

Informational and Instructional Documentation



Website

<https://academics.uccs.edu/~stragess/>

Funding for this project was provided by the Colorado Space Grant Consortium of the NASA Space Grant Program.

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Software and Project Overview

UCCS Mechanical and Aerospace students have been developing a low-cost video tracking software system for use in biomechanical applications. The software

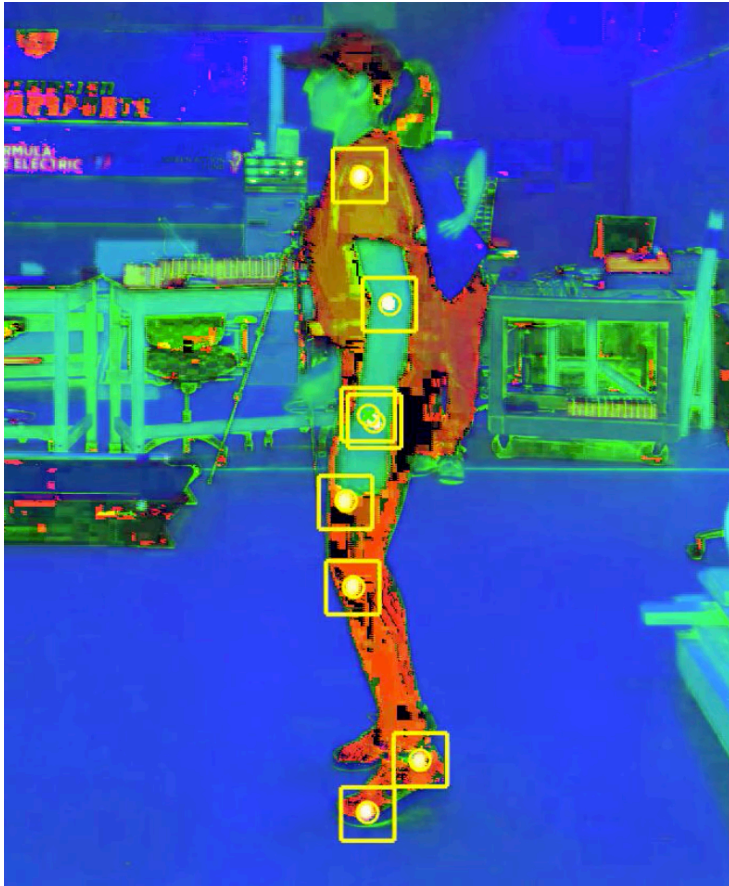


Figure 1: Example of software tracking, the system converts the RGB video frames to HSV. This video shows calculation of the hip marker during occultation.

objective is to provide an alternative to expensive cameras and force plates to the general community for calculating ground reaction forces, joint forces, and joint moments/torques. This documentation covers the overall functionality of the system, instruction on using the system, marker placement, suggestions for how to setup and record videos, and minor troubleshooting tips.

Challenges and System Objectives

This video tracking system utilizes colored stickers placed on the joints of human subjects to calculate the joint position frame-by-frame. One of the challenges with this approach is dealing with occultation, the instance of a marker being covered by either a foreign body or some portion of the body being tracked.

The objectives of this research were to

- Accurately track marker position frame-by-frame to determine position for biomechanical analysis
- Develop an algorithm to achieve accurate results of marker position during occultation, beyond what can be obtained through interpolation or curve fitting
- Accurately model ground force reactions
- Implement joint force and moment estimation capabilities
- Develop an automated segment-mass calculation method

System setup and tracking

The tracking software system (ForceTrak) acquires user input for the initial marker position on the uploaded videos, which are recorded on smart phones or tablet devices at 120fps or 240fps. Next the systems runs through the video or videos frame-by-frame converting each frame from RGB to HSV. Each marker is found by calculating the norm of the HSV pixel values and comparing that norm against the averaged marker pixel values from past frames. Once all the matching pixels (to a set threshold) are found, the marker centroid is calculated. The system loops through the video frames until it has recorded the positions for all joint markers.

Occultation Solution

To solve the occultation challenge, a vector approach was taken. Focus was placed on solving this problem specifically for the knee and hip markers. However, this method could be implemented on other rigid body segments.



Figure 3: Example marker placement on leg

Three markers (hip, thigh, and knee) were placed to define the thigh leg segment. The thigh marker was placed approximately 1 inch below the middle finger of the test subject to minimize the possibility that the hand or arm would block both the thigh and hip marker at the same time. It was also placed slightly off center on the segment as pictured to the left to ensure a triangular geometry.

The diagram below shows the basic formulation of the vector approach. From this setup, with any of the three markers being occulted at once, the system calculates

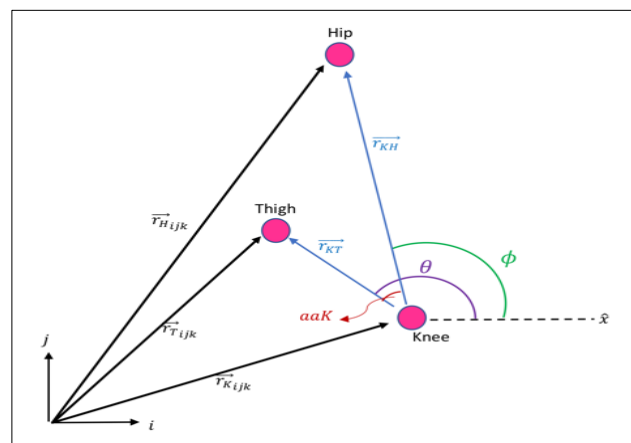


Figure 2: Vector solution for occultation

the position based on the initial and average geometry of the system. It is assumed that the geometry is constant, based on the rigid body assumptions used for the tracking and biomechanics analysis.

Occultation Results

The overall error in the occultation has been plotted for the knee below, Figure 4. Also, the mean error in the occultation is shown in the black table below, Table 1. The mean error for the hip was nearly 6mm for the test video. It is estimated that the error in the tracking system itself is up to 2cm based on the overall width of the markers. Thus, these results are reasonable.

Table 1: Occultation error analysis

Marker	Mean Norm Difference (mm)
Hip	5.7264
Thigh	2.7122
Knee	4.4348

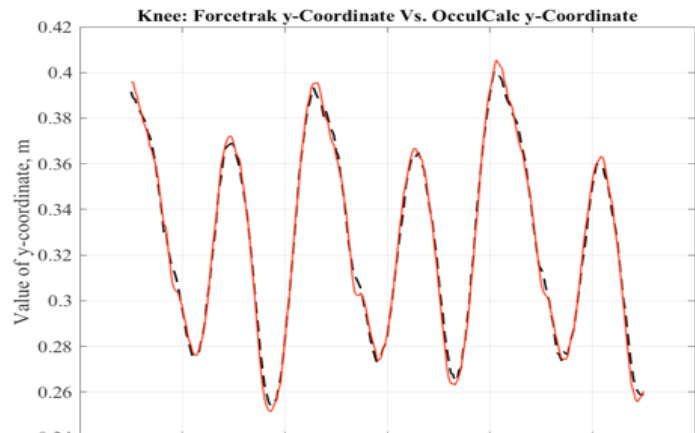


Figure 4: Occultation calculated position vs. actual position for knee marker

Ground Reaction Forces (GRF)

The calculation of ground force reaction utilizes numerical differentiation and data smoothing to compute the velocity and accelerations. Anthropometric data^[1] is used to estimate the percent masses for each body segment and the segment center-Of-mass locations of the subject.

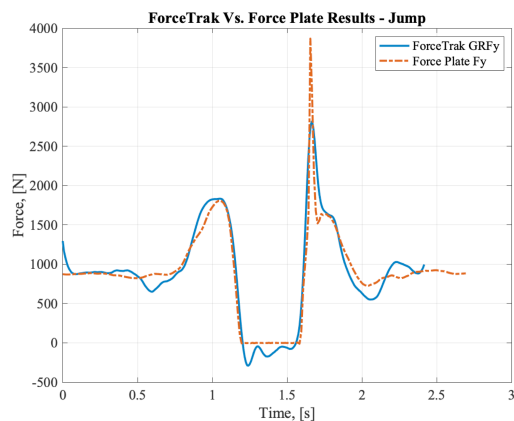


Figure 5: Ground Reaction Forces

The GRF results to the left were obtained from a video of a vertical jump. The force plate data is the baseline for accuracy. The results show some variance in the calculated GRF. Error is introduced by the smoothing techniques and numerical differentiation along with variance in the test subject's anthropomorphic parameters to those used from Winters anthropomorphic data table [1].

Finally, using inverse dynamics, joint forces and moments were estimated. The force results of the bottom-up approach (BUA) and top-down approach (TDA) on the hip are provided by the system for symmetric

movement or movement where both feet do not contact the ground simultaneously (i.e. running). Further research must be done to enhance this feature of the software and provide validation of the results.

Future and Ongoing Work

- Implementation of this solution/software into a mobile phone or tablet application
- Development of a system to automate the estimation of test subject segment masses to increase accuracy of the ground reaction force, joint force, and moment estimations.
- Conduct further error analysis and software accuracy validation
- Collaboration with UCCS Technical Writing Department to include User Experience testing

References

^[1] D. A. Winter, *Biomechanics and Motor Control of Human Movement: Fourth Edition*. 2009.

Using the Software

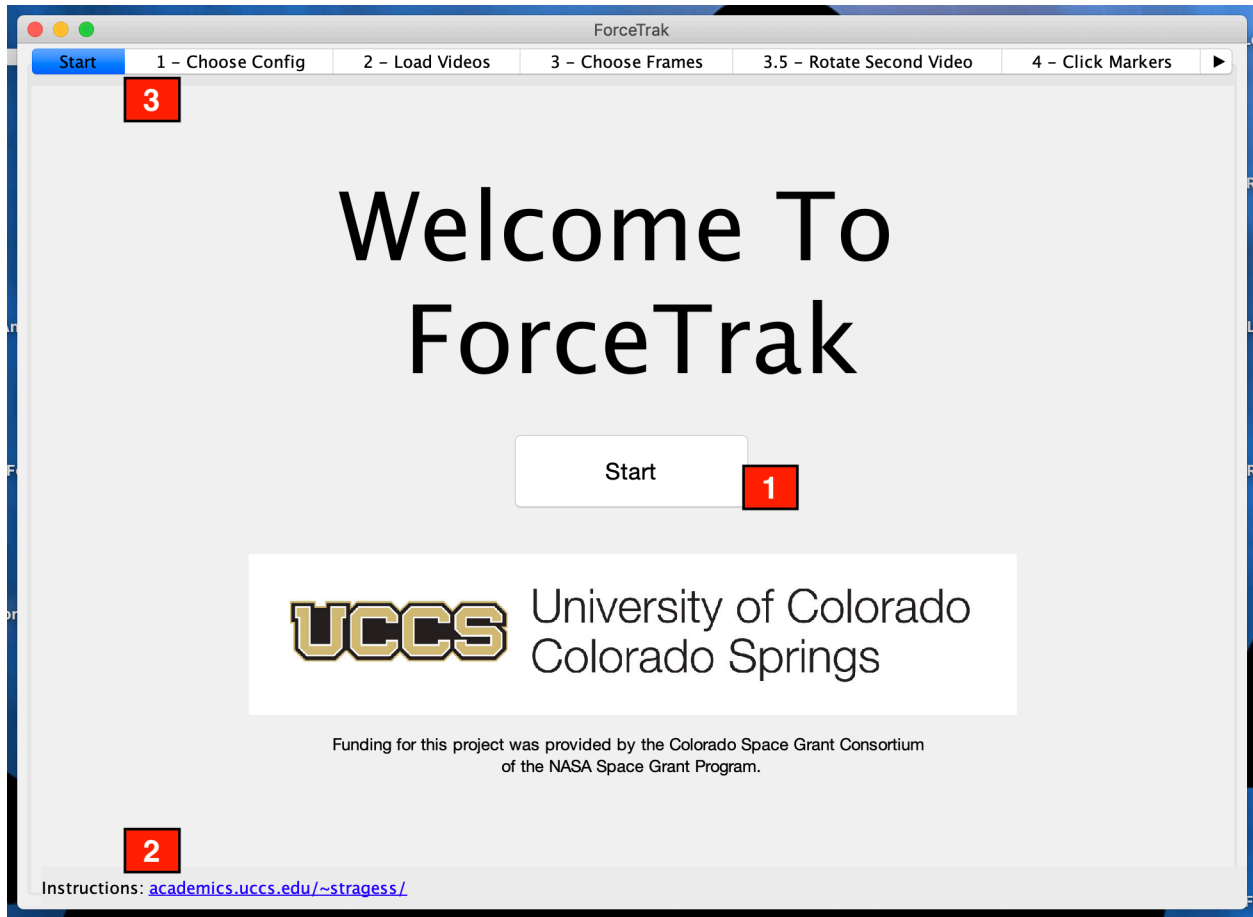


Figure 6: Start Tab - Once the software application launches you will land on this screen.

Notes / Actions:

- 1** Click the Start button to begin the video tracking session.
- 2** The link at the bottom of the screen will take you to the research website.
- 3** Note, the tabs on the top screen allow you to go back and forth between the screens. Try to avoid this, if possible, to prevent the possibility of throwing accidental errors.

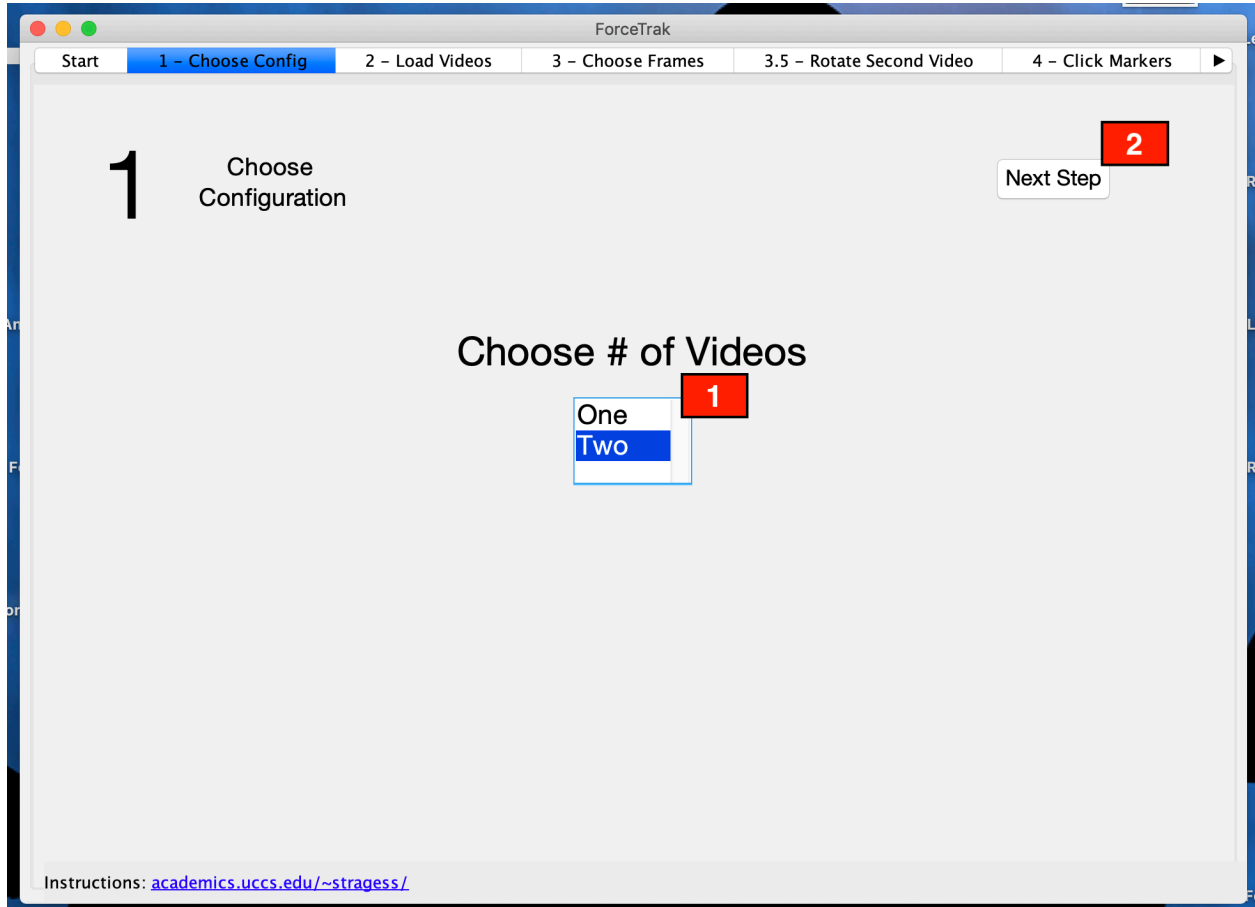


Figure 7: Tab 1 - Choose configuration

Notes / Clicks:

- 1** Select the number of videos that will be tracked. For accurate biomechanical analysis, two videos are recommended; however, one video gives acceptable results if the movement is symmetric (both sides of the body moving in tandem).
- 2** Click the Next Step button to proceed to the next tab.

