

Analysis of Jumping

Introduction

Vertical jump tests are often used by physical trainers to assess leg strength. Simple alterations in the way a vertical jump is performed can alter the amount of force that is produced during the jump, affecting the results. A common testing technique is to have a subject perform a standing vertical jump. To limit interactions from the upper body, the subject may be asked to perform the vertical jump with the arms restricted. This restricted jump is also referred to as a squat jump. To do a restricted jump, the subject keeps their hands on their hips or waist when performing the vertical jump.

Force plates are often used to measure the peak force in these types of strength tests, but force plates can give counterintuitive results. For example, a large person can produce a good deal of force, but they may not be able to jump as high or accelerate as fast as a smaller person. Therefore, in some situations, peak acceleration may be a better measure of leg strength. If you know the peak acceleration, you can use the subject's mass to calculate peak force without the need for a force plate.

The jumping motion can be divided into four distinct phases: the preparatory phase where the subject crouches in preparation for the jump, the push phase where the subject pushes off the ground, the rising phase where the subject's feet have left the ground and the subject rises until they reach a maximum height, and the falling phase where the subject falls back to the ground. Using vertical motion data associated with the push and rising phases of a vertical jump, you can determine several factors commonly used to measure the leg strength of a test subject.

In this experiment, you will use the Vernier Video Analysis app to examine the motion of a test subject performing two standing vertical jumps. The first jump will be a restrictive jump where the test subject holds their hands on their waist during the jump. The second jump will be a full vertical jump where the test subject's arms and hands are free to move. Using the analysis features in the app, you will compare the vertical displacement, as well as the peak accelerations and peak forces generated during these two jumps from the provided video. As time permits (or as required by your instructor), you can complete one or more of the extensions or design your own investigation using videos of jumps that you record.

Objectives

- Use video analysis techniques to obtain position, velocity, and time data for a human subject jumping.
- Analyze the y position and y velocity vs. time graphs for the subject as they jump in two different ways.
- Calculate acceleration using a calculated column to find the maximum acceleration during each jump.
- Use the mass of the subject to calculate peak force during each jump.
- [Extensions] Create and analyze your own videos of a person jumping in different ways.

Materials

Vernier Video Analysis App in a web browser on a computer, Chromebook, or mobile device

Jump-Restricted.mp4 video file

Jump-Full.mp4 video file

Pre-lab Investigation

Your instructor will select a volunteer to perform a standing vertical jump with their hands on their hips or waist. The test subject should stand with their side facing the class so everyone can clearly see their legs bend and then straighten during the jump.

Observe the motion of the jump carefully. Sketch and discuss position vs. time and velocity vs. time graphs that include all four phases of the vertical jump: preparatory, upward push, rising, and falling. Compare your graphs with those created by the other people in your group as well as your classmates.

Procedure

Part 1 Restricted Jump

1. Launch Vernier Video Analysis and import the movie “Jump-Restricted.mp4”. Play the movie once or twice so you are familiar with the motion.
2. Make the movie window large enough to easily see the subject. There are two ways to do this: 1) Click or tap the handle on the divider between the video and the other elements on the screen, and drag the divider to the right, or 2) use View, , to remove the graph and data table from view.
3. Use Step Forward, , and Step Back, , to advance the movie to the frame where the subject is fully crouched and just begins to move up vertically during the jump. This is the beginning of the upward push phase of the jump.
4. Set the origin and the scale in the video.
 - a. Click or tap System, . You will see new icons appear for Scale and Origin. Scale, , is already selected.
 - b. Move the centers of the scale circles to align with the ends of the red bar closest to the subject. The red bar is 2 meters in length, so adjust the displayed length to 2 m.
 - c. Click or tap Origin, . Drag the axes to set the location of the origin, which in this video is at the base of the subject's feet.
 - d. Rotate the axes about the origin so that the X axis is parallel to the red bar.

5. You will be marking the location of the subject as they jump during the video. By default, each time you mark an object's location, the movie advances by just one frame. For this video analysis, it is better if the movie advances more quickly.

To change the setting, click or tap Advanced Video Options, . Change the Advance Frame setting to 5 frames, and then dismiss the window to save your changes.

