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Biomechanics of Parkour: The Vertical Wall-Run Technique

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BIOMECHANICS OF PARKOUR: THE VERTICAL WALL-RUN TECHNIQUE

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Abstract: In this study of the Parkour wall-run technique, we investigated the foot/hand forces applied during the vertical wall-run, the changes in height and vertical velocity throughout the maneuver, and the height contributions gained from the ground step versus the wall step(s). For this study, we recruited 10 advanced-level Parkour runners (the “pros”) and 10 novice-level Parkour runners (the “joes”). Each subject ran 6-10 trials up the wall, attempting to attain the maximum height possible. From our data results we were able to compute the runners CoM height and the runners CoM vertical velocities throughout the wall-run maneuver, track the calculated values of each trial in terms of both time and runner trajectory, and then make comparisons of the height contribution of the vertical jump impulse off of the ground and the vertical impulse exerted on the wall. From these results, we observed that the runners counteracted their downward gravitational acceleration by applying a vertical frictional force on the wall, and the runners were able to effectively achieve a final peak height that was approximately 1.5 times greater than had they jumped without using the wall.

Keywords: biomechanics, parkour, vertical-wall run, jump, ground-reaction forces

Introduction

Parkour is an integrative martial art that integrates running, climbing, jumping, and quadrupedal movements to efficiently traverse obstacles. Parkour originated as a military training discipline in France in the 1980's, and has progressed into a recreational urban activity in Europe and the United States. One of the most popular maneuvers in Parkour is the vertical wall-run, where the Parkour runner attempts to achieve a vertical height that would not otherwise be attainable from a natural jump off of the ground. The runner performs this maneuver by running at a wall, and then initiating forceful impact(s) with the wall by placing one foot (or hand) after another up the wall. By doing this, the runner redirects their horizontal momentum vertically, propelling themselves upward. In our study of this Parkour wall-run technique, we investigated the foot/hand forces applied during the vertical wall-run, the changes in height and vertical velocity throughout the maneuver, and the height contributions gained from the ground step versus the wall step(s).

Wall-Run Technique

There are two primary categories used to describe the phases throughout the wall-run – the aerial phase(s), and the contact phase(s). During the aerial phase, the body's center of mass (CoM) is freely in motion through the air and is only acted upon by the force of gravity. During the contact phase, the runner uses their feet (or hands) to apply a horizontal normal force into the wall, from which they can generate a vertical frictional force to propel themselves upwards.

The figure below (see Fig. 1) diagrams the phases throughout a Parkour runner's trajectory during a single-contact wall-run - where the runner uses a single contact phase on the wall. The first phase is the first aerial phase, which is defined between the point where the runner has left contact with the ground and the point when the runner initiates contact with the wall. During this phase, the runner has applied a vertical impulse off of the ground to propel themselves upwards and towards the wall. This phase is described in the diagram by the transition between points 0 → 1, which notate the changes in height of the CoM (H_0 and H_1) and the changes in vertical velocity of the CoM (V_0 and V_1). The second phase is the contact phase, which is defined between the points were the runner enters contact with the wall and exits contact with the wall. This is described in the diagram by the transition between points 1 → 2, which notate the changes in height of the CoM (H_1 and H_2) and the changes in vertical velocity of the CoM (V_1 and V_2). The third phase of the single-contact wall-run is the second aerial phase, which is defined between the point where the runner is no longer in contact with the wall and the point where the runners peak height is achieved. This is described in the diagram by the transition between points 2 → 3, which notate the changes in height of the CoM (H_2 and H_3) and the changes in vertical velocity of the CoM (V_2 and V_3). It is important to note that at peak height, the vertical velocity of the CoM is 0 (m/s).

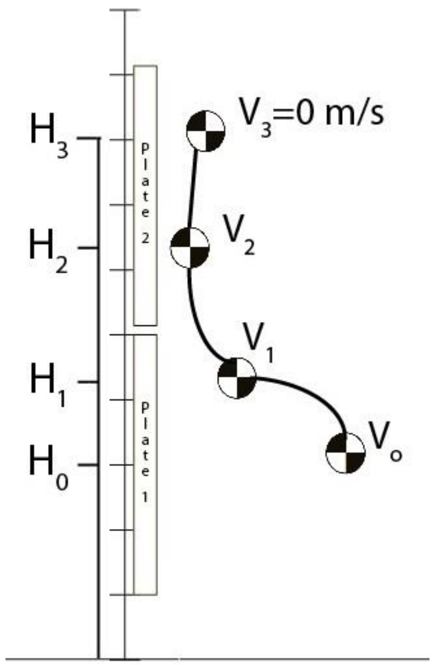


Figure 1: Diagram of a Parkour runner's trajectory during the wall-run, denoting CoM height and CoM vertical velocity.