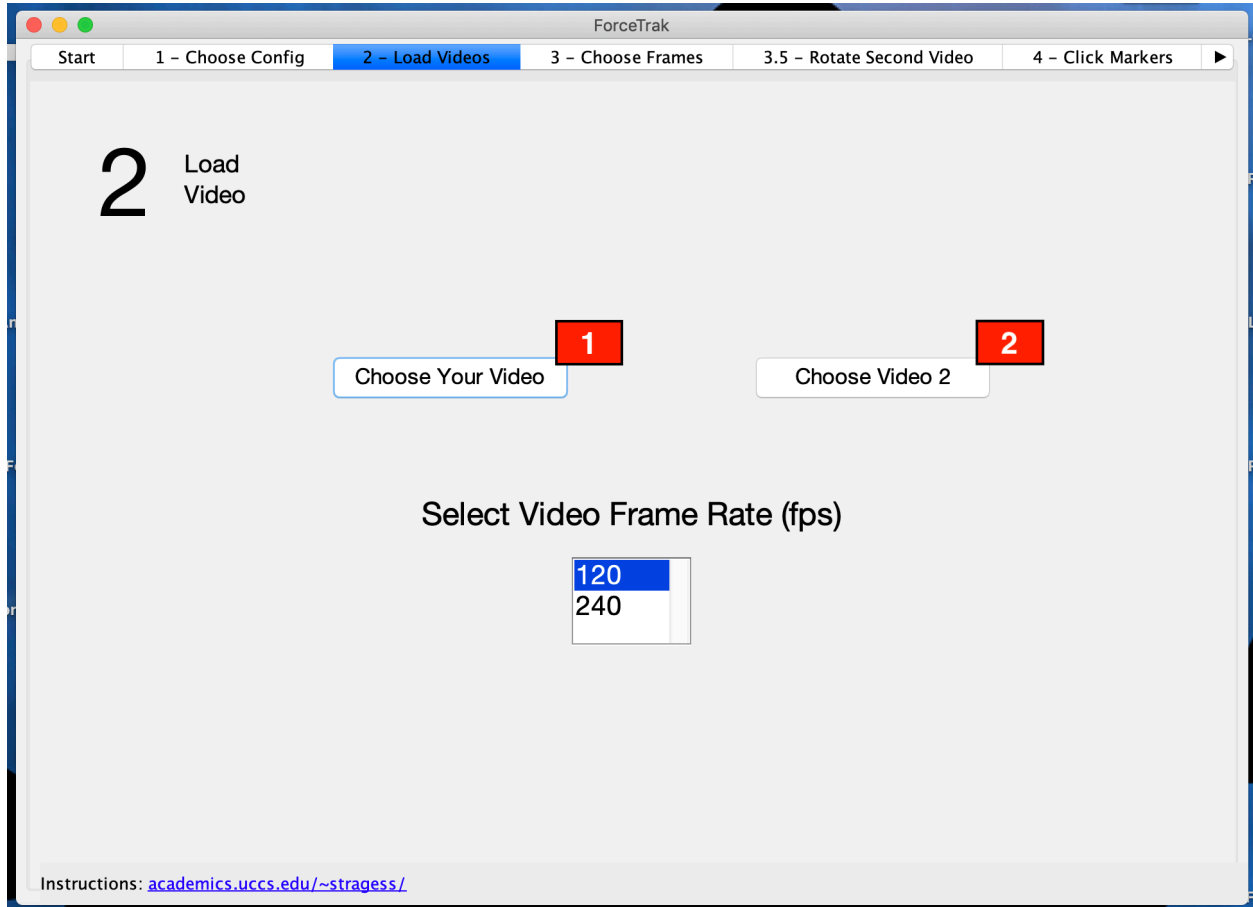


Figure 8: Tab 2 -Load video(s) and select the frame rate

Notes / Clicks:

- 1 Click the Choose Your Video button to load the video you will be using for tracking.
- 2 Load the second video if using two videos.

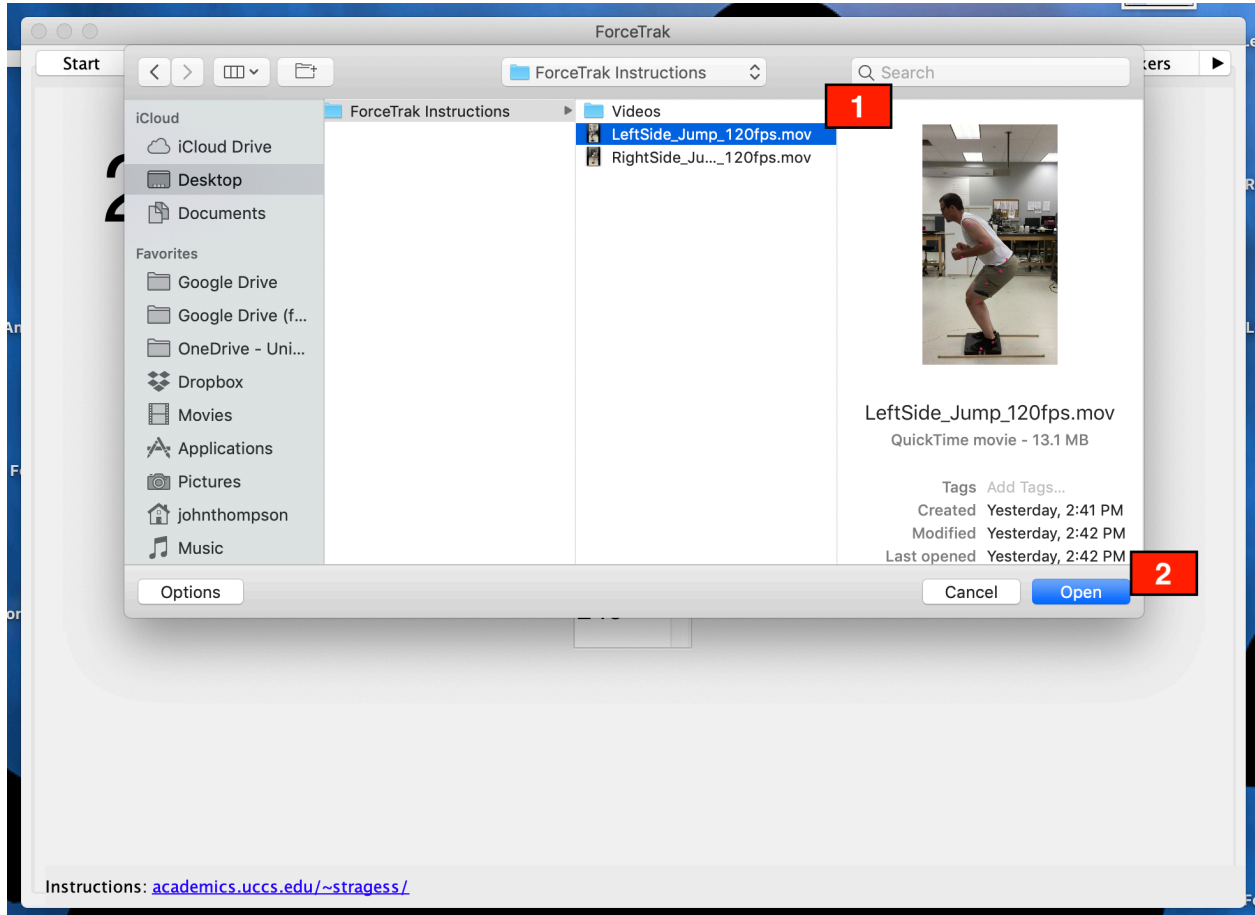


Figure 9: Tab 2 - Example loading a video

Notes / Clicks:

- 1** Find the video you are using to track and select the video file by clicking it.
- 2** Click the Open button to finish loading the video.

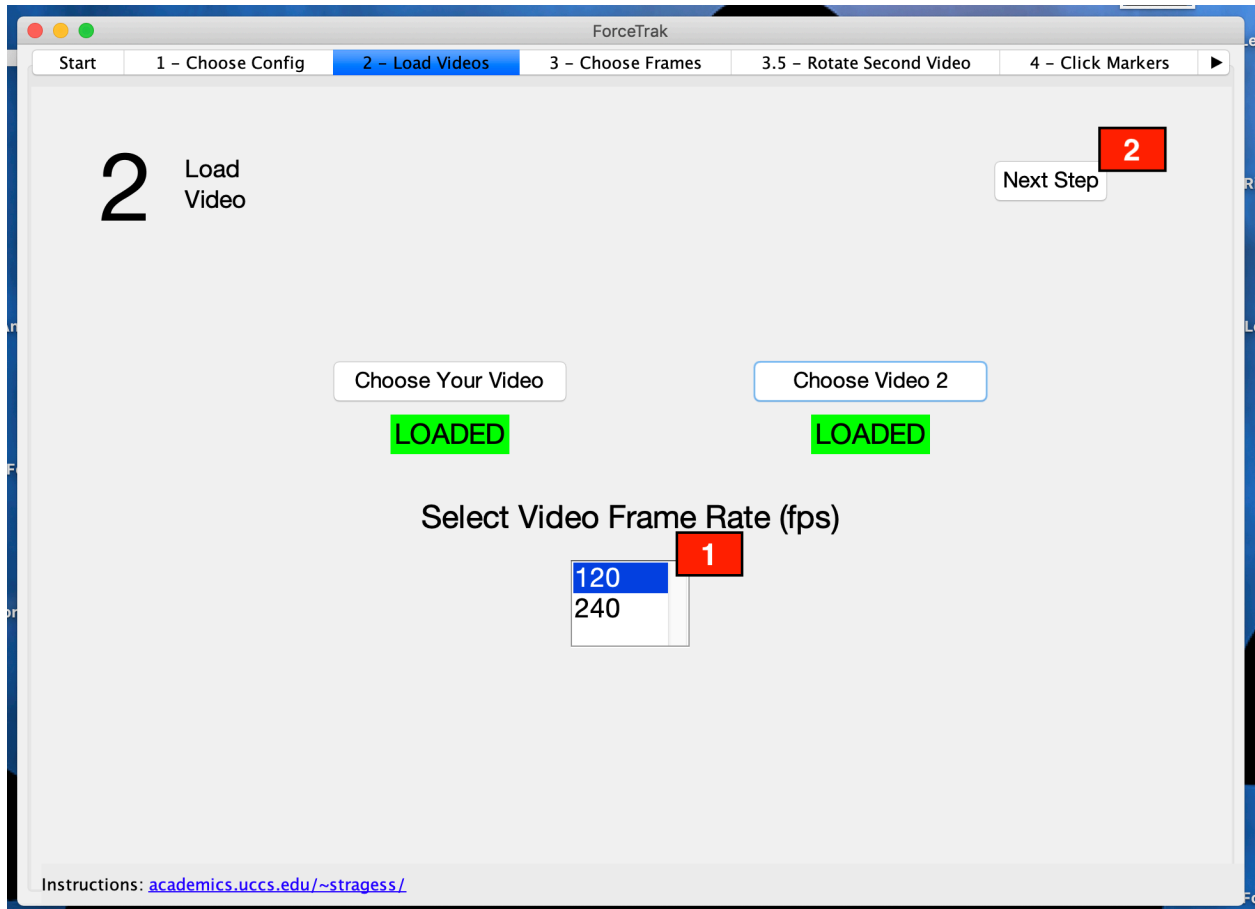


Figure 10: Tab 2 - After loading video(s)

Notes / Clicks:

- 1** Choose the video frame rate. The videos must be recorded with slow motion capture of 120 frames per second (fps) or 240 fps. Consult your camera (or camera phone) user manual to determine how to setup and select the video frame rate.
- 2** After the green “Loaded” icons show up, click the Next Step button to proceed to the next tab.

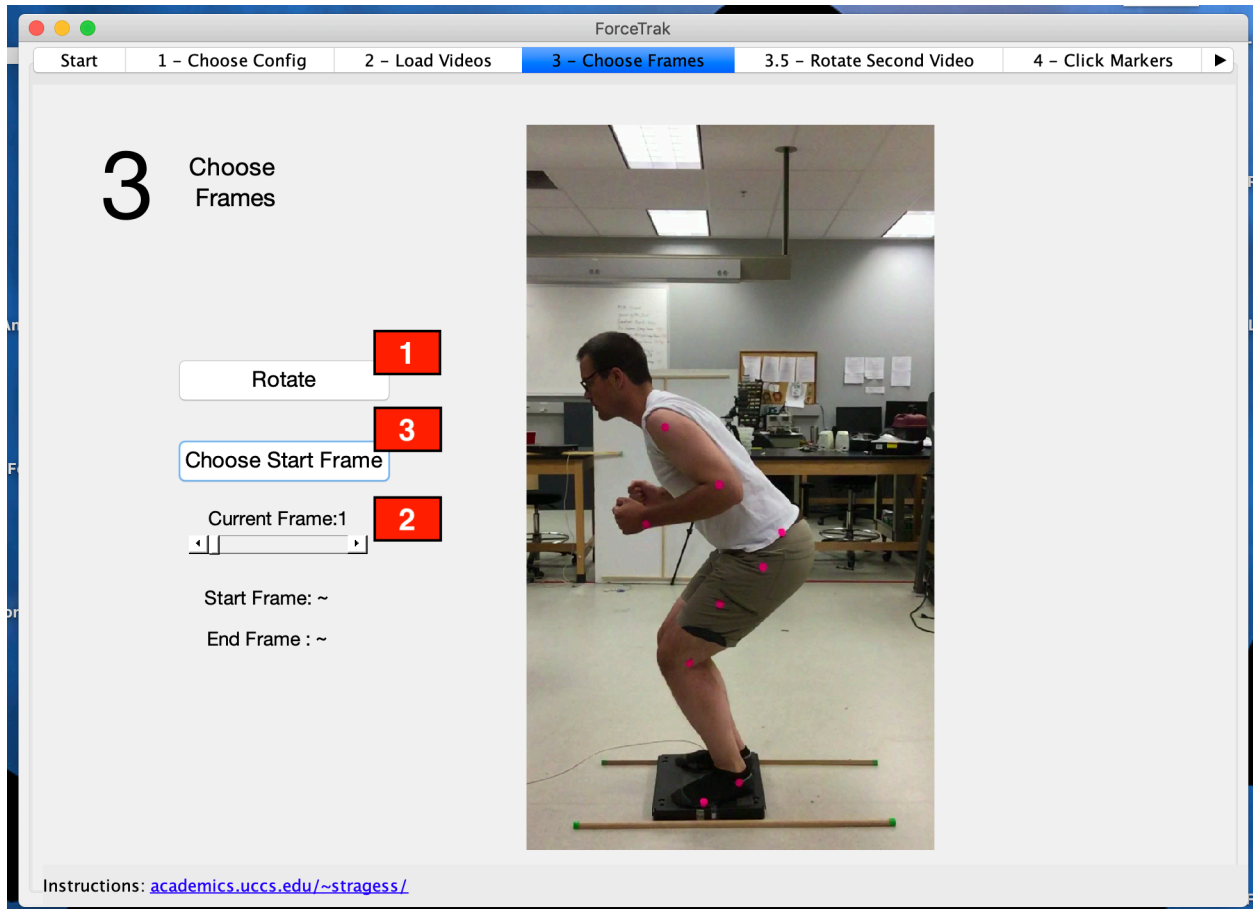


Figure 11: - Tab 3 – Rotating video and choosing the starting frame (the frame the system uses to begin tracking)

Notes / Clicks:

- 1** Rotate the video, as needed, to orient it properly. Each click of the rotate button rotate the video by 90 degrees.
- 2** Use the slider bar to adjust the video frames for selecting the first frame to start tracking on.
- 3** Once the “Current Frame: x” displays the desired start frame, select the Choose Start Frame button to store that frame as the start frame.

