EFFECTS OF ATTACHMENT HEIGHT AND RAIL MATERIAL OF RESISTANCE TRAINING SLED ON TRUNK LEAN AND JERK DURING LINEAR ACCELERATION TRAINING

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Sprint acceleration training has been highly researched and found that resistance sleds are one of the most effective tools for maximizing training adaptations. The resistance sled is being used by many of the world leaders in athletic training but has yet to be researched for the kinetic and kinematic effects some of its key components cause. The aim of this study was to better understand the effects of the attachment height on the sled and sled rail material on the user's trunk lean and jerking effect caused by the sled. This was done because it was hypothesized that the attachment height has a direct impact on trunk lean and sled rail material has a direct impact on jerk caused by the sled. To test these assumptions, experimental and theoretical data was collected using a single subject study analyzing trunk lean and acceleration values of the sled. The results presented a significant decrease in trunk lean (more horizontal line of action) when the attachment height was raised. Additionally, no significant values were attained to support the assumption that by modifying the sled rail material, jerking effects will decrease. The results indicate that there is a direct correlation between attachment height and trunk lean. More research is needed to better understand the relationship between sled rail material and jerk.

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CHAPTER 1

INTRODUCTION

1.1 Background

Over recent years, the sports industry has grown at a remarkable pace. According to a market study published by *Statista*, the North American sports industry was valued at 71.06 billion USD in 2018. By 2023, the North American sports industry is expected to be worth upwards of 83.1 billion USD (13). With economic growth comes the ability to invest money back into the athletes. In the case of this research, the focus will be on the training of high-level athletes off the field to increase performance on the field. One of the most heavily utilized forms of training to improve linear acceleration is resistance sprint training. This can be done using several different pieces of equipment such as weighted vests, parachutes, and weighted sleds. Weighted vests and parachutes both have one major limitation being the amount of resistance applied to the athlete is limited. Additionally, the direction of the resistive force is fixed for both devices as well (Fig. 1.1).

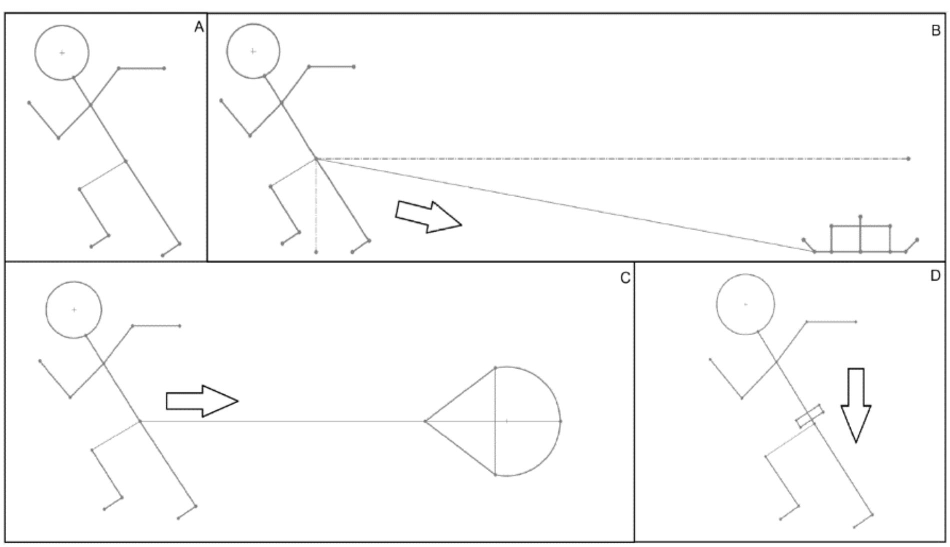

Figure 1.1: Different devices used for resistance sprint training (unresisted (A), resistance training sled (B), parachute(C), and weight belt (D).

This makes the resistance training sled one of the most useful pieces of equipment used across the industry to train for acceleration and functional strength improvements.

The resistance training sled allows users to apply a horizontal resistive force during sprint training of large magnitudes. The device can either be pushed or pulled, but for this study, the focus will be pulling. Resistance training sleds can be attached to the user through the use of a shoulder harness or waist harness. Bentley et al. found that the waist harness is most suitable for acceleration training because it creates a line of action more horizontal compared to the shoulder harness (4). For this reason, the waist harness will be used during this research. The user will fasten a belt-like harness at the waist which is connected to a non-elastic towline via a carabiner. The towline attaches to the sled using one more carabiner allowing the user to pull the sled. Loads of different magnitudes can be added to the sled to fit the prescription given by a certified trainer.

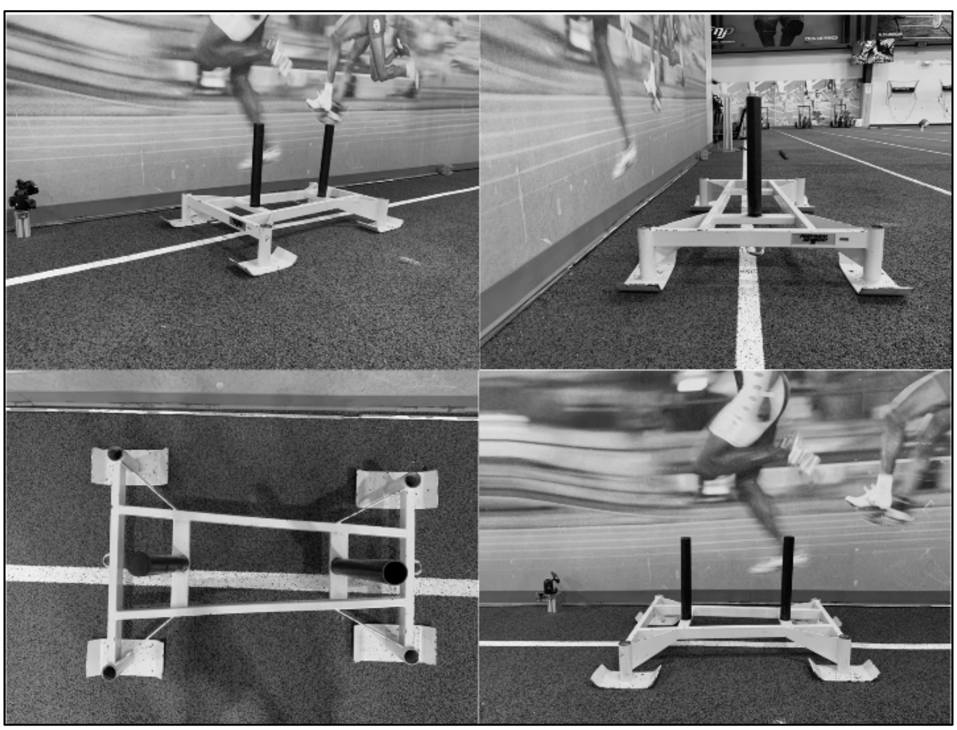

Figure 1.2: Selected control sled (Perform Better, First Place Drive Sled IITM).

Figure 1.2 shows the design of the sled that was used as the control sled (22.7 kg) for this research. This model was chosen because it enables the trainer to load large amounts of weight to the sled via the dual weight stacks which is necessary for training acceleration. Alternate sleds with one weight stack were not chosen because they are limited in the amount of weight that can be loaded. Also, alternate models do not have the capability to be pushed in many cases making the Perform Better sled the most versatile model for various forms of training across many different sports. Because acceleration is a desired trait across most major sports, this research can be useful for a wide range of athletes. According to Bryan McCall, head high performance trainer at Michael Johnson Performance, one of the industry leaders in professional athlete training, "the resistance sled is one of the most effective training methods to improve acceleration because of its biomechanical learning effect and musculoskeletal tissue adaptations for high velocity strength training. The sled's ability to alter body position and provoke a horizontally slanted position provides an advantage for training the ideal kinematics for acceleration. The sled also elicits tissue adaptation in both high velocity muscle fibers and bone integrity that is hard to replicate in any other resisted training method." (Personal communication, 2020).

1.2 Research Overview

Currently, there is minimal research on how to make the resistance training sled as effective as possible from a biomechanical perspective. However, there is research that focuses on key concepts such as the effects of resistance sleds on joint angles. Researchers have found that horizontal force production required to produce acceleration can be trained best with the use of a sled (15,19). Previously, trainers prescribed lighter loads, less than 30% body mass, during training. However, recently researchers have determined that greater loads, up to 133% body mass, result in a greater increase in initial acceleration gains (6,21). Cahill et al. have also found that the best way to prescribe this heavier load is to calculate it based on maximal velocity decrement(v_{dec}), rather than the previous assumption of prescribing load based on body mass (7). For example, an athlete will perform an unresisted maximal sprint. The maximal velocity (v_{max}) will then be recorded, and a prescription of load will be given based on the v_{dec} desired. In the case of improving acceleration, Cahill et al. found that the athlete should train at a velocity decrement of 50% (7). Meaning, if the unresisted sprint v_{max} was 9 m/s, a load should be prescribed that allows the athlete to reach a v_{max} of 4.5 m/s. With the larger loads, it can become more difficult to tow the sled at the desired velocity without forfeiting the users natural sprint acceleration mechanics.

