Developing an Instrumented Scrum Machine to Measure Strength and Stability Performance

A thesis presented in partial fulfillment of the requirements for the degree of

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Abstract

Over the last two decades, there has been plenty of research involving an instrumented scrum machine to understand the forces and biomechanics during the scrum. A lot of the research was aimed at understanding and reducing the risk of injury, which led to significant changes to the scrum and its rules. There was a clear gap in understanding the relationship between the forces in the vertical and horizontal planes of motion during a scrum sustained push. There was also a gap in the research on measuring a player's ability to control force in the vertical plane of motion to indicate stability. A new, prototype, a single-man scrum machine was developed to examine these gaps in the research and provide new measurements of strength and stability performance. Two experiments were carried out on the new scrum machine to provide enough data from four participants. From the resulting data, the conclusion was made that there is a strong positive linear relationship between the vertical and horizontal forces produced in the scrum. There was also enough evidence to conclude that the new scrum machine could measure a player's ability to control the vertical force as they pushed. While also completing the aims of this research, the work completed in this project has opened new opportunities for further development around this topic.

Acknowledgements

This project was possible thanks to the sponsorship from Tim Horgan and his team at Powa Rugby. With their support, access to professional rugby teams and coaches was possible. This allowed for valuable insight and understanding of current scrum tactics while providing the key requirements for a new scrum machine prototype. Big thanks to my project supervisors, Dr. Morio Fukuoka for his guidance and support, and Dr Huub Bakker for his valuable feedback. Another big thank you to my family and friends for their support outside of and during my studies.

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1.0 Introduction

Rugby Union is a 15-side contact team sport that involves high-intensity locomotion and contact workloads. The sport involves multiple sport-specific activities that aim to reset the play. One of the methods of restarting play after a minor infringement is the *scrum,* in which eight players from each team form an interlocking *pack* that crouches down to push against the opposing pack with the ball on the ground in between. The aim is to interfere with the opposing team's ability to gain possession of the ball using their feet. This can involve either pushing the opposing pack off the ball or forcing an illegality, such as upsetting the balance of an opposing player so that they must place a knee on the ground. Both strength and technique are required for this.

This Masters project investigates a training tool to improve a player's strength and technique for the scrum, i.e., when crouching and pushing forward against resistance. To make this project possible a partnership with Powa Rugby Ltd (Palmerston North, New Zealand) was formed with the assistance of postgraduate funding through Callaghan Innovation. Powa Rugby is a Manawatu business that supplies professional rugby teams with training equipment. They had designed a prototype for a new rugby-training product, which they wanted to commercialise. This was a simple one-man scrum machine that measured the horizontal force applied by a player through both shoulders using two loadcells. The prototype also used car shock absorbers to dampen movement and provide resistance in the horizontal direction while allowing horizontal movement, providing a more dynamic feel for the player.

This research aimed to develop a single-man rugby scrum machine to provide strength and stability data to assist in measuring scrum performance. The development should improve on the mechanical and electrical flaws of the previous Powa Rugby prototype in addition to investigating the utility of collecting data on the vertical force generated by a player by using additional loadcells. To achieve the aim the following questions must be answered.

- What is the relationship between the vertical and horizontal force produced in the scrum?
- Can an instrumented rugby machine capture the dynamics of a scrum to measure stability performance?
- Do vertical forces have a significant impact on the stability of a scrum?

The structure of this thesis starts with Chapter 2, the literature review, and then follows the rest of the research. The review investigated the current research around the rugby scrum to determine the areas yet to be investigated. Concluding the review there is a lack of understanding behind the forces leading to instability of the scrum. In chapter 3 the method of conducting the research is detailed. This chapter also details the development of a new rugby scrum machine prototype to conduct experimental research. Chapter 4 covers the initial experimentation and discusses the results from that experimentation. Chapter 5 details the final proposed method formed from the conclusion of the initial experimentation. Chapter 6 discusses the results of the research in detail. Chapter 7 contains an evaluation of the new prototype and the conclusions found with the discoveries of this research. Details of future development and recommendations for the scrum machine end this chapter.

1.1 Understanding the Rugby Scrum

The scrum in Rugby Union is one of the unique activities that define the sport. The scrum is used as a means to restart play after the referee has stopped play due to a minor infringement of the rules, for example, passing the ball forward to another player or losing the ball forward onto the ground from contact with the hands or arms. A ball that becomes unplayable from under players' bodies is also restarted with a scrum.

The scrum concentrates 8 players from each team called the forward pack (referred to as Forwards) in one area of the field so the other 8 players of a team called the backline can create an offensive play in the space left on the field. The scrum formation is as follows with a front row of three that have the tight head prop (1), hooker (2), and loosehead prop (3). The next row has an openside flanker (6), two locks (4&5), and a blindside flanker (7). The number 8 plays at the back of the scrum holding the locks together.

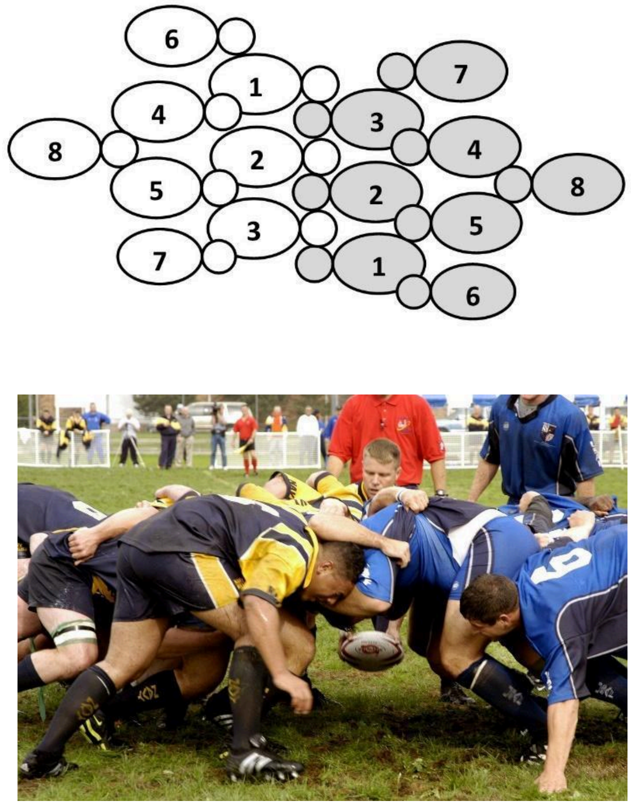


Figure 1: The Scrum

Once the pack is formed the referee will make three calls to safely engage the scrum; Crouch, Bind, and Set. The halfback of the team that was awarded the scrum places the ball into the tunnel created between the two opposing front rows. Once the ball is in the tunnel both teams may engage in pushing the other team off the ball. It is up to the hooker to hook the ball back behind their own team's scrum so either the number 8 or halfback can collect the ball. At the same time, the opposing team has an opportunity to try and push the other team off their ball or cause the other team to make a minor infringement during the scrum. With this information, it is now understood how complex and dynamic a rugby scrum can be in terms of biomechanics.

This research will focus on a single-man scrum machine to capture dynamic biomechanical data from one player only. The additional variables added by a full scrum pack are beyond the scope of the equipment and this thesis. Understanding how a scrum works, however, allows for consideration of how a player will interact with the scrum machine and the best methods to extract the biomechanical data of that player.

2.0 Literature Review

2.1 Introduction to the literature

The scrum is one of the key activities that define the identity of rugby union. A test of physical strength between two opposing forward packs to win possession of the ball after a stoppage in play. The fact that severe injuries can occur during the scrum has encouraged research into the forces and biomechanics in the scrum and methods to avoid injuries.

This literature review will present the laws of the scrum, injuries associated with the scrum, strength and conditioning training, and scrum performance. It will then present the current research into the rugby union scrum and identify the areas that are yet to be investigated, leading to fully defined research questions.

2.2 The Rugby Scrum

The full rules of the rugby scrum are included in Appendix A. The rules have been heavily influenced by a better understanding of injuries sustained in the scrum and the forces involved. Due to the rate and severity of injuries occurring during the scrum, especially to the spines of front row players, a rule change was made to the way the scrum is formed, the engagement. This rule change is important because this changed the focus of scrum performance. Before the rule change the forward packs had a significant gap before engagement. This allowed for heavy impacts at engagement especially to the front-row players. This heavy impact has been found to put stress on the spines of front rowers leading to severe injury (Gianotti, Hume, Hopkins, Harawira, & Truman, 2008).

The rule change to reduce the risk of injury brought the front-row players closer together before engagement while also adding a prebind (before the players 'bind' together). Through studies of professional rugby, the prebind process has reduced the peak loading across front-row players by 35% compared to 25% from the old engagement process (Bradley, Hogg, & Archer, 2018). It was also found in the study done by Cazzola that the prebind process reduces the vertical centre of mass and shoulder movement which indicates a more stable scrum (Cazzola, Preatoni, Stokes, England, & Trewartha, 2014). Over the years after the prebind was introduced Edward (Bradley et al., 2018) noticed an increase in scrum contact time, this may be due to increased scrum stability as found by Cazzola.

This rule change is important because the focus of scrum performance has shifted from producing a high peak force to a more sustained pushing force. This will be important to keep in mind when defining a metric of scrum performance for the development of the new scrum machine prototype.

2.3 Injuries Related to the Rugby Scrum

Most of the literature on the rugby scrum focuses on the injuries resulting from the rugby scrum. The rugby scrum puts a lot of physical strain on the body, so it makes sense that there is a high risk of injury while scrummaging. Studies have found that 11% of injuries to forward players have been associated with scrummaging (Posthumus, 2008). When expressed as injury per event, scrum injuries are more common than injuries associated with any other match contact event at 8.1 injuries/1000 scrum events (Taylor, Kemp, Trewartha, & Stokes, 2014). The common injuries that occur from a scrum are spinal injuries, neck injuries and ankle injuries.

2.3.1 Spinal Injury

Spinal injuries have been the motivation behind studies into injuries related to the rugby scrum. Approximately 40% of all rugby-related, spinal cord injuries result from the scrum (Trewartha, Preatoni, England, & Stokes, 2015). The risk of spinal injury is higher when a scrum collapses (Taylor et al., 2014). Milburn states that the front row contributes the most lateral force that can lead to a collapsed scrum (Peter D Milburn, 1993). The hooker is the player that is exposed to the greatest loads in the scrum and hence the most at risk of a spinal injury.

Wetzler found that 78% of US rugby players that suffered cervical spine injuries were hookers (Wetzler, Akpata, Laughlin, & Levy, 1998). Studies also indicate that there is a higher risk of spinal injury from the initial impact when the scrum engages (Preatoni, Stokes, England, & Trewartha, 2015). Currently, these studies have contributed to a change in engagement rules with the end goal of reducing injury and collapse in the scrum.

Studies have also discussed ways to improve players' technique to improve their stability to reduce the risk of injury or collapse of the scrum (Green, Tee, & McKinon, 2019). Understanding that forces produced in the scrum can have negative results on players' spines is important to know. This knowledge highlights the value of further developing smart scrum machines to indicate what forces are acting when the player is pushing. The literature here also highlights the importance of measuring force data, especially with front-row players. Having players experienced in the front row to test any development on a new scrum machine will be very valuable as indicated by these studies.

2.3.2 Neck Injury

The neck is another area at risk of injury during the scrum which can result in spinal injury. The forces at engagement have the potential to exceed the maximum compressive or bending neck load. Milburn (ibid.) found a controlled engagement in the scrum reduces the forces on the neck compared to previous engagement techniques (P. D. Milburn, 1990). According to Brown, the players most at risk of this injury are front rowers, especially the hooker (Brown et al., 2014). This is understandable as the front rowers are receiving the brunt of each forward pack's force during the scrum. Being at the centre of the scrum front rowers are transitioning the pushing force generated by their teammates behind them along with their own onto the other teams forward pack. On the other hand, front rowers are also the first to receive the opposing forward packs pushing force.

This literature highlights the importance of looking at the performance of front row players. Before the prebind rule changes, the risk for neck injury was found to be higher as players would engage the scrum at high impacts in a less controlled manner. When the Prebind was introduced, there was a noticeable decrease in scrum collapses. With fewer scrum collapses it is assumed that the likelihood of neck injury decreases. Another study looking at ACC (Accident Compensation Corporation) claim data after the change in scrum law showed that the change is likely to have reduced neck injuries during the scrum (Gianotti et al., 2008). The study encountered data analysis issues like some injuries that cannot be claimed by ACC or the number of scrums per game having effect on injury rate. The results from this study were encouraging but inconclusive.

2.3.3 Ankle/Achilles Injury

When observing a scrum, it is expected that you would see stress on the ankle as the player is pushing from his feet onto the ground. Sankey found that forwards suffer more from ankle injuries, particularly second-row players, mainly due to lineouts another rugby related event (Sankey, Brooks, Kemp, & Haddad, 2008). The most common ankle injury for forward playing positions are ankle lateral ligament injuries, however front row players sustain more Achilles tendon injuries. To help reduce injuries rugby players strap up their ankles to reduce injury risk. Semple investigated the effect of kinesiology ankle taping (a form of ankle strapping to support assist injury) on postural stability. Postural stability was assessed by placing a player on a platform capable of tilting up to 20 degrees in any direction. The participant was required to maintain balance while keeping a cursor on screen as close to a marker as possible. Measurement of the foot's centre of pressure was made to quantify the amount of movement in the foot during posture changes. This allowed assessment of overall stability, anterior posterior stability, and medial lateral stability. The study concluded that kinesio ankle taping improved the postural stability of a rugby player but a reduction in injury is still yet to be determined (Semple, Esterhuysen, & Grace, 2012). Because of the way Semple collected data, it is inconclusive if the ankle tape has any improvement to a player’s postural stability during a scrum. The data collected had the player standing up straight on a platform which is different from a player in the scrum position who must hold his weight in a horizontal position.

2.3 Strength and Conditioning

2.3.1 Core Strength

The main focus of current scrum training has been on achieving the greatest impact and impulse force in the scrum. Scrum performance is measured by coaches and sports scientists as a forward pack's ability to produce a large, sustained, coordinated, horizontal impulse (force * time) (Mills, McMaster, & Smith, 2019). The scrum prebind rule change has shifted the importance of a large impact force to a more sustained impulse. Interviewing professional scrum coaches Dan Cron and Greg Feek indicated that the deadlift, back squat, and power clean exercises are effective at improving a player's ability to produce a sustained horizontal force in the scrum. Mills backs this up, as these exercises follow similar movements under load as typically seen in the scrum.