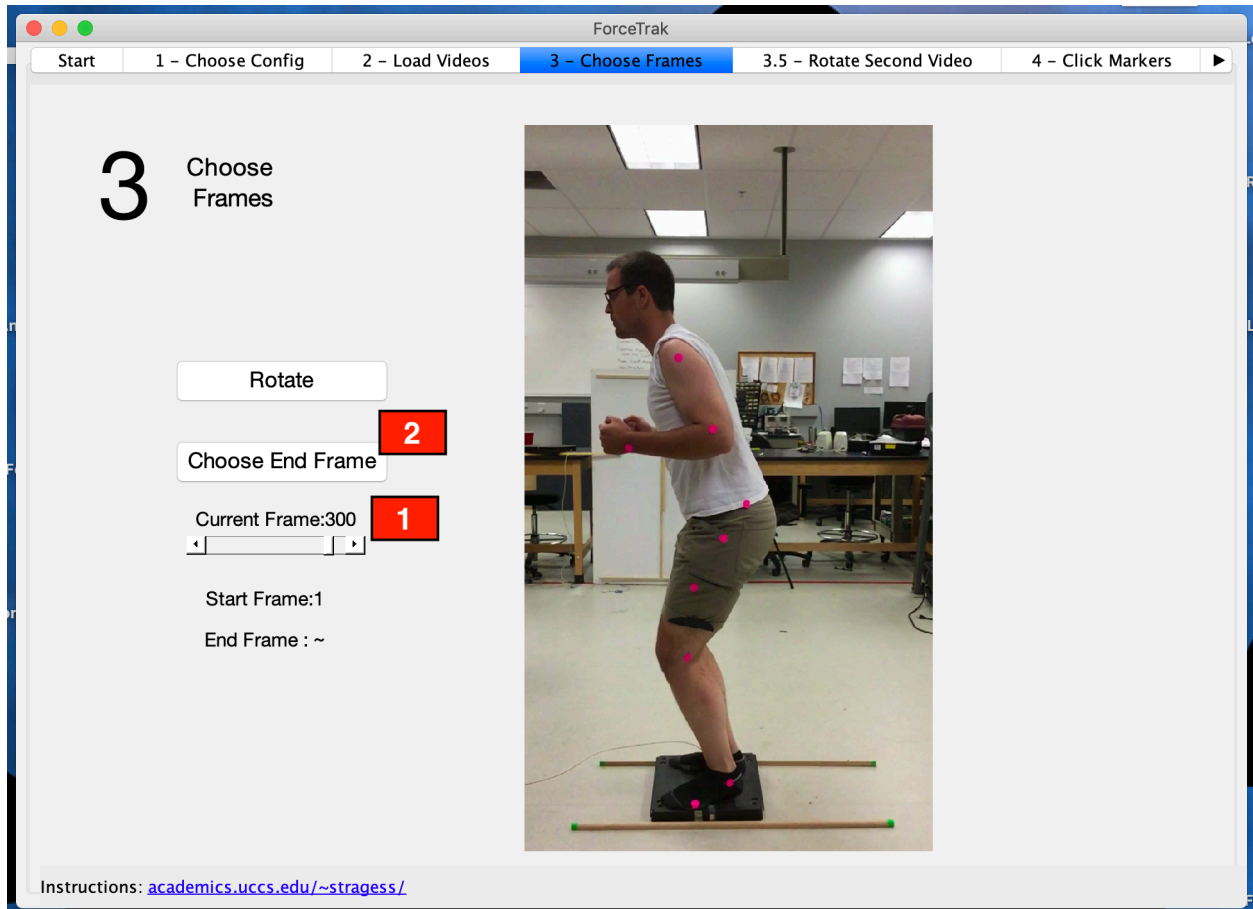


Figure 12: Tab 3 - Choosing the ending frame

Notes / Clicks:

- 1** Adjust the slider to select the ending frame
- 2** Once the “Current Frame: x” displays the desired end frame, select the Choose End Frame button to store that frame as the end frame for tracking.

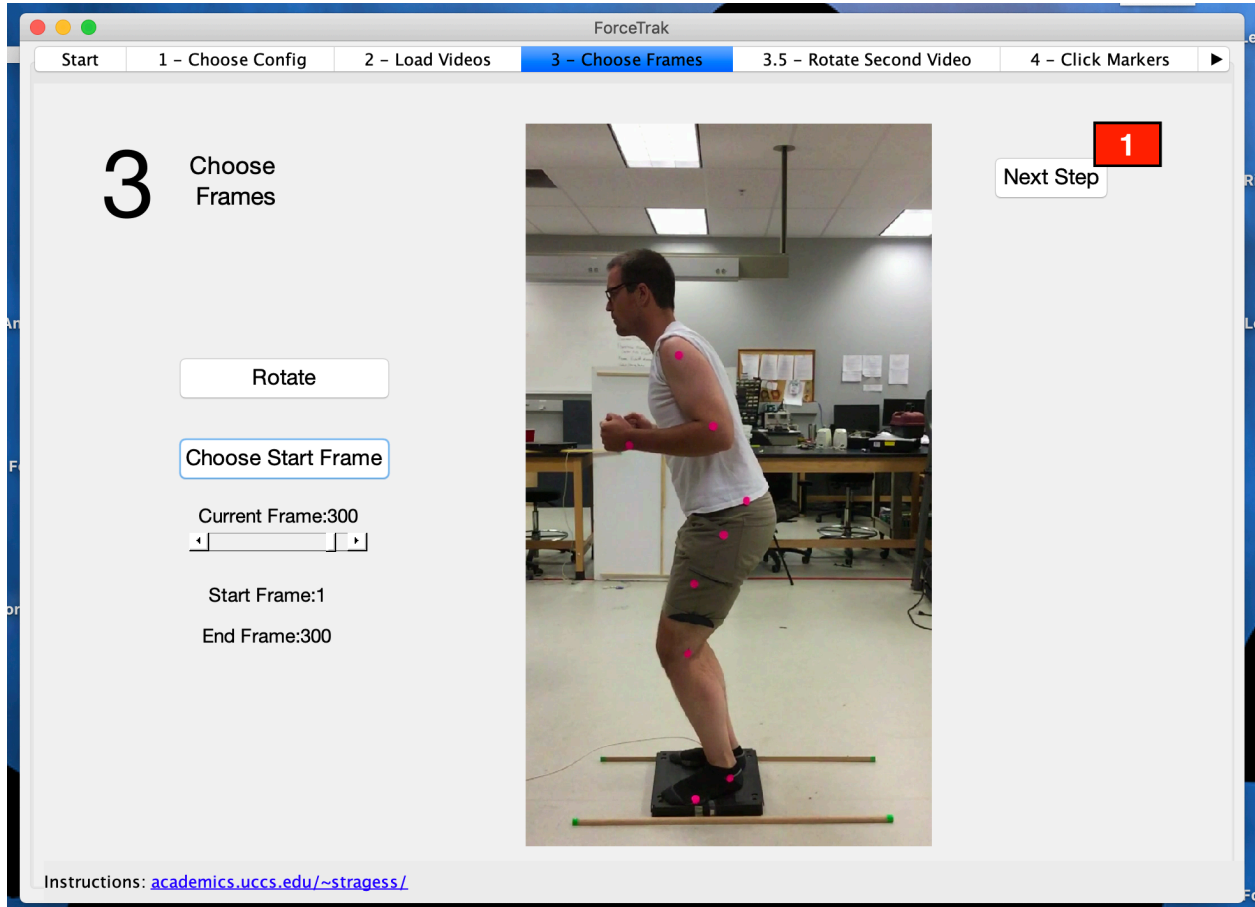


Figure 13: Tab 3 - Proceed to next step

Notes / Clicks:

- 1** After the start and end frames have been selected, click the Next Step button to proceed to the next tab.

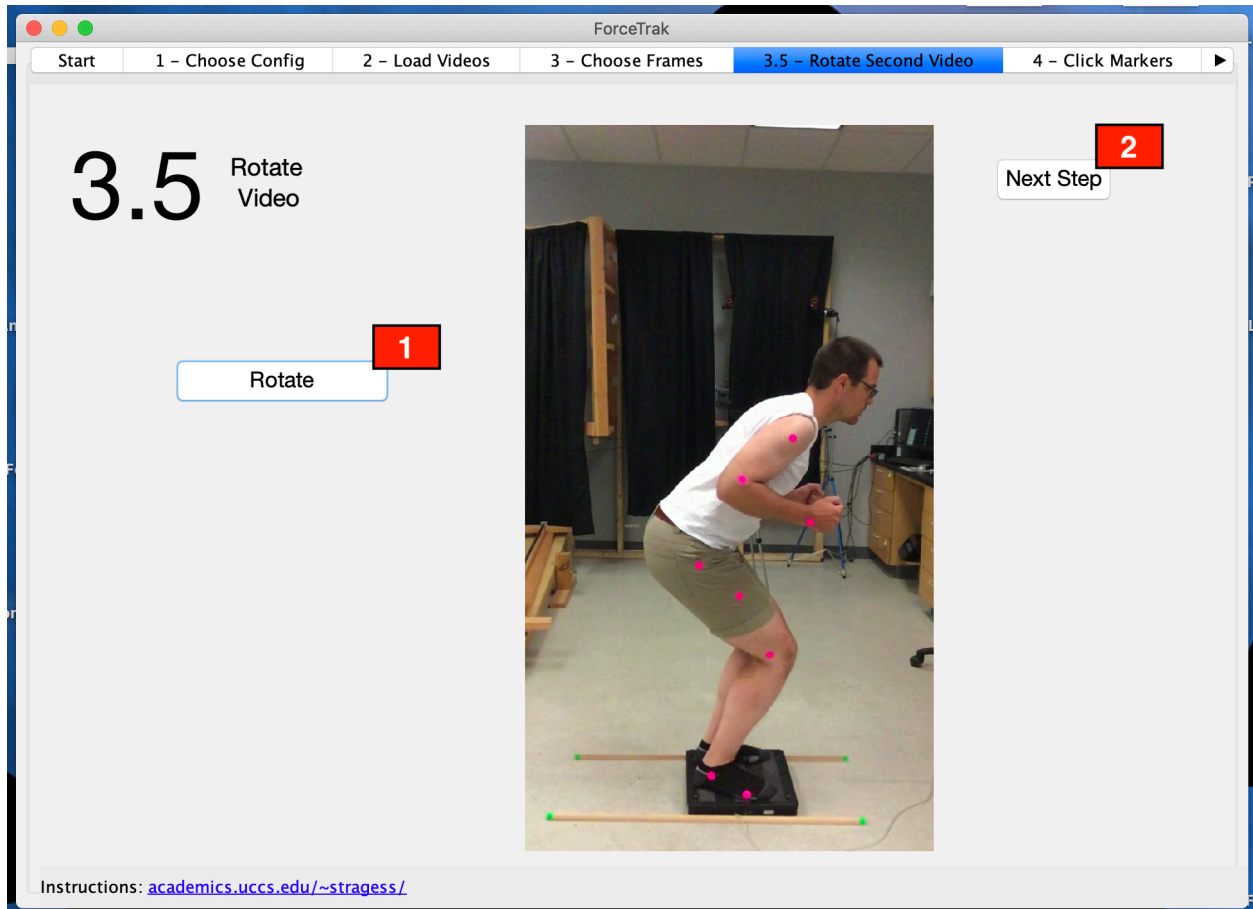


Figure 14: Tab 3.5 - Rotate Second video as necessary and proceed to next step

Notes / Clicks:

1 Rotate the second video (if applicable) as needed by clicking the Rotate button. If only one video was selected, this tab is automatically skipped over.

2 Click the Next Step button to proceed to the next tab.

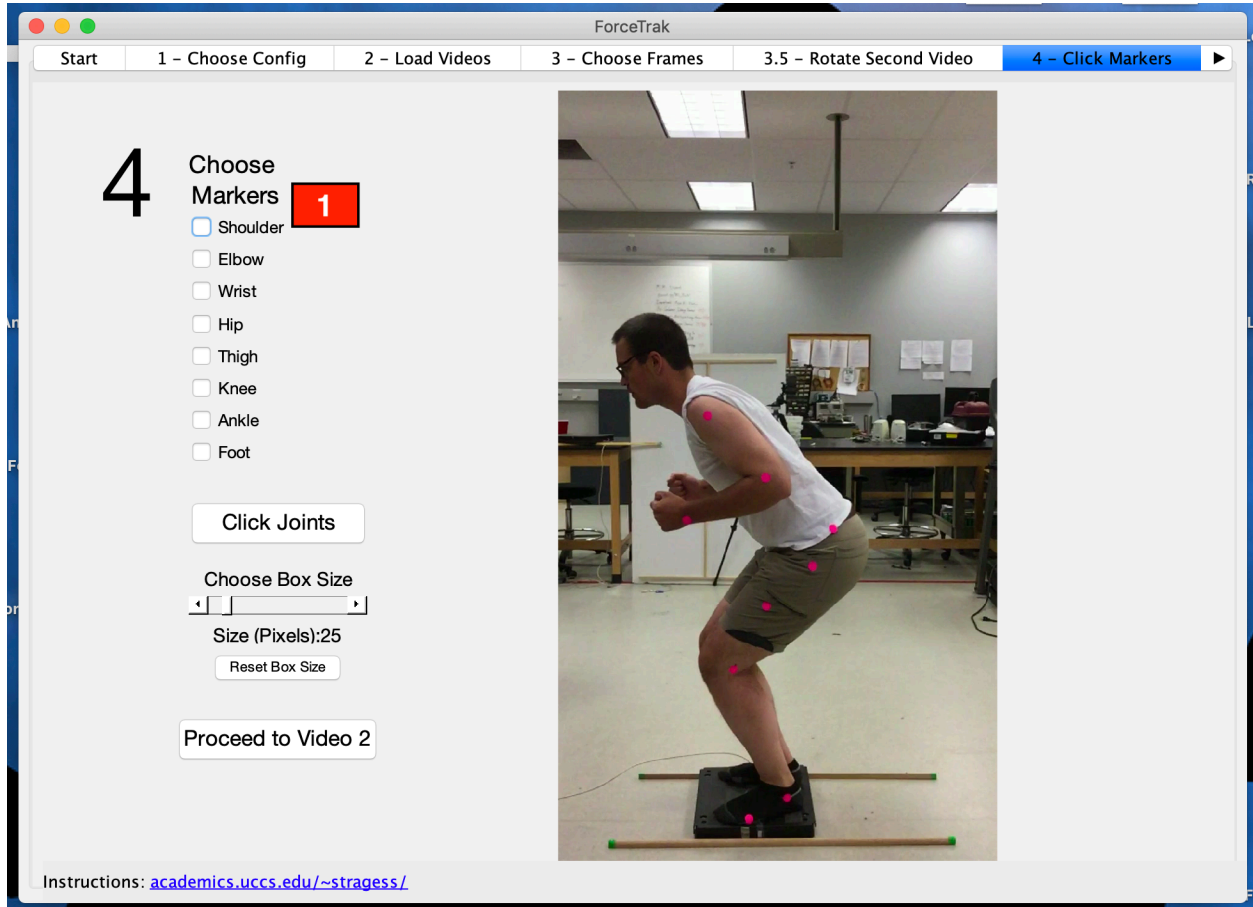


Figure 15: Tab 4 - Choosing markers

Notes / Clicks:

- 1** Choose the joint markers that will be tracked by clicking the associated check box. Not all markers must be selected for the video system to track properly; however, not using all the markers results in inaccurate biomechanical analysis.

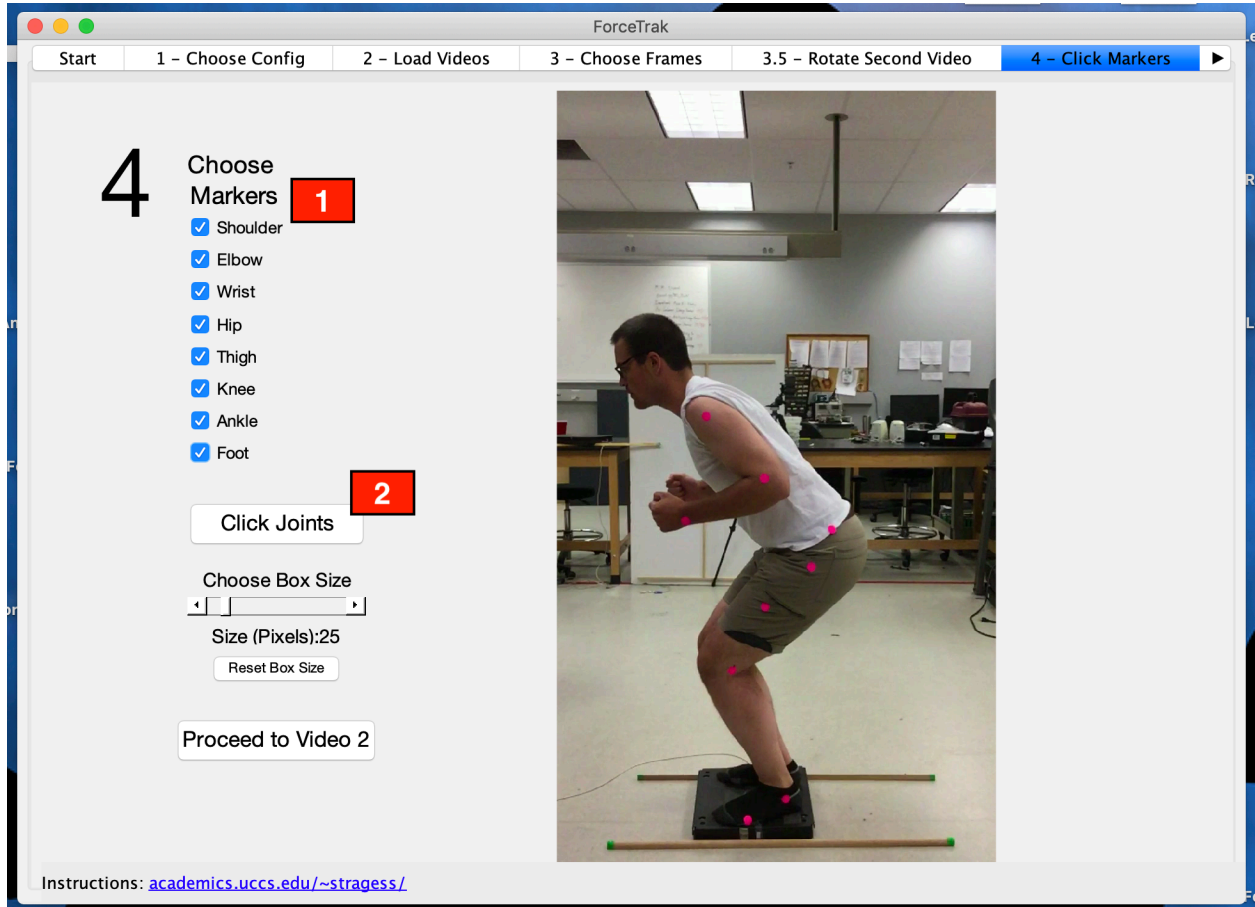


Figure 16: Clicking the joints / markers on the screen video image

Notes / Clicks:

- 1** This shows all markers have been clicked and thereby selected for tracking.
- 2** Click the Click Joints button to begin the process of initializing the starting position of the joint markers.