6. Mark the location of the subject as they move during the jump.
 - a. Click or tap Add, .
 - b. Click or tap Trails, , to hide all marked points except the one in the frame you are viewing. This will make it easier to mark your points.
 - c. The subject is wearing black pants with white stripes on the thigh. Locate where the center stripe ends at the waist and use this point as your marking position of the subject. It is important to be consistent when marking the location; always place the crosshairs on the same location on the subject.
 - d. Position the crosshairs at the chosen location on the subject, and then click to add the first point. **Note:** If you are using a phone or tablet, once you place the crosshairs you can click or tap anywhere in the video frame.
 - e. Continue marking points through the entire rising phase of the jump. To help with analysis, mark at least three points of the descent (after the subject has reached the peak height).
 - f. Review your marked points. Should you wish to edit a point, click or tap Edit, . This allows you to move or delete a mismarked point.
7. Use View, , to display the video and graph, and hide the data table. Click-and-drag or tap-and-drag the divider between the video and graph so you can easily see both elements.
8. Vernier Video Analysis defaults to display both the x and y positions of the object as a function of time. For a vertically moving object like the vertical jumper, you want to examine the graph of the y component only. Click or tap the vertical axis label on the graph to open the Plot Manager. Turn off the X column so only y position (Y) vs. time is plotted.
9. Do Part 1 of the Analysis, then return to Part 2 to continue with the procedure.

Part 2 Full Jump

In this part, you will analyze a video that shows the same subject performing a full vertical jump in which their hands are free to move.

10. Click or tap File, , choose New Experiment, and import the movie "Jump-Full.mp4". Play the movie once or twice so you are familiar with the motion.
11. Repeat Steps 2–8 to analyze the full jump video. **Note:** If needed, use Step Forward, , to skip past a frame (without marking a point) when the subject's waist is blocked by his arm.
12. Complete Part 2 of the Analysis.

Analysis

Part 1 Restricted Jump

1. Examine the graph of y position (Y) vs. time.
 - a. Describe the motion of the subject over the course of the rising phase of the jump. Do you see regions of the graph where the subject accelerated? Explain how you know the jumper is accelerating.
 - b. Tap on the point on the graph that corresponds to the maximum displacement of the hips (height).
 - c. Drag the Examine line back and forth around this point. Observe and note what is happening in the video. With respect to the phases of a jump, what is the significance of this point in the jump? Pay close attention to the feet and knees. Are the feet at their highest point for the jump? Look at the knees; are the legs tucked in or are they fully extended?
 - d. Dismiss the Examine line. Click or tap Graph Tools, , and select View Statistics. Record the vertical amplitude of the jump (Δy from the statistics details), then dismiss the Statistics details box.
2. Examine the graph of y velocity (Y Velocity) vs. time.
 - a. Click or tap the vertical axis label on the graph to open the Plot Manager. Turn off the Y column and turn on the Y Velocity column so only y velocity vs. time is plotted.
 - b. Tap on the point on the graph that corresponds to the maximum velocity.
 - c. Drag the Examine line back and forth around the maximum velocity. Observe and note what is happening in the video at maximum velocity. With respect to the phases of a jump, what is the significance of this point in the jump? Pay close attention to the feet and knees. Are the feet still on the ground? Are the legs still crouched or are they fully extended?
 - d. Dismiss the Examine line. Click or tap Graph Tools, , and select View Statistics. Record the maximum velocity then dismiss the Statistics details box.
3. Create a calculated column to find the y acceleration of the subject as they jumped.
 - a. Use View, , to add the data table to your display.
 - b. In the data table, click or tap Column Options, , for Y Velocity and choose Add Calculated Column.
 - c. Enter **Y Acceleration** as the name of the column and **m/s²** as the units.
 - d. Select Insert Expression. Choose 1st Derivative (Y, X).
 - e. Verify that Y Velocity has been selected for the Column Y box and that Time has been selected for the Column X box.
 - f. Click or tap Apply.
4. Examine the graph of y acceleration (Y Acceleration) vs. time.
 - a. Use View, , to remove the data table from your display.
 - b. Click or tap the vertical axis label on the graph to open the Plot Manager. Turn on the Y Acceleration column and turn off all other columns so only y acceleration vs. time is plotted.