1.3 Disadvantages of Current Sled Models

During the acceleration phase of a sprint, the athlete needs to maintain an aggressive forward trunk lean, according to Bentley et al. (4). A study found that elite sprinters maintain an average forward trunk lean of roughly 130.4° on step one, 137.5° on step two, 138.7° on step three, and 146.6° on step four at the toe-off event, according to Donaldson et al. (12). Trunk lean is defined as the joint angle, created in the sagittal plane, between a line running perpendicular to the ground and the lumbar spine, or trunk (Fig. 1.3). Trunk lean is difficult to maintain with current sleds and is thought to be contributed to the attachment site on the user in relation to the attachment site on the sled. Cronin and Hansen found that the relationship between the attachment sites is thought to create a resistive force at an angle that is not optimal for maintaining the desired trunk lean (11). This tends to force the athlete into a non-optimal position because they are subconsciously attempting to accelerate the sled rather than focusing purely on accelerating themselves. Trunk lean has been found to decrease when heavier loads near 20% of v_{dec} are prescribed, according to recent research (14,17). Because this research is applying a load that produces a v_{dec} of 50%, it is expected that forward trunk lean further decreases along with it.

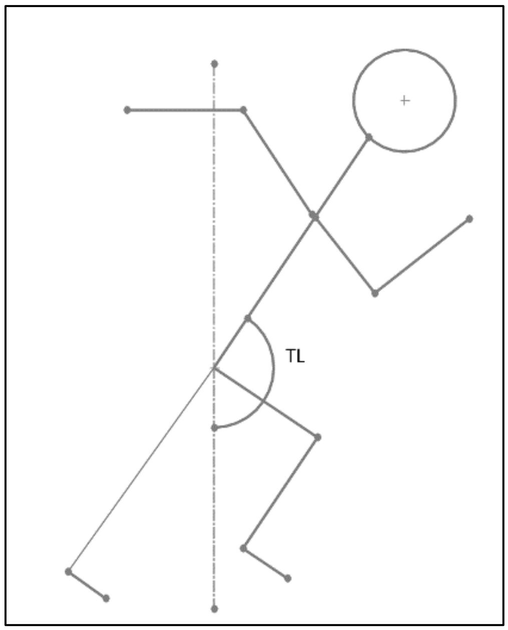

Figure 1.3: Definition of trunk lean joint angle (TL = trunk lean).

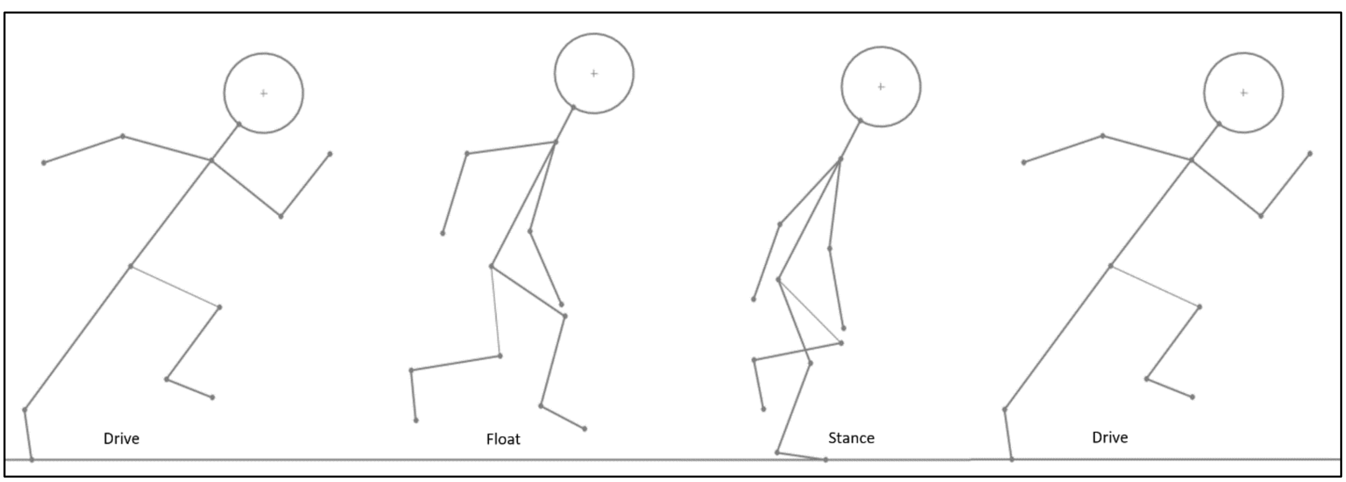

Figure 1.4: Phases of sprint.

Another issue noted that can be contributed to sled rail material is a problem that can be described as jerk. To understand jerk, the phases of a sprint must be explained (Fig. 1.4). First, the athlete is static in the 3-point sprinting stance. Once an overload of weight is shifted to the lead foot, the athlete is ready to begin the drive phase. During the drive phase, the athlete produces maximal extension at the ankle, knee, and hip while the trailing leg swings through. Upon achieving this position, the athlete enters the float phase where they are briefly floating. Following the float phase, the foot contacts the ground and enters the stance phase. The athlete continues forward and then enters the second drive phase. This action continues through the duration of the sprint. This action does not occur again until the next full extension of the second drive phase and continues throughout the duration of the first 0-10 meters of the acceleration portion of the sprint. Jerk simply represents an issue when the athlete reaches full extension in their first drive phase causing the sled to rapidly accelerate with the athlete. As the athlete is in the floating phase, natural deceleration occurs. This motion has been researched by Polet et al. and has shown that the human body is constantly accelerating and decelerating while running (20). This is because during the drive phase, the runner is producing force into the ground behind their center of mass which propels them forward. Once the runner transitions into the float phase, they are no longer contacting the ground and the only force acting on them is gravity. Gravity naturally decelerates the runner until they reach the next drive phase. During the float phase, the cord connecting the user to the sled produces slack. Upon reaching the stance phase of the following step, the cord then becomes taut as the sled decelerates at a higher rate than the athlete. This is thought to be due to the kinetic friction produced between the sled and the surface it is sliding on. At this moment, a jerk sensation is felt by the athlete causing them to forfeit their mechanics to keep the sled moving at maximal velocity. This action does not occur again until the next full extension of the second drive phase and continues throughout the duration of the sprint. No research has been done to attempt to solve this problem however this paper will look into potential solutions.

1.4 Research Goals

Given inefficiencies associated with prior models, this study will support the development of an innovative sled that allows the user to accelerate naturally with proper trunk lean, minimizing the effect of the sled on running mechanics. The scope of this project is to allow for natural running motions during the acceleration phase of a sprint under sled resistance. The disadvantages of the current state of the resistance training sled are that it inhibits the user from performing proper biomechanical motions during a sprint. This study will attempt to bridge the gap of functionality so that the sled allows the user to train within desired biomechanical fields. This will be done by testing different attachment sites on the sled and manipulating the frictional coefficient between the sled rails and the ground.

It is hypothesized that if the attachment site is raised, then the user will have a greater lean that is biased towards horizontal force production. Additionally, if the material of the sled rails is modified, then the user will experience a significant decline in the jerking effects as seen in previous sled models. The methods used to test this will first be a kinematic analysis of the trunk lean joint angle during the acceleration phase on a previous sled model. Secondly, this study will analyze the friction between the ground and the sled rail surfaces to determine if altering this may have benefits for eliminating jerk as well.

CHAPTER 2

MATERIALS AND METHODS

2.1 Experimental Approach

The control sled used was the Perform Better: First Place Drive Sled II. The entirety of the sled is comprised of 11-gauge, heavy duty, welded steel. The sled's mass is 22.7 kg and measures 44" L x 30" W x 38" H. Four sled rails contact the ground that are made up of solid, heavy duty, welded steel.

The independent variables were the four sled types: control (A), modified attachment height (B), modified sled rail material (C), and modified attachment height and sled rail material (D) (Fig. 2.1). The experimental approach used was a single-subject study using the ABCDA condition (control test, modification tests, additional control test).

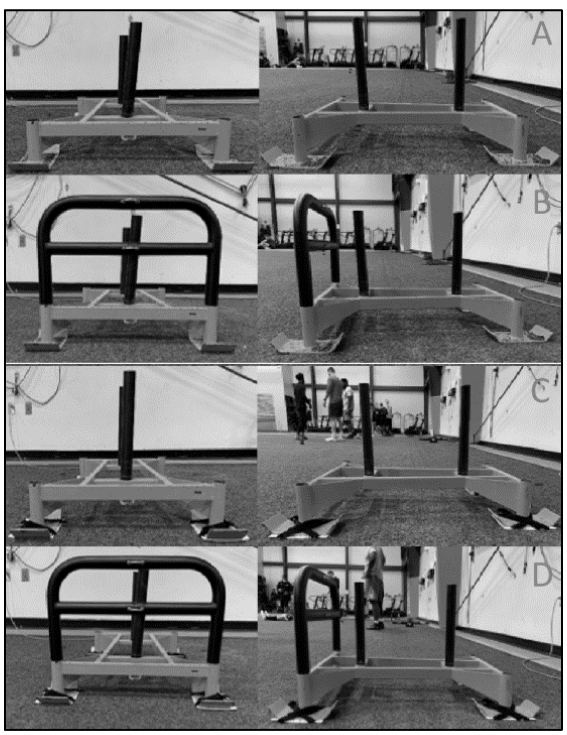

Figure 2.1: Front and side view of each sled type [control (A), attachment height modification (B), rail attachment modification (C), rail and attachment height modifications (D)].