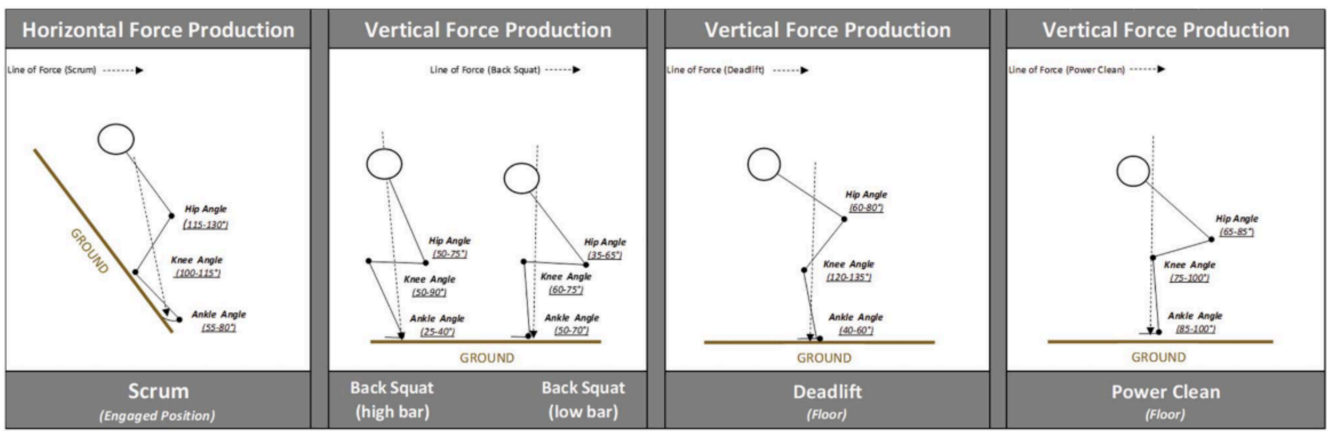


Figure 2: Force Production in different exercises. Reproduced from Mills, 2019 with permission from (Strength and Conditioning Journal)

However, looking at the squat as an example, a pushing force is applied in one vertical plane of motion. When looking at the position a forward takes to apply a pushing force in the horizontal plane, the line of force from feet to shoulders also indicates a magnitude of force in the vertical plane. This will help the research conducted for this thesis evaluate the collected data and find the relationship between vertical and horizontal force. Mills also highlights in their training recommendations how effective a scrum machine is in training scrum performance. This shows the value of providing biomechanical data to coaches through instrumented scrum machines.

2.3.2 Core Stability

A definition of stability in terms of a rugby scrum requires an understanding of core stability, initially defined and understood to assist in the treatment and rehabilitation of spinal injuries (Liemohn, Baumgartner, & Gagnon, 2005). It is also a key component in the training of competitive athletes. The stability of the lumbopelvic (trunk muscle) zone of the body is crucial to provide a foundation for movement of the upper and lower extremities, and to support loads (Willardson, 2007). Panjabi defined core stability as "the capacity of the stabilising system to maintain the intervertebral neutral zones within physiological limits" (Panjabi, 1992).

When the scrum is engaged, there are forces and movements in three planes of motion (vertical, lateral, and horizontal) which apply large physical loads on a player's musculoskeletal structures (S. Brown, Twycross-Lewis, & Padhiar, 2011). Scrum stability could be defined as measuring a player's ability to control these forces in different planes of motion. This could be a good indication of their performance but requires further investigation to be validated. Studies have found that exercises involving more dynamic movement and covering all muscle groups around the core are more effective at improving core stability (Hopkins & Viljoen, 2008). This highlights the limitation that current scrum machines have, as they do not capture the full dynamics of a scrum. This research has highlighted the current understanding of core stability for general sports strength and conditioning training. This research does not provide a definition of what scrum stability is but shows that the most effective way to train stability is with safe dynamic exercise. This will be something to consider with the development of the new scrum machine prototype. If the new development can provide a measurement of a player's ability to control forces in multiple planes of motion, it will open many new opportunities and create significant value for scrum coaches.

2.4 Measuring Scrum Performance

2.4.1 Measuring Strength Performance in the Scrum

The focus of studies associated with rugby scrum has been around the player's performance in terms of strength. In studies, the performance of strength is measured by how much force a player can produce by pushing against practice machines. A study, made at the University of Otago investigates the relationship between anthropometric, strength, and power characteristics of a forward pack rugby player, the body position when scrummaging, and their ability to produce force when scrummaging. An instrumented scrum machine was used to measure the force data of 56 players. From the investigation, it was found that the heavier players were more capable of producing higher individual scrummaging forces than the lighter players (L. Quarrie & Wilson, 2000). It was found that maximal anaerobic power and iso-kinetic knee extension strength correlated significantly to individual scrummaging force. This is a term to simplify explaining the player's capability of endurance and keeping a steady pushing force. The study also concluded that grip strength nor a leg and back lift correlated to individual scrummaging. The study also concluded that an extended lower limb position appeared to be more effective for producing individual scrummaging force. Another study done by Milburn used the same concept of an instrumented scrum machine to measure force of a scrummaging player. This study focused on a static machine mounted to a wall and measured forces along multiple axis. The study compared the pushing contribution of each player's position by testing different scrum formations. These formations were front row only, front row and locks, front row and full second row, and full scrum. The conclusion was made that second-row players contributed to 46% of the forward pushing force of the front row. With the addition of the flankers, there was a 20-27% contribution to forward force and barely any contribution to lateral forces from the number 8 (Peter D Milburn, 1993).

Bayne & Kat (2016) investigated the effect of foot position on the compression and lateral force production on an instrumented scrum machine. S type load cells were attached to a scrum machine to collect the force data along the horizontal, vertical, and lateral axis. Forward rugby players are then to push against the scrum machine with three-foot positions (feet parallel, right foot forwards, and left foot forwards). It was shown that the parallel foot position produces a higher pushing force than either of the other two nonparallel conditions. It was also shown that the nonparallel condition produces a greater lateral force than the parallel foot condition and that the lateral force is directed towards the side of the front foot. Adopting a nonparallel foot position will therefore reduce the compression force that a player will produce, however the effect of the resulting lateral force and moment in the transverse plane on the stability of the scrum needs further investigation (Bayne & Kat, 2016).

2.4.2 Rugby Stability Performance

The fundamental condition of winning a scrum has been to overwhelm the opposition with greater horizontal force. A lot of research has focused on the strength performance of a player to produce a sustained pushing force. Because of this, there has not been much focus on the stability of a scrum. As discussed above there has been research on how different prebind techniques influence the stability of the scrum. Cazzola defines a mechanically stable scrum as one that limits the motion which generates uncontrolled and hazardous (non-axial) loading on front row players and minimizes the risk of scrum collapse (Cazzola et al., 2014). Cazzola's study used pressure transducers in the shoulder padding of scrum props to aim for a scrum experience closer to what happens in game. Scrummaging against a machine has limitations as it does not have a less controllable counteraction offered by an opposition pack. In terms of stability, this study concluded that when the front rows are brought closer at the prebind this decreases the likelihood of collapse compared to the old techniques. In spring-like terms, the old techniques are underdamped which results in the forward packs continuing to oscillate following engagements, whereas the prebind technique is critically damped allowing the forward packs to reach a steady state earlier than the previous techniques. The other conclusion for improved scrum stability is that because the prebind allows for getting a good grip of the opponent and a good position before engagement there is less need for postural adjustment during the pushing phase of the scrum.

2.5 Summary from Literature

From this literature review it can be concluded that the rules of the scrum have changed to make the scrum more stable with a lesser peak and greater average horizontal force requirement. The changes were made after research into rugby injuries caused during the scrum highlighted high forces and strain on players. Research has found with the changes to the rugby scrum rules the risk of these injuries has significantly decreased. In previous research, an instrumented scrum machine has been used to determine the loads of force on a player's neck and spine while scrummaging. This research focused more on the risk of injury to the player rather than the player's performance during the scrum. Other research with instrumented scrum machines uses static mounted machines to measure the force produced by players. This research was conducted before the rule change and shift in focus on a sustained push rather than a dominant first impact. This research is outdated and will not capture the current dynamics and biomechanics of a scrum today. Research identified in this literature has also defined stability in the scrum as limiting motion which generates uncontrolled and hazardous loading and minimises scrum collapse. A study investigated the effect of ankle strapping on a player's postural stability but was inconclusive on the effect on scrum stability. Another study was able to capture the dynamics of a scrum through pressure measuring shoulder pads. This method allowed to overcome the limitations of a machine and provide valuable data for determining if the changes in the prebind rules improved scrum stability.

So far there has been no study going into discussion around the relationship between the vertical force and horizontal force and the implications of this relationship in terms of performance. Also lacking in the research is providing a measurement of how well a player can control vertical force during a scrum. From the gaps in the research evaluated in this literature review the following research questions have been defined.

- What is the relationship between the vertical and horizontal force produced in the scrum?
- Can an instrumented rugby machine capture the dynamics of a scrum to measure stability performance?
- Do vertical forces have a significant impact on the stability of a scrum?

3.0 Method

3.1 Method Summary

The following section details the method carried out to answer the questions highlighted from the literature review. The literature and initial interviews with NZ professional scrum coaches emphasised the importance of capturing vertical and horizontal forces produced in the scrum. Because of this, the decision was made to develop a new scrum machine to capture this force data. Before design, some requirements were set out. The key requirement was to improve on flaws in the prototype supplied by Powa Rugby and add other areas of measuring the force in the scrum. There were major improvements to the mechanical, electrical, and software areas of the prototype which are explained below. The first designed scrum machine was used to collect initial force data. This initial force data will be used to highlight further improvements and development to answer the questions of this research. From the initial data, a stability attachment was developed to make up the final system used in this research. A second experiment was carried out to collect final data for analysis and confirm the developed scrum machine is capable of answering the research questions.

3.2 System Requirements

The following was considered when designing the new prototype for initial data collection.

1) The machine is limited to being for single-person use.
2) The system must keep the existing way of dampening the movement horizontally.
3) The system is required to measure force at multiple points of interest.
4) The machine structure must be robust enough to endure multiple impacts from professional level rugby players without incurring any damage.
5) Integrate measurement of force in the vertical axis.
6) Improve on the flaws of the Powa Rugby's design.

3.3 Scrum machine design

The first focus in the design phase was to improve the flaws of the previous prototype scrum machine provided by Powa Rugby. The new prototype was required for two master’s projects and so the design of the system was carried out by myself and another master's student. Below is the proposed new design (figure 3) to improve on Powa Rugby's design in Figure 4.

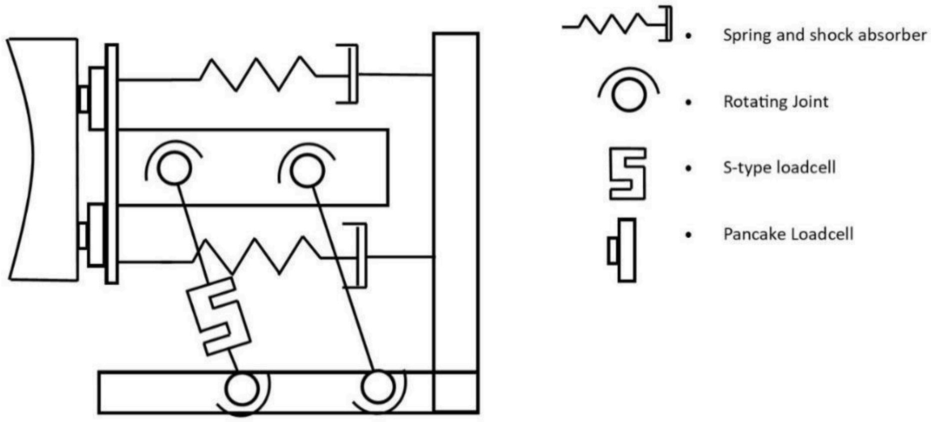


Figure 3: Scrum Machine Symbolic System Diagram

3.3.1 Mechanical

The initial prototype from Powa Rugby as seen below (Figure 4) used a basic steel tube slide with plastic bushings to allow for movement horizontally. A spring was mounted on top of the tube to dampen the movement. A load cell was mounted behind the spring to measure the forces produced by a player. Each shoulder pad was set up, so movement was separate for both shoulders. The flaw found with this design was that while pushing one shoulder tended to bind and lock up. This put the focus of force on one shoulder as that one was free to move. The positioning of the load cell was also a concern as it was behind the shock and so the force the load cell measures is one that has been dampened.

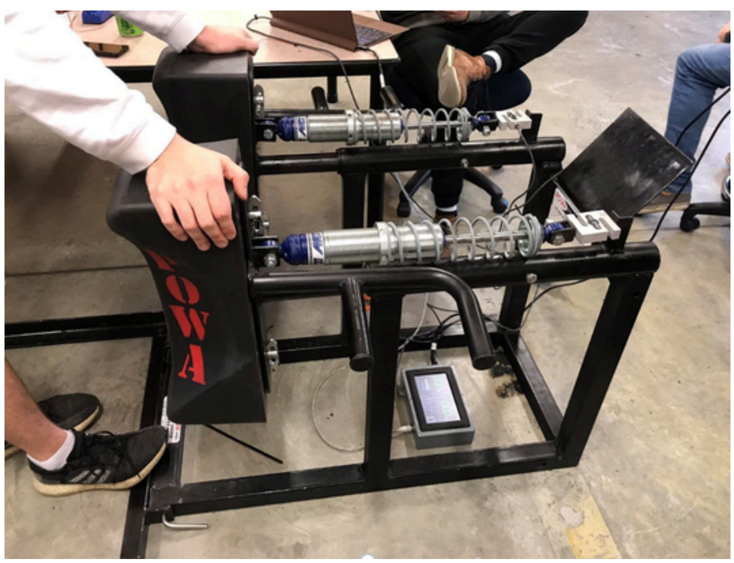


Figure 4: First Prototype

From initial concept brainstorming the idea of using a four-bar linkage was chosen to be integrated into the new prototype as seen in Figure 5. To smoothen the movement in each joint of the four-bar linkage, plastic bushings have been installed. Four pancake load cells have been chosen for their ability to be placed into the design while keeping the design robust. On each shoulder two load cells will be placed behind the pad in a configuration as seen in the figure. This placement will ensure direct measurement of force, unlike the previous design that was dampened by the shock. The load cell configuration has also been chosen to pick up whether the player using the machine is placing his shoulder higher or lower on the pad. To measure vertical force two S type load cells have been placed on the front two linkages of the four-bar linkage. Another improvement from the last design is the addition of two more shocks. This addition of another shock allowed for more resistance to professional rugby players pushing against the scrum machine. The placement of the shocks as seen below allows for less chance of binding to occur.