- c. Tap on the point on the graph that corresponds to the maximum acceleration.
 - d. Drag the Examine line back and forth around the maximum acceleration. Observe and note what is happening in the video. In which phase of the jump is the subject? Are they in the beginning, middle, or end of that phase? Pay close attention to the feet and knees. Are the feet still on the ground? Are the legs still crouched or are they fully extended?
 - e. Dismiss the Examine line. Click or tap Graph Tools, , and select View Statistics. Record the maximum acceleration of the jump, then dismiss the Statistics details box.
5. Calculate the peak force during the jump using the formula $f = ma$. Assume that the subject in the video has a mass of 70 kg.
 6. Save your Video Analysis file.

Part 2 Full Jump

7. Repeat Analysis Steps 1–5 for the full jump.
 - a. Compare the position of the feet and knees for the full jump and the restricted jump for these conditions:
 - i. The jumper is at the highest point in the jump.
 - ii. The jumper's maximum Y Velocity.
 - iii. The jumper's maximum Y Acceleration.
 - b. Note the position and direction of motion of the arms for the conditions noted above.
 - c. Record the following values for the full jump.
 - i. The vertical amplitude (Δy) of the jump.
 - ii. The maximum velocity achieved during the jump.
 - iii. The maximum acceleration achieved during the jump.
 - iv. The peak force during the jump.
 - d. Do the graphs for the full jump appear similar to the graphs you observed for the restricted jump? If not, how are they different?
8. Compare the vertical amplitude, maximum velocity, maximum acceleration, and peak force for the two jumps. Does a restricted jump appear to change the maximum acceleration and peak force generated during a vertical jump? Explain why you think that is.
9. Save your Video Analysis files.

Extensions

Many of the extensions involve making your own video of a subject jumping. You will need a digital camera or some other device capable of recording video; it can be the same device running Vernier Video Analysis. Use the following guidance when making your videos. If you are having difficulty capturing a video, ask your instructor for additional tips.

Production and analysis of your own video

- Once your jumper has been selected, have them practice jumping vertically a couple of times. Make sure the subject uses proper technique when jumping.
- Verify that the vertical jumps can be captured on video.

Activity 4

- Because the jumps happen quickly, you should use the “slow motion” video capture feature on your device. You will want to make sure you can capture the entire video sequence at the same frame rate using “slow motion” before starting your experiment.

Investigate one of these extension ideas, or design your own experiment to investigate.

1. Compare the effect of jumping off a small stool and then performing the vertical jump. A step stool should work for this exercise. Have the subject jump off the step stool, land, crouch, and then perform a vertical jump. This should be done as quickly as possible. Only analyze the rising phase of the vertical jump. Compare the results to Parts 1 and 2 of this exercise. Explain your results.
2. Analyze vertical jumps of a subject wearing a 5–10 lb weight vest. Record any change in velocity, acceleration, and force that occurs when the subject's weight is increased while performing a vertical jump.
3. Analyze a running vertical jump. Have the subject sprint and then perform a vertical jump or leap. Have the subject leap as high as they can into the air. Use the analysis steps in Part 1 to analyze the vertical amplitude, maximum velocity, maximum acceleration, and peak force produced when performing a running vertical jump.
4. Compare a person performing a layup in basketball to a running vertical jump. If you know of someone who can “dunk” a basketball, investigate the vertical velocity and acceleration when performing a “dunk.” Compare the results you find to the results when performing a running vertical jump. Use the same subject for comparisons.
5. Investigate the role of crouching on peak acceleration. Does the depth of the crouch produce a greater acceleration? Design an experiment that investigates this question.
6. Use the videos provided or create your own to investigate the motion of the knee during a jump. How do the maximum displacement, velocity, and acceleration of the knee compare to that of the waist?
7. Use the videos provided or create your own to investigate the motion of the ankle during the jump. How does the maximum displacement, velocity, and acceleration of the ankle compare to the knee and the waist?
8. Use the “Jump-Full” video provided or create your own to investigate the motion of the elbow or hand during the jump. Determine when peak velocity and acceleration happens for the elbow or hand. Compare this to when peak velocity and acceleration happens for the waist.
9. Compare vertical jumps where the legs are kept relatively straight during the jump to jumps where the legs are tucked under the jumper.
10. Compare jumps from athletes that participate in different sports.

Analysis of Jumping

This activity is written with the assumption that the instructor will engage students in discussions during the pre-lab and during the evaluation of data. These discussions can take place with the entire class or with individual lab groups.

