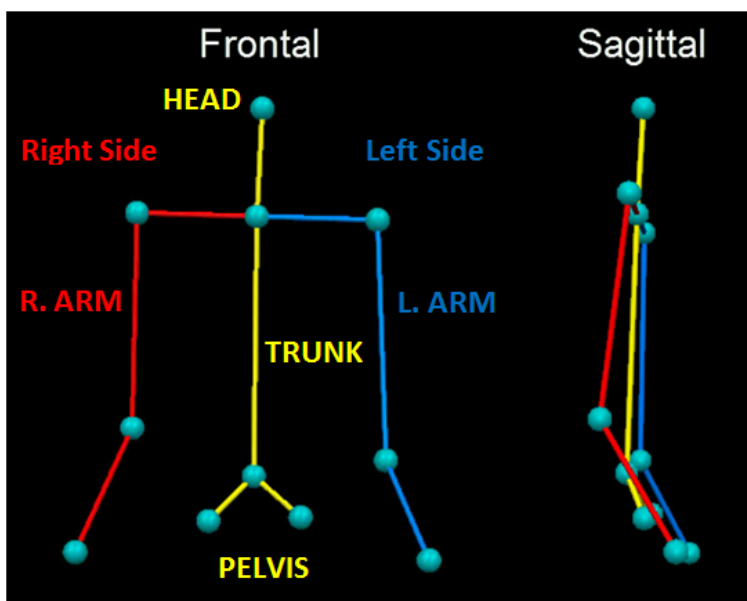


Figure 3: Frontal and sagittal plane stick figure representations of the trunk, head, and arms.

The observer is shown a video clip representing a normal movement pattern of the HAT and then asked to judge potential deviations in the movement of the HAT.

☐ Close to Ideal
 ☐ Apparent Deviations
 ☐ Not Ideal, but cannot distinguish the specific deviations

Trunk Motion:

Items

R. Side
 L. Side
 L. & R. Side
 Front
 Back
 Front & Back

Figure 4: If the user identifies that there is a deviation, then they are asked to judge the nature of the deviation.

Observers are then provided with feedback showing the pattern of motion relative to a vertical axis and comparing the current pattern to a more ideal pattern (Figure 5). Text is also provided that identifies the more obvious deviations.



Figure 5: Once the observer has decided if and what the deviations in HAT motion are, visual feedback is provided showing the pattern of motion relative to the vertical orientation and relative to a more ideal pattern.

Thus far, we have distributed a draft of this module to 15 students in an effort to get feedback on the organization and presentation of the material.

OGA Module 2: Single Lower Limb Module

[Link to this module: https://uiowa.qualtrics.com/SE/?SID=SV_88FI8NcO4ytXxk1]

This module is focused on distinguishing deviations in movement of the lower limb during walking. The observer is asked to consider stick figure representations of motions of the lower limb when viewed from the front (frontal plane) and the side (sagittal plane) relative to what is considered a more ideal pattern of motion (Figure 6).

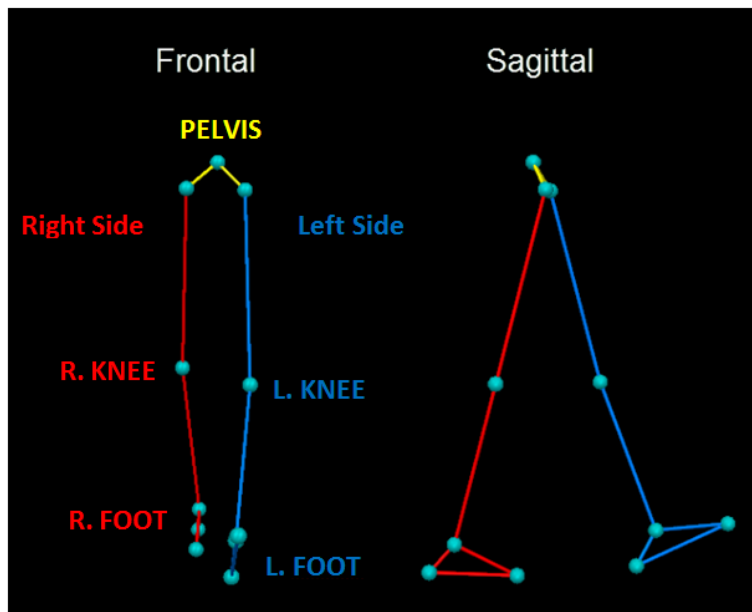


Figure 6: The lower limb module represents the movement of both lower limbs during walking from the frontal and sagittal perspectives.