This condition was chosen to increase internal validity of the study by checking for training adaptations over the period of testing. The dependent variables were trunk lean of the subject and acceleration of the sled. By investigating the dependent variables, the effect of the sled modifications on the user can be determined.

The measurement of trunk lean was used to measure the effect of the sled modifications on the user's forward lean. The measurements taken during the control tests are used as the base trunk lean angles and are then compared to the trunk lean angles recorded during the trials incorporating sled modifications.

The measurement of sled acceleration was used to measure the jerking effect of the sled on the user. Similar to the trunk lean angles, the control sled acceleration values were used to compare with the modified sled trials. This was done to determine the effect of the sled modifications on the acceleration of the sled. By measuring the sled acceleration throughout the duration of the trials, the effect of the modifications on acceleration and jerk can be determined.

2.2 Theoretical Approach

In order to determine the effect of attachment height, a series of mathematical equations were used. A load cell (MOOBOM^{TM} 110lb/50kg Scale, Dardugo) was used to calculate the budging force, or the force needed to initiate motion, for each sled modification. Coban and Boyaci reported that this force value can be used to calculate the static friction coefficient(μ_s) that characterizes the relationship between the sled rail material and the turf surface it rests on (9). Kinetic friction is the friction between two surfaces sliding past each other. To determine the kinetic friction coefficient(μ_k), a complex experimental approach was needed but not viable for this research. Without the kinetic friction coefficient, the accuracy of the theoretical approach is limited however can still be used in conjunction with experimental data to draw inferences and lead to further research. This is because there is a relationship between static and kinetic frictional coefficients. This relationship says that kinetic friction coefficients are always less when compared to the static friction coefficients because it takes more force to create motion than it does to maintain motion (8,9). In general, the magnitude of the static friction coefficient is relative to the magnitude of the kinetic friction coefficient therefore, for this research, the value of the kinetic friction coefficient for each modification was assumed to be equal to that of the calculated static friction coefficient (μ_s=μ_k). When considering attachment height, the angle at which the pulling force is applied by the user on the sled was analyzed to determine the effect of attachment height on horizontal force production. It is known that the greater the horizontally oriented force production, the greater the magnitude of sprint acceleration (5,10,18).

Concerning sled rail material, a series of mathematical equations were used to determine the magnitude of deceleration, the time, and the distance it takes for the sled to come to a complete stop. Bassan further proved these values are all dependent on the friction coefficient between the ground and sled rail material (3). By manipulating the friction coefficient through the variation of sled rail material, an estimation is gathered to determine the material’s effect on jerk caused by the sled. Again, the kinetic friction coefficient values are assumed to be equal to those of the static friction coefficient values that were calculated through the use of the load cell.

2.3 Subjects

One male trained athlete (25 years; height, 187.96 cm; and weight, 94.8 kg) participated in the research conducted. The subject has been practicing resistance training as well as endurance training for over a year. The subject was found to be healthy and injury free making him suitable for linear sprint acceleration testing. IRB approval was not necessary for this research as the subject was the also the researcher in this study.

2.4 Procedures

Prior to beginning data collection, the subject was familiarized with all equipment he will be using throughout the duration of the study. The setting in which all data collection occurred was indoors with a temperature of approximately 23°C. This ensured consistency in environmental conditions. The running surface was an artificial turf field. The subject wore tight-fitting black clothing and cleats on each test day. The color of the clothing was important because the joint markers used to determine trunk lean were white. This created an important contrast between the clothing and markers and allowed for accurate trunk lean measurements. The subject did not perform any training during the duration of the testing period to minimize changes in performance. Test days had a minimum of 3 full days between them to ensure the recovery of the subject. The total time needed to collect all data was 18 days with 6 data collection days.

2.4.1 Load Prescription Protocol

A standardized dynamic warmup was completed at the beginning of each test day, including the load prescription testing day. For the load prescription that was used throughout the duration of the study, a running lane on the turf field was measured to be 30 m. A radar (Pocket Radar™, Model: PR1000) was placed 10 m behind the starting line elevated 1 m from the ground (COM height). This testing setup was used in accordance with Simperingham's protocol (22).

After completing a standardized dynamic warmup, the runner performed three, un-resisted, maximal sprint efforts starting in a three-point sprinter stance. A minimum of 6 minutes of passive recovery was required between each trial to allow for maximal recovery, according to Baker et al. (2). The maximal velocity for each trial was recorded and then a mean, maximal velocity (mean v_{max} = 8.5 m/s) was calculated. The v_{max} is then used to determine the proper load by adding a weight to the resistance sled that limits maximal velocity by 50%. Using the load-velocity relationship established by Cahill (7), a starting load was added to the control resistance sled at 50% v_{dec} (≈80% BM, body mass). This load, summing the weight of the sled and additional weight added, was 75.9 kg. The control sled was positioned 3.3 m behind the starting line with a non-elastic tether attaching the subject to the sled via a waist harness. The running lane length was reduced by 10 m to 20 m. This is because with the added resistance of the sled, the runner reaches maximal velocity at a faster rate than during unresisted sprint trials. To begin each trial, the subject approaches the start line by reducing all slack in the tether and positioning themselves in the three-point stance. Maximal resisted sprint efforts were performed, with 6 minutes of passive recovery between each, until the v_{dec} of 50% (4.25 m/s) was established. The load corresponding to the desired v_{dec} was found to be 63.5 kg. This load was used throughout the duration of the testing period, which according to Cahill (2020), is the optimal load for training power and acceleration (6).

2.4.2 Experimental Data Collection Protocol

The data collection trials were setup in the same setting and conditions as the load prescription trials. The running lane was set to be a total length of 10 m and the control sled was positioned 3.3 m behind the starting line for each trial on each data collection day.

Acceleration of the sled was measured using an iPhone Xs Max^{TM} (Model MT592LL/A) secured to a VDP Sports Armband that was securely fastened to the midpoint of the right crossbar facing outwards (Fig. 2.2). The accelerometer within the iPhone was used in-conjunction with an application called Gauges^{TM} (Version 4.2.2) in order to record acceleration values (g_n). Gauges recorded data at a sampling rate of 20 samples per second (1 sample per 0.05 seconds). The data was then exported as a .csv file for data analysis.

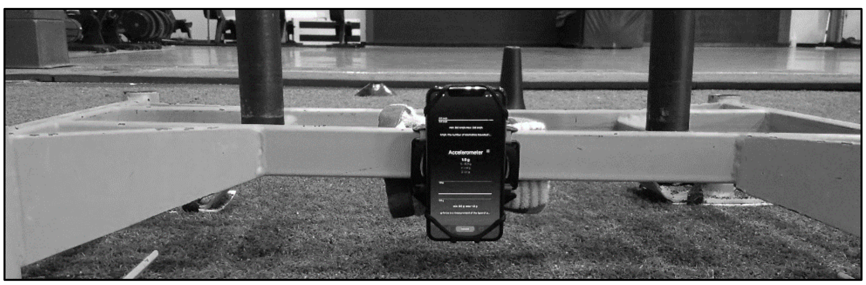

Figure 2.2: iPhone accelerometer placement.

Following the placement of the iPhone accelerometer, the motion capture system (iPad (4^{th} generation, Model MD511LL/A)) must be properly set up for each data collection session (Fig. 2.3). The iPad was set up perpendicular to the position of the 6^{th} step in the trial at an elevation of 1 m from the ground and 12.3 m from the subject so that the sagittal plane body position could be analyzed using the camera for the entirety of the 10 m sprint. Trunk lean was measured up until this point for each trial because the trunk lean values, following the 6^{th} step, remained relatively constant. The placement of the iPad at this point was used to capture the entire duration of the sprint from the sagittal plane. The iPad camera was used to capture each trial.

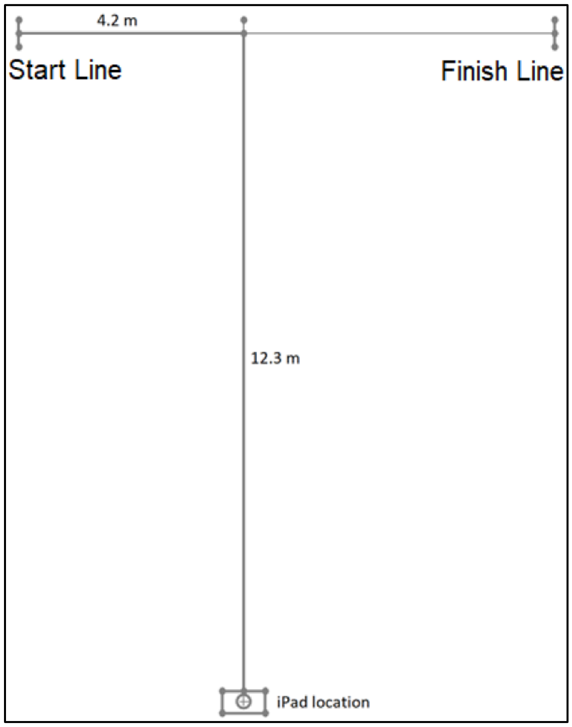

Figure 2.3: Top plane view drawing of iPad location for motion capture system.