If this is your students' first time using Vernier Video Analysis, we recommend giving them the Guided version of the instructions. If your students are already familiar with using Vernier Video Analysis, consider giving them the Abridged version of the instructions.

OBJECTIVES

In this experiment, the student objectives include

- Use video analysis techniques to obtain position, velocity, and time data for a human subject jumping.
- Analyze the y position and y velocity vs. time graphs for the subject as they jump in two different ways.
- Calculate acceleration using a calculated column to find the maximum acceleration during each jump.
- Use the mass of the subject to calculate peak force during each jump.
- [Extensions] Create and analyze your own videos of a person jumping in different ways.

During this experiment, you will help the students

- Recognize that they can measure the distance the hips move during the jump by using the y position (Y) vs. time graph.
- Recognize that they can use the y velocity (Y Velocity) vs. time graph to find the maximum velocity of the subject during a jump.
- Recognize that they can use a calculated column to create a y acceleration (Y Acceleration) vs. time graph of the subject during the jump.
- Recognize that they can use the y acceleration (Y Acceleration) vs. time graph to find maximum acceleration.
- Recognize that they can calculate peak force using the formula $f = ma$.

EQUIPMENT TIPS

Students have the opportunity to create and analyze their own video in the extensions for this activity. To do this, students will need a device capable of recording video, a tripod or other supporting device, and some object they can use for scaling. A 2 m wooden bar was used for the example video. A meter stick could also be used, or a set of cones positioned a known distance apart.

Always remind the students to be safe. Jumps should be made from the ground or stable platform. Don't allow students to jump from or onto surfaces that can roll.

PRE-LAB DISCUSSION

This experiment should be performed only after students have had the opportunity to observe a subject performing a restricted vertical jump. Demonstrate a restricted vertical jump with a subject (if possible), then ask the students to sketch a position *vs.* time and velocity *vs.* time graph of the subject during the jump. The movement may be too fast for them to notice differences in velocity and acceleration during the jump. You may want to show them the “Jump-Restricted.mp4” video replayed at 0.125x speed. (This is equivalent to playing the 240 frames-per-second video at 30 frames per second.)

LAB PERFORMANCE NOTES

We advise that students first learn how to do video analysis using the “Jumping” movies provided, before recording and analyzing their own videos. Analysis of the provided movies will yield results that are easy to interpret because care was taken when creating the videos to reduce issues related to scaling, perspective, and blurred images, which often appear in student-made videos. In addition, students can use the sample videos as models for designing their own experiments.

When marking points in the provided videos, there are times when the hand or arms are blocking the waist, making it difficult for the student to know where to place the point. The students can either make an educated guess, or use Step Forward, \odot , to skip past a frame without marking a point.

Extensions

After students have become familiar with performing video analysis on the sample movie clips, they can move on to making their own. Provide students with a copy of Appendix A; the included tips will help students capture video appropriate for analysis. For additional tips, visit <https://www.vernier.com/tit/1464>

Note: Extensions 6, 7, and 8 can be done using the sample videos provided.

SAMPLE RESULTS AND EVALUATION OF DATA

Part 1 Restricted Jump

Step 1

In the example video provided, the position *vs.* time graph of the subject jumping with their hands on their waist should be similar to Figure 1. The subject rises to a peak height and then begins to fall. Acceleration can be identified by a curved position *vs.* time graph.

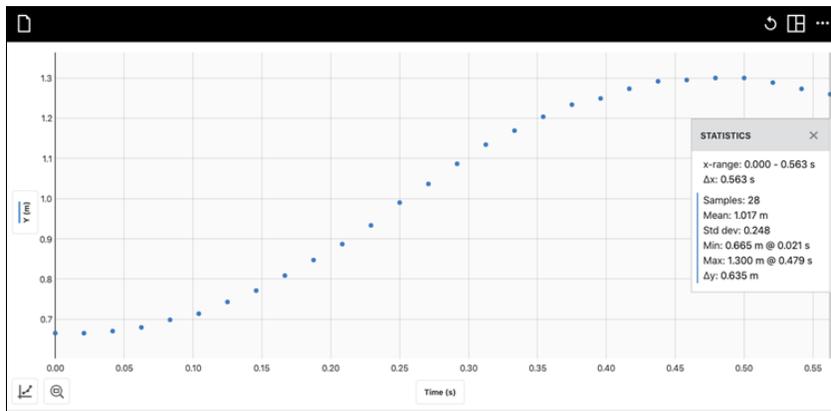


Figure 1 *y* position vs. time graph for restricted jump

The subject is at the end of the rising phase of the jump since peak vertical amplitude has been reached. The legs should already have straightened and the feet have clearly left the ground. The knees are bent once again as the legs are brought under the subject as they begin to prepare to drop back to the ground.