Observers are asked to focus on four critical times during the walking cycle and to detect differences from the ideal (Figure 7).

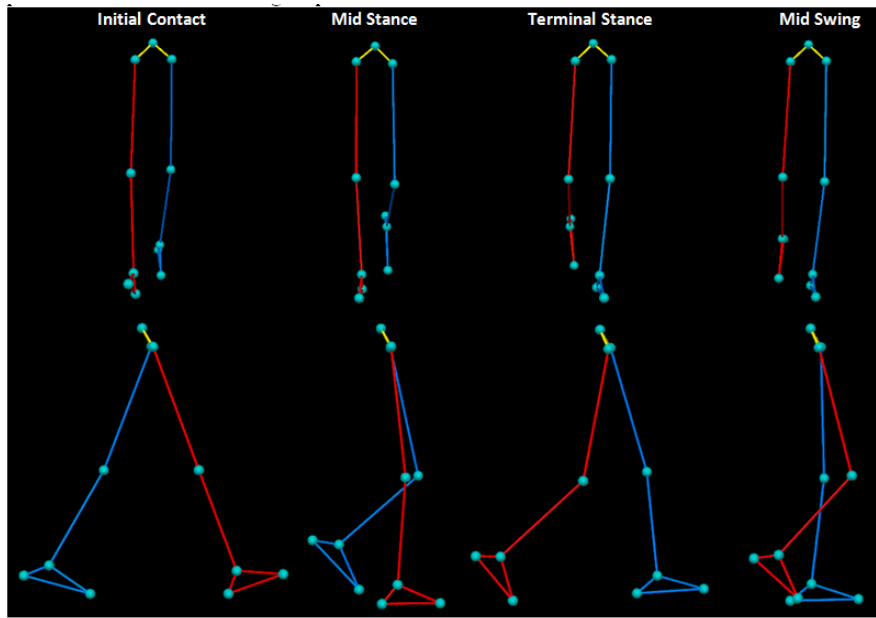


Figure 7: The position of the lower limb at four critical times during the walking cycle as seen from two perspectives.

Observers will initially be asked to determine if they perceive a deviation. If they have identified a deviant pattern, they will be asked to attribute the deviation to specific issues in the frontal and sagittal planes (Figures 8 & 9).

Frontal Plane Deviations

Base of Support

- ☐ Close to Ideal
- ☐ Too Wide
- ☐ Too Narrow

Lower Limb Stance Alignment (Choose all that apply)

- ☐ Close to Ideal
- ☐ Knees In (Genu valgus)
- ☐ Knees Out (Genu varus)
- ☐ External Rotation
- ☐ Internal Rotation

Lower Limb Swing Alignment (Choose all that apply)

- ☐ Close to Ideal
- ☐ Circumduction
- ☐ Abduction
- ☐ Adduction
- ☐ External Rotation
- ☐ Internal Rotation

Figure 8: Possible lower limb deviations observed in the frontal plane.

Sagittal Plane Deviations

Joint Range of Motion around Initial Contact

	Increased Flexion/Decreased Extension	Decreased Flexion/Increased Extension	Close to Ideal
Hip	☐	☐	☐
Knee	☐	☐	☐
Ankle (Dorsiflexion/Plantarflexion)	☐	☐	☐

Joint Range of Motion around Mid Stance

	Increased Flexion/Decreased Extension	Decreased Flexion/Increased Extension	Close to Ideal
Hip	☐	☐	☐
Knee	☐	☐	☐
Ankle (Dorsiflexion/Plantarflexion)	☐	☐	☐

Joint Range of Motion around Terminal Stance

	Increased Flexion/Decreased Extension	Decreased Flexion/Increased Extension	Close to Ideal
Hip	☐	☐	☐
Knee	☐	☐	☐
Ankle (Dorsiflexion/Plantarflexion)	☐	☐	☐

Figure 9: Possible lower limb deviations observed in the sagittal plane.