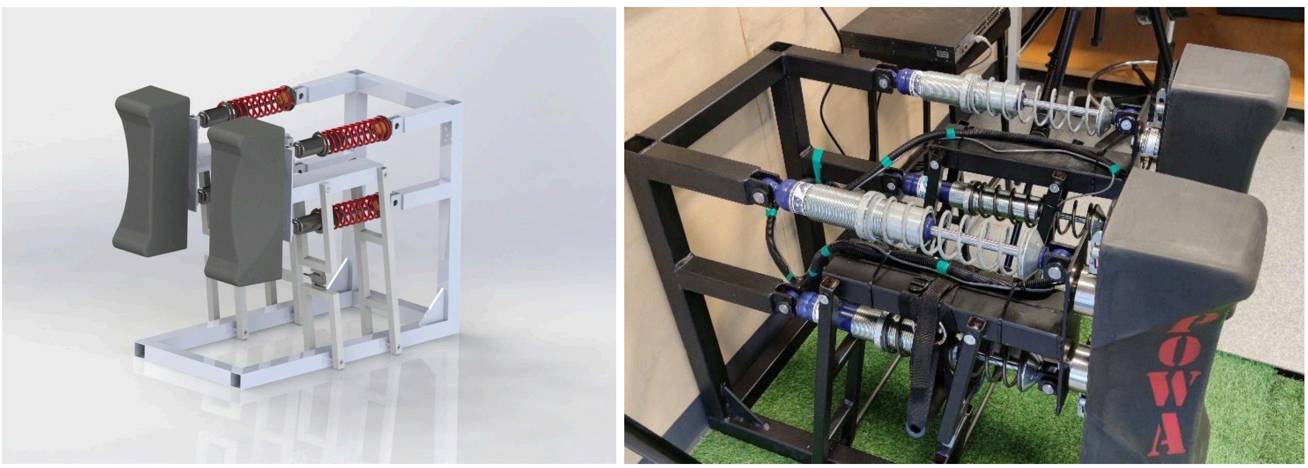


Figure 5: Final Scrum Machine Design

For the final implementation of this prototype design some protective shrouds and fixed handles were attached. The protective shrouds are to help prevent fingers from being caught in the pinch points of the shocks when in use. The fixed handles were chosen over loose handles due to the preference from rugby players. During fabrication, the decision was made to widen the linkages from 25x25mm to 50x50mm. This was done to increase the integrity of the prototype so it can handle big impacts of strong professional front row players.

3.3.2 Electrical

3.3.2.1 Sensors

In this section the sensors used for the new prototype will be described. In the previous design, the use of aluminium s type load cells was used and mounted behind the shocks. In this design, the change to universal pancake load cells was made as they are more suitable for extraneous loads. Because as stated in the mechanical design the load cells are being moved behind the pads, they will be experiencing off centre loading which is not suitable for s type load cells.

Table 1: Electrical Components

Sensor Type	Use	Description	Reason
Universal Pancake Load Cell	Measuring the Horizontal force produced during the scrum	250kg rated pancake load cells x2.	Can handle the loads on multiple axis. Ideal for its mounting location.
S type Load Cell	Measuring the vertical force.	1-ton rated S-type load cells x2.	Cheaper option of load cell. Can only handle loads along one axis.
Encoder	Measuring the angle of displacement in the linkages.	Magnetic precision encoder.	To have a comparison of forces to horizontal displacement.

3.3.2.2 PCB

The main board designed for this prototype was designed to log all data from the load cells in the scrum machine. The printed circuit board is using an analogue-to-digital converter to read the signals of each load cell and then outputs raw data to an Arduino microcontroller embedded into the board via SPI communication. The microcontroller on the board reads the ADC at a rate of 50 Hz and converts it into force data ready to send to a PC by serial communication. As seen below the board outputs to multiple plugs so can be easily swapped with replacement sensors. The PCB also has header pins that allow access to 5 GPIO pins and 5 other pins for grounding and various voltages.

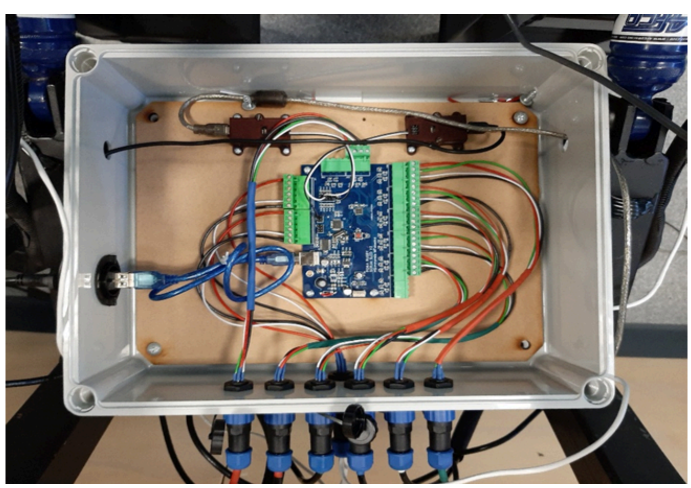


Figure 6: Electrical Control Box

3.3.3 Software

The software design for the new prototype is split into two sections: the control board algorithm and the user interface algorithm. The control board algorithm was developed using the Arduino IDE to take in the raw data outputted by the load cells and convert it into readable force data.

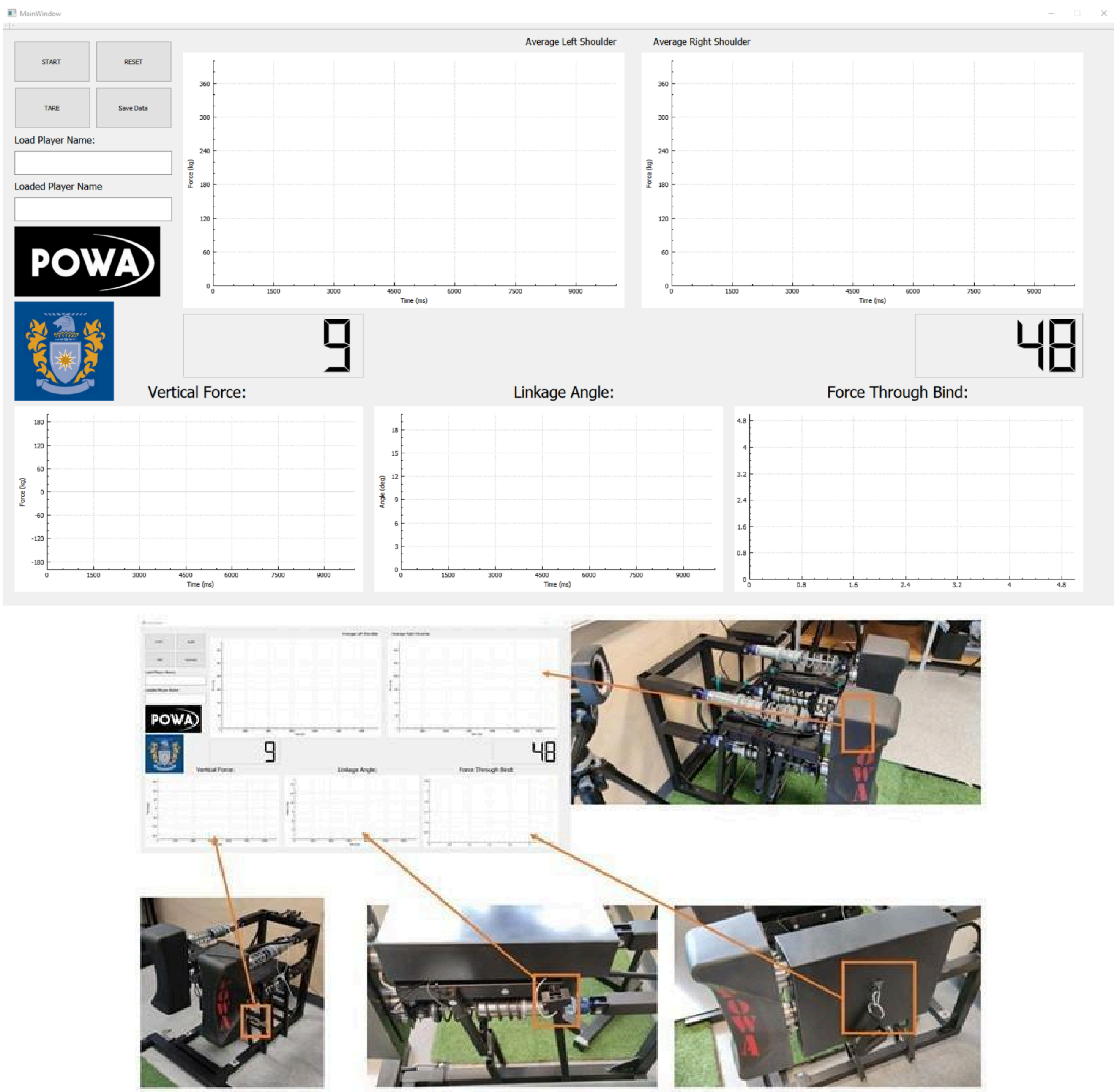


Figure 7: Scrum GUI

The diagram above shows the location of a sensor and where its data appears on the graphical user interface. The data will stream on multiple graphs to get live comparisons of forces being applied during a sustained push. The data plots over 10 seconds as that is the time coaches aim for their players to produce the most sustained force. In the diagram, it shows a force through bind. The binding force is a placeholder for recommended research and development that was cut due to the time constraints of this project. The user interface has the ability to record the user's name to organise data. Once the user has been loaded the start button can be pressed which will give the user 3 seconds to engage the machine and then record their data over a 10 second push. After the 10 second push, the user has the option to save the data which will be stored in an Excel file for further analysis.

4.0 Initial Experimentation

The aim of this initial experimentation is to test the first prototype of a new instrumented scrum machine to record scrum force data in multiple locations. The data will be used to determine the performance of the design while also assisting in understanding the force biomechanics of scrummaging with one person. Once sufficient data has been collected and analysed further development into improvements of the prototype can be made to measure scrum stability performance.

4.1 Setup

The final design of the scrum machine was placed in the electronics lab on campus and bolted to the floor so there was no movement when pushing against the machine. As seen below in figure 7 The scrum machine was fitted with a gym mat with artificial turf. Participants taking part in the data collection have the choice of placing their feet on the turf mat or to use the metal ladder. The data collected from the machine is sent to a computer to process from raw data to readable force data. The tv seen in Figure 7 displays the user interface to show graphed force data in real time.

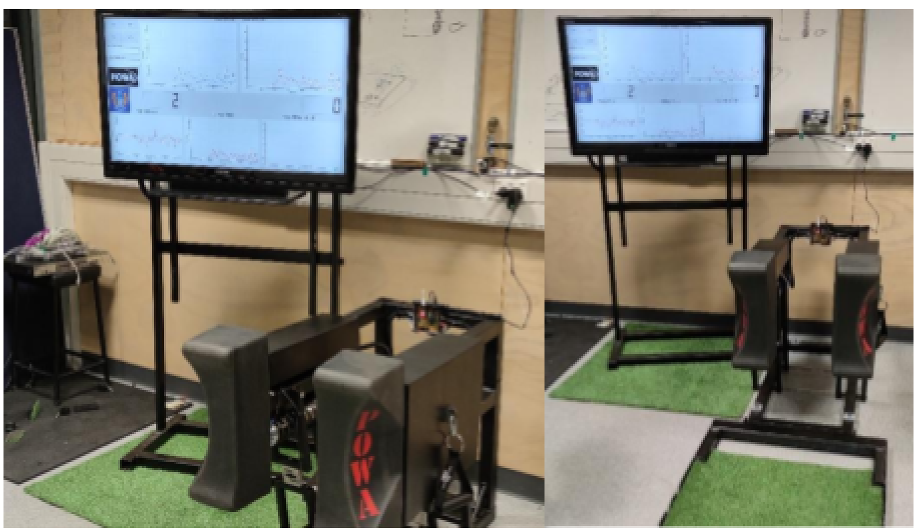


Figure 8; Initial Experiment Setup

When participants are brought in to collect data, they are informed of pinch points on the scrum machine and asked to use the handles when pushing against the machine. There are also metal covers that are placed over moving joints and shocks to prevent any injuries due to pinch points. A consent form is given to all participants to ensure compliance with human ethics regulations. Once the participant has given consent and has been briefed on safety the procedure of data collection will be explained as follows. The participant will position himself ready to engage in a scrum. The GUI will start with the calls Crouch, Bind, set resembling what happens in the game. The participant will engage the scrum machine and push for 10 seconds. Once the 10 seconds is up then sufficient data is collected for that push, it is saved into a csv file for later analysis.

4.2 Force and Biomechanics Initial Theory

To help in the analysis of the data collected from the prototype an understanding of forces acting on a rugby player as they push in the scrum was made. The following diagram was produced to assist in understanding where the forces are acting during the scrum. The source of the pushing force will be from the player's feet against the ground. Mills shows the line of force in the scrum travels from the shoulders to the toes during force production (Mills, McMaster, & Smith, 2019).

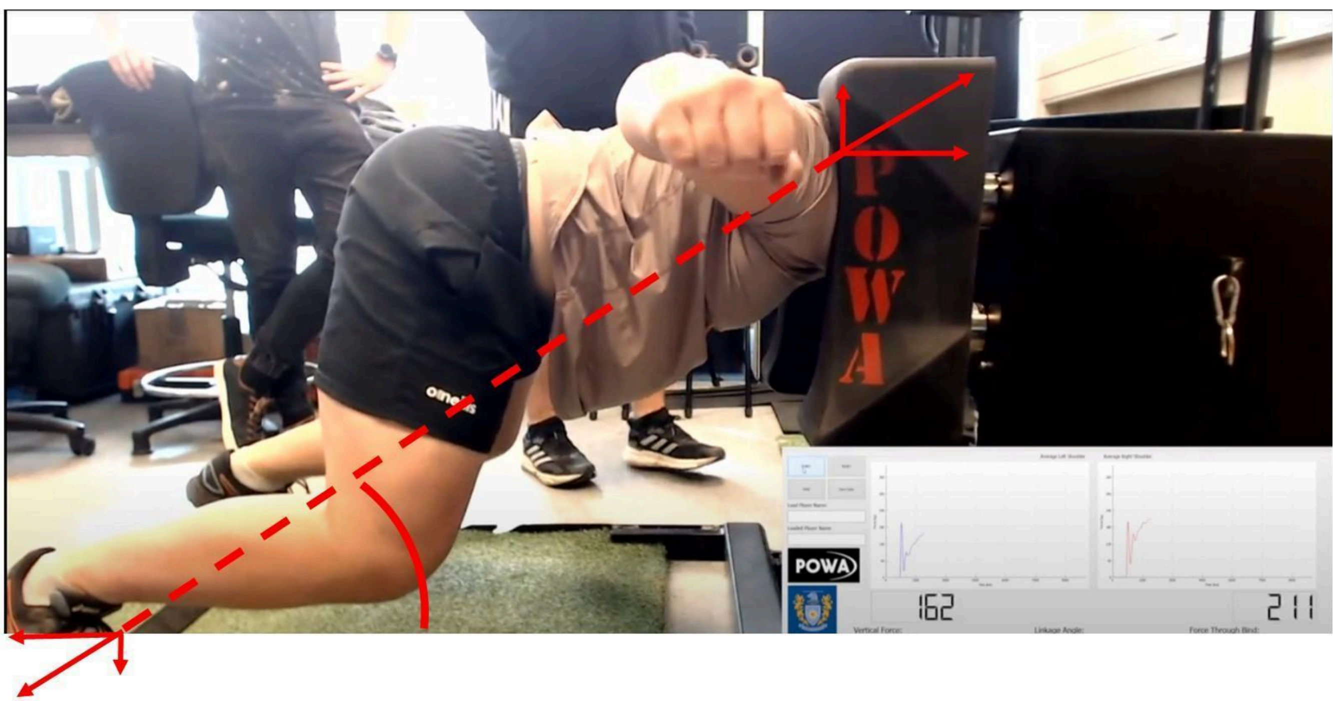


Figure 9: Scrum Force Diagram

Going off what is seen above in Figure 8 the theory is, that as a player's pushing force increases along a horizontal plane, there should be an increase in force along the vertical plane. So, it is expected from the data to be gathered that there will be a positive linear relationship between vertical and horizontal forces. In that case, Pythagoras' theorem can be applied to estimate one force if the other is known.