For the sample analysis shown, the vertical amplitude (Δy) was 0.635 m for the restricted jump. This is the vertical displacement of the hips/waist during the jump.

Step 2

Students should observe that the *y* velocity vs. time graph is relatively linear leading up to the maximum velocity as shown in Figure 2. This indicates that the acceleration over this period is roughly constant.

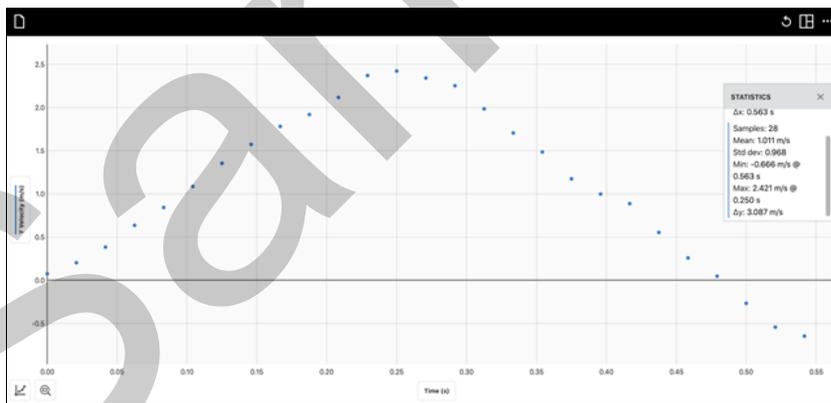


Figure 2 *y* velocity vs. time graph for restricted jump

The subject is at the end of the pushing phase of the jump when peak vertical velocity has been reached. The legs should be fully extended and the toes should be just about to leave the ground.

For the sample analysis shown, the maximum velocity for the restricted jump was 2.42 m/s.

Step 3–4

Students should observe that acceleration increases at first but then is almost constant during the early part of the jump as shown in Figure 3.

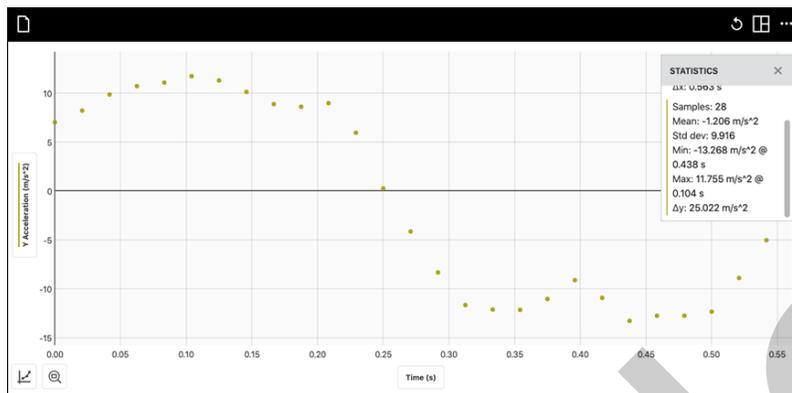


Figure 3 y acceleration vs. time graph for restricted jump

In the video, peak acceleration happens early in the rising phase of the jump while the feet are still on the ground. The knees are still bent and the feet have not begun to move.

For this sample analysis, the maximum acceleration for the restricted jump was approximately 11.8 m/s².

Step 5

The peak acceleration for a restricted jump is approximately 11.8 m/s². The subject has a mass of 70 kg. Using the formula $f = ma$, the peak force for the restricted jump is approximately 826 N.

Part 2 Full Jump

Step 7

There are some differences in knee and foot positions noted for the full jump. The position of the arms are also important when looking at the full jump.