Once the user has registered an assessment, visual and text feedback is provided that helps to identify the more obvious deviations (Figure 10).

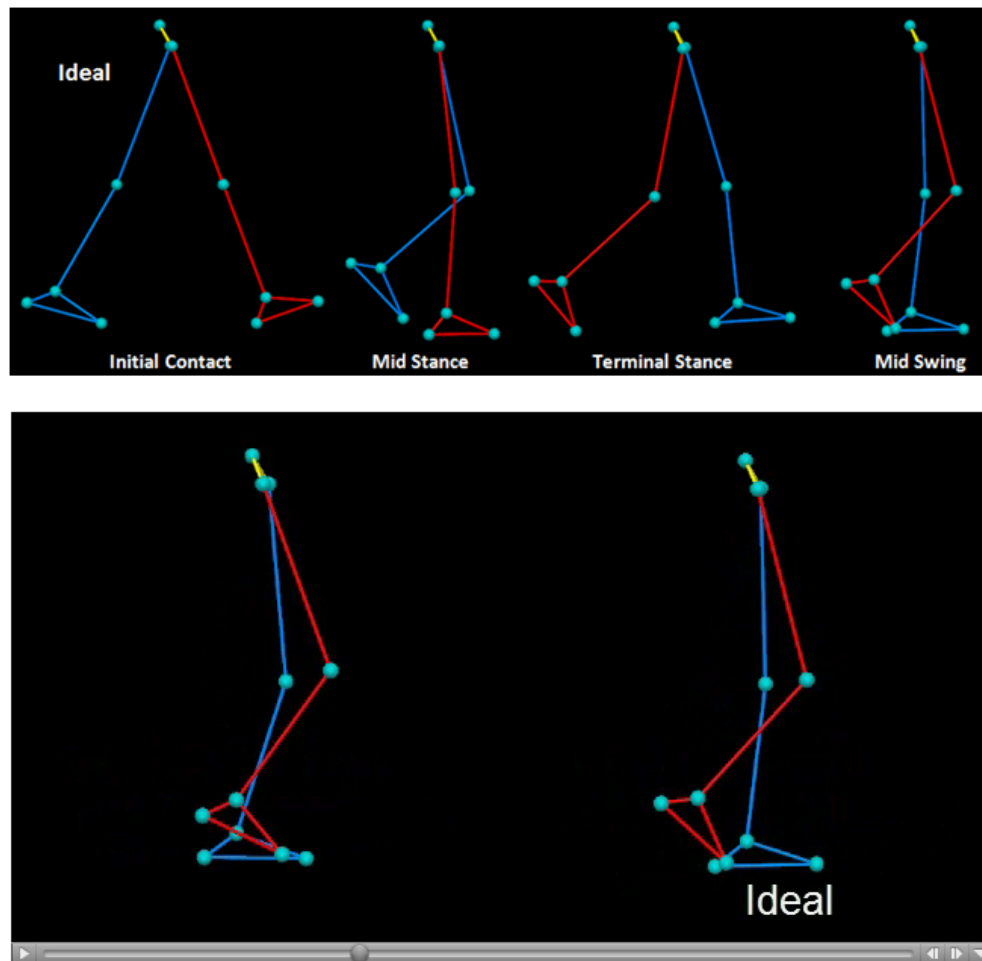


Figure 10: Visual feedback provides information on the ideal pattern at specific time in the gait cycle, as well as a side-by-side comparison of the gait pattern relative to the ideal pattern.

This module has been distributed to project personnel for feedback. We are currently revising it and plan to send it out for additional feedback.

Goals

Our immediate goals are to complete modification, development, and testing of the modules in Phase I. We are also in the process of integrating these modules into the environment generated by CCAD. In Phase II, we will develop the training modules specific to the gait patterns of individuals with amputations, based on the gait data collected at MPL.

Prosthetic Gait Software

The functionality and visual appeal of the Prosthetic Gait software has improved significantly over the past year. The layout and usage of the software has been developed into a more intuitive and user-

friendly format, and the accompanying quiz window has been remodeled to feature many new capabilities.

With the default startup of Prosthetic Gait, the Santos avatar is displayed in the center of the screen with 50% opacity and his color-coded line body skeleton shown. The avatar is initially loaded with a control MoCap file. The main toolbar, including access to the slide-out MoCap library, the playback tools, and the slide-out additional tools/settings, is positioned at the top of the screen. Minimized by default, the quiz window makes up the bottom of the screen.