Also, there are three classical physics equations that are important to recognize in their application to these two phases.

$$V_f^{\,2} = V_i^{\,2} + 2*a*(H_f - H_i) \quad (1)$$

This equation (commonly referred to as the "V-squared" equation), is used to calculate changes in velocity and height in situations that are known to have a constant acceleration. This equation can be applied during the aerial phases of the wall-run, as we can assume the acceleration due to gravity ($g = -9.81 \text{ m/s}^2$) to be constant.

$$I = \int F \cdot dt = m*(V_f - V_i) \qquad (2)$$

This equation (commonly referred to as the "Impulse-momentum" equation) is most often used in biomechanics to calculate changes in velocity of a body in motion. From this equation, and our measurements from the AMTI force platforms set up on the wall, we are able to calculate the changes in the body's velocity as a function of the force applied on the wall during the contact phase.

$$F_{friction} = F_{normal} * \mu_{frictional\ coefficient} \qquad (3)$$

This equation is used to calculate the force of friction, which is a function of the normal force and the coefficient of friction. We used this equation during our analysis of the contact phase, as a basis for relating the runners normal (horizontal) forces applied into the wall, and the frictional (vertical) forces applied up the wall.

Apparatus

For this study we had to construct an apparatus that would firmly hold the weight of the AMTI force platforms off of the ground and onto the wall, and that would be able to sustain the additional impact force from the wall-runners. The majority of our apparatus was made up of telespar and toggle bolts, which created a rectangular framework that was approximately 13 feet high and 16 inches wide. This structure was bolted into a metal stud-wall in Apex Movement gym, and then stabilized with the addition of the force platform mounting plates (see Image 1). After the frame was mounted to the wall, we attached two force platforms to the two mounting plates, so that the bottom force platform spanned heights off of the ground from 1-5 feet and the top platform spanned heights from 5-9 feet (see Image 2). Lastly, we covered the force platform surfaces with extremely gritty adhesive sandpaper (Vicious Tape) to increase our frictional coefficient on the wall, and we added a wooden box – that spanned from 9-13 feet off of the ground - above the force platforms so that we could measure the runners achieved peak height (see Image 3).

Image 1: The rectangular frame with mounting plates, bolted into the metal stud-wall in Apex Movement gym.

Image 2: The apparatus in its prototyping stages in the lab, with its force platforms mounted to the framework and mounting plates.

Image 3: The wooden box used for measuring peak height above the force platforms; and the force platforms with the Vicious Tape.

There were many pros and cons to our apparatus structure. Some of the pros were that the apparatus was stable and it was able to withstand many trials, the force platforms and wooden box were nearly flush with each other, and that the gritty sandpaper enabled our subjects to apply a greater frictional force. The two major cons of the apparatus were that it was very heavy and difficult to install into the wall, and that it resonated the vibrations from the runners' impacts on the wall throughout the apparatus and force platforms – which made the force platforms liable for picking up additional vibrational noise.

Methods

For this study, we recruited 10 advanced-level Parkour runners (the "pros") and 10 novice-level Parkour runners (the "joes") who all volunteered and provided informed consent to participate in our study. First, we recorded each subjects' mass, height, leg length, and extended-reach height. Then, each subject ran 6-10 trials up the wall, attempting to attain the maximum height possible. For each trial, we measured the forces applied into (horizontal) and up (vertical) the force platforms on the wall, and we recorded each runner from three different camera angles using high-speed (300 frames-per-second) cameras. Via frame-by-frame video analysis we approximated the height of the hip joint (a generally accepted approximation of the bodies CoM) at all four noted heights (H_0, H_1, H_2, H_3) throughout the wall-run. Ultimately each trials' data set included a measurement of the heights throughout the wall-run (H_0, H_1, H_2, H_3); as well as the forces applied into and up the wall ($F_{Vertical}$, $F_{Horizontal}$) and the duration of time the force was applied on the wall (t_2), from which we calculated the impulse applied on the force platform ($I_{Vertical}$, $I_{Horizontal}$). The assumed measurements made for all trials were that the vertical velocity at peak height was zero ($V_3 = 0$ m/s), and that the acceleration due to gravity ($g = -9.81$ m/s^2) was constant. It is important to note that no measurements of horizontal distance from the wall or horizontal velocity were made, and that calculations and analysis were limited to the vertical direction.