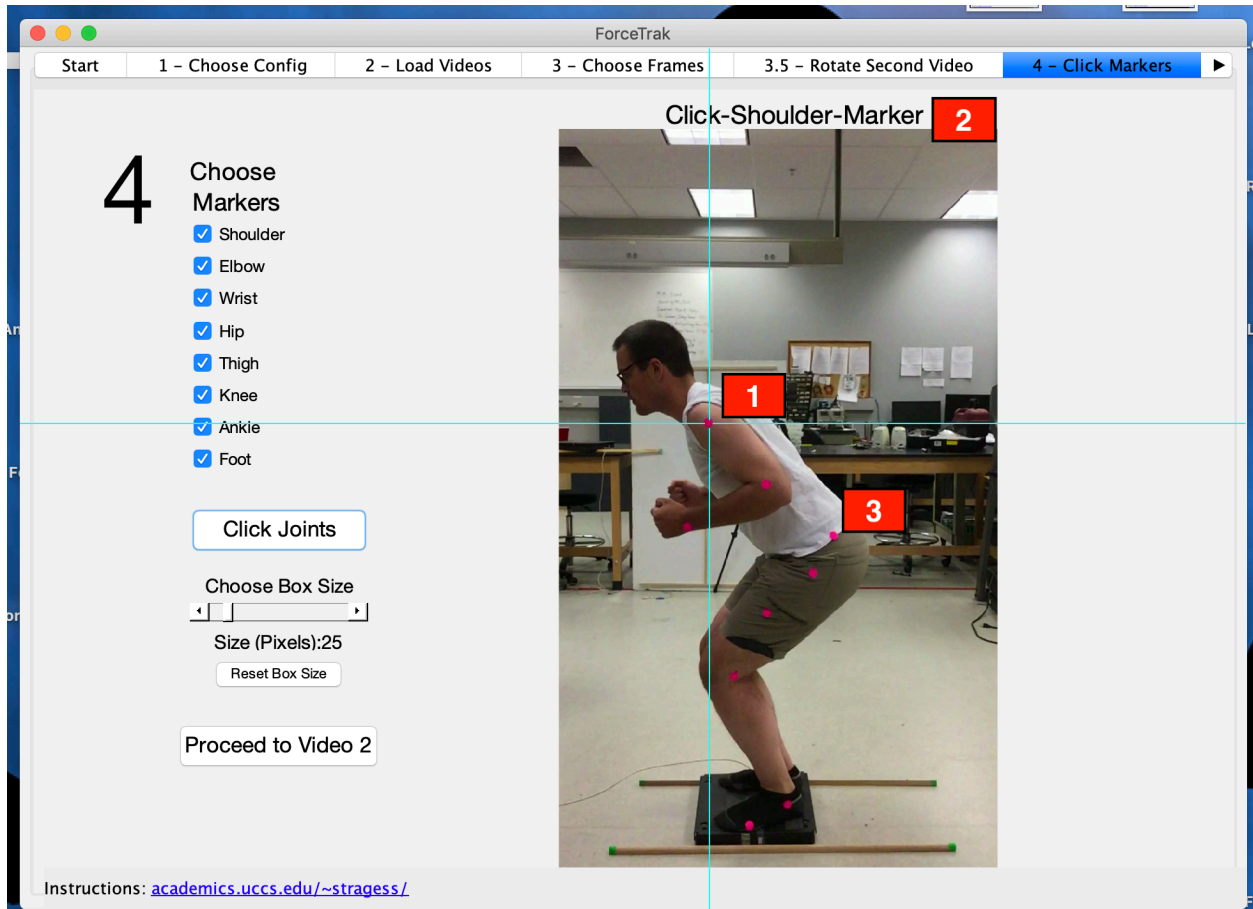


Figure 17: Tab 4 - Clicking the joint markers

Notes / Clicks:

- 1** After clicking the Click Joints button, crosshairs will be displayed on the screen. Use these to click the markers. You do not have to be incredibly accurate at this point, as long as you get close to the marker before clicking that will work.
- 2** At the top of the screen the system displays the current marker you are supposed to be clicking. Make sure to follow this. Clicking the wrong marker will create problems with both the tracking and biomechanical analysis, rendering the results meaningless.
- 3** This is an extra marker that shows poor hip marker placement. The correct placement for the hip is just below this marker.

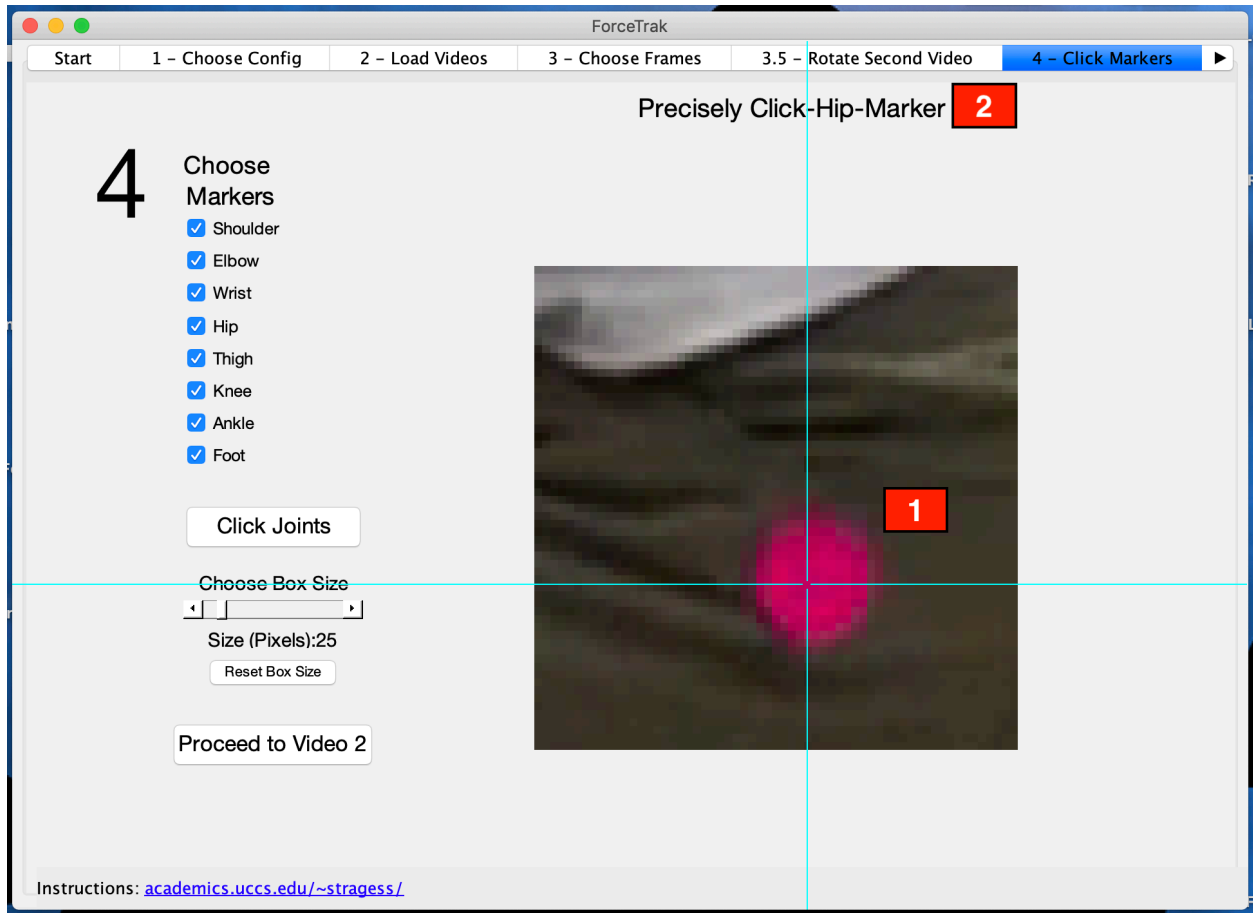


Figure 18: Tab 4 - Clicking the joint markers (Continued)

Notes / Clicks:

- 1** After the initial clicking of the markers, the system will zoom in and ask for a more precise click of the markers. Try to click somewhere near the middle of the marker.

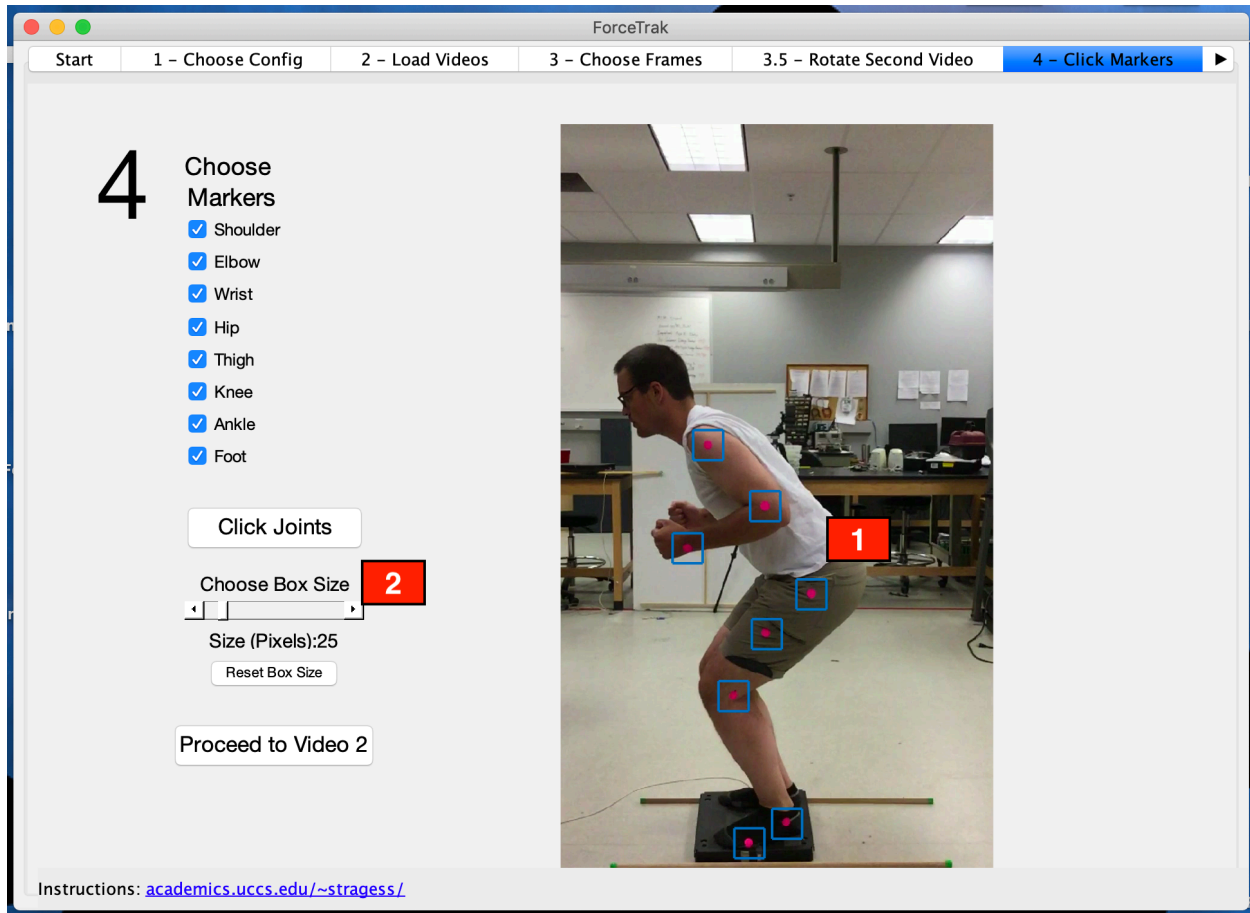


Figure 19: Tab 4 - Adjusting the box size

Notes / Clicks:

- 1** This shows what the system will display once all the markers have been clicked. You should see a blue box around every marker. If something went wrong, repeat this process using the Click Joints button.
- 2** You can adjust the box size if your video resolution is either very high or very low. You want the box size to closely resemble the size in the picture above. for most camera phones purchased prior to 2019, you should not have to adjust the default box size.

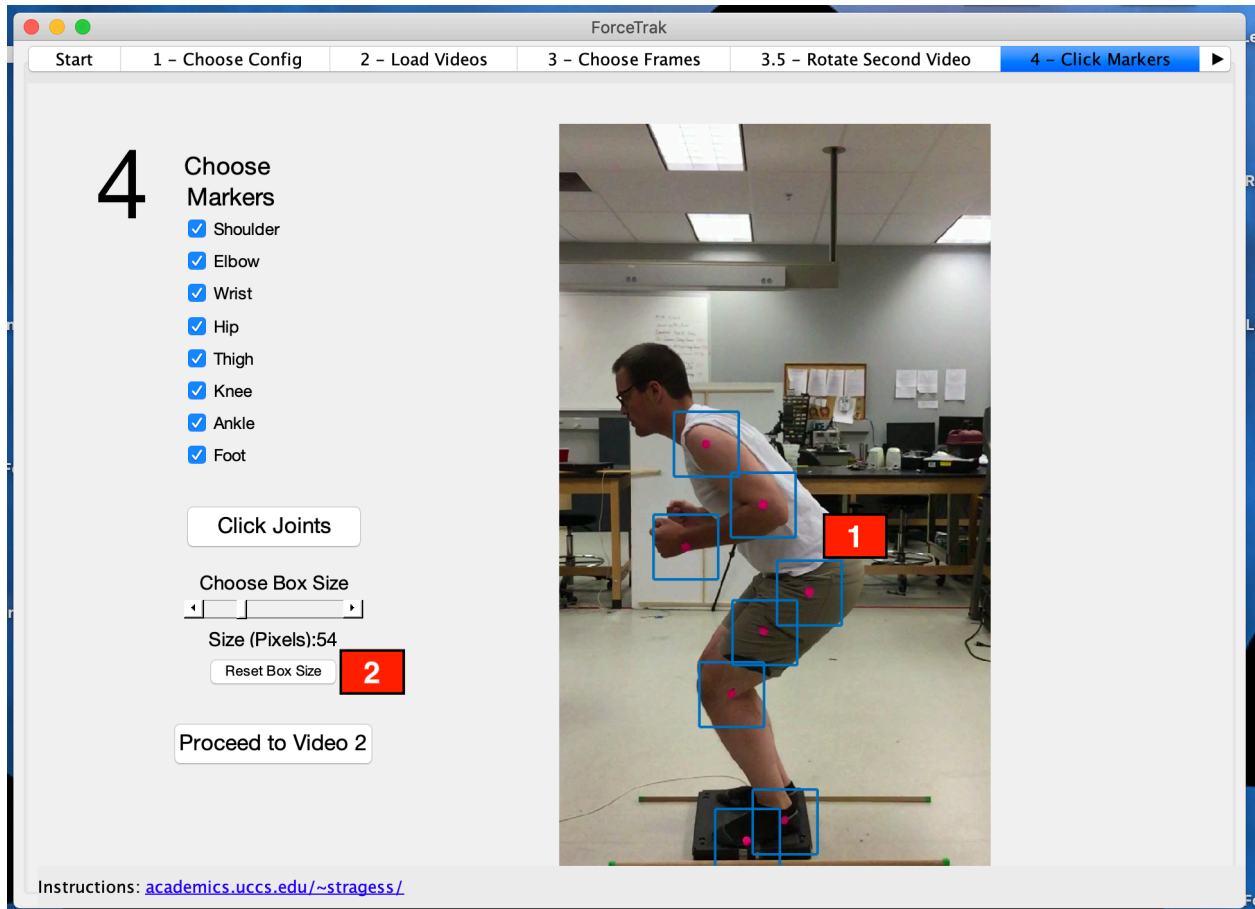


Figure 20: Tab 4 - Example of box size that is too big for tracking

Notes / Clicks:

- 1** This shows an example where the box size is way too large. Adjust the size using the Choose Box Size slider bar.
- 2** There is a Reset Box Size button that, when clicked, resets the box size to the default value.