Equation 1: Pythagoras Theorem

Tan (Angle from feet to shoulder) = Vertical Force / Horizontal Force

4.3 Results and Discussion

At the start of engagement there is an initial spike of force which levels out as a sustained force over the time of 10 seconds. On the GUI the force displaying the participant was producing more horizontal force than what is considered realistic. This is believed to come down to an error in converting the raw data with a linear calibration equation to show force for each shoulder. The GUI was set up to also save the raw data and so during analysis, the raw data conversion was fixed with a new conversion equation to result in more accurate force data. The equation was created by calibrating the load cells on the Instron force producing machine.

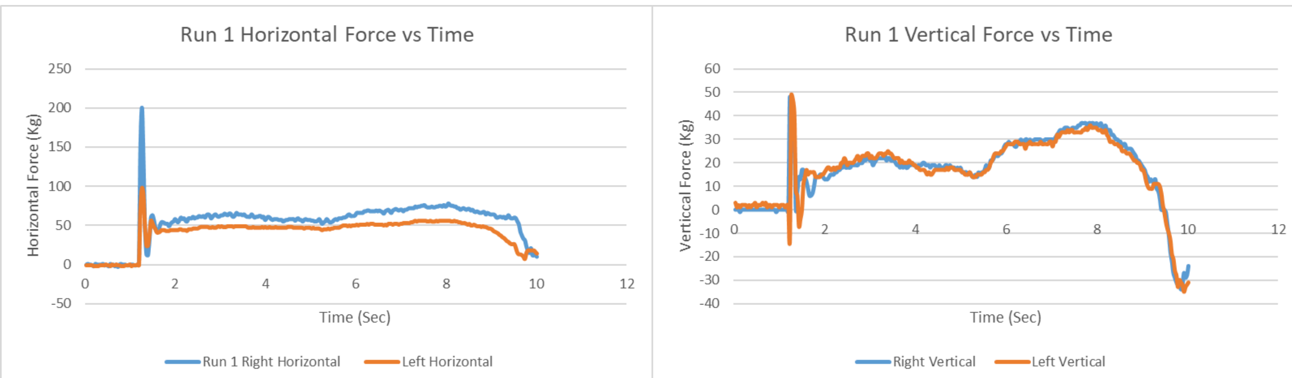


Figure 10: Example of Captured Force Data

The force data was graphed over time to help visualise what was happening in the data analysis as seen above in Figure 9. Below in Figure 10 is the force data for Participant 1 over time for both horizontal and vertical forces. From observing Participant 1's force data after each run the force produced at the sustained push phase increases which most likely is caused by the participant getting acquainted with the machine. Another observation to be made is that as the participant generates more force during the sustained phase the difference in force readings between each shoulder increases.

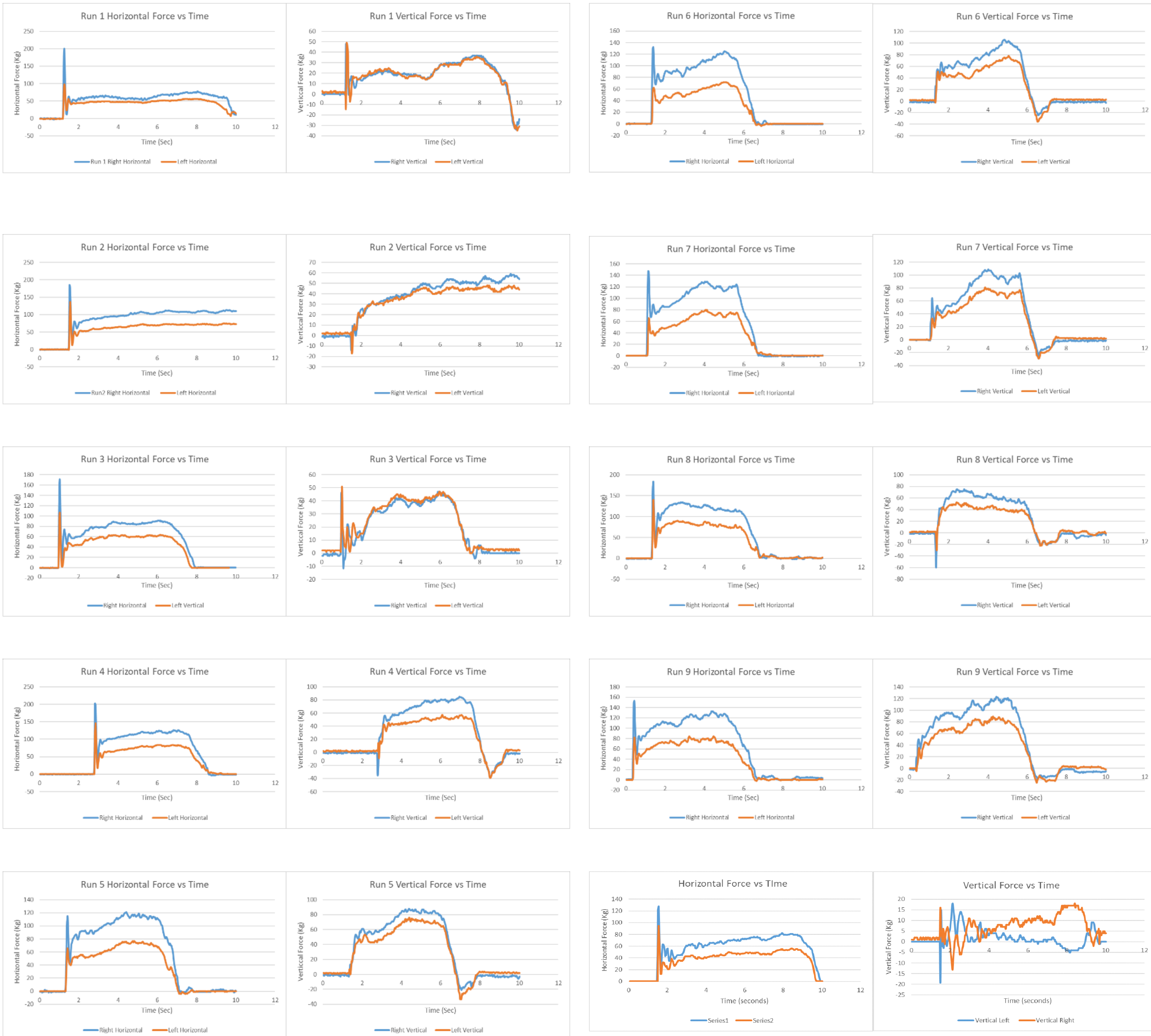


Figure 11: Participant 1's Results

The force data for Participant 2 over each run during the sustained push stayed reasonably consistent. The horizontal force produced by Participant 2 the right shoulder always produced the most force. Knowing the position the participant plays in the scrum this observation is to be expected as it is assumed this is his dominant shoulder. Another observation to be made from Participant 2's data is that in the first 5 runs, the difference in vertical force produced on each shoulder is minimal. In the last 5 runs of Participant 2's data, the difference in vertical force produced on each shoulder has increased. This could be from changes in posture which leads to a subtle twist in shoulder position allowing one shoulder to generate greater vertical force.

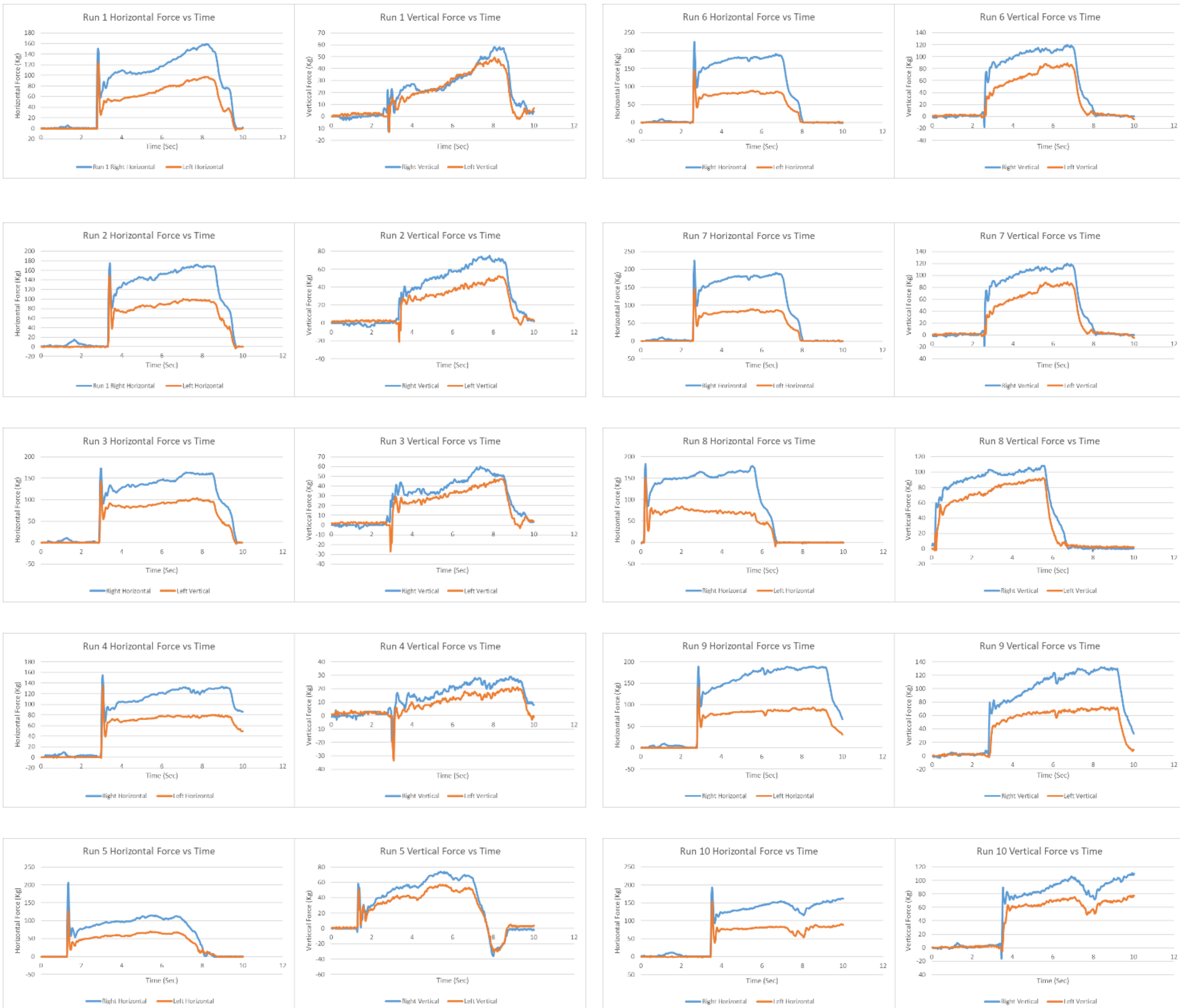


Figure 12: Participant 2's Results

The force data from the sustained push phase of the scrum was then extracted so the vertical force and horizontal force could be graphed against each other. The literature shows that there used to be a big focus on the initial impact of the scrum (Mills et al., 2019) but due to rugby law changes coaches have moved to focus players on a more sustained push. For this study, the analysis will focus on the sustained push and determine the relationship between the vertical and horizontal forces. To help visualise what relationship these forces had during the sustained push the vertical and horizontal forces were graphed in an X, Y scatter plot. Once graphed, the line of best fit was applied, and then the R squared value was calculated to determine how well the data fit a linear model. The data can be found in Appendix B in Data Sets 1 and 2. The Data sets were evaluated by comparing both shoulders of each participant over the 10 runs. Below is a table of all the r squared values from the data of the first experiment.

Table 2: Experiment 1 R Squared Results

	Participant 1		Participant 2	
Run	Left Shoulder	Right Shoulder	Left Shoulder	Right Shoulder
1	0.903	0.875	0.949	0.912
2	0.936	0.965	0.949	0.954
3	0.96	0.921	0.791	0.924
4	0.922	0.983	0.614	0.892
5	0.952	0.929	0.977	0.9563
6	0.923	0.933	0.73	0.981
7	0.933	0.992	0.8163	0.983
8	0.916	0.953	0.562	0.987
9	0.895	0.967	0.973	0.971
10			0.744	0.98
Average	0.927	0.946	0.811	0.954

Participant 1 has no R-squared value for run 10 as that run was pulled from the data set due to a unique occurrence in the vertical-force-over-time graph. From the table above we can see that Participant 1, on average, showed a strong positive linear relationship between the vertical and horizontal forces during the sustained push phase. Participant 2 on average also showed a strong linear relationship between the vertical and horizontal forces. However, Participant 2's right shoulder on average showed a stronger relationship between these forces than the left shoulder. This is assumed to be due to the right shoulder being the participant's dominant shoulder and applies more force on that shoulder. Participant 2 plays in the position of loose head prop which is different from Participant 1 who plays hooker. It is expected that Participant 2 shows a higher force in one shoulder being the dominant shoulder because of the position in the scrum the participant plays.

Below is the outlier data of Participant 1's force data. The Horizontal force over time is consistent to the rest of the data but the Vertical Force over time shows something unique. The left shoulder appears to produce a low force in an inverted representation of the right shoulder's force data.