From these measurements we calculated the vertical velocities (V_2, V_1, V_0) essentially in reverse, as we tracked backwards from the direction of the runner's trajectory up the wall. First we analyzed the second aerial phase to calculate V_2 – the vertical velocity of the CoM as the subject exited contact with the wall. By rearranging the "V-squared" equation (Equation 1), and incorporating the measured values (H_3, H_2, V_3, g) we were able to calculate V_2 using the equation shown below:

$$V_2 = \sqrt{[\ V_3{}^2 - 2*g*(H_3 - H_2)\ ]} \qquad (4)$$

Once we calculated V_2, we were able to work backwards even further by analyzing the contact phase to calculate V_1 – the vertical velocity of the CoM as the subject entered contact with the wall. By rearranging the "impulse-momentum" equation (Equation 2), and incorporating the measured values (V_2, m) and the integrated value ($I_{Vertical}$) we were able to calculate V_1 using the equation below:

$$V_1 = V_2 - (I_{Vertical} / m) \qquad (5)$$

After calculating V_1, we analyzed the first aerial phase to calculate V_0 – the take-off vertical velocity of the CoM as the runner left contact with the ground. The same principles were used to calculate V_0 as were used to calculate V_2, and thus by incorporating the measured values (H_1, H_0, V_1, g) we were able to calculate V_0 using the equation shown below:

$$V_0 = \sqrt{[\ V_1{}^2 - 2*g*(H_1 - H_0)\ ]} \qquad (6)$$

Once all vertical velocities were calculated, we calculated the elapsed time for both aerial phases. By successively summing the calculated elapsed times of the first aerial phase (t_1), the measured elapsed time in contact with the force plate (t_2), and the second aerial phase (t_3), we were able to track the total elapsed time throughout the wall-run up to the runners peak height. Given that V_1 and V_3 were the respective final velocities and V_0 and V_2 were the respective initial velocities, the time elapsed for both the first aerial phase (t_1, V_1, V_0) and the second aerial phase (t_3, V_3, V_2), were calculated by using the general equation shown below:

$$t = (V_f - V_i) / g \qquad (7)$$

The summation of total time (t_{total}) is shown below:

$$t_{total} = t_1 + t_2 + t_3 \qquad (8)$$

Ultimately, we wanted to compare how much additional height was gained from the runners using the wall, so we calculated what the theoretical peak height of the runner would have been had they not used the wall and then compared that theoretical peak height to the actual peak height achieved. To calculate the theoretical peak height, we again used the "V-squared" equation in this theoretical aerial trajectory, and by incorporating the measured values (H_0, V_0, g) and knowing that the vertical velocity at the theoretical peak height would be zero ($V_{TheoreticalJump}$ = 0 m/s), we were able to calculate $H_{TheoreticalJump}$ using the equation shown below:

$$H_{TheoreticalJump} = [(V_{TheoreticalJump}^2 - V_0^2) / (2*g)] + H_0 \quad (9)$$

To calculate the height contribution from the wall (H_{Wall}) we calculated the difference between the theoretical jump height ($H_{TheoreticalJump}$) and the actual peak height achieved (H_3) using the equation shown below:

$$H_{Wall} = H_3 - H_{TheoreticalJump} \quad (10)$$

From all of these calculations we were able to track the heights and vertical velocities of the runners' CoM throughout the wall-run maneuver, compare the calculated values of each trial in terms of both time and runner trajectory, and then make comparisons of the height contribution of the vertical jump impulse off of the ground and the vertical impulse exerted on the wall.

Results & Discussion

From our collected trials, we focused on subjects that used a one-foot-contact wall-run technique (n=4, 16 jumps). The average CoM vertical velocities, CoM heights, and elapsed time that were calculated throughout the athlete's wall-runs are shown below (see Table 1). Additionally, a comparison of the height contributions of the vertical jump impulse off of the ground and the vertical impulse exerted on the wall are shown below (see Table 2). Furthermore, the average CoM vertical velocities and CoM heights – as shown in Table 1 - are plotted in comparison to the trajectories of both the theoretical peak height achieved without the wall impulse, as well as the theoretical take-off vertical velocity needed when leaving the ground to achieve the same final peak height (see Figure 2).