2.4.3 Experimental Data Collection Procedure

Each day of data collection began with the dynamic warmup. The dynamic warmup consisted of active, static, and dynamic stretching. Following the warm-up, two white markers are placed on the greater tuberosity (shoulder) and greater trochanter (hip) (Fig. 2.4). Next, the load (63.5 kg) was added to the resistance sled and the experimental trials began. Each test day had five maximal effort resisted sprint trials separated by 6 minutes of passive recovery between each trial for each condition. Day one tested the control sled (A). Day four tested the modified attachment height on the sled (B). Day eight tested the modified sled rail material (C). Day eleven tested the modified attachment height and sled rail material (D). Day fifteen tested the control sled one final time (A) (In reference to Fig. 1.4). The second control sled testing day was done to monitor for training adaptations over the duration of the testing period.

Figure 2.4: Joint markers (greater tuberosity (shoulder) and greater trochanter (hip)).

2.4.4 Sled Modification Conditions

The first modification tested was an elevated attachment height on the sled. The control attachment height was 10.1 cm from the ground and was raised to 54.6 cm from the ground. This was done by adding the “Perform Better: Dual Low Push Handle Attachment”. A U-bolt was fastened to the dual low push handle attachment where the tether could be connected via the carabiner. It is important to note that the weight of the added attachment is 6.8 kg, therefore this was subtracted from the added load on the sled to ensure load consistency.

The second modification tested was sled rail material. This was done by purchasing two “Chemical-Resistant Slippery PTFE Sheets” made of Polytetrafluoroethylene (PTFE), and the specifications were 6”x8”x1/8”. This material was chosen due to its much lower frictional properties when compared to the heavy-duty 11-gauge welded steel of the control sled’s rails (steel μ = 0.6; PTFE μ = 0.08). The

PTFE sheets were cut into four, 6” x 8” rectangles using a “Gravograph Laser Solution LS100”. A second cut was used to add 1”x1/8” slits in the four corners of each rectangular sheet to allow for velcro straps to pass through them (Fig. 2.5). This was necessary to be able to secure the PTFE sheets to each sled rail. The final modification tested was the attachment height and sled rail material modifications together.

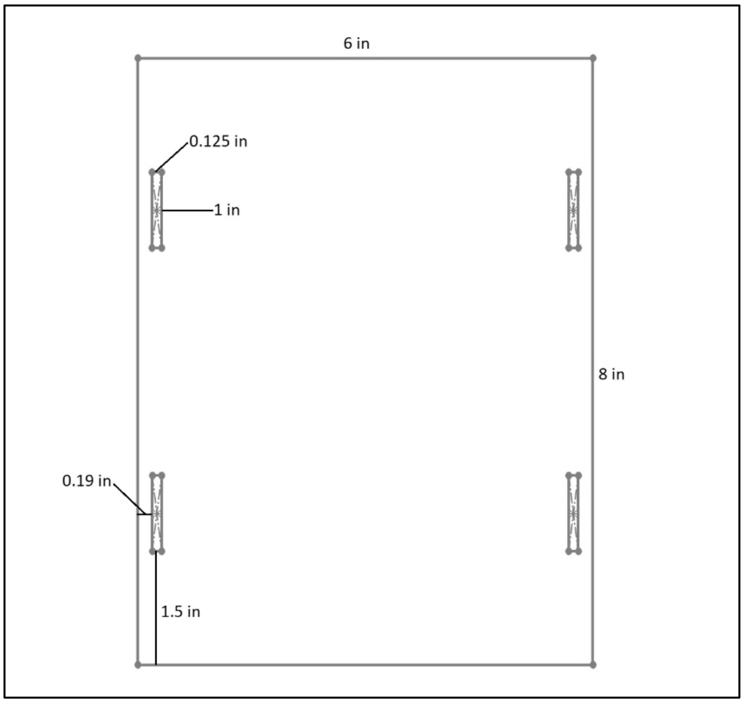

Figure 2.5: PTFE sheet drawing for modified sled rail material.

2.4.5 Theoretical Data Collection Protocol

To perform the theoretical approach, budging force (F_b; force required to move object from static to kinetic state) must first be gathered using the load cell (MOOBOM 110lb/50kg Scale) with ±0.1 kg accuracy. The control resistance sled was positioned on the testing turf field with the prescribed load (63.5 kg). The towing cord was attached to the sled with the load cell attached to the opposite end. The load cell was pulled on so that there is no slack in the towing cord, elevated to waist height, to mimic the angle at which the sled was pulled during experimental trials (θ_C = angle of pulling force for control height, θ_{AH} = angle of pulling force for raised attachment height). Gradually apply a pulling force to the load cell until the sled initially moves from its static state. After each trial, the load cell was reset by detaching it from the towing cord and setting it back to 0 kg. The budging force values were recorded for 10 trials. Repeat this same process for each modification (attachment height, sled rail material, and sled rail material and attachment height).

2.5 Experimental Data Analysis

The mean and standard deviation were calculated for all results using Microsoft Excel™. T-tests were performed using the significance set at $p \leq 0.05$*. The significance value of 0.05 was chosen because within the research community, this is the typical threshold used for determining if a value can be considered significant or not.

2.5.1 Trunk Lean

Beginning with trunk lean, each trial for each modification was measured in the Hudl Technique™ application (Version 6.4.0) (Hudl; Boston, MA). This was done by using the angle measurement tool. The first point of the angle was placed on the joint marker located on the shoulder (greater tuberosity). The vertex of the joint angle was then placed on the joint marker located at the hip (greater trochanter). The final point of the angle was placed so that it created a vertical line between the ground and the hip joint marker. The point at which the angle was measured occurs when the runner reaches maximal extension at the ankle, knee, and hip while still contacting the ground (Fig. 2.6). This point was measured for the first 6 steps for each trial. The measurements were input to an excel file for further analysis.

Figure 2.6: Trunk lean measurement example.

2.5.2 Sled Acceleration

The sled's forward and backward acceleration were determined for each trial. Due to the iPhone's orientation, the acceleration values were recorded as negative values and deceleration values were recorded as positive values. To fix this, the (-) g-force acceleration values were converted to (+) m/s^2 by multiplying each value by gravity (-9.80655 m/s^2). Acceleration values before the start and after the end of the sprint were deleted from each trial by graphing the values for each trial and determining the start and end of the sprint. The sprint start is characterized by the first spike visible on the graph of a magnitude greater than 5 m/s^2. The end of the sprint is characterized by a leveling out of the acceleration values within ±1 m/s^2. Next, a time value in milliseconds was added for each trial because the format in which the Gauges application reports time is not conducive for analysis. Because the Gauges application recorded an acceleration sample every 50 ms, the time of the sprint start began at 0 s and increases each acceleration value by 0.05 s. This means that there were 20 samples taken every 1 s.

Using the Hudl application in conjunction with the acceleration data, the local maximum and minimum acceleration values were located for steps 1-6 for each trial. This was done by locating the time in each video at which the runner reached maximal extension at the ankle, knee, and hip while still contacting the ground for each step. At this time point, sled acceleration is at its maximum. The local minimum acceleration (a_{min}, t_2) was located by determining the valley following the local maximum acceleration (a_{max}, t_1). This process was done for the steps of each trial, recording the time value and acceleration value for each local maxima and local minima. Average jerk ($jerk_{avg}$) per step was then calculated by using Eq. 2.1, used by An et al. (1).

$$jerk_{avg} = \frac{a_{min} - a_{max}}{t_2 - t_1} \qquad \text{(Eq. 2.1)}$$

Following the calculation of average jerk, two relationships were established between the local maxima and local minima. The first relationship (R_1) created was the quotient of local acceleration maximum and local acceleration minimum. This is shown in Eq. 2.2.

$$R_1 = \frac{a_{max}}{a_{min}} \qquad \text{(Eq. 2.2)}$$

The second relationship (R_2) uses the same values but instead of dividing the acceleration values, the difference between the two values was calculated using Eq. 2.3.

$$R_2 = a_{max} - a_{min} \qquad \text{(Eq. 2.3)}$$

2.6 Theoretical Data Analysis

To begin the theoretical analysis, the budging force values, initially recorded in kilograms (kg), were converted to newtons (N) by multiplying the kg values by 9.80655 m/s^2. After converting the budging forces, the mean budging forces (F_b) and standard deviations for each modification were calculated. The static friction coefficient (μ_s) was calculated using Eq. 2.4 for each modification, used by Coban and Boyaci (9). The variable F_n represents the magnitude of the normal force (622.74 N).