By clicking the MoCap library arrow in the top left corner, folders containing MoCap files slide into view. Tooltips containing each folder's category can be seen by hovering the mouse over each folder. The folders are currently organized into three categories: Control, Lower Body, and Upper Body. Opening a folder displays either the sub-folders inside of each category, if any exist, or the motion capture files. For instance, if the Lower Body folder is clicked, two more folders (Running and Walking) pop up. Selecting either of these folders brings up the corresponding MoCap files associated with lower body gait issues. The avatar is loaded with the appropriate data upon clicking a specific motion file. After selecting a new MoCap file, an icon is displayed on the respective file to enhance ease of user navigation within the folders, as seen in Figure 11.

MoCap files can be played on the avatar through the use of the playback tools. The toolbar consists of a play button, pause button, playback slider, running time, and a play speed dropdown button. The playback slider allows for the user to manually select a frame of motion, and the time updates with sliding as well. The playback speed dropdown can be used to view motion at various speeds (x2.0, x1.0, x0.75, x0.5, x0.25). Although the playback speed functionality is not currently working, it will be corrected in the future.

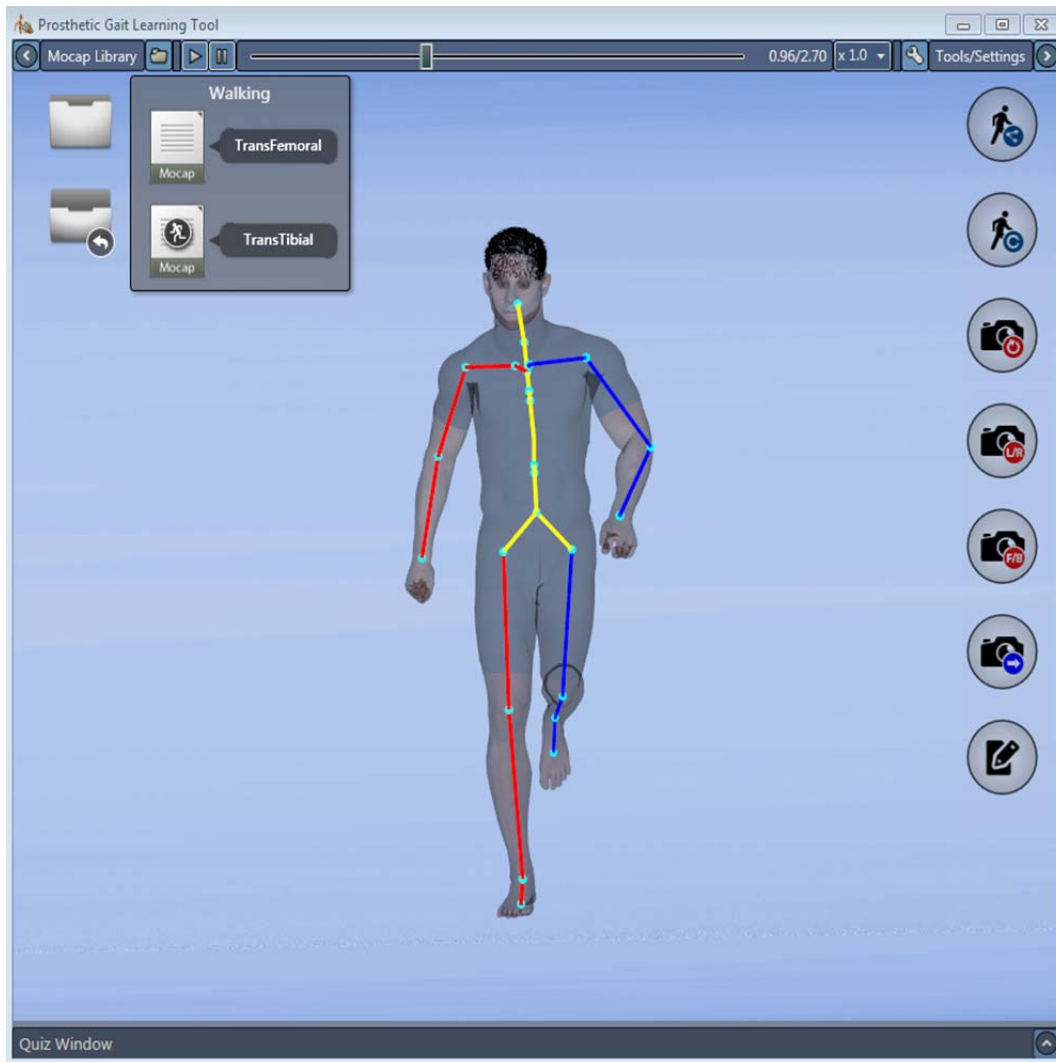


Figure 11: The Prosthetic Gait software after a MoCap file has been selected from the slide-out library. Additional tools have also been brought into view using the arrow on the main toolbar, which also includes access to the playback tools.