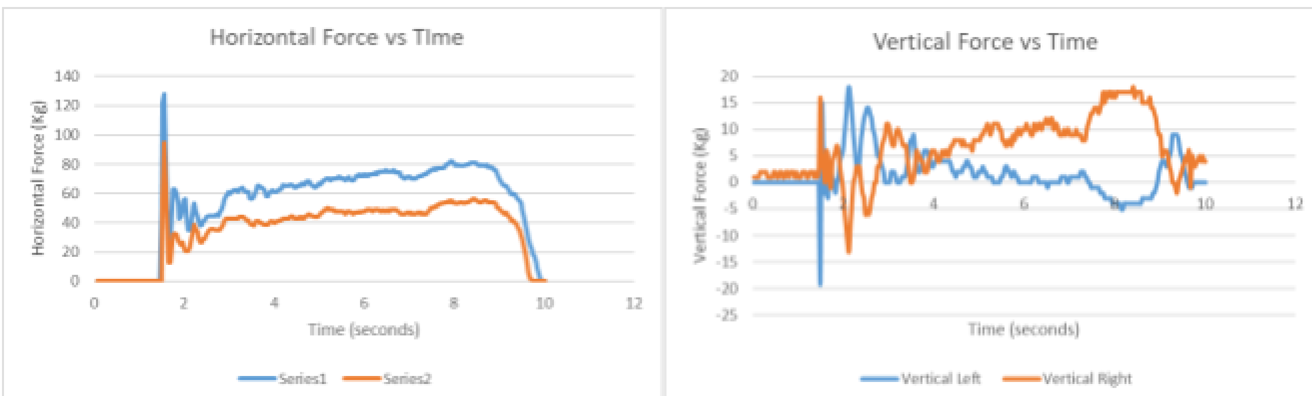


Figure 13: Participant 1 Outlier Data

4.4 Conclusion and Improvements

From the results of the initial experimentation there is a clear positive linear relationship between the vertical and horizontal forces. Comparing each shoulder's ability to produce a relationship between the vertical and horizontal forces, one shoulder can be found to have a stronger relationship than the other. This may be due to one shoulder being the player's dominant shoulder during that push. During the test of the machine, it was observed that the location of loadcells reading vertical force might not give an accurate reading of how much vertical force the player is producing. Because of where the loadcells have been placed when the player pushes the system can apply leverage on that loadcell giving a higher reading that is true.

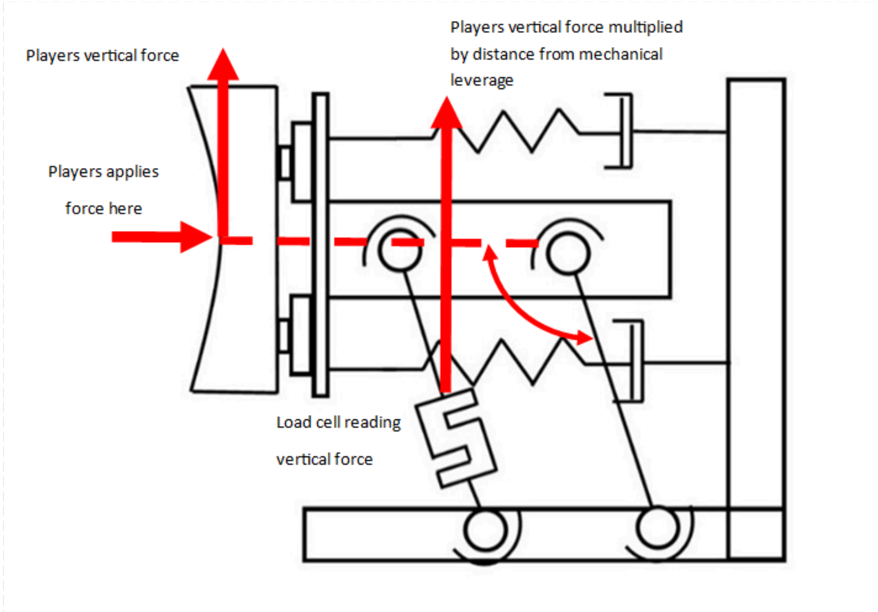


Figure 14: Mechanical Leverage on Prototype

As seen from Figure 14 the player will apply a force to the pad of the machine and any vertical force will be multiplied by the distance the loadcell is away from the origin of force. This has led to the further development of the scrum machine. This next development will focus on moving the vertical loadcells to a more optimal position where the vertical data can be read true without any mechanical leverage. There will also be an addition of vertical dampened movement to the system to assist in replicating a scrum while keeping the machine safe to use.

5.0 Second Experiment Method

5.1 Summary

From initial experimentation it was concluded that to further understand stability and vertical forces in the scrum improvements to the machine are required. The design of an attachment to fit behind the pads was carried out to allow for dampened movement along the vertical axis. As it was found in the literature, to determine the stability of a scrum minimal displacement in the vertical axis must be achieved.

5.2 Stability Attachment Design

5.2.1 Initial Concepts and Component Selection

To avoid complete reconstruction of the prototype scrum machine the idea of developing an attachment to be placed behind the pads was used. To achieve the goal of examining stability in the vertical forces the attachment had to allow for vertical displacement. This vertical displacement must be dampened so that any users do not hurt or strain themselves. The following will describe the initial concept development and choice of linear guide The first concept used a simple idea of having two arms from the pad plate that runs along a linear rail as seen in Figure 13. The ends of the rails would require hard stops and heavy springs would be placed over the rails to dampen the motion. A limit of rail length was set to 300mm as anything above that would be extreme motion and instability. To measure stability during a scrum the idea of performance is shown in the player's ability to hold zero or very minimal displacement vertically. The flaw of this initial design is that it will be weakened over time by torque forces and bend in the round rails.

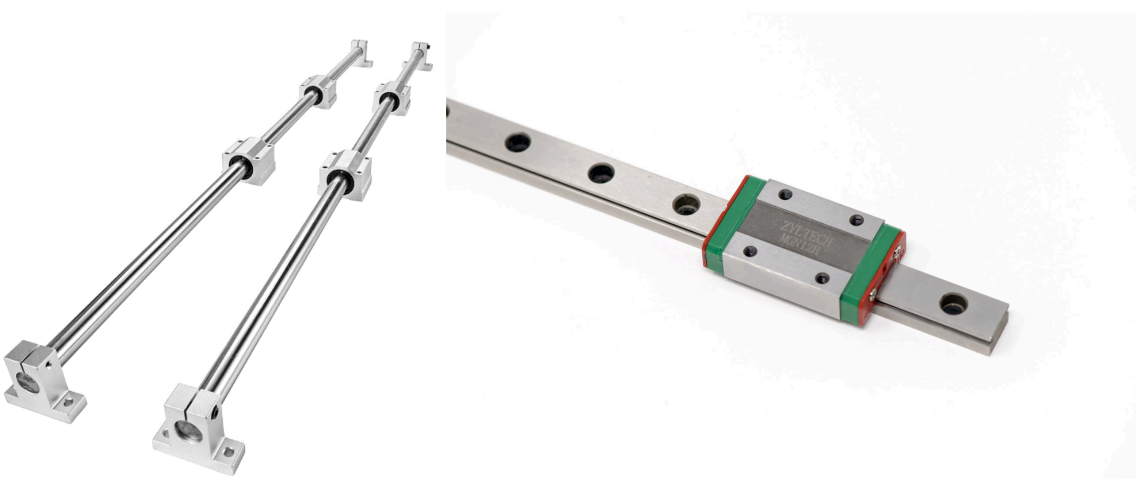


Figure 15: Linear Guide Options

The next concept was to replace the round rails with low profile carriage and rail guides seen in Figure 14 that mount to the back plate of the attachment housing. This change will allow the horizontal forces to distribute onto the back plate and remove the problem of bending in the rails. The choice of a low-profile carriage as well will reduce torque forces being applied in another axis of the design. With this choice of guide, there is a challenge of sourcing an appropriately sized carriage that can handle torque forces applied in the design. Another option for a low-profile linear carriage and rail is seen below which achieves the same as above but might allow for another method for fitting additional components required for the attachment. This linear guide can also be arranged so the wheels are fixed to the housing and the rail can be moved in a vertical motion. The downside to this concept is the rail will end up moving up with the pad and stick out of the housing.

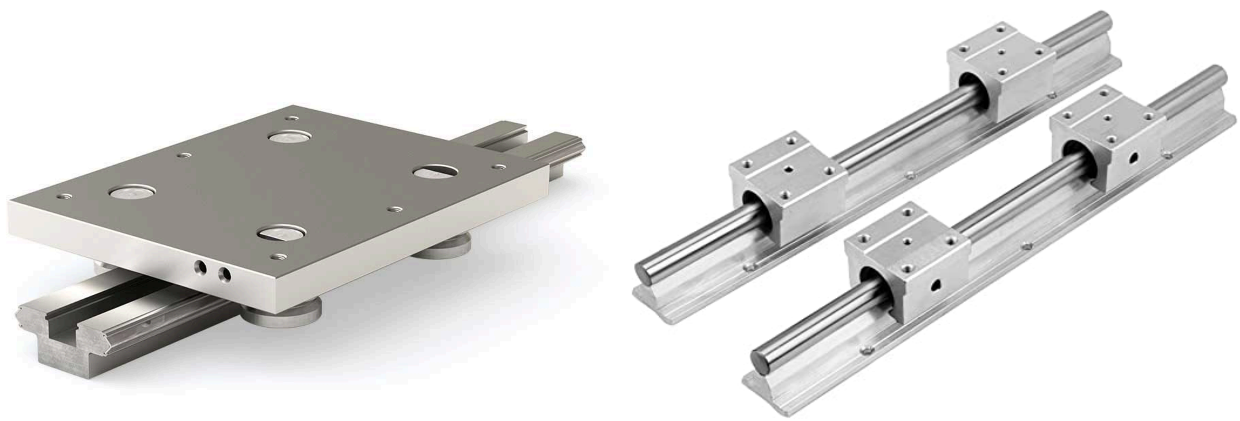


Figure 16 Further Linear Guide Options

The final choice of the linear guide is as seen to the right in Figure 14. This choice was made due to the availability of components and their suitability to this application. This guide uses the same idea of a round rail as above but instead allows for fixture and support and so removes the problem of bending. With these linear guides, the choice to add two more attachment points and side by side rails was made to add strength to the design. With this arrangement of these linear guides, there is room in the middle to apply dampening and a load cell to measure vertical force. For dampening the motion of the vertical motion, the initial idea was to use heavy duty springs were discarded due to the difficulty of finding an appropriately sized spring. Instead, the idea of using shocks is used. After sourcing for shocks the use of mountain bike shocks was the most appropriate for this design for their size and not requiring oil for damping. The mountain bike shocks chosen for this design use compressed air to dampen force and motion. With air shocks, the load capacity can be altered by changing the pressure in the two chambers. Along with this the rebound and lock out can be adjusted on the shock.

Figure 17: Adjustable Air Shocks

5.2.2 Final Design

Below shows the final Design of the stability attachment which sits behind the pad and the loadcells. The pad plate has been altered from the last design to mount onto the linear rails and have a way of adjusting the mountain bike shock. Since it is an air shock the window in the pad plate allows for a bike pump to change the pressure inside two chambers.

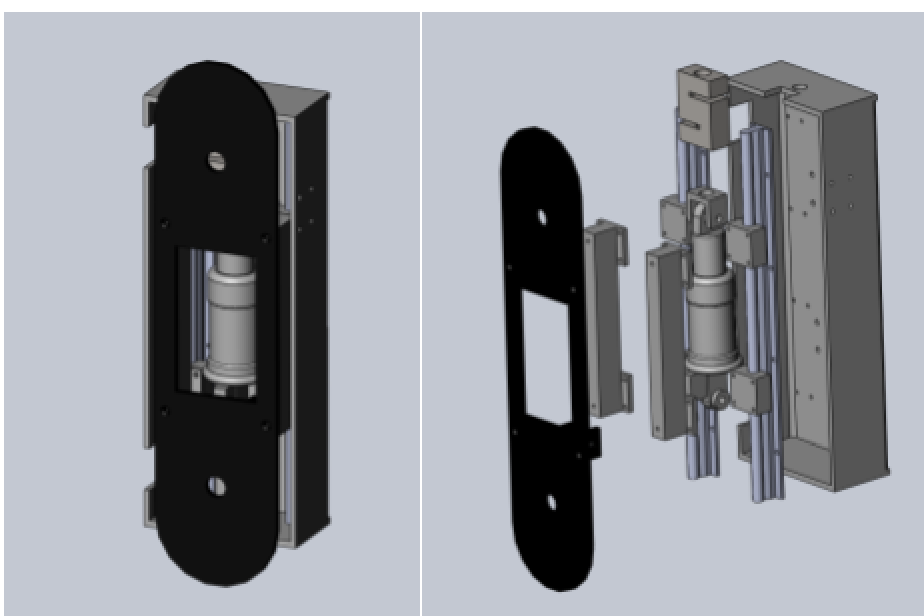


Figure 18: Final Attachment Design

The casing of the stability attachment is built from a box section cut into a C channel to fit the linear rails, vertical load cell, and shock inside. This design has been made so there is a very minimal gap between the pad plate and the outer casing. This has been done for safety reasons and to prevent anyone from placing fingers into any pinch point inside the mechanism when using the scrum machine. The pancake cake load cells are mounted behind the casing one above the other. Below is the stability attachment in an exploded view to show how the mechanism goes together. The load cell for measuring the vertical force has been mounted as seen above between the casing and the small shock.

5.3 Final Experimentation Setup

The final experiment will run like the previous, two participants will be recruited to scrum against the machine. The Participants will scrum against the machine for 10 seconds. The Participants will also be encouraged to scrum against the machine 10 times but if feeling fatigued can take a rest or pull out of the experiment. The same User Interface will be used for this experiment to collect the data. The vertical data will now be collected from the stability attachment rather than the linkage joint. Unfortunately, professional rugby players were unavailable for this final testing, so it was carried out by amateur rugby players. Like the previous experiment, the participants will sign consent forms to follow human ethics regulations. The new participants will be informed of where to place their hands to ensure no injury is caused by the pinch points of the machine.