$$\mu_s = \frac{F_b}{F_n} \qquad \text{(Eq. 2.4)}$$

The next step in the theoretical analysis was to calculate the angle of pull for the control and raised attachment heights. This was done by using the Pythagorean Theorem and trigonometric ratios. The known values for these calculations were the hypotenuse (length of the towing cord, 359.9 cm) and the opposite side to the pulling angle. This opposite side varies depending on the attachment height to the sled. For the instances where the control attachment height is used, the length of this side is calculated by measuring the length from the ground to the attachment site on the waist harness. Then, the length from the ground to the sled's attachment site was measured and subtracted from the length of the waist harness' attachment site to the ground (99.1 cm). For the instances where the attachment height was raised (54.61 cm), the same process was used. The third side was calculated using the Pythagorean theorem. Next, to calculate the angle at which the pulling force was applied (θ_C = angle of pulling force for control height, θ_{AH} = angle of pulling force for raised attachment height), Eq. 2.5 was used (Fig. 2.7).

$$\sin(\theta) = \left(\frac{Opposite}{Hypotenuse}\right) \qquad \text{(Eq. 2.5)}$$

Using the calculated theta values (θ_C = 15.9°, θ_{AH} = 8.7°), the distribution between vertical (F_{vert}) and horizontal forces (F_{horiz}) can be calculated for each modification. This was done using Eqs. 2.6 and 2.7.

$$F_{vert} = F_b \times \sin(\theta) \qquad \text{(Eq. 2.6)}$$

$$F_{horiz} = F_b \times \cos(\theta) \quad \text{(Eq. 2.7)}$$

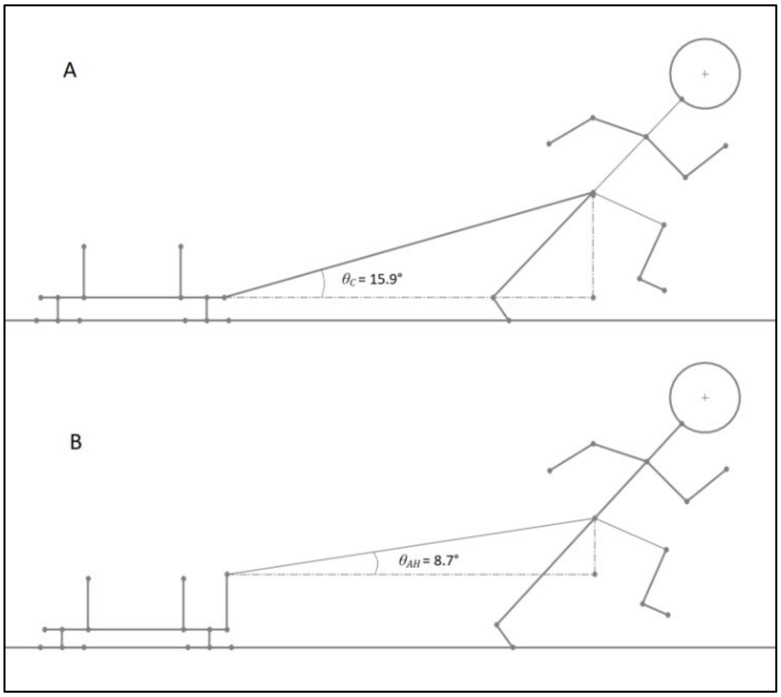

Figure 2.7: Pulling angle representation for the control attachment height (A) and modified attachment height (B).

Upon calculating the distribution of forces, in the vertical and horizontal directions, the quotient of the two values was calculated using Eq. 2.8 to determine the relationship (R_3) between vertical resistance and horizontal resistance.

$$R_3 = \frac{F_{vert}}{F_{horiz}} \quad \text{(Eq. 2.8)}$$

The final calculations to support the experimental data were stopping distance, deceleration magnitude, and stopping time for each modification. Stopping distance (d_{stop} (m)) was calculated using Eq. 2.9, deceleration magnitude (a_m (m/s^2)) was calculated using Eq. 2.10 and stopping time (t_{stop} (s)) was calculated using Eq. 2.11. In order to determine the effect of the friction coefficient on stopping distance, deceleration magnitude and stopping time, some variables were set to theoretical values (v = 4.0 m/s, $\mu_s = \mu_k$, g = 9.80655 m/s^2).

$$d_{stop} = \frac{v^2}{2 \times \mu_k \times g} \quad \text{(Eq. 2.9)}$$

$$a_m = \mu_k \times g \quad \text{(Eq. 2.10)}$$

$$t_{stop} = \sqrt{\frac{2 \times d_{stop}}{a_m}} \quad \text{(Eq. 2.11)}$$

2.7 Design Study

With any new design, the specifications must be tested to ensure that it does not fail under stresses created by its environment. To test this, the Solidworks™ add-on simulation was used. The control sled was previously safety tested, as it is a product on the market for sale. The only modification that needed to be tested was the attachment height modification to ensure that the device would not fail with the added modification. For this reason, the control sled was recreated to its exact measurements and a load of 622 N was applied to the weight stack. Additionally, an external force was applied to the attachment height modification to mimic the pulling force (800 N) applied by the user.

CHAPTER 3

RESULTS

Results were deemed significant or insignificant through the use of a two tailed, independent t-test. The *p-value* was set to 0.05*. If the calculated *p-value* < 0.05, then the effect of the modification was deemed significant. If the calculated *p-value* > 0.05, then the effect of the modification was deemed to be insignificant. Table 3.1 presents the mean trunk lean values (°) recorded for all modifications. Figure 3.1 displays the mean trunk lean values for all modifications and Figure 3.2 shows the difference (*Δ(Control-Modification)*) in mean trunk lean values compared to the mean trunk lean values recorded during the control testing.

Table 3.1: Trunk lean values (mean and SD) for all modifications in sagittal plane.

	Control 1	Attachment Height	Rail Material	Both
Step 1	133.6 ± 2.6	124.6 ± 5	119.8 ± 3.7	121.4 ± 2.3
Step 2	141.8 ± 2.2	130.2 ± 2.8	125.6 ± 2.5	125.8 ± 2.6
Step 3	151.8 ± 4.8	141.2 ± 6.4	138.4 ± 4.2	140.6 ± 3.4
Step 4	142.8 ± 6	131.8 ± 1.3	132.4 ± 3.4	134.8 ± 2
Step 5	158.8 ± 3.6	147.4 ± 4	144.2 ± 3.5	147.6 ± 2.7
Step 6	146 ± 3.5	136.8 ± 2.4	134.4 ± 3.4	137.2 ± 1.9

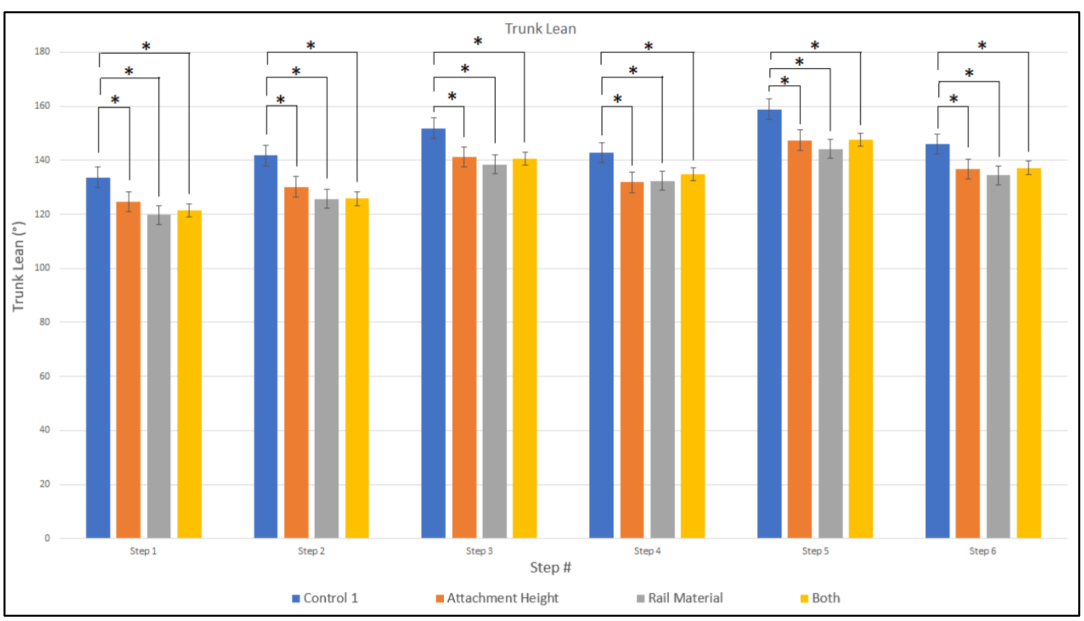

Figure 3.1: Trunk lean values (mean and mean SD) for all modifications in sagittal plane.

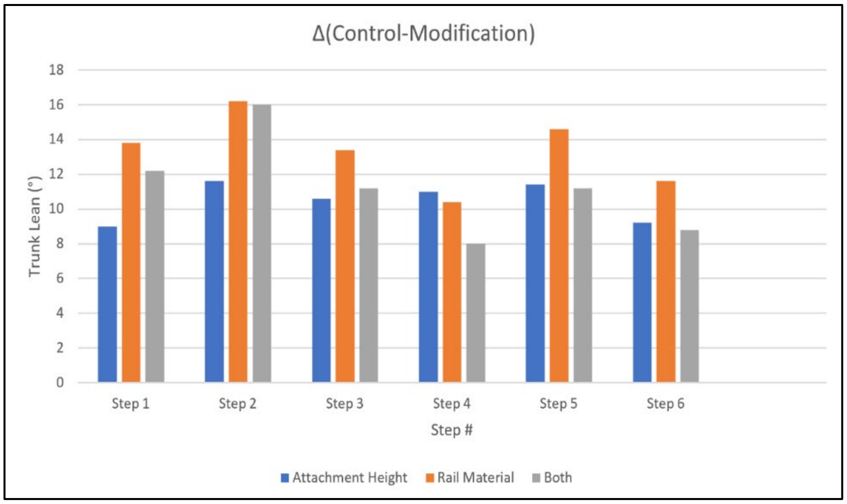

Figure 3.2: Difference (Δ(Control-Modification)) in mean trunk lean values compared to the mean trunk lean values recorded during control testing in the sagittal plane.