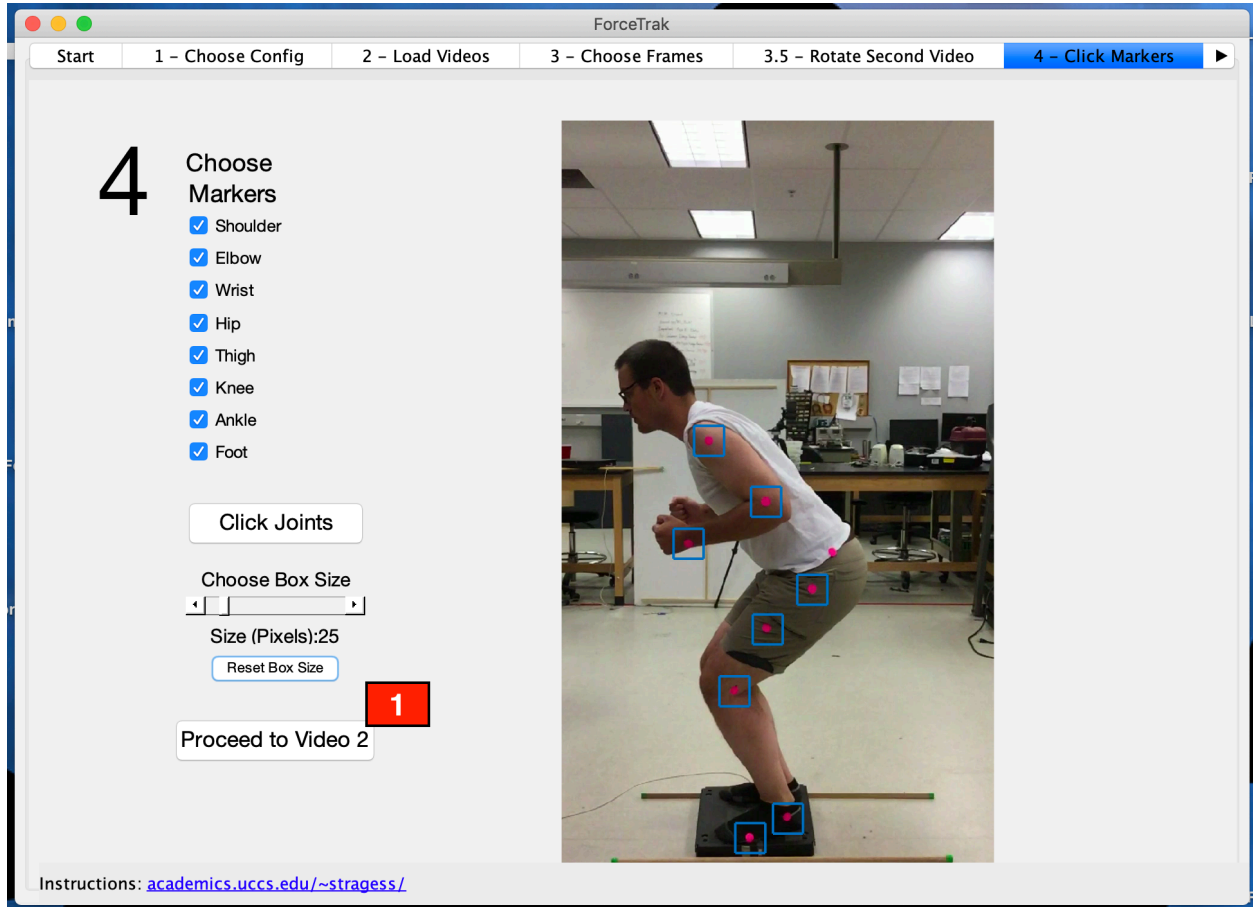


Figure 21: Tab 4 – Box size set to default and proceeding to video 2 (if applicable)

Notes / Clicks:

1

Once all markers and the box size have been selected, proceed to repeat this process on the second video (if applicable) by clicking the Proceed to Video 2 button.

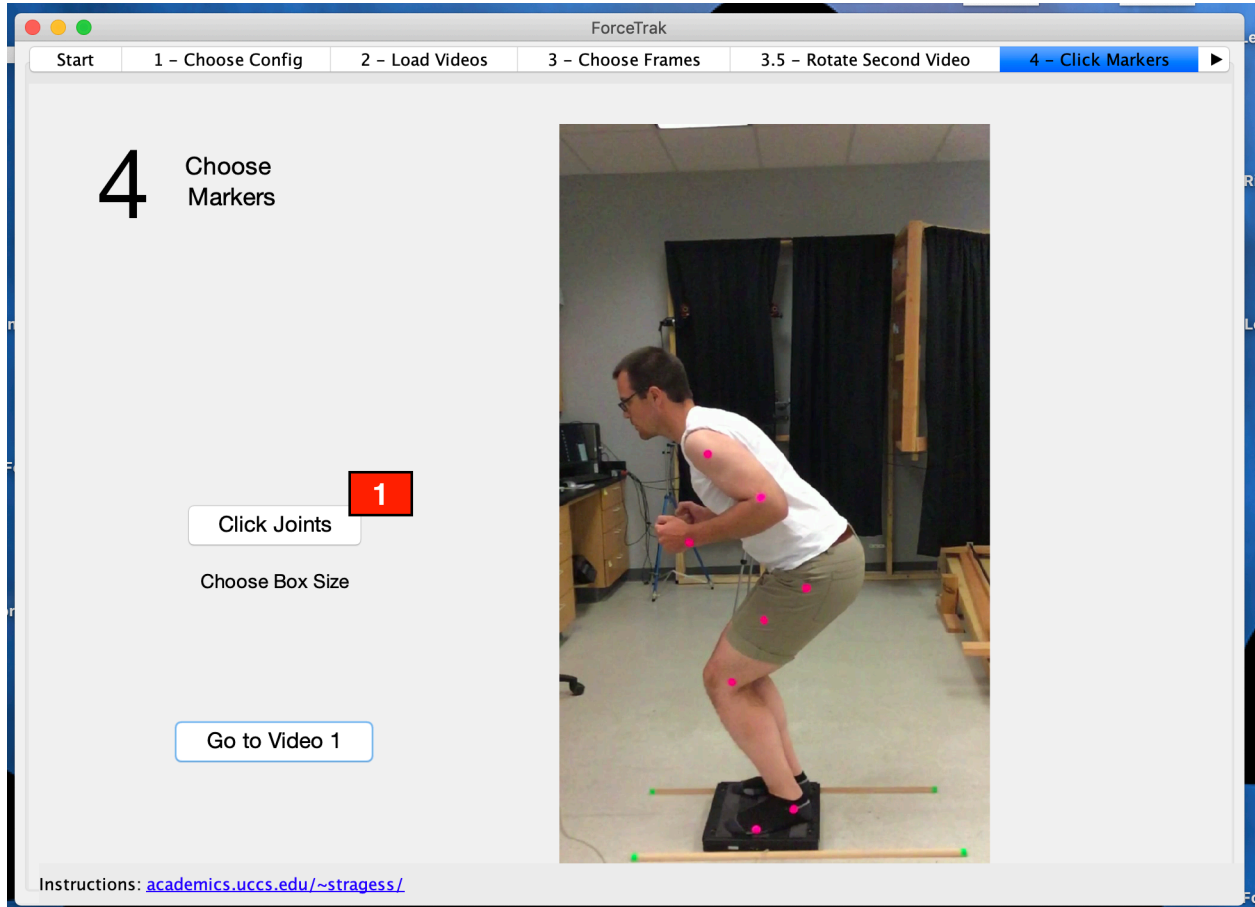


Figure 22: Tab 4 - Click joints for second video (if applicable)

Notes / Clicks:

- 1** Click the Click Joints button to click the markers on the second video. This process is identical to the process outlined previously for the first video.

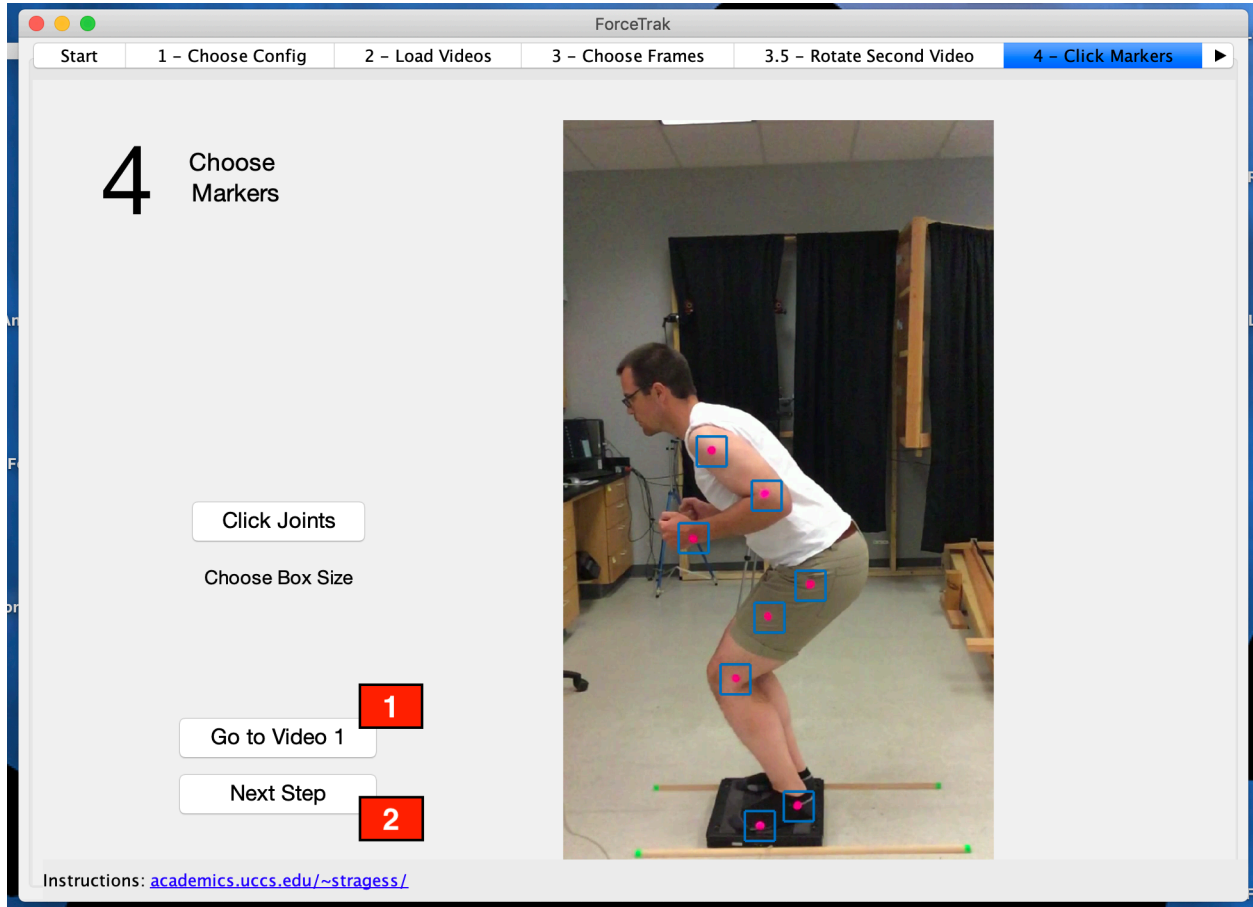


Figure 23: Tab 4 - Proceed to next step

Notes / Clicks:

- 1** You can go back to video 1 if needed. This is not recommended unless there was an error while clicking during the first video or if you need to adjust the box size.
- 2** Once you are done selecting the markers on the second video (if applicable) click the Next Step button to proceed to the next tab.

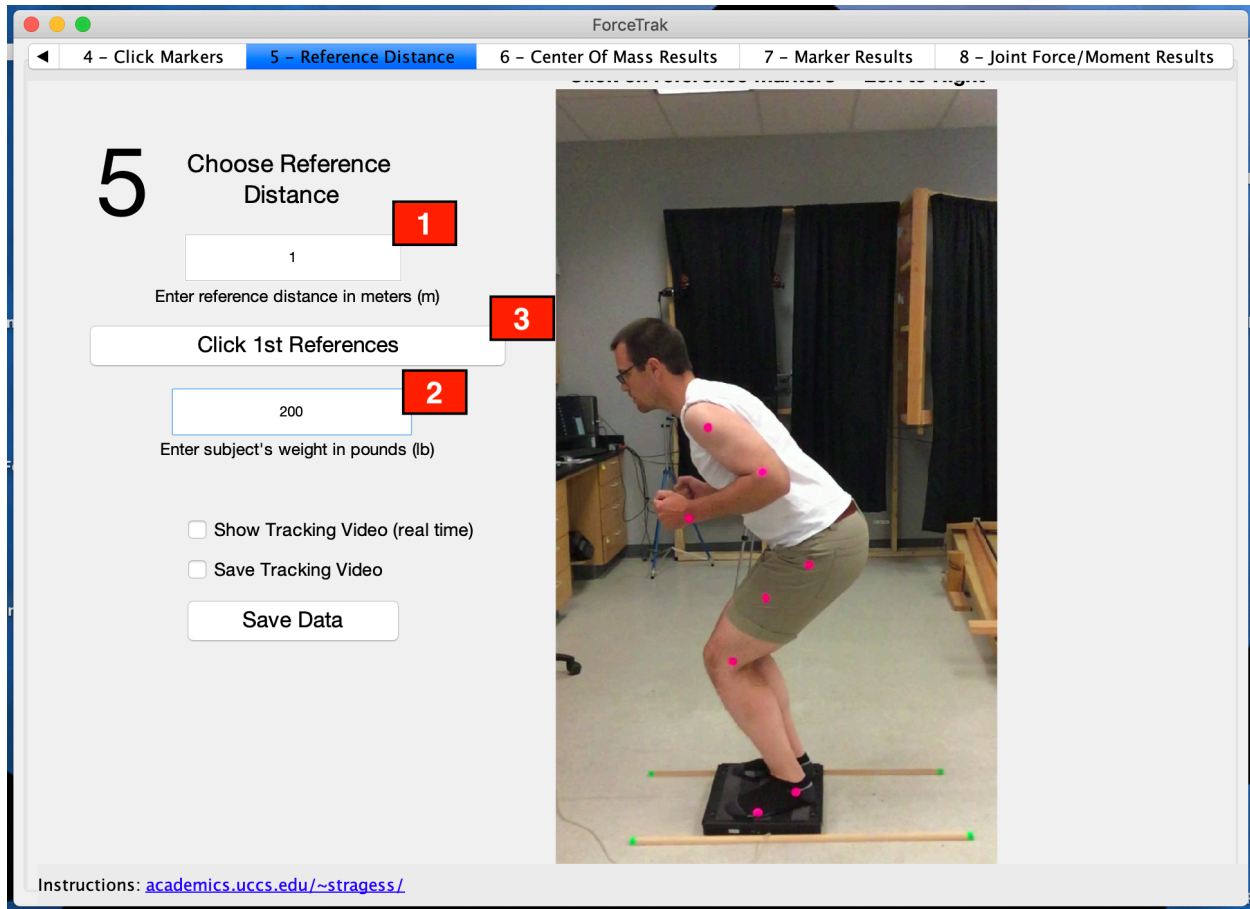


Figure 24: Tab 5 - Entering parameters for physics analysis

Notes / Clicks:

- 1** Enter the reference distance in meters. In the image above, this is the distance between the green tape on the wooden sticks on the ground. This distance is needed to conduct the biomechanical analysis as it is used to convert between pixels and a unit of distance for the final marker position results.
- 2** Enter the test subjects' weight in pounds. A more accurate weight value results in better biomechanical analysis.
- 3** Click the Click 1st References button to begin the process of clicking the reference distances points on the video frame.

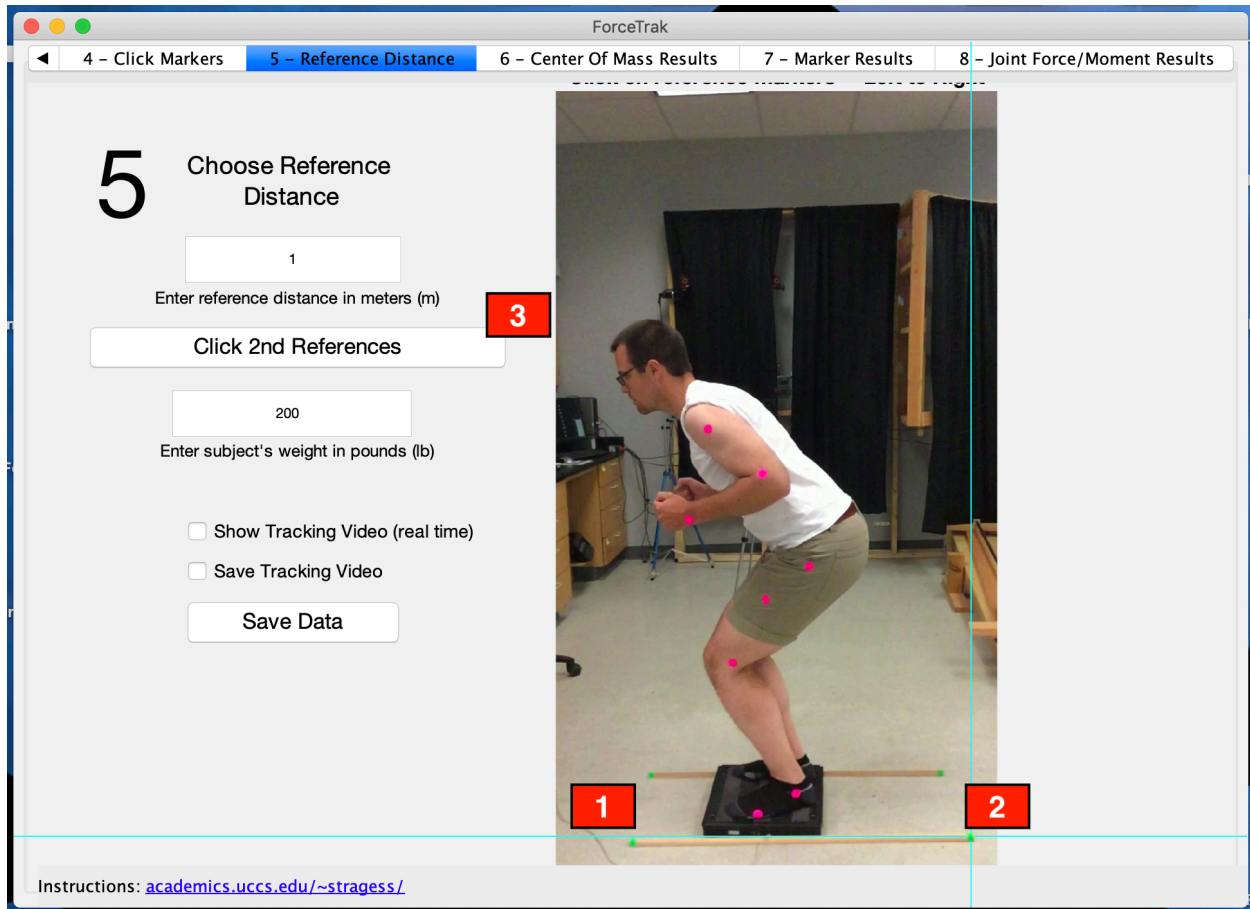


Figure 25: Tab 5 - Clicking the reference distance markers

Notes / Clicks:

- 1** After clicking the Click References button, the teal crosshairs will display. You will make two clicks. The first click on the reference stick (green tape on the wooden stick above in front of the test subject) is not shown above.
- 2** This shows the second click on the reference distances. It is best to always ensure the first click on the stick is on the front most side (relative to the direction the subject is facing) and the second click on the back side of the stick. Always click the front most stick in the frame if using two videos (the stick closest to the camera).
- 3** Once done with the above, click the Click 2nd References button to begin clicking the reference distance for video 2 (if applicable).