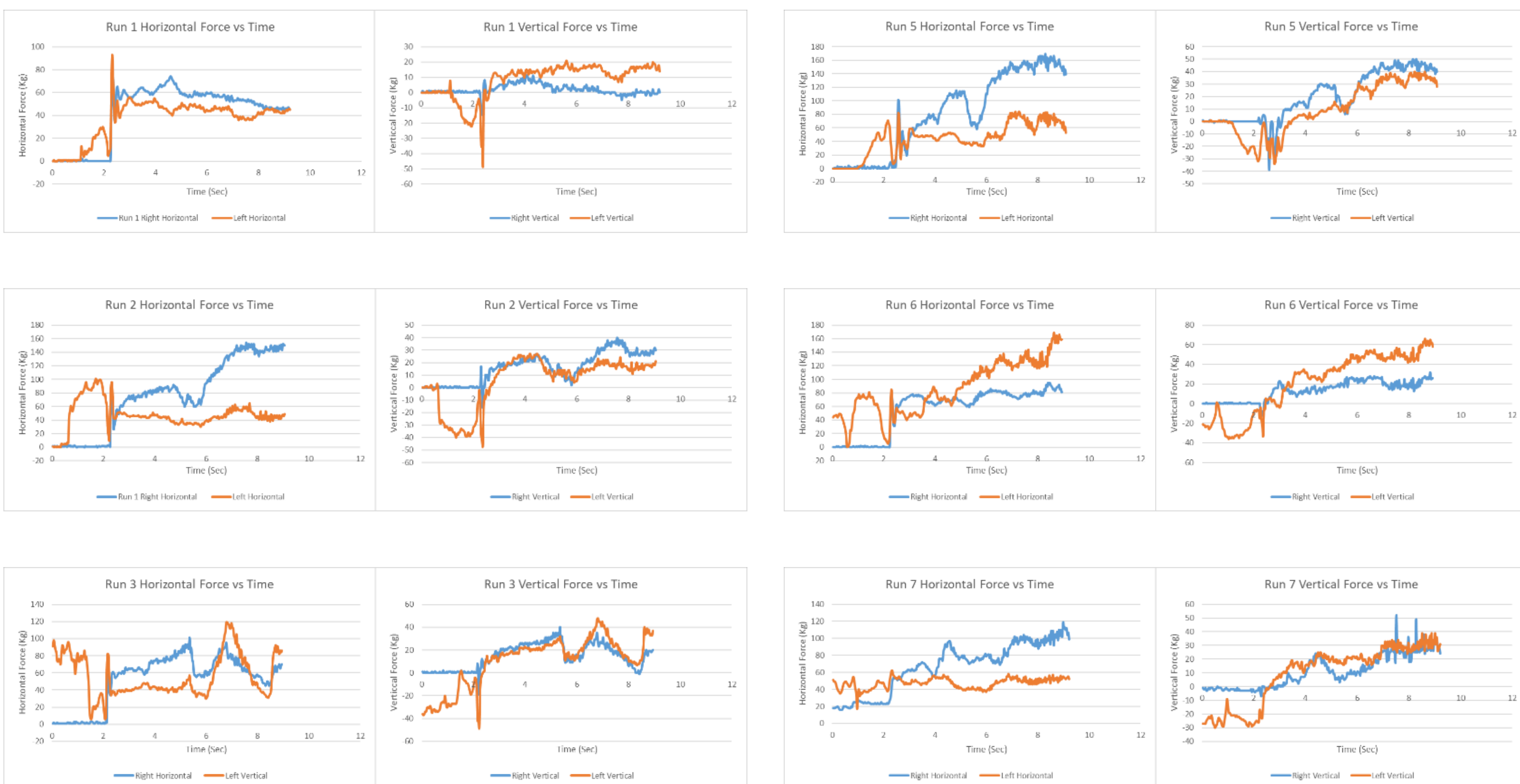
Figure 19: Final Experimentation Setup

6.0 Results and Discussion

This section discusses the data collected from the final experimentation while also making a comparison to the data collected from the initial experiment. The Vertical and Horizontal Force Data is analysed first to determine if the stability attachment has any effect on the relationship between the vertical and horizontal force. The sustained push is then analysed to determine if there is a stable production in force over time.

6.1 Vertical Vs Horizontal Force

The force data like the initial experiment is graphically presented over a time of 10 seconds. A total of 10 runs have been graphed showing both vertical and horizontal force over time. Seen below in Figure 18 is Participant 3's force overtime data. Participant 3 only has data for 8 runs as there was an error in the data files for two runs. This may be caused by an error in the data saving function of the prototype software which was realised after the experimentation. An analysis was still carried out with the remaining data that was collected. Looking at the data below Participant 3 showed more horizontal force on the right shoulder than the left shoulder for the majority of the runs. When producing vertical force Participant 3 showed both shoulders were producing a similar increase in force. This observation is consistent over all of Participant 3's runs.



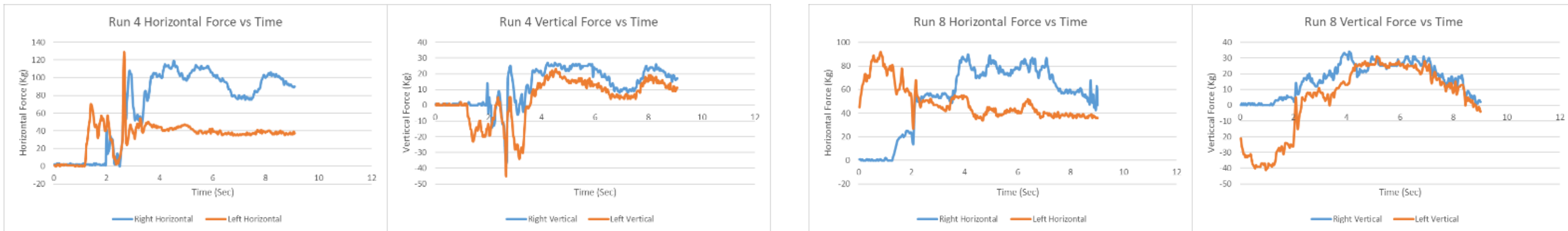


Figure 20: Participant 3's Results

Participant 4 had different results for their force vs time graphs over all runs as instead of engaging the machine they pushed the machine with their shoulders already in contact with the machine. That is why Participant 4's results as seen in Figure 19 do not show an initial massive peak force. This push was the Participant's preference and gives another aspect to look at when evaluating the data that the machine reads. From below it is observed that the right shoulder was producing a greater horizontal force than the left shoulder. It is assumed that in this push the Participant's dominant shoulder is the right shoulder as it is producing the most amount of force below. Out of all the force data collected Participant 4 showed that both shoulders produced the same amount of vertical force consistently over all runs. As the only participant to not have an engagement stage and only a sustained push this can lead to the assumption that the participant is in a comfortable position to produce force on both shoulders. Other Participants had an engagement phase and so had a chance to place their shoulders in a position that required adjustment to generate force comfortably. So, it is believed that when there is high variation in produced vertical force, that is the machine picking up an adjustment in shoulder placement.

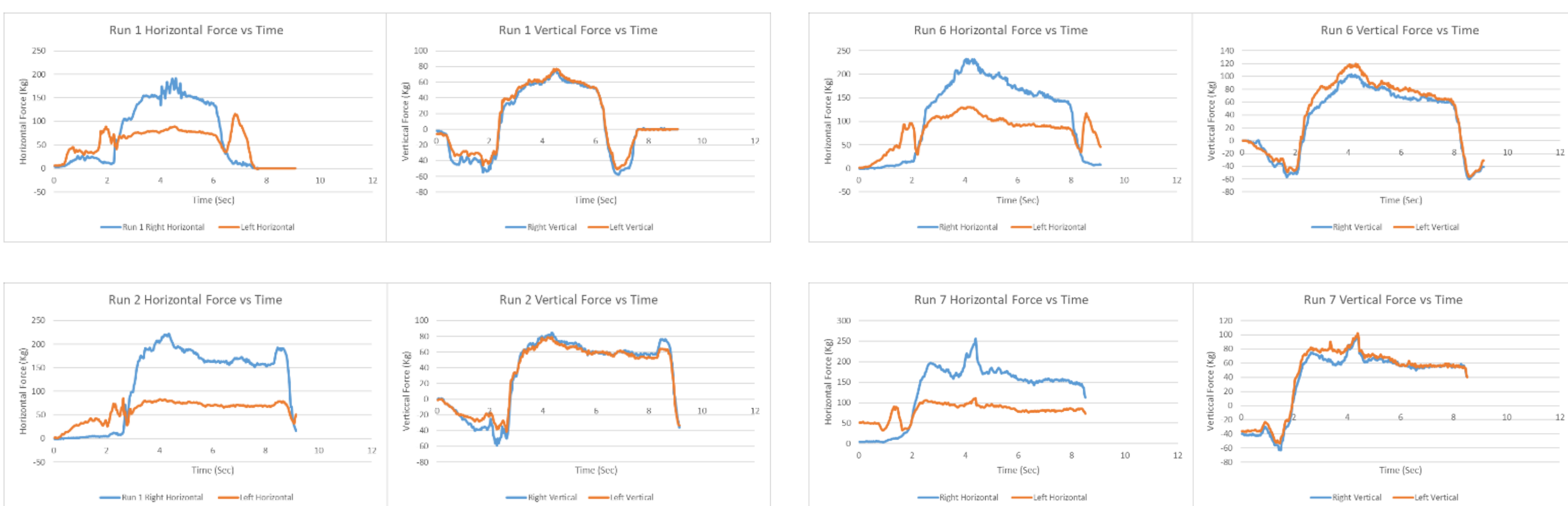


Figure 21: Participant 4's Results

Like the first experiment the relationship between vertical and horizontal force was evaluated with X Y Scatter plots. The data like before is still evaluated with a comparison of each shoulder. Below in Table 3 is the resulting R squared values of both the first experiment and this experiment for comparison. The first observation is that Participant 1 still generates on average a stronger relationship between both forces. Participant 3 has on average generated less of a relationship between the vertical and horizontal force but still provided evidence of that relationship. Looking at the force overtime generated by Participant 3 it is also the least amount of force generated compared to the other participants. This observation can lead to the conclusion that when producing low amounts of force, the relationship between the vertical and horizontal force is weakened.

Table 3: Experiment 1 and 2 R Squared Results

	Participant 1		Participant 2		Participant 3		Participant 4	
Run	Left Shoulder	Right Shoulder	Left Shoulder	Right Shoulder	Left Shoulder	Right Shoulder	Left Shoulder	Right Shoulder
1	0.903	0.875	0.949	0.912	0.0197	0.632	0.948	0.891
2	0.936	0.965	0.949	0.954	0.1786	0.737	0.817	0.972
3	0.96	0.921	0.791	0.924	0.753	0.869	0.795	0.987
4	0.922	0.983	0.614	0.892	0.26	0.919	0.889	0.972
5	0.952	0.929	0.977	0.9563	0.778	0.984	0.944	0.892
6	0.923	0.933	0.73	0.981	0.916	0.412	0.891	0.972
7	0.933	0.992	0.8163	0.983	0.0582	0.839	0.815	0.969
8	0.916	0.953	0.562	0.987	0.0212	0.774	0.853	0.986
9	0.895	0.967	0.973	0.971			0.961	0.972
10			0.744	0.98			0.919	0.856
Average	0.927	0.946	0.811	0.954	0.373	0.771	0.883	0.947

As seen in table 3, Participants 3 and 4 provide a linear relationship between the vertical and horizontal force. The changes made to the scrum machine design have not affected this relationship so we can still conclude there is a positive linear relationship between the vertical and horizontal forces. The left shoulder showed a lower relationship between the vertical and horizontal force. Looking at the force overtime graphs the left shoulder horizontal force did not increase over time as much as the right shoulder. However, the vertical force over both shoulders was increasing about the same over time. This observation can explain why the relationship is weaker in the left shoulder than in the right shoulder.

The above shows that Participant 4's results also show a very strong relationship between the vertical and horizontal forces. Both shoulders have shown this strong relationship which could mean the participant is applying an almost even push with both shoulders instead of applying more force on one shoulder.

6.2 Stability in the Sustained Push

In the next section of the results the vertical force was evaluated to determine if the data coming from the scrum machine indicates stability performance. The sustained push phase of the scrum was evaluated. During this phase, it is already confirmed that as horizontal force increases, vertical force increases. Literature from the review has indicated that stability is measured by how well a player limits vertical displacement but also indicates that it should be measured by vertical load control (Cazzola et al., 2014). To determine the stability of the vertical force data collected a line of best fit has been fitted from the start of the sustained push to the peak of generated force. Stability will be determined by the least amount of variation from the line of best fit.

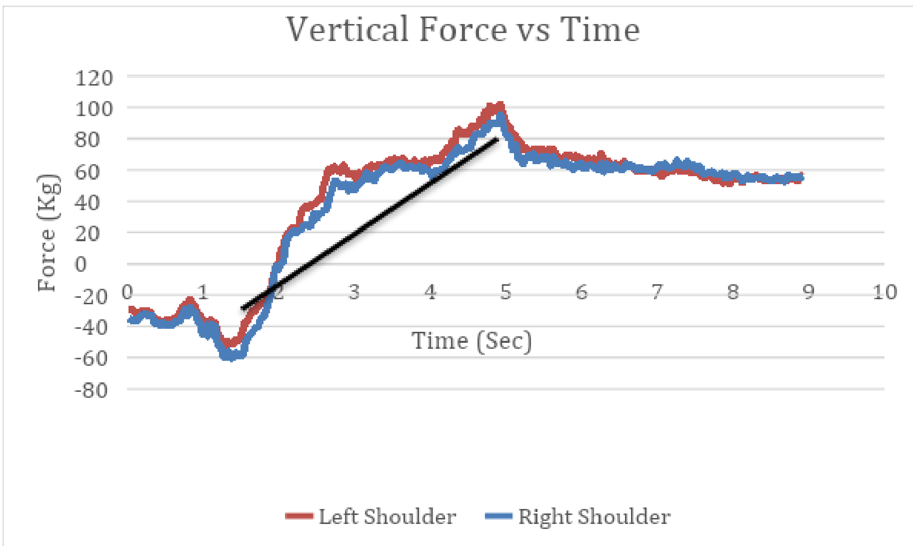


Figure 22: Stability Analysis Example

Using this line of best fit the equation of that line is used to determine the residuals of the data. The residuals are then plotted to visualise their distribution. At the same time, the standard deviation of the residuals is calculated using the formula below.

Equation 2: Residual Standard Deviation Formula

$$\text{Residual} = (Y - Y_{est})$$

$$S_{res} = \sqrt{\frac{\sum (Y - Y_{est})^2}{n - 2}}$$

where:

S_{res} = Residual standard deviation

Y = Observed value

Y_{est} = Estimated or projected value

n = Data points in population

Once the standard deviation has been calculated it is assumed if there is less deviation within the residuals the player is producing a steady increase in vertical force. The standard deviation is also divided by the mean to find the coefficient of variation (CV) which will determine if the scale of force produced has any effect on the results.

Table 4: Stability in the Sustained Push Results

	Particpant 1				Participant 2			
	Left Shoulder		Right Shoulder		Left Shoulder		Right Shoulder	
Run	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation
1	2.09	9%	2.66	12%	1.96	7%	5.46	17%
2	3.66	9%	8.46	19%	1.99	5%	2.85	5%
3	6.01	17%	5.40	17%	2.12	6%	4.76	11%
4	5.13	11%	6.53	9%	1.48	10%	2.07	9%
5	4.87	9%	5.01	8%	5.69	13%	8.81	15%
6	3.89	7%	4.28	5%	6.83	10%	7.99	8%
7	3.86	7%	4.57	6%	5.00	7%	7.02	6%
8	6.46	16%	6.86	12%	5.92	8%	6.69	7%
9	10.40	16%	11.12	12%	3.54	6%	7.46	7%
10					4.49	7%	2.81	3%
Average	5.15	11%	6.10	11%	3.90	8%	5.59	9%

	Participant 3				Participant 4			
	Left Shoulder		Right Shoulder		Left Shoulder		Right Shoulder	
Run	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation	Std Deviation of Residuals	Coefficient of Variation
1	2.71	19%	1.41	21%	4.29	8%	5.51	11%
2	5.73	35%	6.66	30%	6.19	11%	9.44	16%
3	2.47	13%	2.49	11%	7.79	9%	14.70	17%
4	5.10	37%	3.74	17%	4.56	7%	6.59	10%
5	7.03	23%	4.49	21%	12.02	14%	12.00	19%
6	7.07	19%	4.34	23%	6.92	8%	6.44	9%
7	3.80	17%	5.88	37%	11.95	16%	13.36	21%
8	3.84	32%	4.65	22%	11.35	12%	11.57	13%
9					8.30	14%	7.62	14%
10					5.07	6%	4.58	5%
Average	4.72	24%	4.21	23%	7.85	10%	9.18	14%

From above we can see that Participant 1 produced on average a low standard deviation and CV on both shoulders. This indicates the Participant can produce on average a stable increase in vertical force during a sustained push. Below is Participant 1's sustained push from run 6 which was the Participant's best run-in terms of variation in force produced. Visually from the graph we can see that the Participant's vertical force on both shoulders does not deviate significantly from the line of best fit. The left shoulder shows slight deviation from the line of best fit at the start but steadies out. This may be due to the Participant making subtle adjustments in the shoulder position after the engagement phase. Participant 1's right shoulder shows a similar pattern but has slightly less deviation as it steadies out at the end. The CV for the Participant's right shoulder was 5% while the left shoulder was 7%. From this, we can determine that the right shoulder showed slightly more stability in the increase of force over time.