Table 3.2 presents the local maxima and minima mean sled acceleration values (m/s^2) for each step. Table 3.3 presents the average jerk values (m/s^3) of the sled that were calculated using Eq. 2.1. Figure 3.3 presents the average jerk values (m/s^3) of the sled. Table 3.4 presents the budging force values (N) collected experimentally. Table 3.5 presents the theoretical data gathered through the use of Eqs. 2.4 – 2.11 (μ_s, F_{vert}, F_{horiz}, R_3, d_{stop}, a_m, and t_{stop}).

Table 3.2: Local maxima and minima sled acceleration values (mean and SD) (m/s^2) for each step.

	Control 1		Attachment Height		Rail Material		Both	
Step #	Max	Min	Max	Min	Max	Min	Max	Min
Step 1	10 ± 1.1	-3.9 ± 0.7	7.4 ± 1.7	-2.2 ± 2.3	10.9 ± 0.9	-3.5 ± 1.4	10.7 ± 2.3	-6.4 ± 8.4
Step 2	9.8 ± 1.8	-6.6 ± 2.5	14.1 ± 1.9	-7.7 ± 5.2	10.2 ± 6.9	-7.4 ± 4.5	12.6 ± 5.7	-8.7 ± 6.4
Step 3	9 ± 3.6	-3.6 ± 0.8	11.6 ± 3.3	-3.6 ± 4.1	9.5 ± 4.1	-4.7 ± 5.3	9.6 ± 4.0	0 ± 2.0
Step 4	6.8 ± 3.0	-3.4 ± 1.9	11.4 ± 2.8	-9 ± 3.6	8.1 ± 14.4	-4.9 ± 6.9	8.3 ± 4.1	-7.5 ± 7.5
Step 5	5.5 ± 2.7	-3 ± 1.0	6.7 ± 2.3	-8.1 ± 1.4	3.4 ± 4.6	-2.7 ± 7.5	7.3 ± 6.7	-2.9 ± 1.8
Step 6	5.8 ± 3.3	-4.6 ± 1.9	7.5 ± 3.5	-2.4 ± 2.6	4.7 ± 2.4	-2.3 ± 2.1	4.8 ± 2.1	-4.3 ± 3.2

Table 3.3: Average jerk values (mean and SD) (m/s^3) of the sled.

	Control 1	Attachment Height	Rail Material	Both
Step 1	-81.3 ± 22.1	-57.9 ± 16.1	-95.1 ± 39.5	-94.1 ± 34.5
Step 2	-126.8 ± 51.8	-190.4 ± 90.5	-167.3 ± 77.7	-146.3 ± 76.3
Step 3	-82 ± 23.4	-157 ± 52.7	-142.8 ± 63.4	-93.1 ± 43.3
Step 4	-104.6 ± 30.6	-184.4 ± 113.2	-120.5 ± 52.8	-170.1 ± 101.7
Step 5	-80.3 ± 36.3	-187.2 ± 263.4	-84 ± 43.8	-96.7 ± 72.3
Step 6	-93.9 ± 42.0	-65.9 ± 22.0	-80.8 ± 56.7	-134.2 ± 86.2

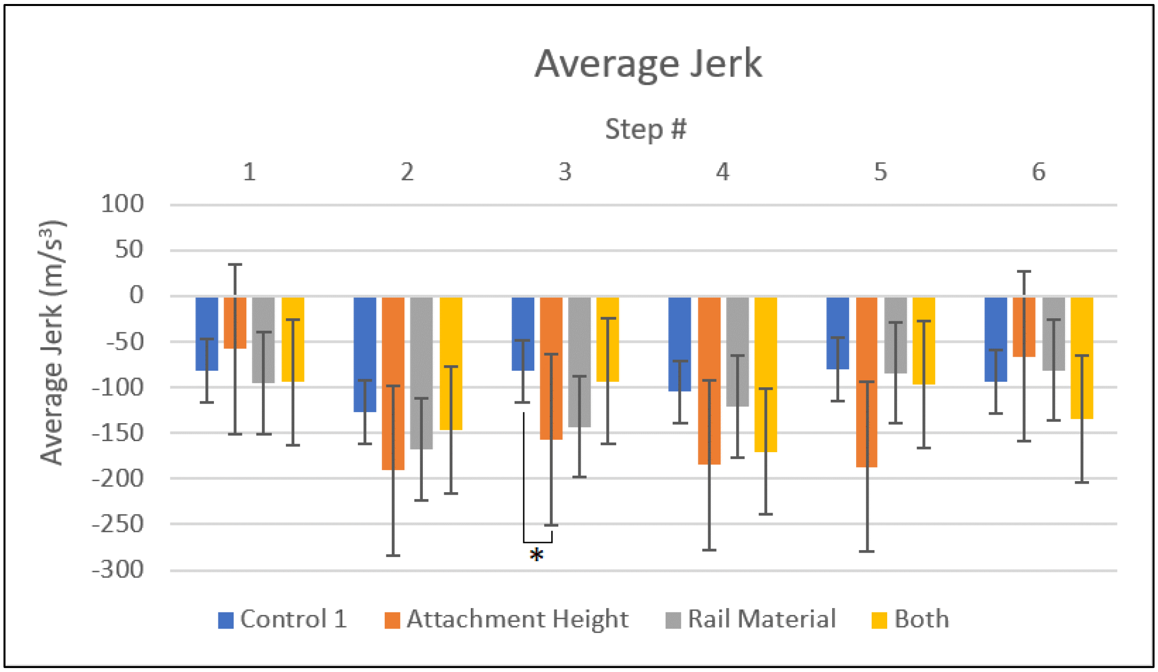

Figure 3.3: Average jerk values (mean and mean SD) (m/s^3) of the sled.

Table 3.4: Budging force values (N) collected experimentally.

	Control	Attachment Height	Rail Material	Both
1	186.3	166.7	156.9	147.1
2	176.5	156.9	166.7	166.7
3	166.7	166.7	166.7	137.3
4	196.1	156.9	156.9	147.1
5	176.5	147.1	176.5	147.1
6	196.1	156.9	156.9	156.9
7	186.3	147.1	166.7	147.1
8	205.9	176.5	166.7	137.3
9	186.3	166.7	156.9	156.9
10	196.1	147.1	176.5	156.9
Mean	**187.3**	**158.9**	**164.8**	**150.0**

Table 3.5: Theoretical data gathered that predicts static friction coefficient (μ_s), vertical and horizontal applied pulling force (N), relationship 3 (F_{vert}/F_{horiz}), stopping distance (m), acceleration magnitude (m/s^2), and time to stop (s).

	μ_s	F_{vert} (N)	F_{horiz} (N)	R_3	d_{stop} (m)	a_m (m/s^2)	t_{stop} (s)
Control 1	0.301	51.3	180.1	0.28	-2.7	-2.9	1.4
Attachment Height	0.255	24	157	0.15	-3.2	-2.5	1.6
Rail Material	0.265	41.5	158.4	0.28	-3.1	-2.6	1.5
Both	0.241	22.7	148.3	0.15	-3.4	-2.4	1.7

Beginning with trunk lean, the results show that there was a significant decrease observed for all six steps for the attachment height modification, compared to the control sled. The results show that there was a significant decrease observed for all six steps for the rail material modification. The results show that there was a significant decrease observed for all six steps for “the both” modification.

The results for average jerk show that there was no significant effect observed for attachment height modification on any step measured except for Step 3. Step 3 resulted in a significant increase in average jerk. The results show that there was no significant effect observed on any of the six steps for the rail material modification. The results show that there was no significant effect observed on any of the six steps for “the both” modification. Relationship 1 and Relationship 2 were not used as they did not show any significant data after analyzing results.