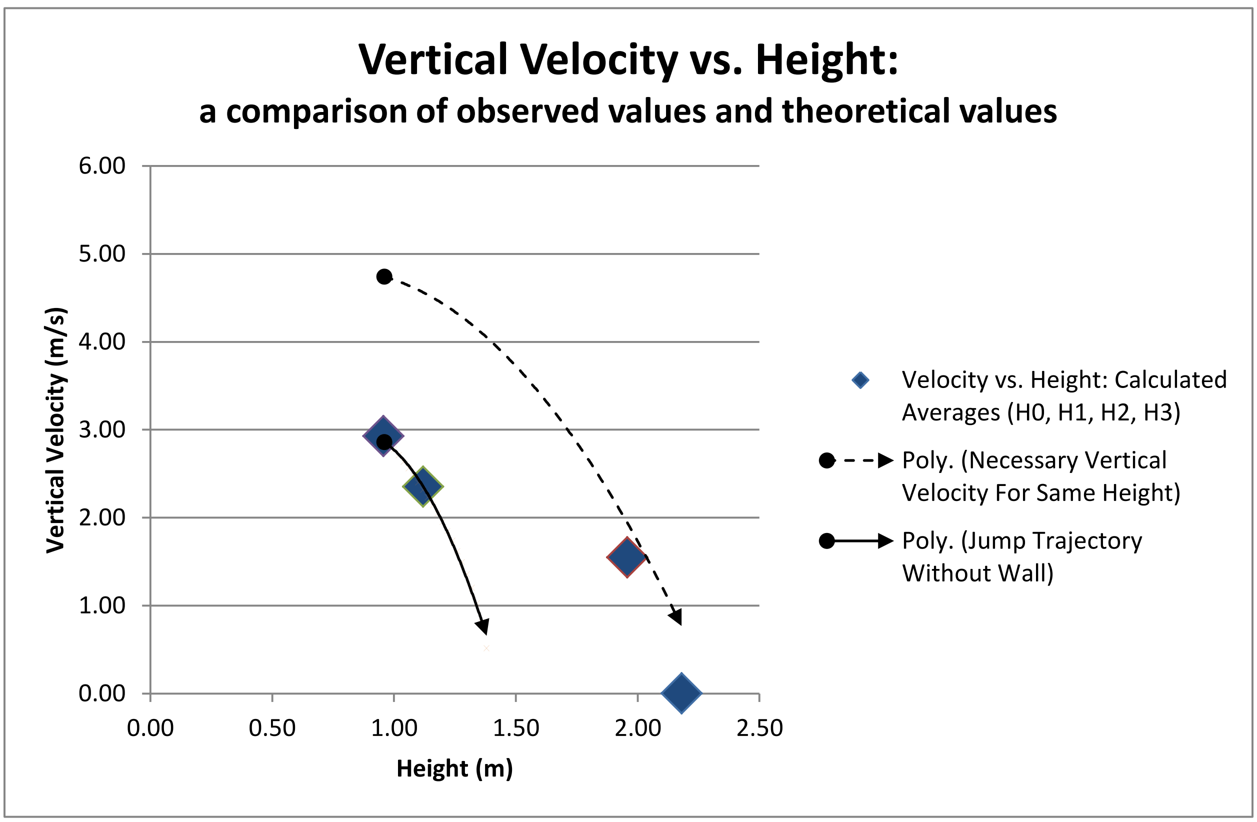
Table 1: The average height and vertical velocity of the body's center of mass (n=4, 16 jumps).

	Position in Reference of Wall-Run Trajectory			
	H0	**H1**	**H2**	**H3**
CoM Height (m)	0.96 ± 0.03	1.12 ± 0.12	1.96 ± 0.26	2.18 ± 0.36
CoM Vertical Velocity (m/s)	2.93 ± 1.08	2.35 ± 1.00	1.55 ± 1.46	0.00
Elapsed Time (s)	0.00	0.06 ± 0.02	0.43 ± 0.08	0.58 ± 0.11

Table 2: A comparison of the height contribution of the jump impulse off of the ground and the wall impulse off of the wall (n=4, 16 jumps).