- i. The legs are not tucked under the jumper at peak amplitude for the full jump. The legs remain extended as the subject prepares to land. The arms initially swing up and then fall back to the side as the subject reaches peak vertical amplitude.
- ii. The knees are still slightly bent at peak velocity for the full jump. The feet are also not fully arched off the ground. This was not the case in the restricted jump. Students should observe that the change in velocity occurs as the arms begin to swing up. Peak velocity occurs when the arms and hands have swung up and are extended. They should observe that this happens before the feet leave the ground.
- iii. Peak acceleration appears to occur later in the full jump. The feet are more arched and the legs have begun to extend. This was not the case in the restricted jump. Students should observe that the change in acceleration occurs as the arms are swinging up from the hips. Peak acceleration happens when the feet are still on the ground and the arms have swung past the hips and have begun to go up.

Example data for the analysis shown in Figures 4–6.

- i. The vertical amplitude (ΔY) for the full jump was 0.747 meters.
- ii. The maximum velocity achieved during the jump was approximately 3.38 m/s.
- iii. The maximum acceleration achieved during the jump was approximately 36.2 m/s^2 .
- iv. The peak force during the jump was approximately 2530 N.

Example graphs for the full jump are shown below.

The vertical motion graphs of the subject during an unrestricted (full) jump will appear different from the restricted jump graphs. The graphs will not appear as smooth. The full jump should show a change in velocity and acceleration that coincides with the movement of the arms as they swing forward and up. The same change in velocity and acceleration will not be observed when the hands are restricted.