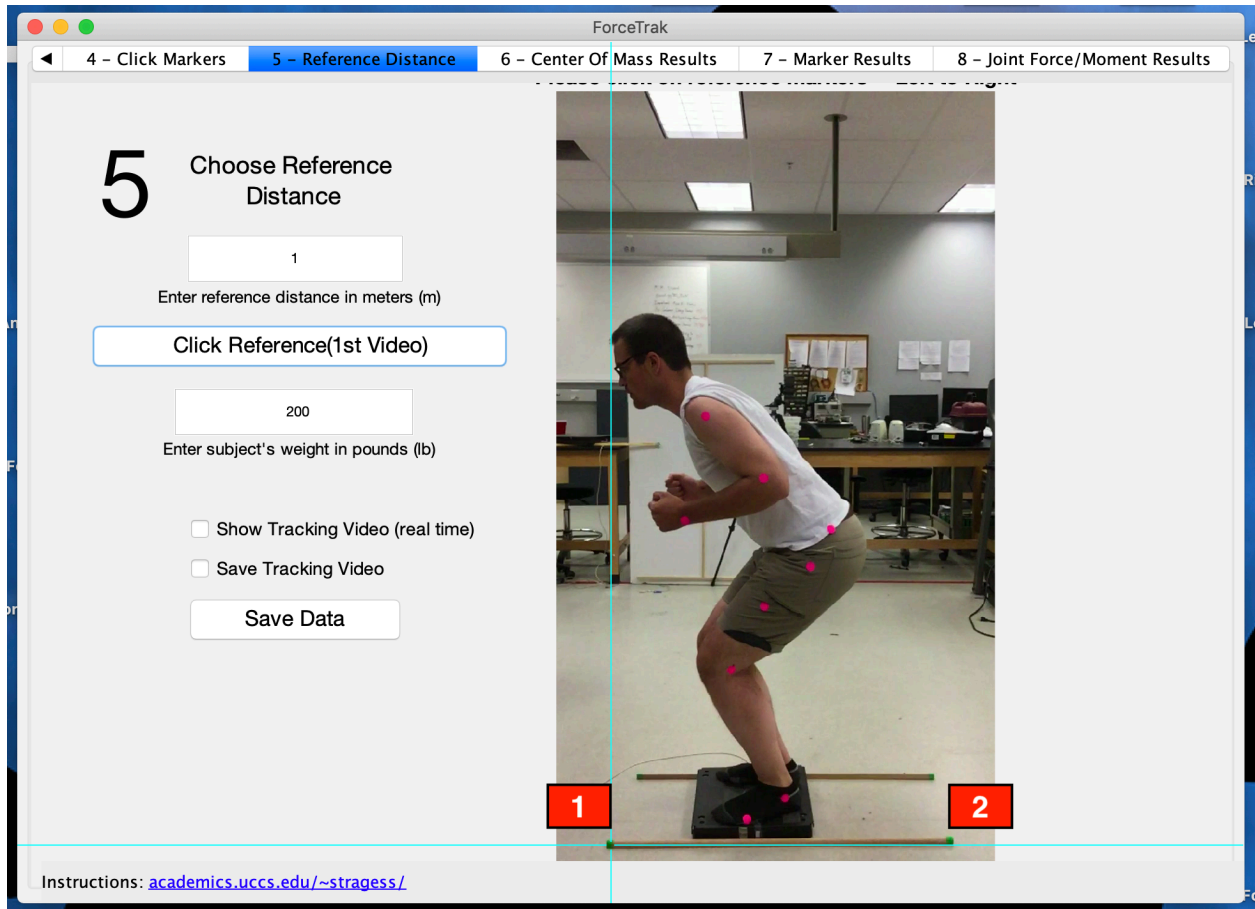


Figure 26: Clicking the reference distance markers for video 2 (if applicable)

Notes / Clicks:

- 1** Click the reference distance point (green tape on wooden stick in image above) like that of video 1. Make sure to click in the same orientation (i.e. in the example above the first click is on the left or the front the stick/forward facing direction of the test subject).
- 2** Make the final and second click on the reference stick. Like the notes previously, always make clicks on the reference distance stick closest to the camera.

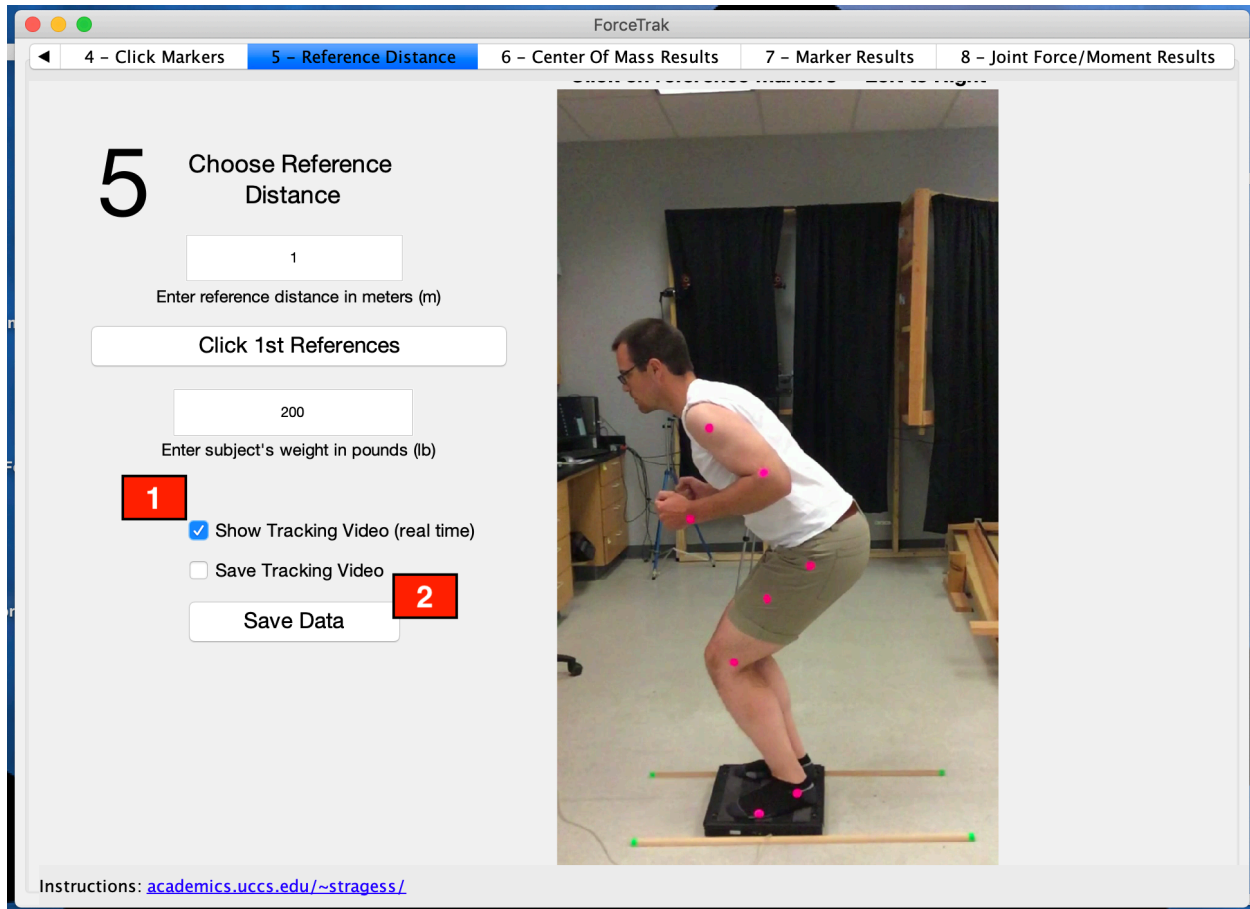


Figure 27: Tab 5 - Selecting tracking options

Notes / Clicks:

1

Once the reference distances have been clicked, select the tracking options.

1. **Show Tracking Video (real time)** – this option displays the tracking in real time on the screen in the application. This slows the tracking down slightly.
2. **Save Tracking Video** – this option does not display the tracking but saves it to a video to review at the end of tracking. This is nice if tracking many frames without having to watch to ensure there were no issues. This option is very slow.
3. **No box selected** – the default option – neither a video nor display of the tracking is conducted. This is the fastest option.

2

Click the Save Data button to specify where all the results will be saved.

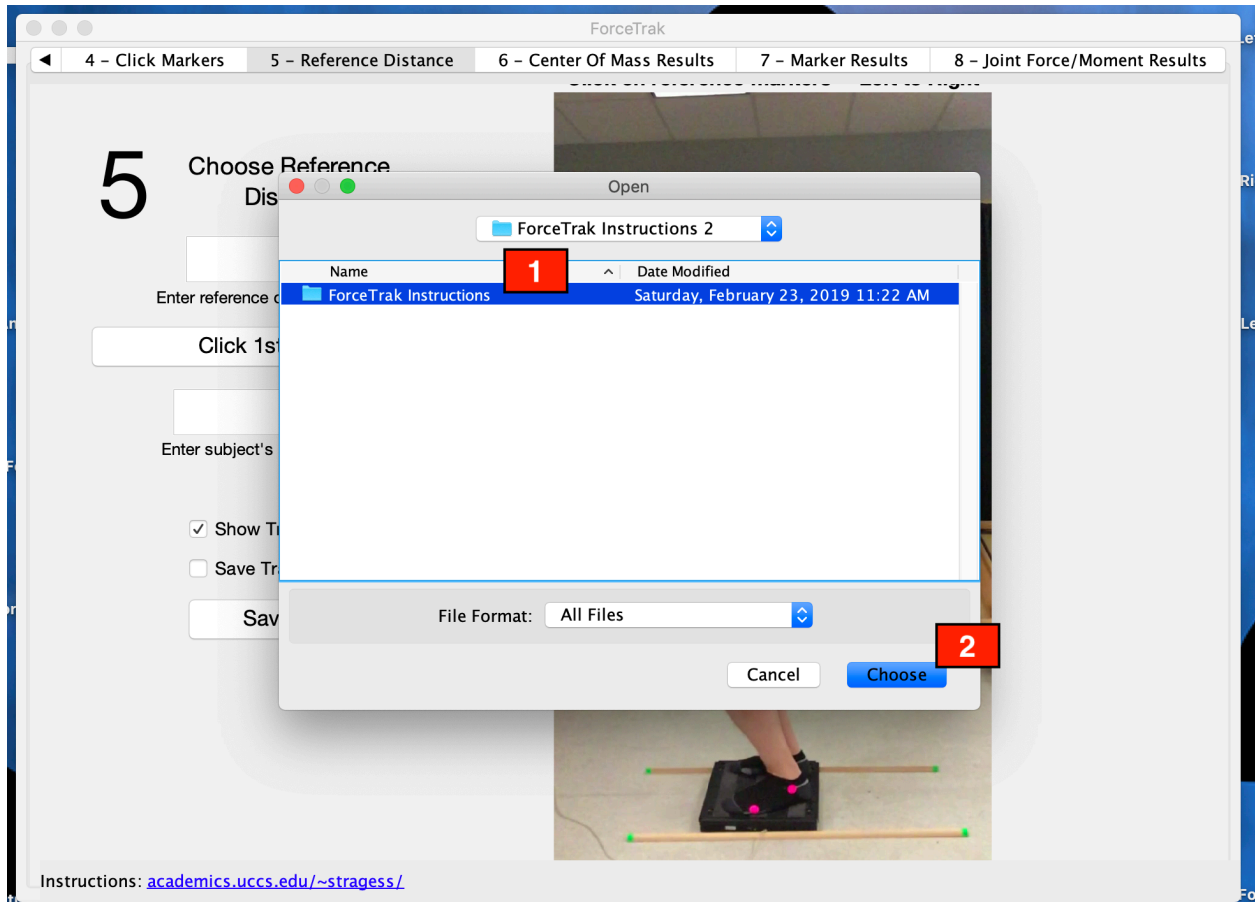


Figure 28: Selecting the directory (or file) in which to save tracking results

Notes / Clicks:

- 1** After clicking the Save Data button, this screen will pop up. Navigate to the file where you will save the tracking session data. It is recommended to create a separate file for each tracking session to keep all data organized.
- 2** Once the file has been selected, click the Choose button.

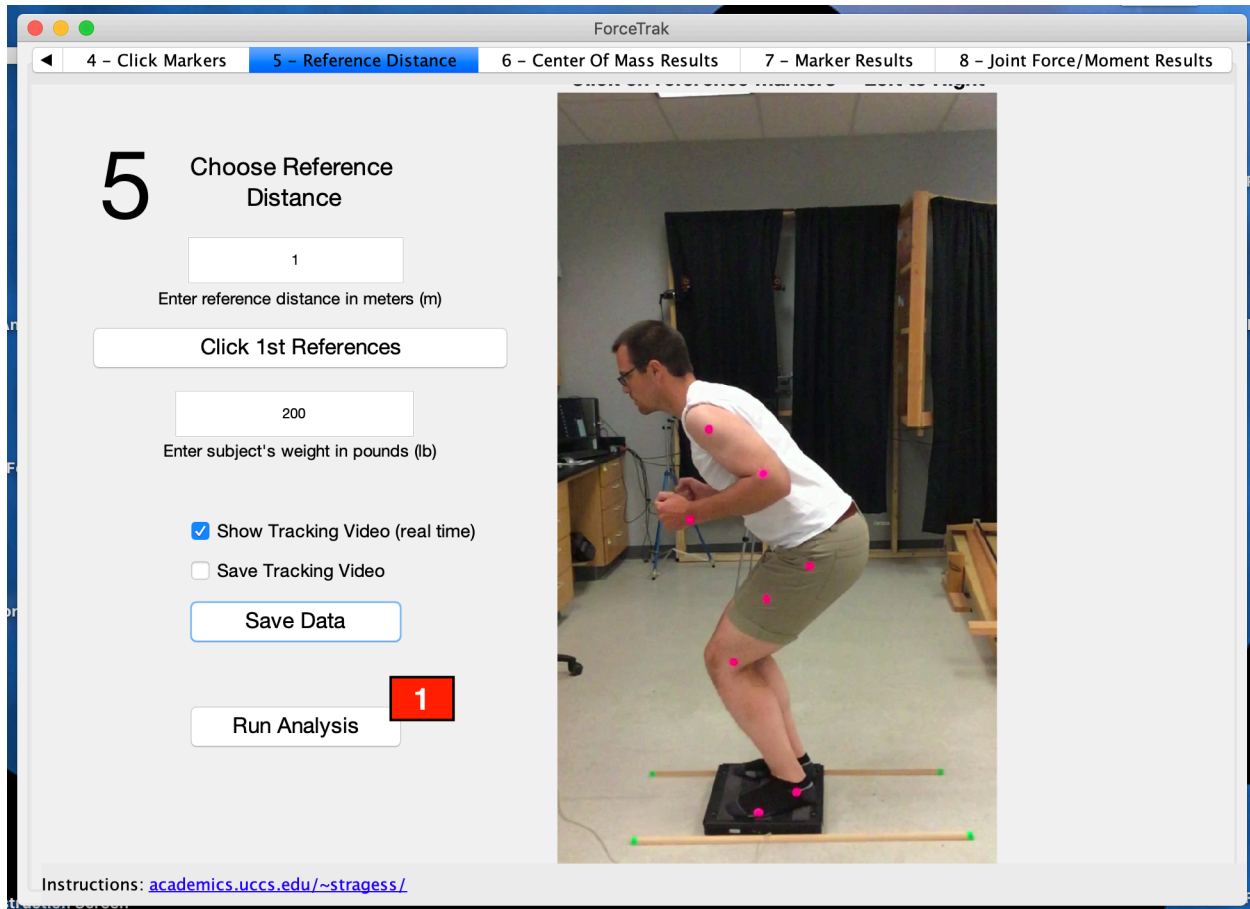


Figure 29: Run analysis

Notes / Clicks:

- 1** Click the Run Analysis button to conduct the video tracking. When tracking is done the system will automatically take you to the next tab, Tab 6. The tracking and analysis can take some time depending on how many frames are being tracked and which tracking option you chose. It is recommended to wait for the tracking to complete before doing other tasks on the computer (i.e. checking email, surfing the internet, etc.).