The results for budging force (F_b) show that there was a significant decrease observed for all three modifications compared to the control sled. Budging force decreased by an average of 28.4 N with the attachment height modification. Budging force decreased by an average of 22.5 N with the rail material modification. Finally, budging force decreased by an average of 37.3 N with “the both” modification. Because the static friction coefficient is dependent on budging force, these values varied as well (control μ_s= 0.301, attachment height μ_s= 0.255, rail material μ_s= 0.265, both μ_s= 0.241). Because vertical and horizontal force production is dependent on budging force and pulling angle, the magnitude of vertical and horizontal force production varied with each modification (control F_{vert}= 51.3 N; F_{horiz}= 180.1 N, attachment height F_{vert}= 24.0 N; F_{horiz}= 157.0 N, rail material F_{vert}= 45.1 N; F_{horiz}= 158.4 N, both F_{vert}= 22.7 N; F_{horiz}=

148.3 N). The results for relationship 3 show a difference in vertical versus horizontal force applied due to the change in attachment height. The control sled and rail material modification both showed a ratio of 0.28, while the attachment height modification and “the both” modification showed a ratio of 0.15, with a larger bias towards horizontal force application. The results for stopping distance varied due to the differences in the kinetic friction coefficient values used (control d_{stop}= 2.7 m, attachment height d_{stop}= 3.2 m, rail material d_{stop}= 3.1 m, both d_{stop}= 3.4 m). The results for acceleration magnitude varied due to the kinetic friction coefficient values, as well (control a_m= -2.9 m/s^2, attachment height a_m= -2.5 m/s^2, rail material a_m= -2.6 m/s^2, both a_m= -2.4 m/s^2). The results for stopping time also varied due to the differences in stopping distance and acceleration magnitude for each modification (control t_{stop}= 1.4 s, attachment height t_{stop}= 1.6 s, rail material t_{stop}= 1.5 s, both t_{stop}= 1.7s).

After running the design study within the Solidworks simulation add on, the sled variations that incorporated a modified attachment height were found to be 100% reliable. The design study reported a yield strength of 2.92E+08 N/m^2, which the entirety of the modified sled falls well within. Because of this, there were no concerns with the new design and was used safely.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

This research's aim was to determine the effect of the sled's attachment height and rail material on the runner's trunk lean and jerk caused by the sled during linear acceleration. Experimentally, the attachment height on the sled was raised and the sled rail material was altered. Trunk lean and acceleration of the sled were measured and compared to the values collected during control sled trials. Theoretically, mathematical equations were used to determine the static friction coefficient, vertical versus horizontal force distribution, stopping distance and time, and acceleration magnitude for each sled modification. This research will be used to better modify resistance training sleds for practical applications.

Results collected show that there was a significant decrease in trunk lean for all modifications when compared to trunk lean values collected during control sled trials. This finding confirms the first hypothesis that states if the attachment height is raised, then the runner will perform the sprint with more forward lean at the trunk, which is correlated with increased acceleration magnitudes. This hypothesis can further be supported when analyzing relationship 3. This relationship shows that by modifying the attachment height, pulling forces further favor the horizontal axis rather than the vertical axis. This means that the resistive force is also favored on the horizontal axis rather than the vertical axis. The research has found that resistive forces along the horizontal axis are optimal for training sprint acceleration (5,10,18). Because the raised attachment height was found to shift forward trunk lean to the horizontal axis, it may be further researched in a GRF (ground reaction force) study to further support that it is the best option for training sprint acceleration. The decrease in trunk lean during sled rail material modification testing is thought to be due to the decrease in the resistive kinetic friction force along the horizontal axis. The decrease in trunk lean present for this modification was slightly greater than the attachment height modification. Because kinetic friction was reduced, the subject may have experienced less of a jerking force compared to the control sled rail material that is hypothesized to effect running mechanics. Although this is not evident in experimental data, theoretical data suggests that the sled rail material does have a direct effect on the deceleration of the sled. The "both" modification produced a decrease in trunk lean that was on average greater than the attachment modification and less than the sled rail material modification. With both modifications present in the testing, trunk lean is thought to decrease due to a combination of the modifications. The attachment height is thought to have more of a significant impact on trunk lean which could explain why the trunk lean values for the "both" modification are not greater than the sled rail material modification trunk lean values. The "both" modification produced just slightly greater decreases in trunk lean values because the kinetic friction was reduced allowing for slight deviation from the trunk lean position evident in attachment height modification testing.

Sled acceleration results show that there was no significant change in average jerk for any modifications when compared to the average jerk values collected during control sled trials. This finding rejects the second hypothesis that states if the sled rail material is modified, then jerk caused by the sled will significantly decrease. Although experimental data does not support this hypothesis, the theoretical data does support this hypothesis when analyzing the calculated static friction coefficient, stopping distance and time, and acceleration magnitude. Previous research also supports this theory when analyzing the relationship between friction and acceleration (16). With the modified sled rail material, static friction coefficient and acceleration magnitude decreased while stopping distance and stopping time increased. This shows that by altering sled rail material from steel to the PTFE used, the sled decelerates at a slower rate. For these reasons, further research may be done to better understand the relationship between sled rail material and jerk.

The results of this study can only be deemed valid for the conditions under which they were tested and the population they were performed on. These conditions were a trained male athlete under a 50% v_{dec} of sled resistance.

4.1 Limitations

There were multiple limitations associated with this study. Only one male trained athlete was used for experimental testing due to limited availability of participants and COVID-19 safety concerns. This severely limits the application of the results on varying population types. Also, because there was only one subject rather than multiple, this limits the validity of the results for this specific population. The theoretical data was used to aid the experimental data gathered from the subject. The study was also limited due to the budget. This was evident in some of the equipment used to gather experimental data. The trunk lean data may not be accurate to the reality of the subject due to the angle at which the camera is capturing each step. This limits the accuracy of the values. However, the trunk lean values are still relatively accurate and precise when data is compared to itself within the same testing setting.

A limitation surrounding the average jerk value calculations was the sampling rate in which Gauges recorded the raw data. The true maxima and minima values used to calculate average jerk may not be 100% accurate as they could have occurred at a time point that the Gauges application did not record. Also, the technique used to coordinate time to each maxima and minima via video synchronization may have been a flaw as well. Additionally, another limitation was the fashion in which the sled rail material modification was fastened to the sled. Because, the sled was not owned by the researcher, the rail material could not be permanently fixed to the sled. The velcro straps were the best option for testing a sled rail modification in this case, although they were not quite synonymous with the sled. This lack of proper fixation was thought to potentially increase friction between the ground and the rail material modifications. Within the theoretical data, the assumption that $\mu_s = \mu_k$ limited the validity of the results. This was done because the experimental setup to properly measure the kinetic friction coefficient of each modification was not feasible to be completed.

4.2 Conclusions

This study began by attempting to look at the effects of attachment height and sled rail material on trunk lean and jerk caused by the resistance training sled during the acceleration phase of linear sprinting. This was done by conducting experimental testing through the use of a motion capture system and accelerometer. Theoretical approaches were also used to support experimental data.

After analyzing the results, this study concluded that by raising the attachment site on the resistance training sled, trunk lean significantly decreased. This decrease in trunk lean quantifies the fact that by raising the attachment height, the resistive force produced by the sled is shifted closer to the horizontal axis. This was further supported by analyzing the angle of pull through the theoretical approach. By shifting the resistive force, the athlete is forced into a more horizontal orientation which is correlated with increased acceleration magnitudes in linear sprinting.

The experimental data collected involving jerk was inconclusive however, with an adjusted approach to data collection, there still may be valuable information to be discovered. This idea comes from the data collected through the theoretical approach which suggests that jerk caused by the sled is directly dependent on sled rail material and the kinetic friction coefficient it creates between the material and the surface it is sliding on.

In conclusion, the research gathered over the course of this study supports the idea of raising the attachment site on resistance training sleds when training linear acceleration. Although, there was no conclusive evidence gathered surrounding jerk caused by the sled, further research may be conducted to better understand how to minimize this unwanted impulse on the user.

4.3 Future Applications

The research gathered throughout the duration of the study can be used to further progress the functionality and specificity of the resistance sled. The results indicate that the attachment site on the resistance sled has a direct impact on trunk lean. This leads to the idea that an adjustable attachment height on resistance sleds may be the best for future use. This is because not all users are the same height and run with the same mechanics. The attachment height could be adjusted to best fit the user as well as target certain advantageous body positions. Additionally, the adjustable attachment height can be useful for training acceleration one day and then maximum velocity mechanics the next day. More research is necessary to understand the correct attachment height for different phases of sprint training, but it is likely that this is specific to the user.

Although there was no significant experimental data collected surrounding average jerk, the theoretical data suggests that there is still a direct correlation between sled deceleration magnitude and the kinetic friction coefficient. Future studies may be conducted to better understand this relationship and how to minimize jerking effects caused by the resistance sled.

APPENDIX A

DYNAMIC WARM-UP

Exercise	Repetitions	Distance	Time
Forward skip with arm circles	1	20 m	
Backward skip with reverse arm circles	1	20 m	
Lateral forward cross scissor run	2	20 m	
Lateral reverse cross scissor run	2	20 m	
Forward a-skip	1	20 m	
Backward a-skip	1	20 m	
Forward lunge	4 each		
Drop-step lunge	4 each		
Inch worm with push-up	4		
Quad pull	4 each		
Knee to chest pull	4 each		
Shin to waist pull	4 each		
Hip flexor	1		10 s
Butterfly	1		10 s
60% build up sprint	1		
75% build up sprint	1		
90% build up sprint	1		
100% build up sprint	1		

APPENDIX B

P-VALUES

Table B.1: Trunk Lean P-values.

	Control vs AH	Control vs Rail Material	Control vs Both
Step 1	0.0072	0.0001	0.0001
Step 2	0.0001	0	0
Step 3	0.0177	0.0015	0.0026
Step 4	0.004	0.01	0.0227
Step 5	0.0015	0.0002	0.0005
Step 6	0.0013	0.0007	0.0012

Table B.2: Average Jerk P-values.