Additional tools and settings can also slide in and out of view using the arrow in the top right corner. Tooltips display the capabilities of the buttons, which include: Show/Hide Skeleton, Show/Hide Control Avatar, Free Camera View, Left/Right View, Front/Back View, Camera Follow On/Off, and MoCap Offsets. Clicking the Show/Hide Skeleton button toggles between an almost transparent avatar with line skeleton, a fully opaque avatar with no line skeleton, and the default 50% opacity avatar with line skeleton. The color scheme of the line skeleton has been modified to match the online quiz developed by OGAL. The Show/Hide Skeleton button will add or remove a fully opaque avatar with no line skeleton next to the current avatar. The avatar produced by this button will always play the control MoCap file. The Left/Right and Front/Back Camera View buttons will display the avatar(s) facing the corresponding direction. Free Camera View, meaning the user is able to click and drag the camera around, can be applied through the button itself or by clicking on the background. The Camera Follow On/Off button can be clicked to hold the camera stationary or fix it to follow the main avatar. This functionality of this button is disabled, however, when the camera is not in free camera mode. The last button, MoCap

Offsets, displays a separate window containing a list of all of the joints of the avatar and boxes containing their current offset value, which is displayed in Figure 12. The joints and values are all generated through an XML file. These values can be altered and applied to the specified joint of the main avatar via this window.