	Height Contribution (m)	Height Contribution (%)
Jump Impulse off of the ground	1.45 ± 0.33	66.2 ± 8.4
Wall Impulse off of the wall	0.73 ± 0.22	33.8 ± 8.4

Figure 2: A plot of the CoM vertical velocity vs. the CoM height; displaying average values at the H_0, H_1, H_2, and H_3 positions, in comparison to the theoretical trajectory if the runner had not used the wall and the theoretical take-off velocity to achieve the same peak height as the wall-runner (n=4, 16 jumps).



From these results, we observed that the runners counteracted their downward gravitational acceleration by applying a vertical frictional force on the wall. Effectively, this caused the runners to decelerate at a lesser rate - in comparison to the natural acceleration due to gravity - when in contact with the wall. This enabled the runners to gain additional height while losing less of their vertical velocity. As a result of the one-foot-contact wall-run technique, the runners were able to achieve a final peak height that was approximately 1.5 times greater than had they jumped without using the wall.

What happened to the runners that used multiple-contact wall-run maneuvers?

Many subjects used a multiple-contact wall-run technique that involved the runner following their first foot-plant with either a hand-plant, a second foot-plant, or in some cases they used a variation of both. These second contact points were recorded on the second (top) force platform, but the numerical results produced were inconsistent and did not compute to realistic results (see Figure 3). As a consequence of this, the multiple-contact wall-run maneuvers can only be discussed qualitatively.

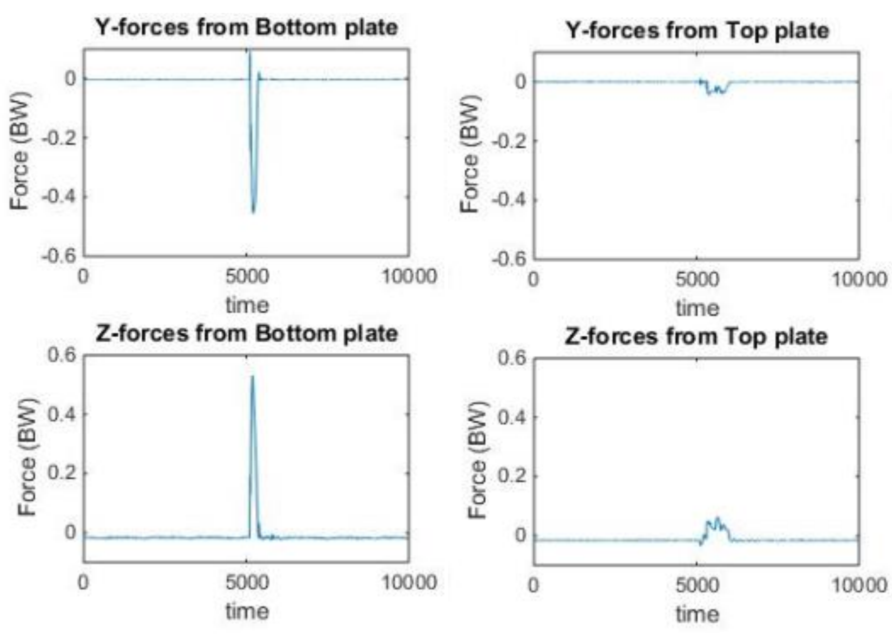


Figure 3: Plots of force vs. time on both the top and bottom force platforms during a single trial; emphasizing the difference between the stability of the measurements on the bottom force platform and the instability of the measurements on the top platform recording the second contact points.

From our video analysis, it was apparent that the subjects that used multiple-contact techniques achieved a greater peak height. The majority of these runners used a hand-plant technique on the wall where they first swiped their hands in a downwards direction towards the floor (from approximately their shoulder height to their hip height), and then they effectively appeared to plant the palm of their hand into the wall - while continuing to extend their arm at the elbow joint - to push themselves further upward. An additional height gain was consistently observed for all runners using variations of the multiple-contact techniques, but differences in height gains between the techniques could not be distinguished.

The additional height gain from the runners' second contact point must come from a vertical frictional force applied on the wall. However, it is known that any frictional force requires a normal force – which we have observed in the wall-run maneuver, comes from the runner pushing into the wall. Thus, if the runner is running up the wall in a vertical (or nearly vertical) trajectory, than they must push themselves away from the wall to be able to produce the frictional force necessary to propel themselves further upwards. While this maneuver is beneficial within strict terms of vertical height gain, this push away from the wall can be detrimental for Parkour runners in practical application as they often are targeting a ledge on the wall to grasp on to. By pushing away from the wall (in order to gain additional height) the runner risks increasing the distance between their bodies CoM and the runners targeted ledge-grasp point on the wall.