	Control vs AH	Control vs Rail Material	Control vs Both
Step 1	0.0919	0.5144	0.5036
Step 2	0.21	0.361	0.6486
Step 3	0.0196	0.079	0.6253
Step 4	0.1664	0.5765	0.2048
Step 5	0.3953	0.8891	0.6638
Step 6	0.2231	0.6889	0.3744

Table B.3: Budging Force P-values.

	Control vs AH	Control vs Rail Material	Control vs Both
mean	1.70E-05	8.00E-05	3.10E-07

APPENDIX C

TRUNK LEAN RAW DATA

1st Contol						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Step 1	133	137	133	130	135	133.6
Step 2	140	140	145	143	141	141.8
Step 3	149	147	159	154	150	151.8
Step 4	138	135	147	149	145	142.8
Step 5	156	154	161	161	162	158.8
Step 6	142	143	146	150	149	146
Rail						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Step 1	126	120	119	117	117	119.8
Step 2	125	128	128	125	122	125.6
Step 3	139	140	144	133	136	138.4
Step 4	131	137	135	129	130	132.4
Step 5	146	146	146	138	145	144.2
Step 6	134	139	130	136	133	134.4
AH						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Step 1	130	124	124	128	117	124.6
Step 2	134	131	128	131	127	130.2
Step 3	150	141	138	144	133	141.2
Step 4	131	132	133	133	130	131.8
Step 5	149	151	150	141	146	147.4
Step 6	137	134	135	138	140	136.8
Both						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Step 1	120	125	119	122	121	121.4
Step 2	123	127	123	128	128	125.8
Step 3	138	143	137	140	145	140.6
Step 4	135	135	133	133	138	134.8
Step 5	148	149	143	148	150	147.6
Step 6	136	140	138	135	137	137.2

APPENDIX D

JERK RAW DATA

1st Control																									
	T1					**T2**					**T3**					**T4**					**T5**				
	Accel Max	**Accel Min**	**Time 1**	**Time 2**	**Avg. Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**
Step 1	11.3	-4.2	1.2	1.35	-103.1	10.7	-4.9	0.4	0.55	-104.1	10.3	-3.6	0.9	1.15	-55.4	9.0	-3.8	0.5	0.7	-64.3	8.7	-3.2	0.8	0.95	-79.5
Step 2	8.2	-9.5	1.5	1.6	-177.0	12.2	-7.2	0.7	0.9	-97.1	8.3	-2.9	1.3	1.45	-75.2	9.0	-5.5	0.85	1	-96.7	11.1	-7.8	1.1	1.2	-188.2
Step 3	6.7	-5.0	1.8	1.9	-117.0	15.2	-3.5	1	1.2	-93.4	7.0	-3.4	1.55	1.7	-68.8	8.9	-2.7	1.1	1.3	-58.0	7.4	-3.5	1.4	1.55	-72.6
Step 4	5.4	-6.2	2.05	2.2	-77.6	9.9	-4.4	1.3	1.4	-143.3	5.1	-2.1	1.85	1.95	-71.9	3.5	-1.7	1.45	1.5	-104.0	10.0	-2.6	1.65	1.75	-126.0
Step 5	9.6	-1.9	2.35	2.45	-115.6	5.5	-4.0	1.55	1.65	-94.5	3.4	-2.8	2.1	2.2	-61.7	6.1	-4.3	1.65	1.75	-103.7	3.0	-2.3	1.8	2	-26.3
Step 6	8.7	-6.8	2.6	2.75	-102.9	5.1	-5.3	1.8	1.9	-103.4	9.8	-5.7	2.3	2.4	-154.9	2.0	-3.3	1.9	2	-53.3	3.3	-2.2	2.15	2.25	-55.0
Rail																									
	T1					**T2**					**T3**					**T4**					**T5**				
	Accel Max	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**
Step 1	10.6	-3.0	0.65	0.85	-68.2	11.2	-5.0	1	1.1	-162.0	8.8	-1.5	1.1	1.25	-68.5	10.3	-1.2	0.85	1	-77.1	13.3	-6.6	0.7	0.9	-99.7
Step 2	10.7	-13.7	1	1.1	-244.4	10.8	-5.7	1.25	1.35	-164.8	9.5	-3.7	1.35	1.5	-87.7	12.5	-12.2	1.15	1.25	-246.9	7.3	-2.0	1	1.1	-92.8
Step 3	3.8	-2.2	1.25	1.35	-59.7	10.7	-1.2	1.55	1.65	-118.9	10.1	-5.0	1.6	1.7	-151.4	11.0	-3.9	1.45	1.55	-148.9	12.0	-11.5	1.25	1.35	-234.9
Step 4	11.7	-2.6	1.45	1.6	-94.8	4.2	-3.1	1.75	1.85	-73.8	9.7	-11.3	1.85	1.95	-210.3	6.6	-3.8	1.7	1.8	-104.4	8.2	-3.7	1.5	1.6	-119.0
Step 5	4.9	-2.7	1.75	1.8	-151.4	4.1	-4.0	1.95	2.1	-54.1	0.7	-3.8	2	2.05	-90.9	6.0	-2.6	1.95	2.05	-86.4	1.3	-0.6	1.8	1.85	-37.3
Step 6	5.6	-2.2	1.95	2.1	-52.3	1.0	-1.8	2.3	2.35	-57.8	3.1	1.0	2.15	2.25	-21.3	3.3	-2.0	2.2	2.25	-106.2	10.2	-6.4	1.95	2.05	-166.4
AH																									
	T1					**T2**					**T3**					**T4**					**T5**				
	Accel Max	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**
Step 1	7.9	-4.6	0.55	0.7	-83.1	8.7	-1.7	0.45	0.65	-51.9	6.7	-1.2	0.75	0.9	-52.3	7.1	-2.2	0.75	0.9	-61.9	6.6	-1.4	0.65	0.85	-40.1
Step 2	11.2	-13.5	0.9	1.05	-164.7	13.1	-11.2	0.75	0.85	-243.7	7.6	-3.4	1	1.1	-110.3	12.8	-4.2	1.05	1.2	-113.1	25.9	-6.1	0.95	1.05	-320.2
Step 3	12.4	0.4	1.15	1.25	-120.1	15.8	-0.4	1.05	1.2	-107.6	10.5	-1.1	1.2	1.25	-231.2	5.1	-4.5	1.25	1.3	-192.3	14.2	-12.5	1.25	1.45	-133.6
Step 4	8.8	-6.8	1.4	1.5	-156.0	1.9	-16.1	1.25	1.3	-360.1	4.2	-1.0	1.35	1.45	-52.1	5.5	-16.4	1.55	1.7	-146.0	36.7	-4.8	1.5	1.7	-207.6
Step 5	7.3	-4.1	1.7	2	-38.0	0.8	-12.1	1.4	1.5	-128.8	6.2	-4.8	1.5	1.7	-55.2	5.6	-0.4	1.8	1.9	-59.6	13.6	-19.1	1.8	1.85	-654.3
Step 6	5.7	-0.2	2.1	2.25	-39.5	9.4	-2.4	1.6	1.75	-79.0	4.5	-2.2	1.8	1.95	-44.6	7.5	-1.2	2.05	2.15	-86.9	10.2	-5.7	1.95	2.15	-79.4
Both																									
	T1					**T2**					**T3**					**T4**					**T5**				
	Accel Max	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**	**Accel Max**	**Accel Min**	**Time 1**	**Time 2**	**Jerk**
Step 1	9.3	-2.4	0.95	1.15	-58.6	10.0	-0.6	0.6	0.75	-71.2	14.1	-4.0	0.7	0.9	-90.7	8.4	-21.2	0.45	0.65	-148.2	11.8	-3.5	0.4	0.55	-102.0
Step 2	10.3	-2.6	1.2	1.3	-128.9	9.3	-4.7	0.9	1.05	-93.3	11.9	-17.7	0.95	1.2	-118.2	9.1	-13.0	0.75	0.95	-110.6	22.6	-5.4	0.65	0.75	-280.8
Step 3	10.7	-1.9	1.5	1.7	-63.1	5.2	0.4	1.15	1.25	-48.2	5.5	0.8	1.3	1.35	-94.2	12.6	2.6	1	1.1	-99.7	14.0	-2.0	0.95	1.05	-160.5
Step 4	3.3	-18.3	1.8	1.9	-215.9	4.9	-3.7	1.35	1.5	-57.3	11.8	-4.3	1.55	1.6	-321.3	8.8	-11.7	1.2	1.35	-136.6	12.6	0.7	1.2	1.3	-119.5
Step 5	5.5	-3.6	2	2.1	-90.5	3.7	0.2	1.65	1.75	-35.2	4.1	-4.6	1.8	1.9	-87.1	3.9	-3.8	1.6	1.75	-51.6	19.2	-2.7	1.4	1.5	-219.0
Step 6	4.1	-9.2	2.2	2.25	-265.7	8.4	-2.8	1.85	1.95	-111.2	3.7	-0.7	1.95	2.05	-44.2	4.8	-3.5	1.9	2	-82.6	3.0	-5.3	1.55	1.6	-167.4

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