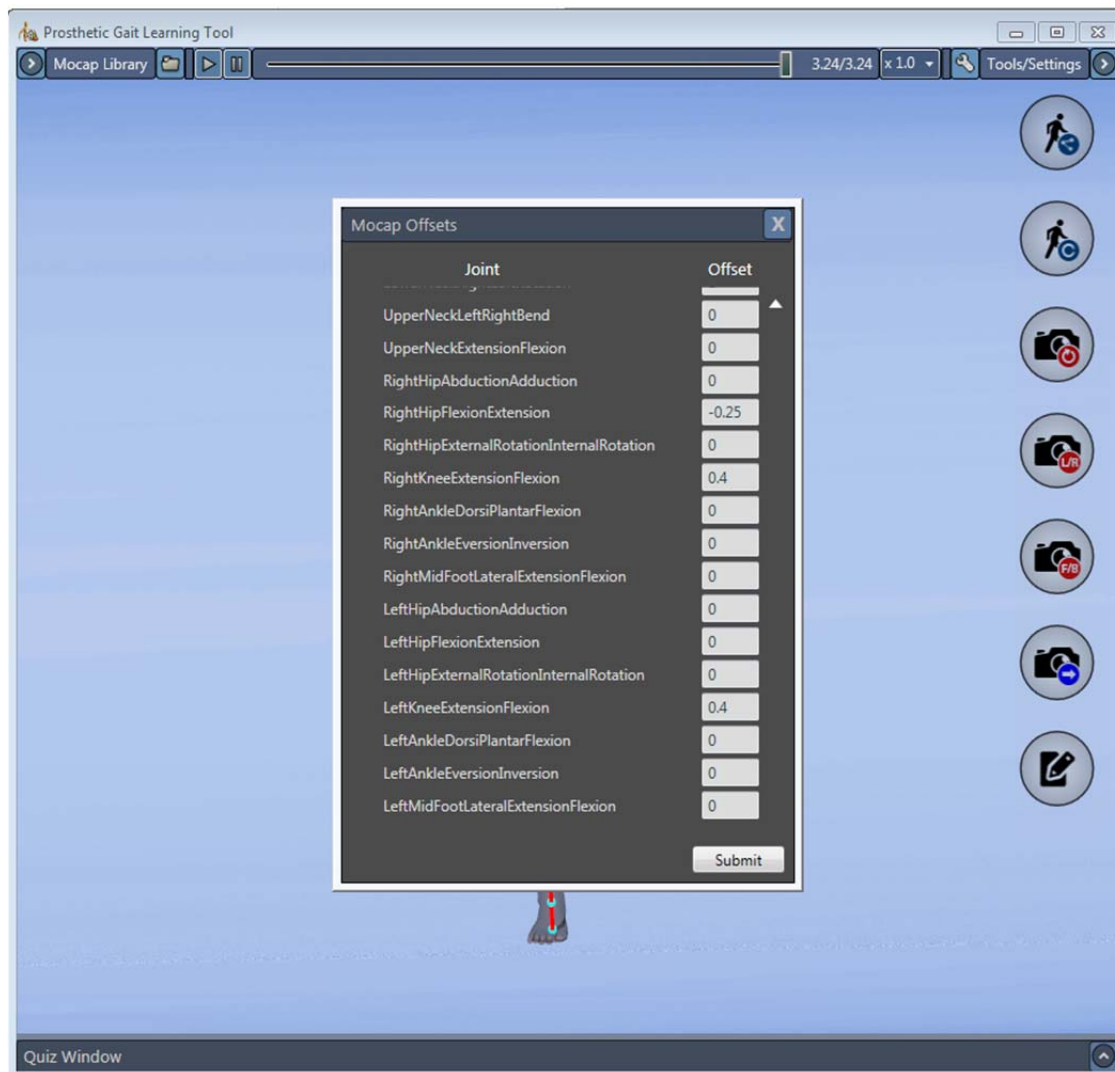


Figure 12: Any joint offset of the main avatar can be modified through the MoCap Offsets window.

After viewing the online quiz developed by OGAL, substantial changes were made to the layout and capabilities of the quiz window to match the format used. In the top left corner of the quiz window, there are buttons for navigating between previous or next questions and a replay button. The bottom right corner of the quiz window contains a Submit/Continue button, and the bottom left corner displays a quiz completion progress bar. Upon the expansion of the quiz window, the user may begin the quiz after reading through the instructions on the introductory page. The quiz is XML generated, and it is relatively simple for the developer to modify various properties of each question. A major feature that has been added includes an option to auto-play a selected MoCap file at the beginning of each question. The motion will be played once with a view of the frontal plane, followed immediately by the same

motion viewed in the sagittal plane. Clicking the replay button at the end of auto-play will replay the auto-played motion, while clicking the regular play button on the main toolbar will play the last selected MoCap file. The question format can be either multiple choice (with or without an additional question/options) or a checklist, as shown in Figure 13.