Special Note: When the system is done tracking it will automatically save the position data of the marker tracking results in the file you specified earlier. These files are saved as spreadsheets (Excel .xlsx files).

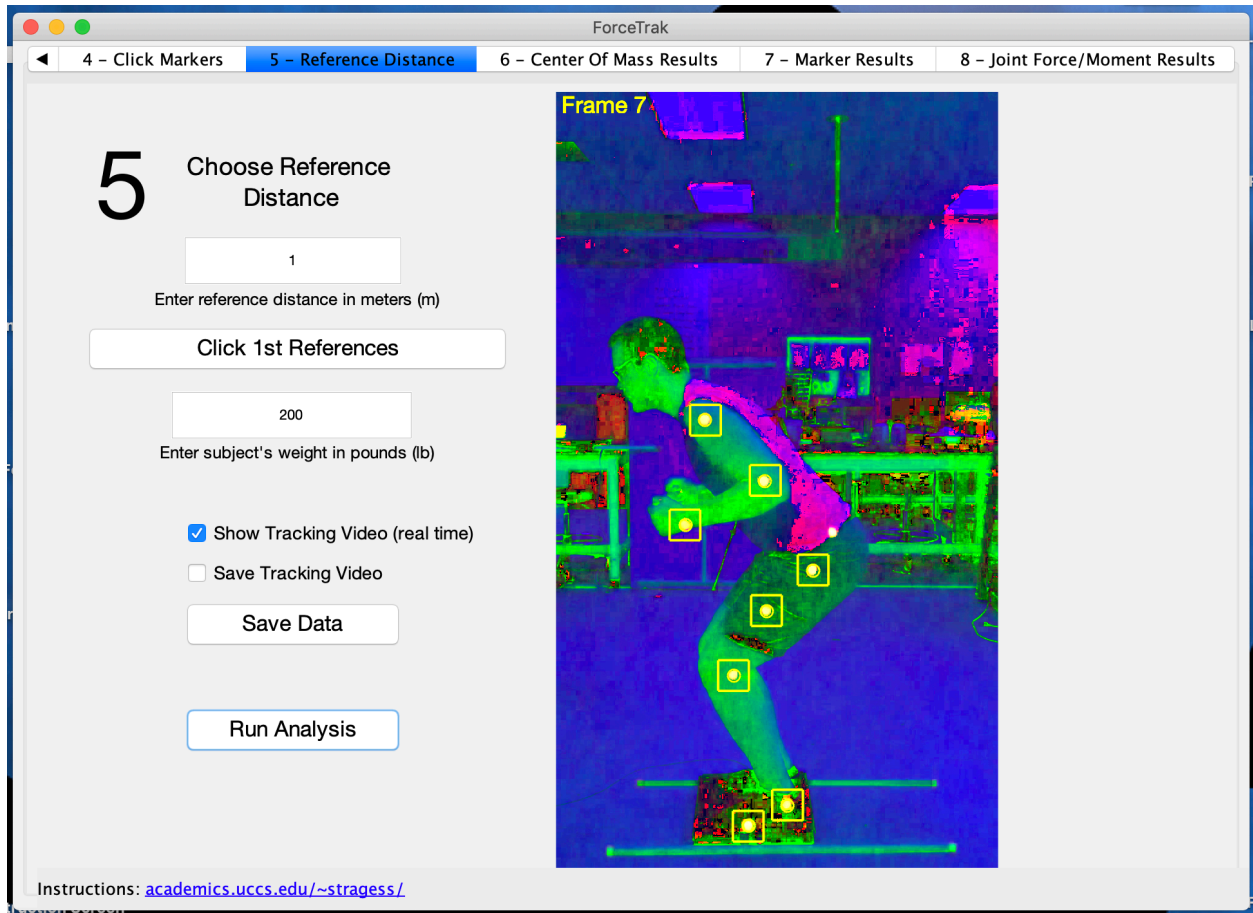


Figure 30: Example of selecting the real time tracking option

The screen capture above shows the tracking system running. For this example, the option of Show Tracking Video (real time) was selected.

When selecting the Save Tracking Video option or leaving both boxes unchecked, a wait bar will display showing the progress of the tracking (see image below for example of the wait bar).

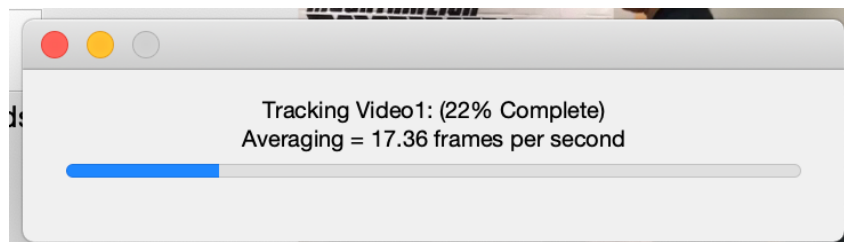


Figure 31: Tracking wait bar

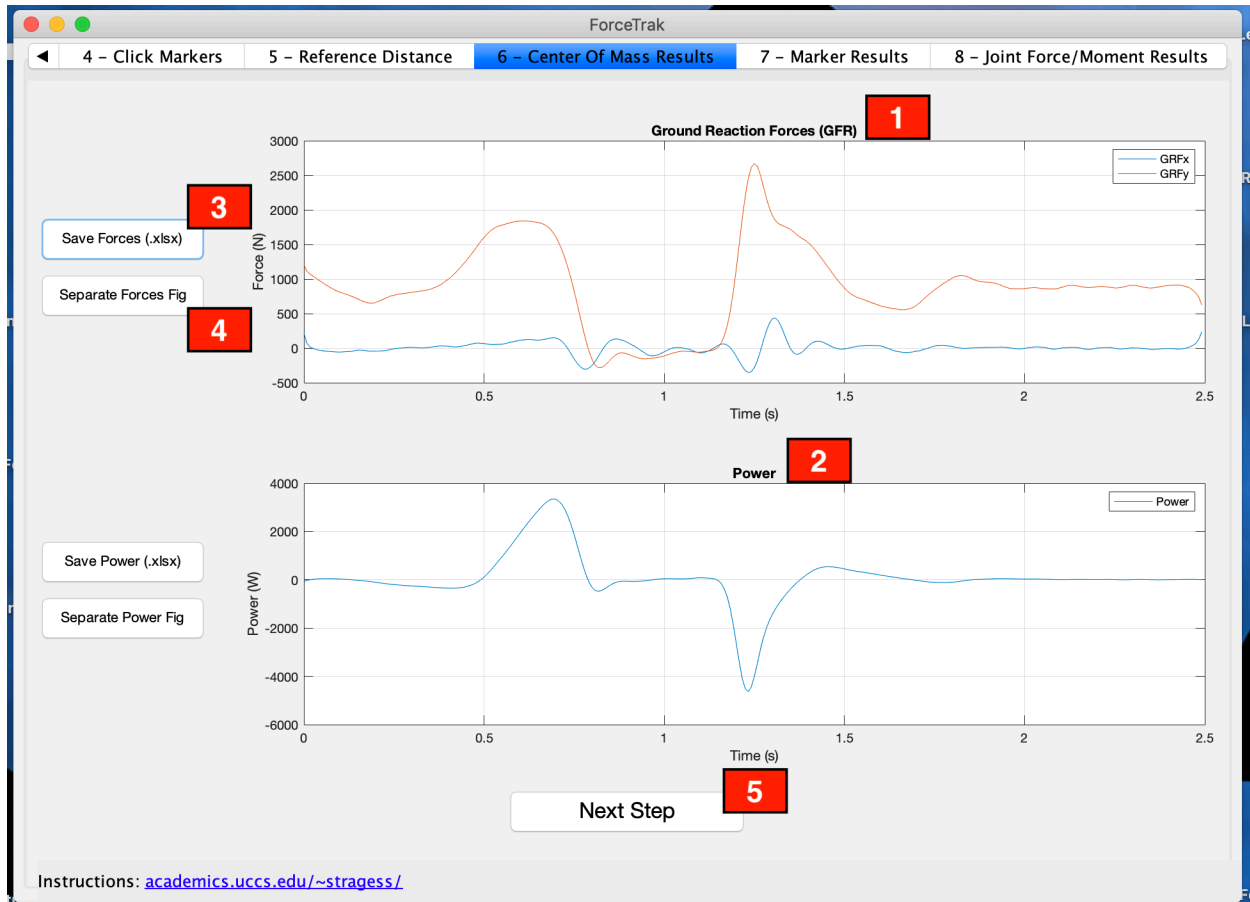


Figure 32: Tab 6 - Ground reaction force and power results

Notes / Clicks:

- 1** A plot of the ground reaction forces is displayed in the application in component x, y form. This is for the body as a whole.
- 2** A plot of the power is shown as well.
- 3** Clicking the Save Forces (.xlsx) button saves the results to a spreadsheet in the file designated on Tab 5.
- 4** Clicking the Separate Forces Fig button displays a separate figure of the plot (item #1 above). This allows for printing or saving of the figure as desired.
- 5** Click the Next Step button to proceed to the next tab.

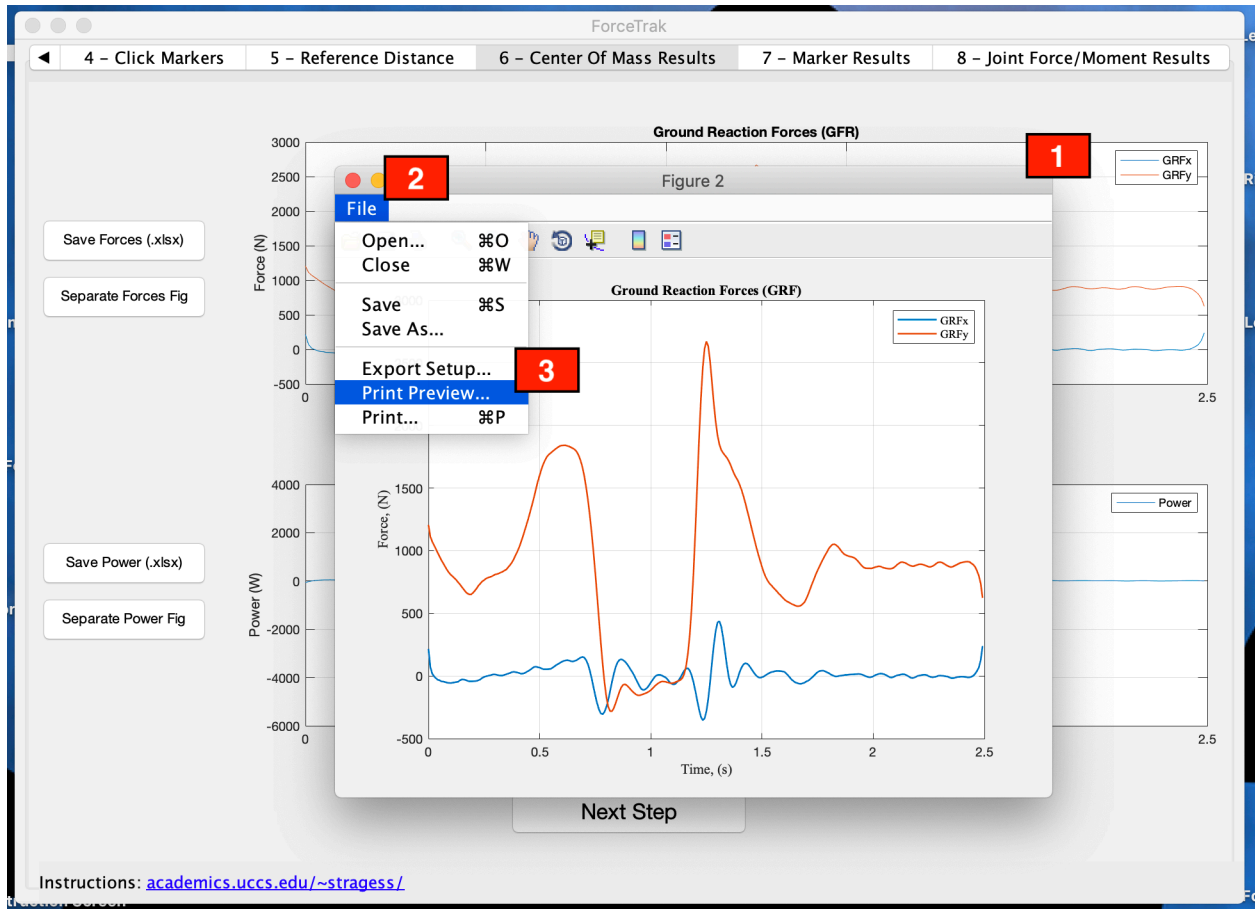


Figure 33: Saving or printing a figure

Notes / Clicks:

- 1 This shows what the secondary figure will look like when clicking on a separate figure button. This figure can be saved or printed as desired.
- 2 For printing or saving click the file tab in the figure window.
- 3 For printing, it is recommended to use Print Preview and select the desired parameters (i.e. color, black and white, size and position, etc.) prior to printing.

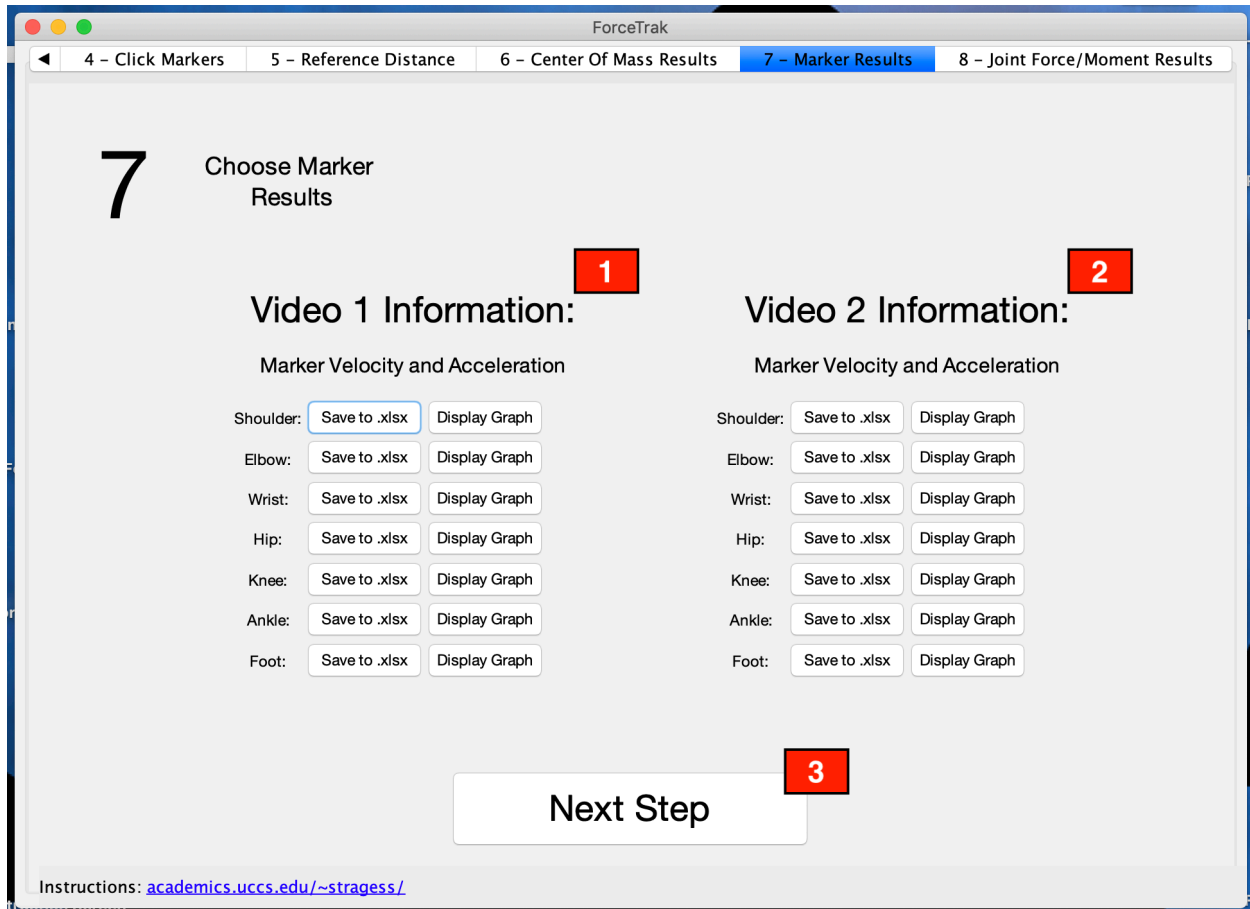


Figure 34: Tab 7 – Marker/joint velocity and acceleration results

Notes / Clicks:

- 1** Video 1 marker data is provided automatically. You have the option of saving the velocity and acceleration data of the marker to an Excel spreadsheet or display the graph of a given marker. When clicking the Save to .xlsx button, Excel spreadsheets are automatically saved to the file selected on Tab 5.
- 2** If video 2 was selected, marker velocity and acceleration data is available. If not, a prompt will show warning of no marker data available.
- 3** Click the Next Step button to proceed to the next tab.