Conclusion

Overall, it is clear that the Parkour wall-run technique allows athletes to enhance their vertical jumping performance and achieve greater vertical heights. This improved performance resulted from an applied vertical impulse, which opposed the force of gravity and reduced the net vertical deceleration of the runners body in motion. The use of this technique does bring into question whether the height gained from the vertical frictional force applied on the wall is more beneficial than the normal force applied into the wall, which may risk further distancing a runner from their desired target. Parkour runners should focus most on the vertical impulse applied in their ground-step, as this step both contributes most to the runners total height and it does not put the runner at risk to push too far away from the targeted point on the wall.

Future Studies

I recommend that future studies focus on improving the quantitative analysis on the second-contact forces applied on the wall, and analyzing the take-off forces applied on the ground.

A force platform should be installed in a position so that the runner plants their ground-jumping foot on the force platform, in the step prior to running up the wall. This will provide a more detailed insight into the vertical impulse that comes from the ground during the wall run. Additionally, this may help provide information towards the horizontal positions and velocities that are traced throughout the vertical-wall run.

To better study the second contact-point, I recommend constructing an apparatus where the force platforms are not connected to each other on the same frame structure. I believe that the errors in the second contact-point data on the top force platform were a result of vibrations caused by the first contact point. Essentially, it appears that the runners' first wall-impact force vibrated through the apparatus framework and caused measurements of the second contact-point to be interfered with by vibrational forces. I would recommend constructing a framework that less-directly connects (or entirely disconnects) the bottom and top force platforms from each other on the apparatus, so that vibrational forces are less likely to be transferred, measured or interfered with between the two force platforms. Additionally, I would recommend that in future studies each subject performs the vertical wall-run using various techniques (1-step, two-step with hand, two-step with second foot, etc.) each in multiple trials, so that the benefits of each component of the various techniques can be more specifically analyzed.

References

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Appendix

Tables and Figures

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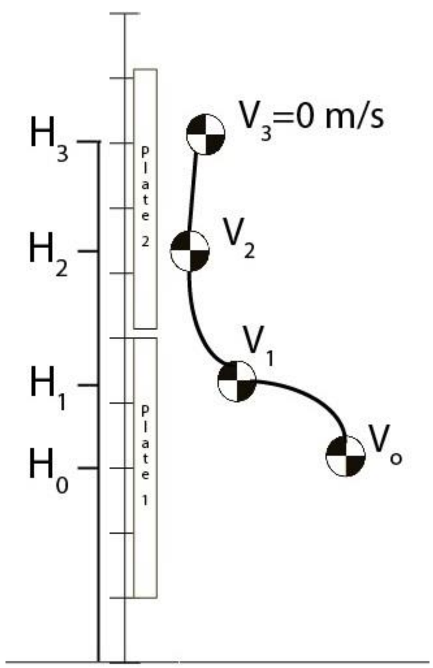