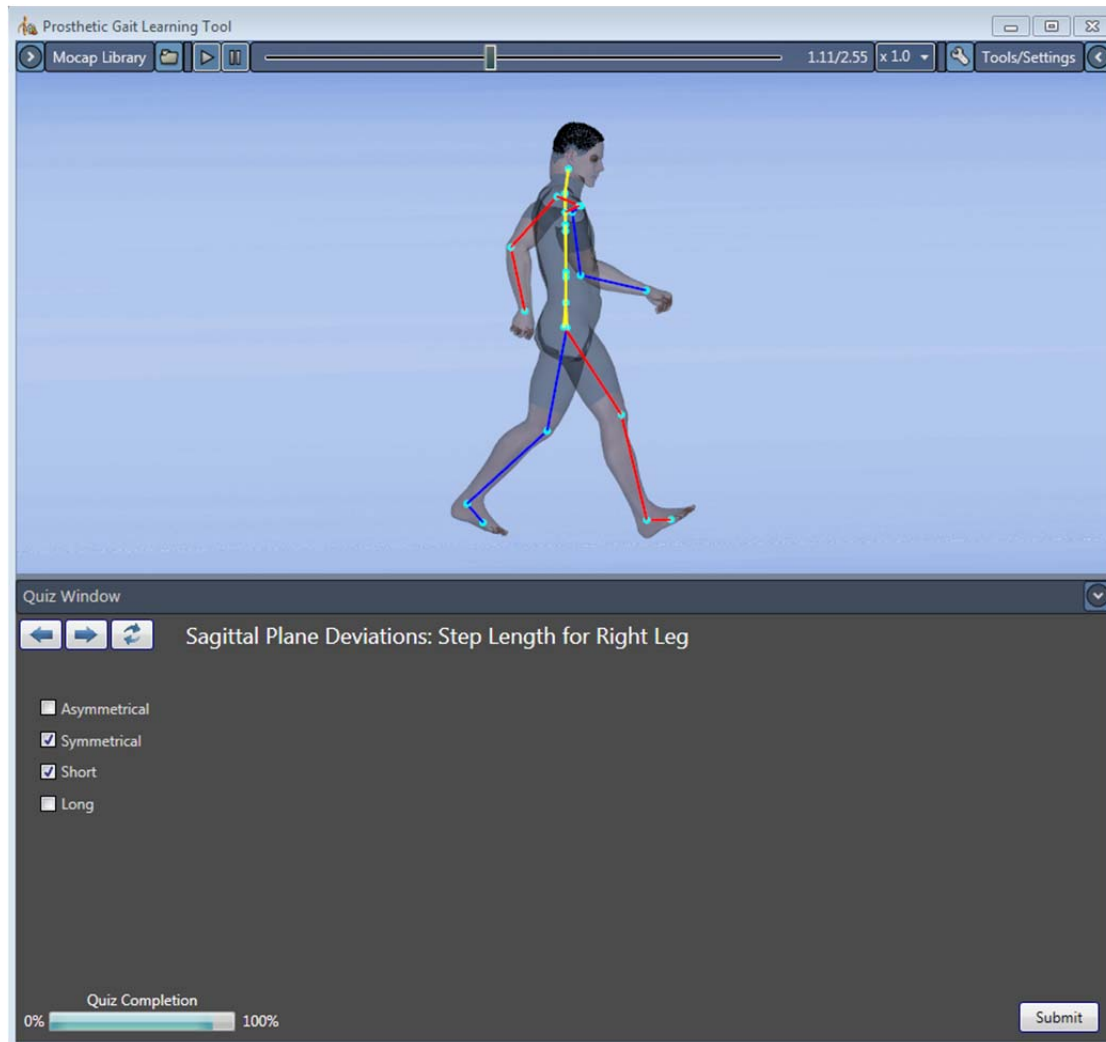


Figure 13: A question in the current quiz posed using a checklist format.

The user is restricted from moving past the current question until an answer has been submitted, but once an answer has been submitted, a feedback page is displayed. The user's response(s), as well as the correct answer(s), are displayed. If incorrect, the user's response is shown in red text next to a red X icon. If the user answers correctly, a green icon with a check mark is displayed. Pictures of the ideal gait during initial contact, mid stance, terminal stance, and mid swing are also provided on the feedback page; an example is shown in Figure 14. Furthermore, the main avatar is auto-played with the motion corresponding to that question, if one exists, with the control avatar playing next to it. The quiz developer can also specify if the feedback auto-play should be viewed using only the frontal or sagittal plane instead of the default showing the motion in both planes.



Figure 14: Quiz feedback page based on the user's response of one correct checkbox and one incorrect checkbox marked.

Discussion and Conclusion

Most of the time and effort for MPL was focused on getting the IRB. The team had regular discussions during this year where the progress with various aspects of the project was evaluated and next steps planned. However, a lot of resistance to progress was felt due to the lack of IRB and actual data to visualize the tutorials. In the absence of such data, mock up data was created to make some progress on the gait deviations ratings development and the software development. Now that the team has IRB approval, it cannot wait to make further progress on all fronts with an approval of a No Cost Extension request. The development version of the software tool has been deployed at the OGAL lab to prove the capability of distribution of the software when it is ready.

When the tool is fully developed, it will provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art

gait laboratories. The tool will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans. This system will, thus, provide a comprehensive training experience, allowing practitioners to benefit from a broad array of patient data previously collected by the US Army, thus bridging a critical gap in current medical training practices. The system will be developed to accommodate additional sequences captured over time, thus offering an extensible, distributable, and sustainable training library.