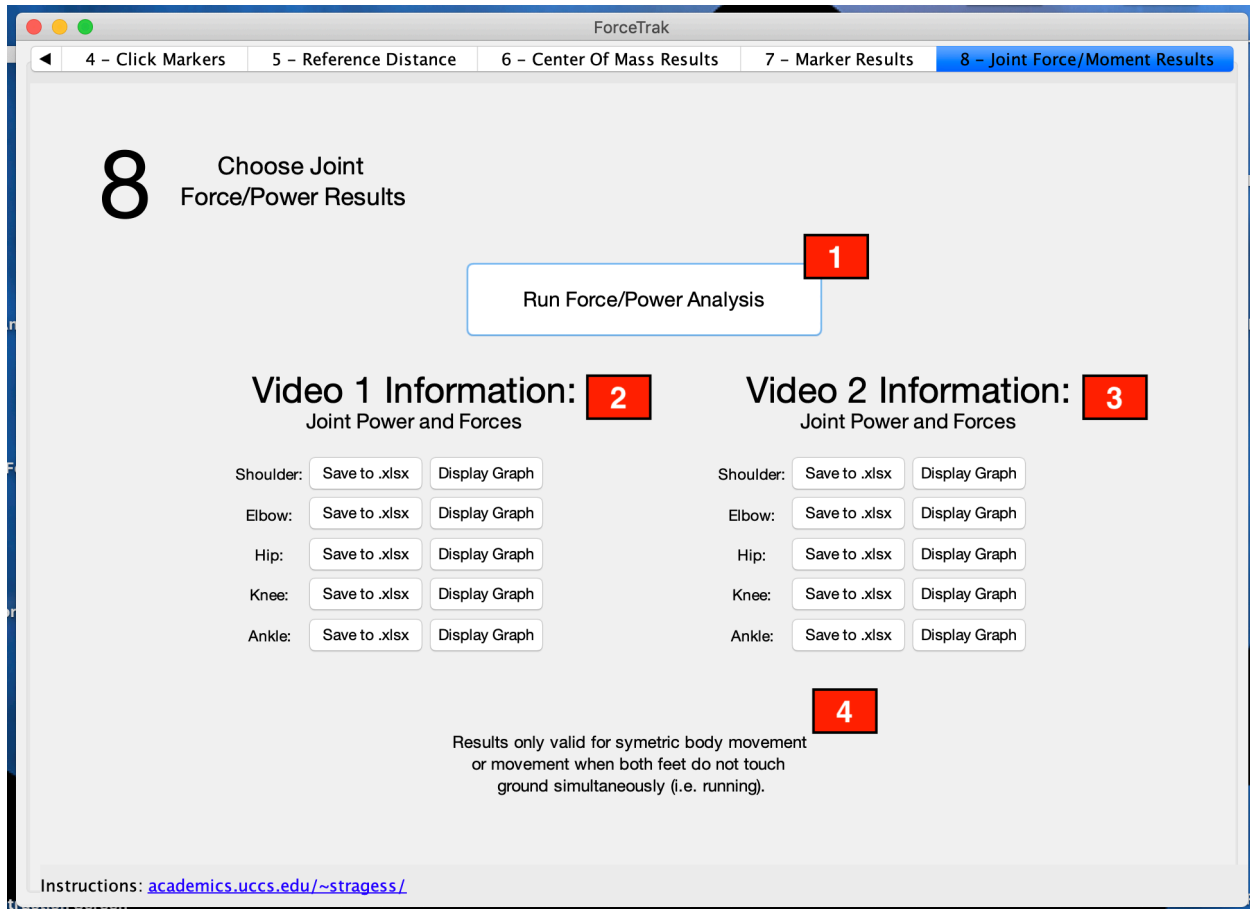


Figure 35: Joint Forces and Joint Power

Notes / Clicks:

- 1** To calculate the joint forces and joint power click the Run Force/Power Analysis button.
- 2** Video 1 information for the joints can be saved or displayed.
- 3** Video 2 information for the joints can be saved or displayed.
- 4** This Tab's results are only valid for movements that are symmetric or for movements where only one foot is contacting the ground on any frame. For details on this the reader is directed to Biomechanics and Motor Control of Human Movement by David A. Winter (reference on page 6 of this document).

Troubleshooting software problems

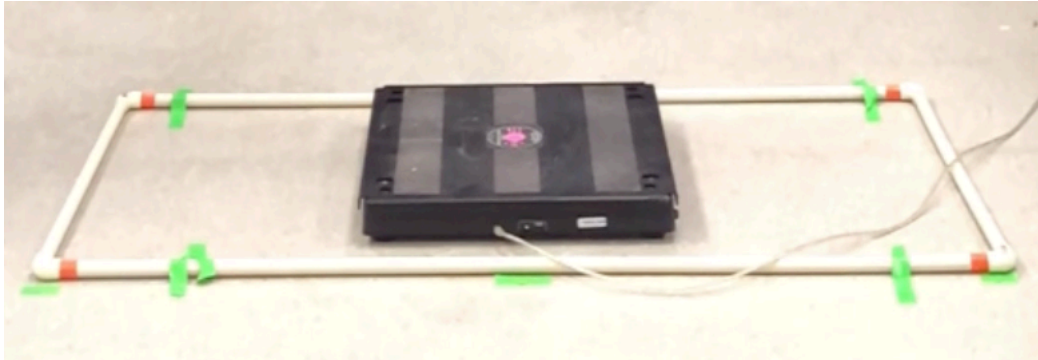


This section is a work in progress.

The system may throw an error that is only detectable by an audible error sound. If, for any reason, the system doesn't seem to be working properly, close out the program and re-launch it. This will require going through the frame selection and marker selection process from the beginning but may resolve issues.

Reference distance sticks

Reference distance sticks must be fairly accurate and aligned as parallel as possible when setting up the video. The below picture shows an example of pipes used to create the reference distance markers. This particular setup may not work for all applications but is a relatively inexpensive and easy way to ensure the sticks remain parallel during testing.



Another alternative is a set of simple meter sticks with bright colored markers or tape on the ends. With any setup, try to ensure the sticks are placed as close to the feet as possible without disrupting the physical motion of the participant. Finally, some of the biomechanical analysis uses the reference distance clicks to determine where the ground is in relation to the test subject. As such, it is recommended that the reference distance sticks always be placed on the ground to ensure all results from the software are as intended.



**Place bright tape
or sticker on ends**

Marker guidance

Marker materials

- 0.75-inch diameter round pink stickers have proven to work best in indoor lighting. Depending on the test subject's skin tone, outside lighting may make the pink stickers less effective. The following pictures and [link](#) shows the recommended stickers.
- Double sided tape may work well for high humidity environments, or for activities where body perspiration is likely. A picture and [link](#) have been provided to tape designed for sticking fabric to skin, but any double sided tape that resists moderate amounts of moisture should suffice.



Test subject attire

- Tight fitting clothes of a neutral tone are best. Stark color contrast between the clothing and marker makes tracking much more effective.
- The clothing below is an example of a good choice for tracking.



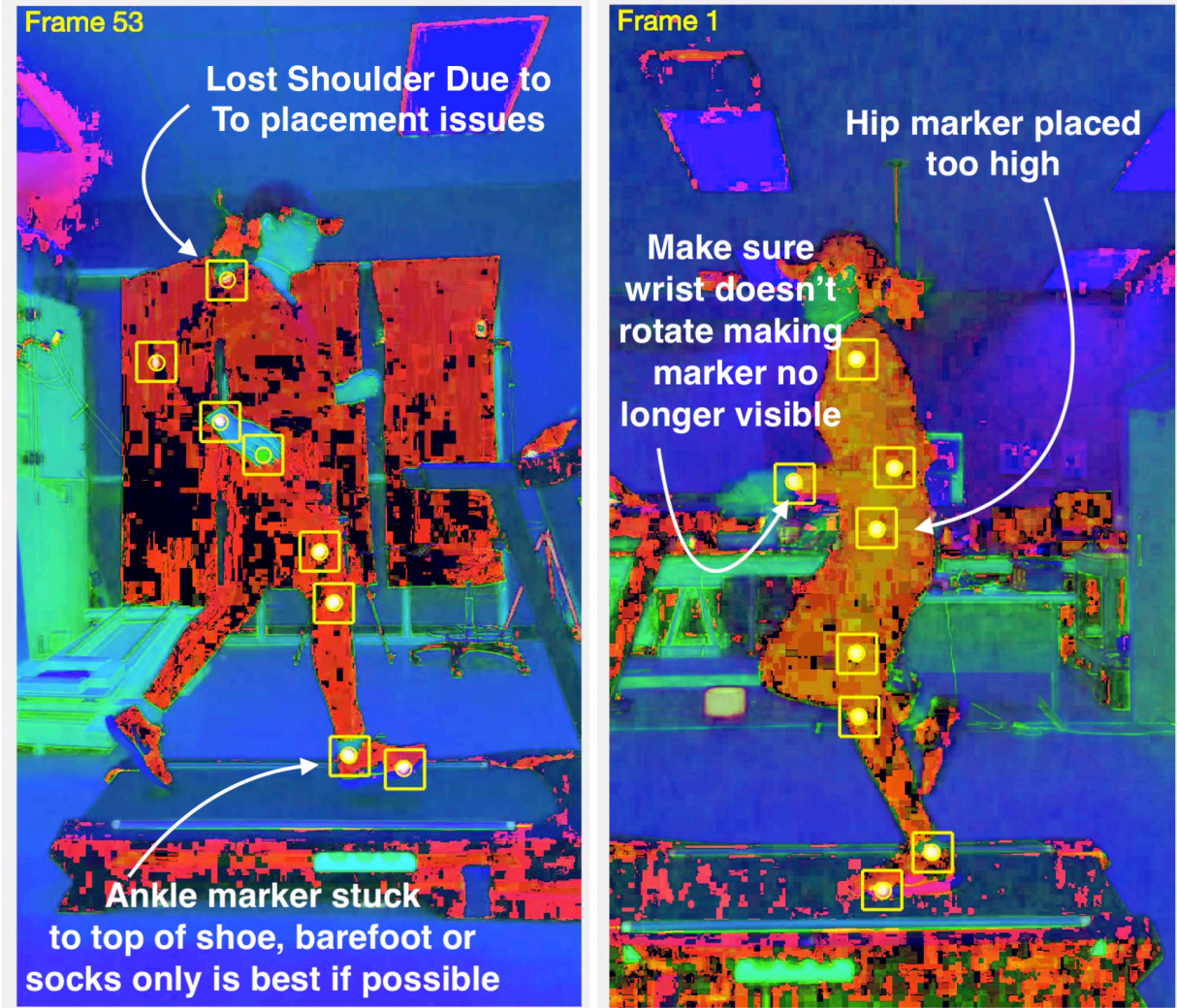
Marker placement

- A Google search of the anatomy listed below (Second column in table) and look at images for the precise placement of markers paying special attention to the placement on the shoulder and hip is advised.

Segment	Precise Marker Placement
Forearm (elbow and wrist)	Elbow axis/ulnar styloid
Upper arm (elbow and shoulder)	Glenohumeral axis/elbow axis
Foot (ball of foot and ankle joint)	Lateral malleolus / head metatarsal II
Leg (calf – ankle and knee)	Femoral condyles / medial malleolus
Thigh (knee and hip)	Greater trochanter / femoral condyles
Trunk head neck (hip and shoulder)	Greater trochanter / glenohumeral joint

- Ensure markers are not covered by excessively loose clothing
- Ensure markers will not be covered at any point while taking the video by clothing – for example tuck in the shirt
- Double check that marker placement, is correct, see below for two common issues.

Common examples of bad marker placement



Troubleshooting and setup tips



This section is a work in progress.

Viable cameras

- Android Phone / iPhone / iPod with Slow motion capture of 120fps or 240fps
- Any other smart phone / camera with 120fps or 240fps

Notes on videos / camera setup

- Best video resolution is 720x1280
- Videos sync by noise – so ensure a loud hand clap or equivalent while recording and keep other sounds to a minimum
- Ensure that both cameras are set to either 120fps or 240fps, they must be the same for the velocity and acceleration calculations to match.
- 120 fps works nicely for most movements. High velocity movements (markers moving in excess of 8m/s) will work better with 240fps.
- Ensure reference sticks are perfectly aligned for best results
- Try to ensure the phones are perfectly normal to the subjects (x,y) plane of movement and the tripods are set to ensure the camera is level with the hip region of the user.

Physics capabilities

- Ground reaction forces will only be accurate if all markers are selected and you are using two videos from either side or one video if the body movement is symmetric on either side.
- Joint forces and moments button will NOT work for walking. Do not trust these results in those circumstances.
 - o This part of the program is still in the developmental phase.

General video environment / suggestions

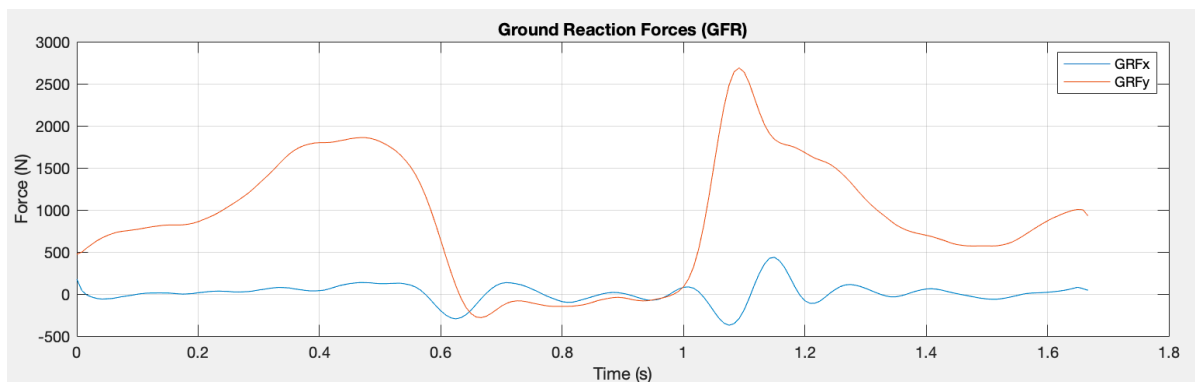
- Ensure lighting is good.
- Take multiple videos.
- Keep videos less than 1-2 minutes otherwise at 120fps or 240fps you are dealing with very large frame counts.
- Saving the tracking video / displaying frames while tracking makes the tracking system much slower (up to 6 times longer to do the tracking)

Testing the software with example videos

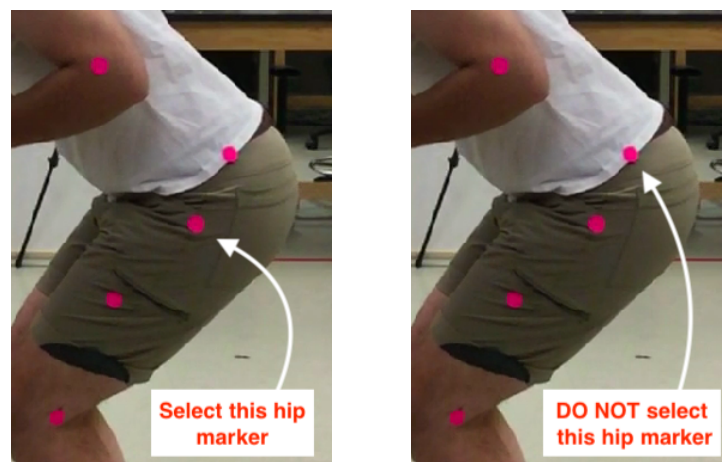
There are two videos available for downloading and testing of the program. These videos are free for use and have been thoroughly tested to ensure they track well. If you are having issues with your own videos, it may be wise to test these to ensure the software is working correctly. You can compare the ground reaction forces with your test of these videos with the image below to ensure things are working properly.

Testing parameters

- Video 1 file name: [LeftSide_Jump_120fps.mov](#)
- Video 2 file name: [RightSide_Jump_120fps.mov](#)
- Frame rate: [120fps](#)
- Suggested start frame: [20](#)
- Suggested end frame: [220](#)
- Reference distance (m): [1](#)
- Subject Weight (lb): [200](#)



Example of Ground Reaction Force Results (2 video tracking with all markers)



Make sure you select the correct hip marker when using these testing videos.
Disregard the extra marker.

Acknowledgements

This software would not be possible without the incredible vision and mentoring of Dr. Steven Tragessor of the University of Colorado Colorado Springs, Mechanical and Aerospace Department. Many undergraduate students have contributed to the realization of this project over the years. A listing of all those who have made contributions is below. Finally, funding for this project was provided by the Colorado Space Grant Consortium of the NASA Space Grant Program.

Faculty Advisor

University of Colorado Colorado Springs

Associate Professor Department of Mechanical and Aerospace Engineering

- Dr. Steve Tragesser

Student Researchers

University of Colorado Colorado Springs

Undergraduate Mechanical and Aerospace Engineering Students

- John Thompson
- Austen Knapp
- Mike Schenck
- Ian Hermson
- Estell Moore
- Faith Ortiz