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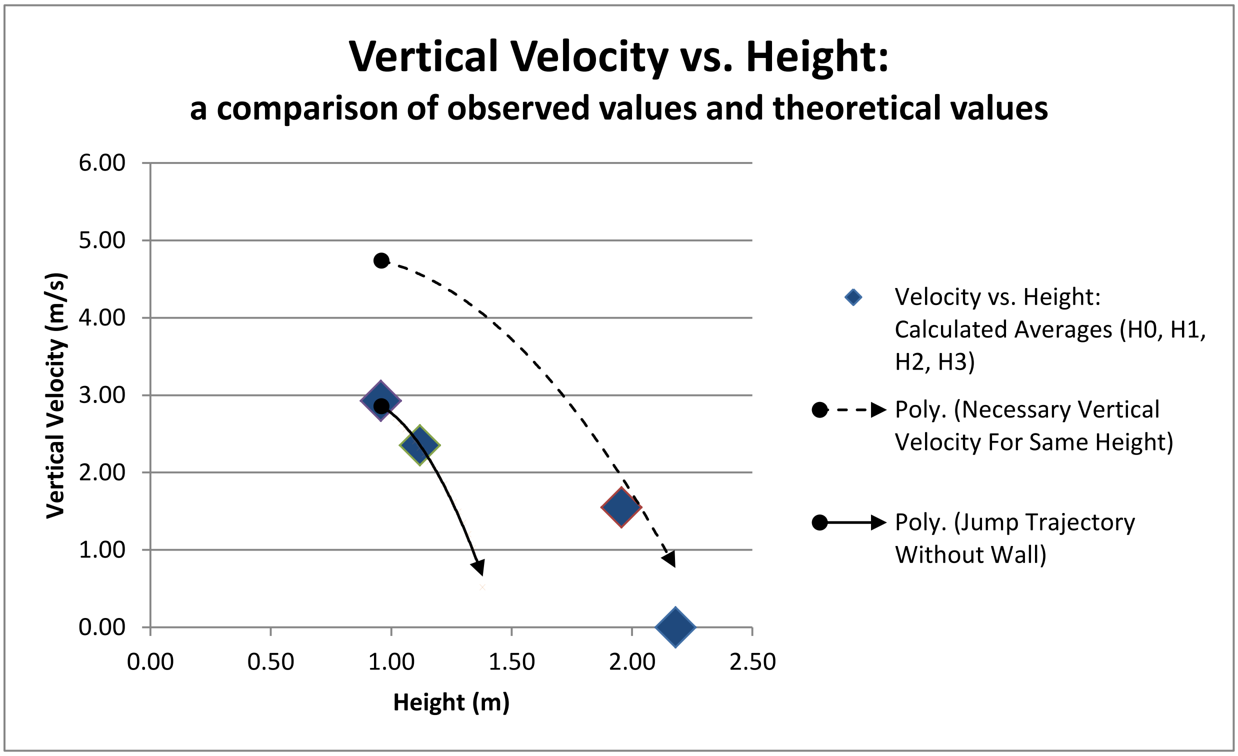

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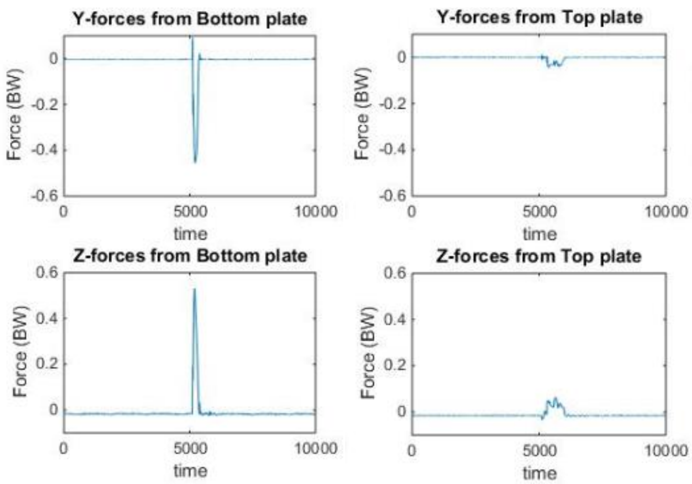

Apparatus

Image 1: The rectangular frame with mounting plates, bolted into the metal stud-wall in Apex Movement gym.

Image 2: The apparatus in its prototyping stages in the lab, with its force platforms mounted to the framework and mounting plates.

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Equations

$$V_f^{\,2} = V_i^{\,2} + 2*a*(H_f - H_i) \quad (1)$$

$$I = \int F \cdot dt = m*(V_f - V_i) \quad (2)$$

$$F_{friction} = F_{normal} * \mu_{frictional\ coefficient} \quad (3)$$

$$V_2 = \sqrt{[\ V_3^{\,2} - 2*g*(H_3 - H_2)\ ]} \quad (4)$$

$$V_1 = V_2 - (I_{1\text{-}Vertical} / m) \quad (5)$$

$$V_0 = \sqrt{[\ V_1^{\,2} - 2*g*(H_1 - H_0)\ ]} \quad (6)$$

$$t = (V_f - V_i) / g \quad (7)$$

$$t_{total} = t_1 + t_2 + t_3 \quad (8)$$

$$H_{TheoreticalJump} = [(V_{TheoreticalJump}^{\,2} - V_0^{\,2}) / (2*g)] + H_0 \quad (9)$$

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Acknowledgements

I would like to recognize Bryant Pham and Dr. Rodger Kram for their knowledge and mentorship that helped guide me through every step of this project.

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