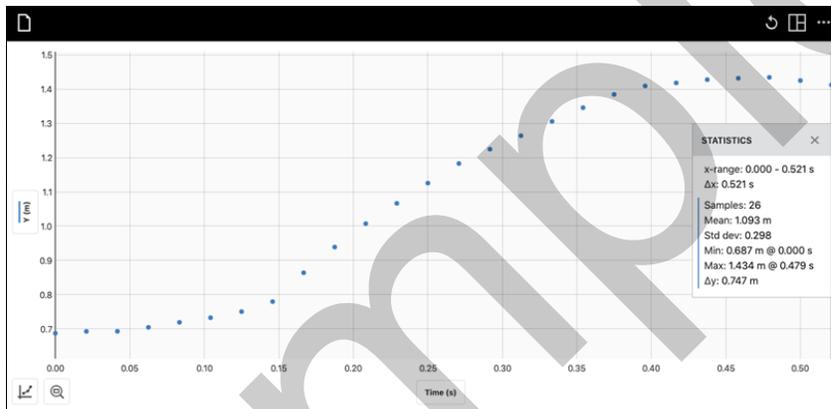


Figure 4 y position vs. time graph for full jump

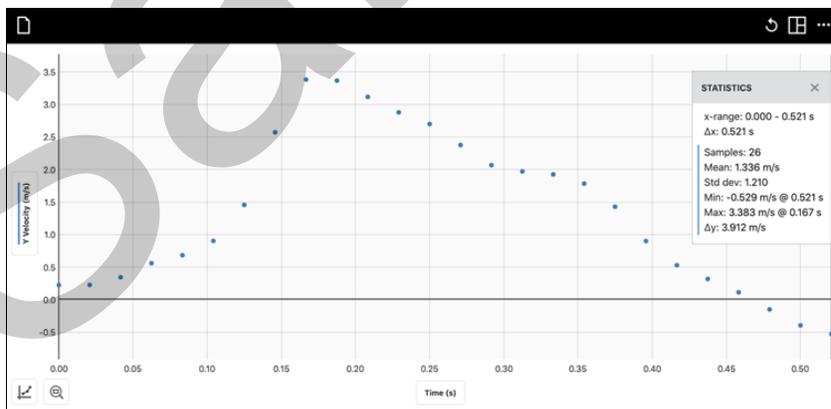


Figure 5 y velocity vs. time graph for full jump

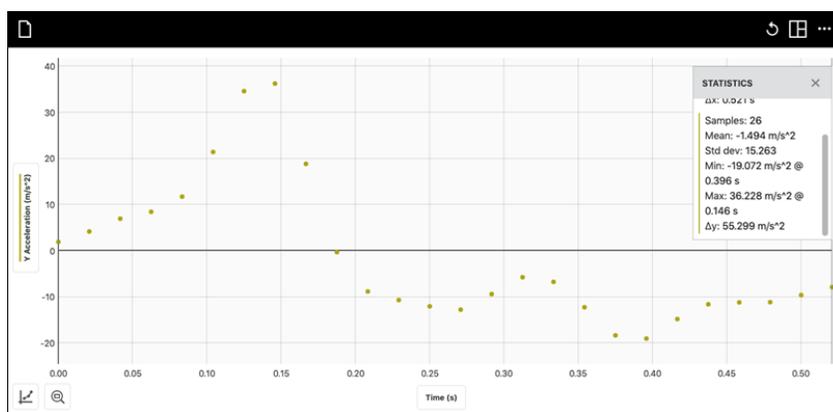


Figure 6 y acceleration vs. time graph for full jump

Step 8

A restricted jump limits the amount of force and acceleration the subject can generate, which decreases maximum velocity and leads to a jump with less vertical amplitude. One key factor is the use of the arms because they are allowed to swing during a full jump. The swinging motion of the arms creates momentum that helps the subject create more force during the jump. Less obvious, but also important, is the fact that the arms are used to help balance as the subject lands. In a restricted jump, the knees extend but then the legs are brought up under the subject. This is not observed in a full jump. The hands remain on the hips for the restricted jump, so the subject compensates by moving the legs faster to gain more upward momentum.

Sample data for both forms of jumping are provided in Table 1. Student results can vary depending on which frames they mark, where on the jumper they mark, and their consistency in marking the points. However, clear differences in vertical amplitude, velocity, acceleration, and peak force should be observed for both jumps.

Condition	Vertical amplitude (m)	Max velocity (m/s)	Max acceleration (m/s^2)	Peak force (N)
Vertical jump (restricted)	0.635	2.42	11.75	823
Vertical jump (full)	0.74	3.38	36.2	2530

EXTENSIONS

1. Results will vary depending on the subject. This type of jump is often referred to as a depth jump. A subject jumping off a small step and performing a vertical jump may not be able to jump as high. Velocity and acceleration may be lower than when performing a standing vertical jump. However, athletes that are used to performing a depth jump may be able to jump higher, and you may see an increase in the other parameters.

2. Results will vary. Subjects should not be able to jump as high. Velocity and acceleration should be lower when performing a jump when the subject is using a weight vest. Remind students to be safe.
3. Results will vary. The subject will already be traveling at an increased velocity when they begin the vertical jump. They should be able to jump higher. Maximum velocity, acceleration, peak force should be greater when the subject runs before performing a vertical jump.
4. Results will vary. Performing a layup or “dunking” a basketball shares certain characteristics with a running vertical jump. Have students compare the results obtained when performing a running vertical jump to the results they observe in this extension. Make sure to use the same subject for any comparisons. In the case of a layup or “dunk”, the subject is performing a specialized motor task. They must dribble the ball with one hand and then hold it while they jump in the air and place the ball at a given position (backboard or basket). Vertical displacement, maximum velocity, and maximum acceleration should be lower than when comparing this task to a running vertical jump.
5. Results will vary, but the depth of the crouch should be associated with an increase in all of the parameters measured. It may be best to use the restricted vertical jump in this case, as you can limit the involvement of the arms and look only at the depth of the crouch.
6. Results will vary. The legs will straighten during the jump. This action will move the waist up while the knees move up less. The velocity of the knee after the subject leaves the ground will vary depending on whether the subject's legs remain extended or are pulled up as the subject completes the rising phase of the jump. Peak velocity and acceleration of the knee should happen after peak velocity and acceleration of the waist.
7. Results will vary. The ankle should move after the waist and knee have already begun to move. All three positions should track close together as the subject leaves the ground. Peak velocity and acceleration of the ankle should happen after peak velocity and acceleration of the waist and knee.
8. Results will vary. The arms should swing down and then up. This motion will happen before the waist, knee, and foot begin to move. Peak velocity and acceleration of the arms should happen before peak velocity and acceleration of the waist, knee, and ankle.
9. Results will vary. Compare the same subject when looking at a straight leg jump or a jump where the legs are allowed to bend.
10. Results will vary. Athletes that participate in sports that focus on sprinting and jumping should be able to jump higher and produce larger velocities and accelerations than athletes that participate in sports that focus on endurance.