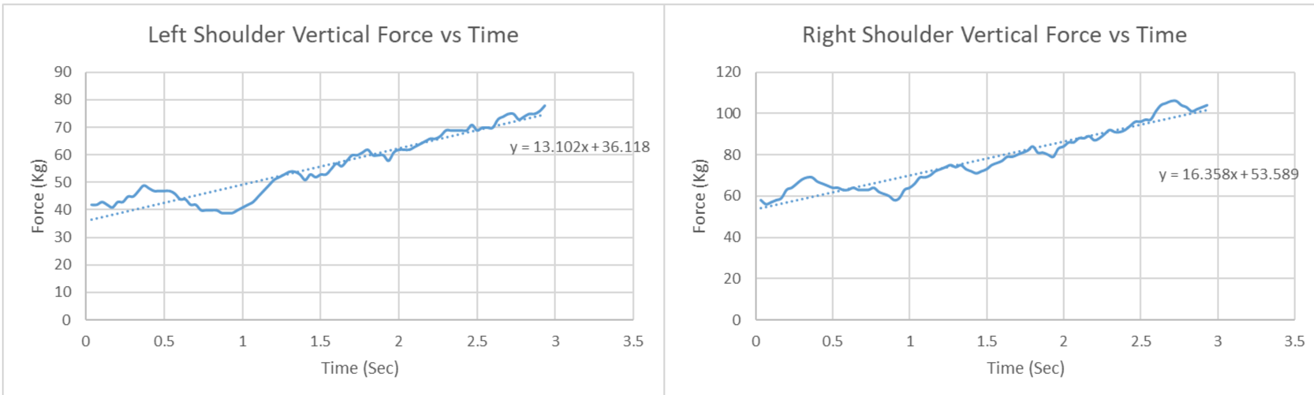


Figure 23: Participant 1 Run 7 Vertical Force vs Time

Below shows Participant 1's force overtime graph from run 3 which resulted in the highest CV out of this Participant's runs. For both shoulders, the CV was %17 which is still quite a low value. As observed in the graphs of run 3 there is more deviation from the line of best fit compared to run 7.

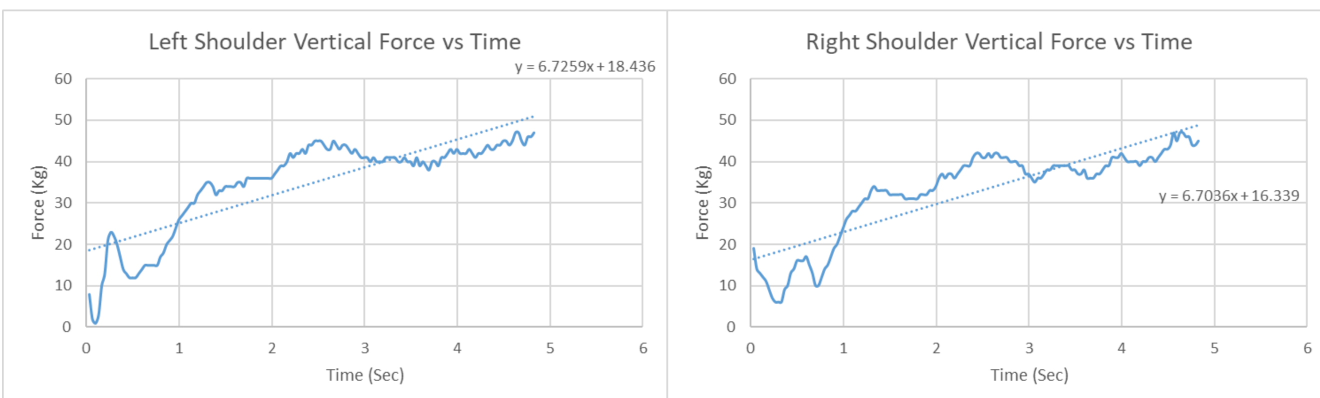


Figure 24: Participant 1 Run 3 Vertical Force vs Time

From Table 4 Participant 2 had on average the lowest CV of all the participants with 8% on the left shoulder and 9% on the right shoulder. Seen below is Participant 2's force overtime graph for run 2 which resulted in the lowest CV of all runs. Observed in the graph below that the force data is very close to the line of best fit. Both shoulders resulted in a 5% variation which so far, this Participant has resulted with the most stable increase in vertical force.

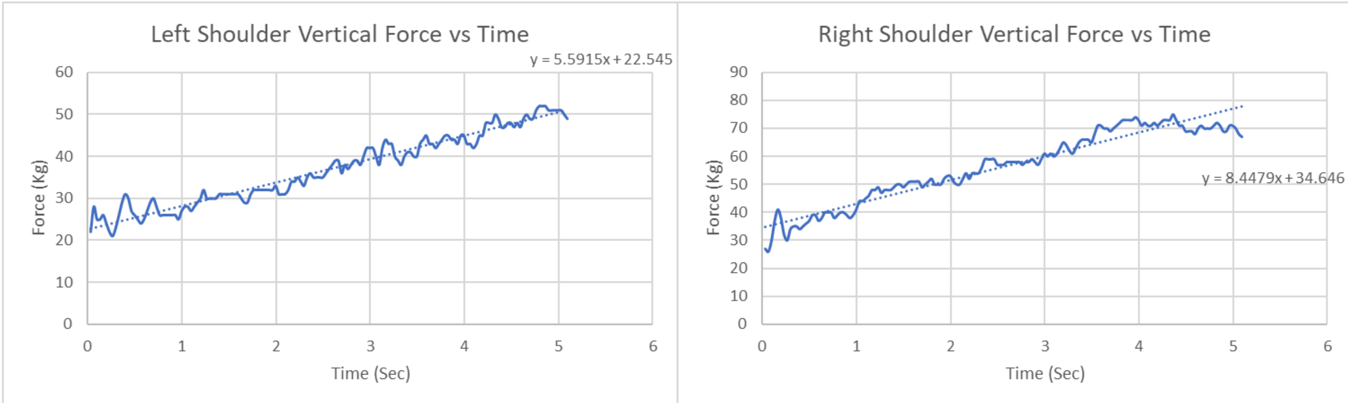


Figure 25: Participant 2 Run 2 Vertical Force vs Time

Run 5 was Participant 2's run with the highest CV compared to their other runs. This run had a CV of 13% on the left shoulder and 15% on the right shoulder. Even though this run was the highest variation in force the participant produced is still very low compared to the other participant's results. The conclusion can be made that Participant 2 can produce a more stable increase in vertical force and is most unlikely to collapse in a scrum.

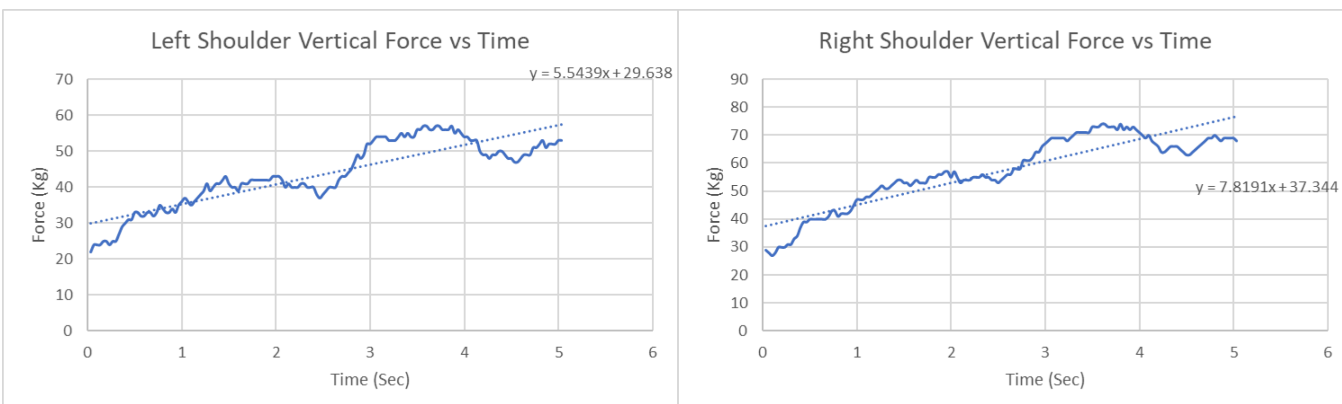


Figure 26: Participant 2 Run 5 Vertical Force vs Time

Participant 3 had a low standard deviation on average for both shoulders, but a high CV. Participant 3's force data was less than the other participants. The CV of Participant 3 is larger by 10% than Participant 1. The data indicates that Participant 1 showed the same variation as Participant 3 but at a greater average force. The increase in force over time in the left shoulder as seen below showed less variation to the line of best fit than the right shoulder. The Residual Standard Deviation resulted in 4.5 for the left shoulder which indicates this shoulder was producing a more stable push. The Standard Deviation/Average Force resulted in 21.33% which is also 10% higher than Participant 1's result.

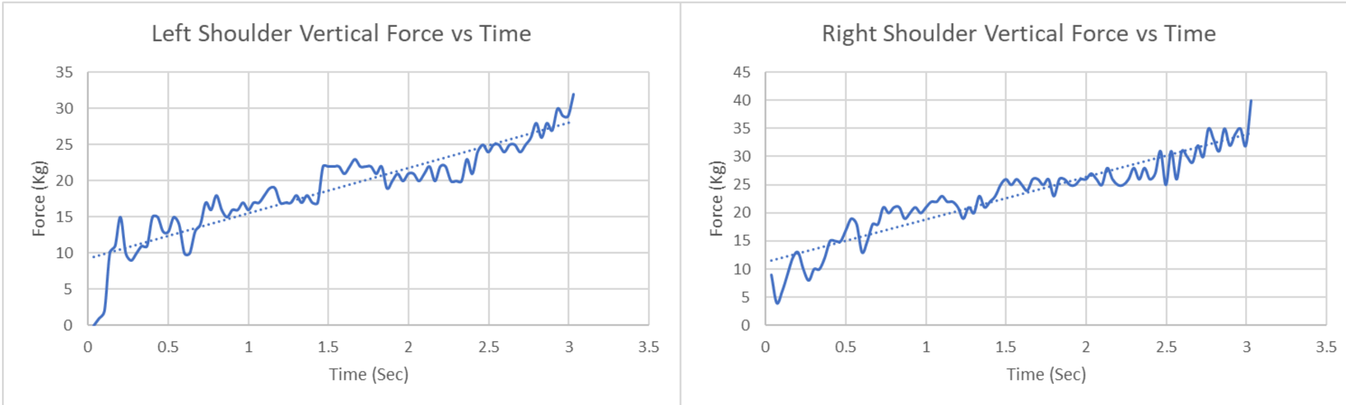


Figure 27: Participant 3 Run 3 Vertical Force vs Time

Below we can see Participant 3's graph of vertical force overtime for run 2. Already we observe that there is a big variation in the force around the line of best fit indicating partial instability. The left shoulder started with high variation and started to level out. The CV for the left shoulder resulted in a force variation of 35% in the left shoulder and 30% in the right shoulder. Participant 3 had the highest variation in vertical force out of all the participants.

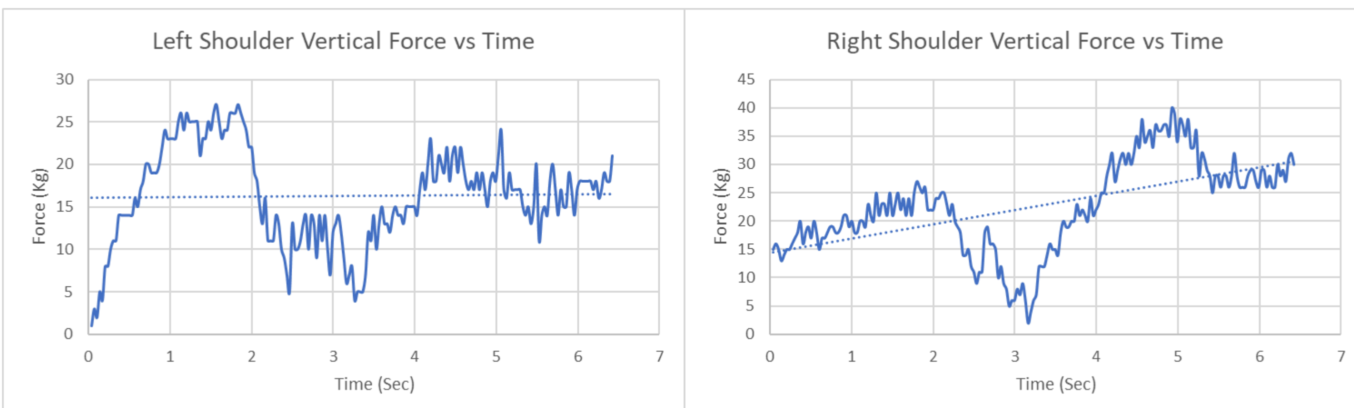


Figure 28: Participant 3 Run 2 Vertical Force vs Time

Participant 4 had low variation in vertical force data on average with a CV of 10% on the left shoulder and a CV of 14% on the left shoulder. Below in Participant 4's Vertical force overtime graph for run 10 it is observed that the variation in force is minimal around the line of best fit. This indicates the left and right shoulder is producing a stable increase in force. The CV for this run resulted in a force variation of 6% for the left shoulder and a 5% force variation for the right shoulder. This run was Participant 4's best run in terms of stable vertical force production meaning they are less likely to collapse on this run.

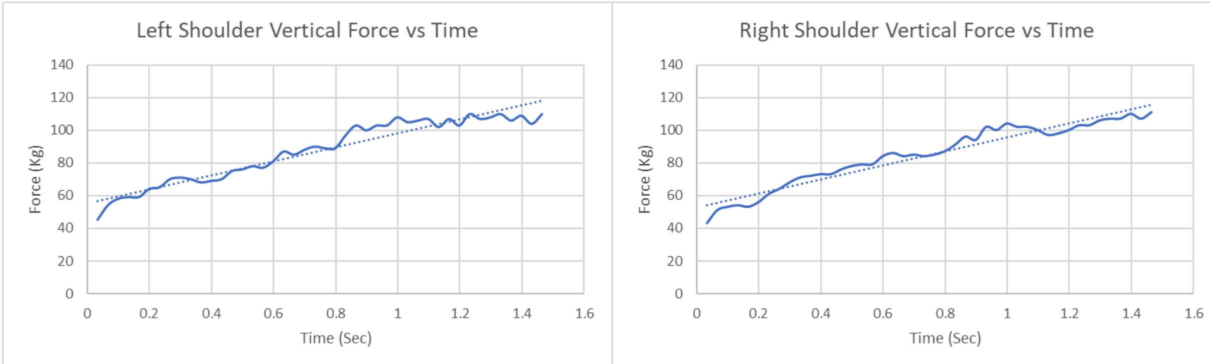


Figure 29: Participant 4 Run 10 Vertical Force vs Time

Below is the vertical force overtime graph for Participant 4's run 7 which had the most variation in force. The left shoulder resulted in a CV of 16% and a CV of 21% in the right shoulder. This run showed more variation than the participants run 10 but still is less variation than the results of Participant 3.

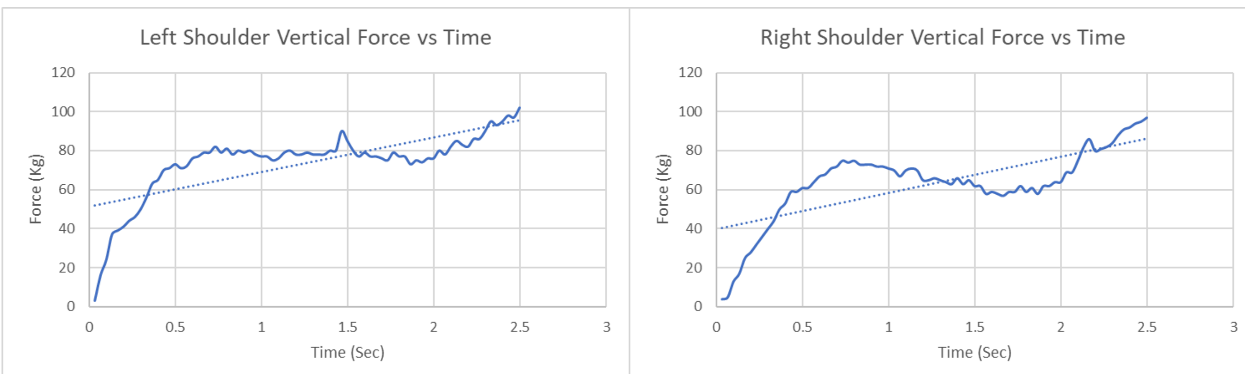


Figure 30: Participant 4 Run 7 Vertical Force vs Time

It is surprising that Participant 4 did not achieve the lowest CV whereas Participants 1 and 2 had the lowest on average in comparison. Participant 4 was expected to have the lowest variation in vertical force due to their method of engaging. As stated above Participant 4 had a preference of already being engaged with the machine starting in the sustained push phase on their runs. From the literature, the decrease in distance between two forward packs at the engagement of the scrum showed significant stability during the rest of the scrum (Bradley, Hogg, & Archer, 2018). This is believed as players will not make perfect contact and will make subtle adjustments in shoulder positions to find the optimal posture to produce the most amount of force. Participant 4 has started with their optimal shoulder placement with all their runs and therefore in theory should show the most stable increase in vertical force. The reason to why this is not the case could be down to skill and player position differences between the participants. Participants 1 and 2 have both had experience as front players being a hooker and loosehead prop whereas Participant 4 doesn't have any experience in the front row.

7.0 Conclusion

The aim of this research was to develop a single-man rugby scrum machine to provide strength and stability data to assist in measuring scrum performance. The development of the scrum machine resulted in the discovery of a strong positive linear relationship between the vertical and horizontal forces produced by a player against the machine. The new prototype machine also collected useful data that can provide an indication of the player's posture based on the difference in forces that the player can produce on each shoulder. This requires further investigation and comparing the postural data collected through motion capture to the force data on each shoulder to further validate this discovery.

The measurement of stability in the scrum was also investigated in the fulfilment of this research project. The literature review showed that the current understanding of scrum stability reduced a player's shift in vertical displacement and motion as they pushed in the scrum. This research validated a measurement indicating a player's ability to apply a controlled force in the vertical plane of motion. The data collected with the developed instrumented scrum machine showed different participants' ability to control force in the vertical plane of motion. Even though the machine was providing an indication of stability performance there are still many variables and dynamics in a scrum in an actual game. Having this new prototype machine available to rugby coaches to further apply their training regime and see the results on the rugby field will be the best way to determine the effect this machine has on performance. It is recommended that further study analyse a full rugby season with the application of this new machine to a rugby team. This will further validate the value of instrumented scrum machines in the use of improving scrum strength and stability performance. Even though this research and new prototype resulted in a good outcome the research also exposed areas of improvement and future research for this topic.

7.1 Future Research and Development

To summarise expanding on this research it is recommended to investigate these areas identified while this project was carried out:

- Collect postural data alongside force data on both shoulders to determine any correlations between these variables.
- Continue to make improvements to the scrum machine to further prove that the dynamics of the scrum can be captured.
- Investigate how a player's ability to produce stable vertical force will affect their ability to produce horizontal impulse force.
- Analyse the use of the new prototype scrum machine over a full rugby season to determine the effectiveness of improving strength and stability performance.

8.0 References

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Appendix

Appendix A: Rugby Scrum Rules

FORMING A SCRUM

1. A scrum is formed in the scrum zone at a mark indicated by the referee.
2. The referee makes the mark to create the middle line of the scrum, which runs parallel to the goal lines.
3. Teams must be ready to form the scrum within 30 seconds of the mark being made. Sanction: Free kick.
4. When both teams have 15 players, eight players from each team bind together in formation as outlined in the diagram. Each team must have two props and one hooker in the front row and two locks in the second row. Three back-row players from each team complete the scrum. Sanction: Penalty.
5. When a team is reduced to fewer than 15 for any reason, then the number of players in each team in the scrum may be similarly reduced. Where a permitted reduction is made by one team, there is no requirement for the other team to make a similar reduction. However, a team must not have fewer than five players in the scrum.
6. The players in the scrum bind in the following way:
    a. The props bind to the hooker.
    b. The hooker binds with both arms. This can be either over or under the arms of the props. c. The locks bind with the props immediately in front of them and with each other.
    c. All other players in the scrum bind on a lock's body with at least one arm. Sanction: Penalty.
7. The two groups face each other, either side of and parallel to the middle line.
8. The two front rows stand not more than an arm's length apart with the hookers at the mark.

ENGAGEMENT

9. When both sides are square, stable, and stationary, the referee calls "crouch".
    a) The front-rows then adopt a crouched position if they have not already done so. Their heads and shoulders are no lower than their hips, a position that is maintained for the duration of the scrum.
    b) The front-rows crouch with their heads to the left of their immediate opponents', so that no player's head is touching the neck or shoulders of an opponent. Sanction: Free kick.
10. When both sides are square, stable, and stationary, the referee calls "bind".
    a) Each loose-head prop binds by placing the left arm inside the right arm of the opposing tight-head prop.
    b) Each tight-head prop binds by placing the right arm outside the left upper arm of the opposing loose-head prop.
    c) Each prop binds by gripping the back or side of their opponent's jersey.
    d) All players' binding is maintained for the duration of the scrum. Sanction: Penalty.
11. When both sides are square, stable, and stationary, the referee calls "set".
    a) Only then may the teams engage, completing the formation of the scrum and creating a tunnel into which the ball will be thrown.
    b) All players must be in position and ready to push forward.

c) Each front-row player must have both their feet on the ground, with their weight firmly on at least one foot.
d) Each hooker's feet must be in line with, or behind, the foremost foot of that team's props. Sanction: Free kick.

THROW

12. The scrum-half chooses which side of the scrum to throw in the ball.
13. The scrum-half holds the ball as shown in the diagram.
14. When both sides are square, stable and stationary, the scrum-half throws in the ball:
    a. From the chosen side.
    b. From outside the tunnel.
    c. Without delay.
    d. With a single forward movement.
    e. At a quick speed.
    f. Straight. The scrum-half may align their shoulder on the middle line of the scrum, thereby standing a shoulder-width closer to their side of the scrum.
    g. So that it first touches the ground inside the tunnel.

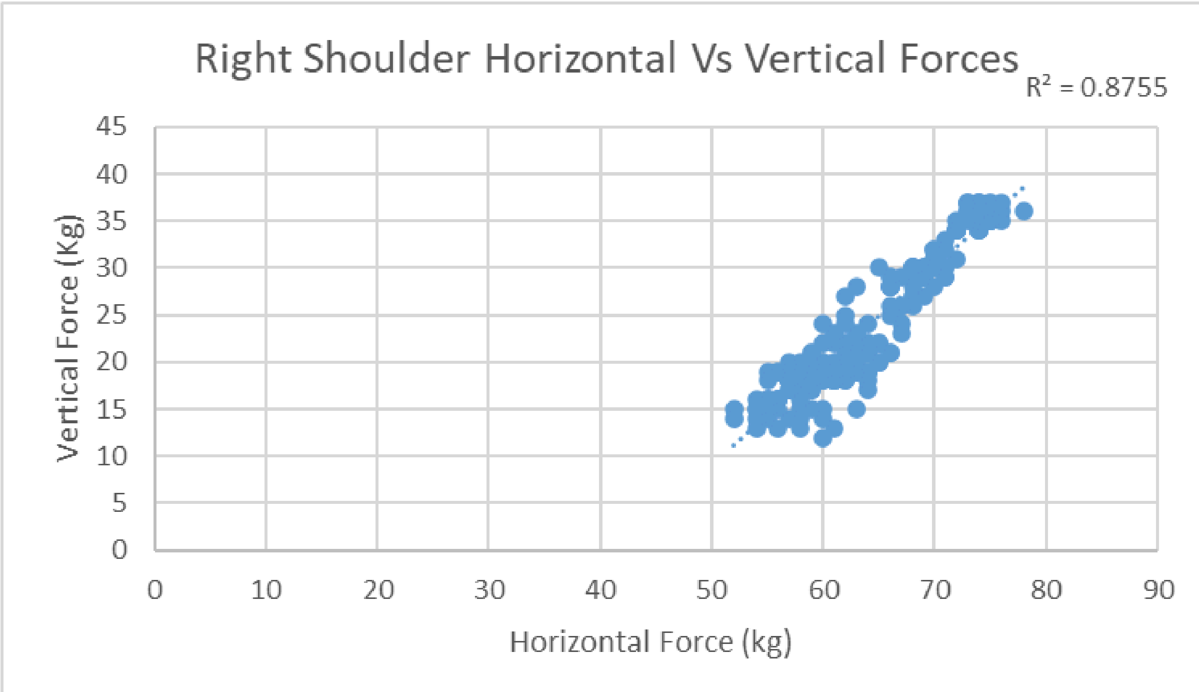
Sanction: Free-kick.

DURING A SCRUM

15. The scrum begins when the ball leaves the hands of the scrum-half.
16. Only when the scrum begins may the teams push. Sanction: Free-kick.
17. Possession may be gained by pushing the opposition backwards and off the ball.
18. Players may push provided they do so straight and parallel to the ground. Sanction: Penalty.
19. Front-row players may gain possession by striking for the ball but only once the ball touches the ground in the tunnel. Sanction: Free-kick.
20. A front-row player striking for the ball may do so with either foot but not both at the same time. Sanction: Penalty.
21. The hooker from the team which threw in the ball must strike for the ball. Sanction: Free-kick.
22. A front-row player must not intentionally kick the ball out of the tunnel from the direction it was thrown. Sanction: Free-kick.
23. Any player within the scrum may play the ball but only with their feet or lower legs and they must not lift the ball. Sanction: Penalty.
24. If a scrum collapses or if a player in the scrum is lifted or is forced upwards out of the scrum, the referee must blow the whistle immediately so that players stop pushing.
25. When the scrum is stationary and the ball has been available at the back of the scrum for three-five seconds, the referee calls "use it". The team must then play the ball out of the scrum immediately. Sanction: Scrum.

Appendix B: Push Phase Vertical Vs Horizontal Data

Data Set 1 (Participant 1):



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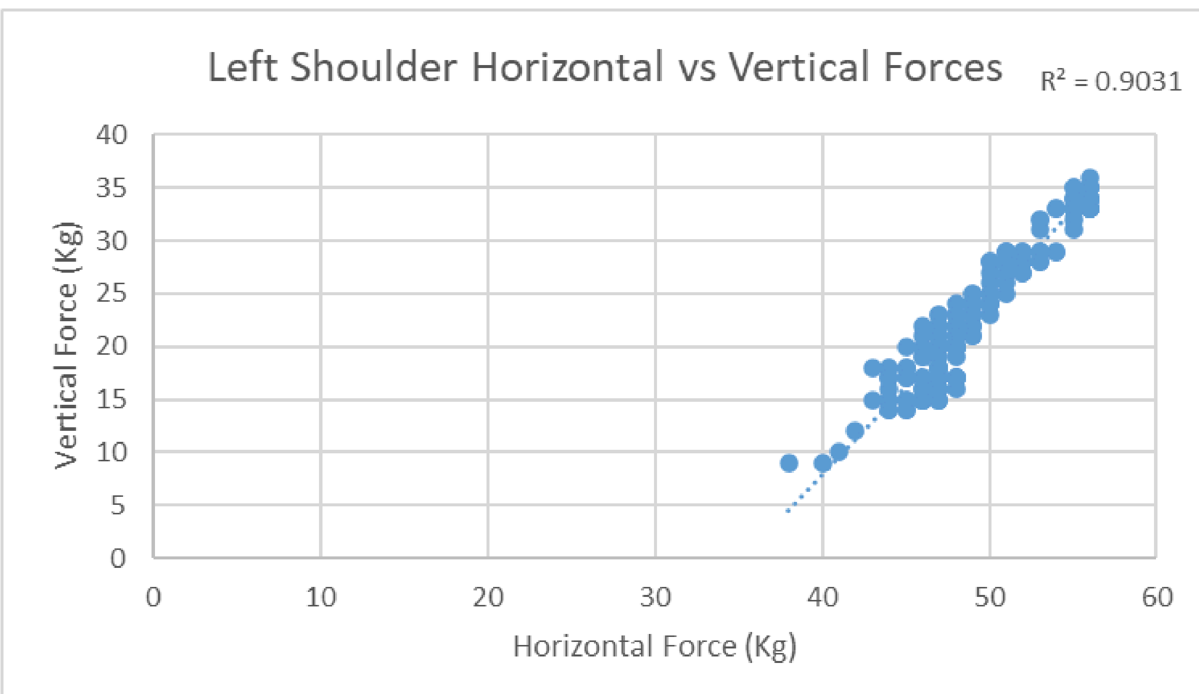

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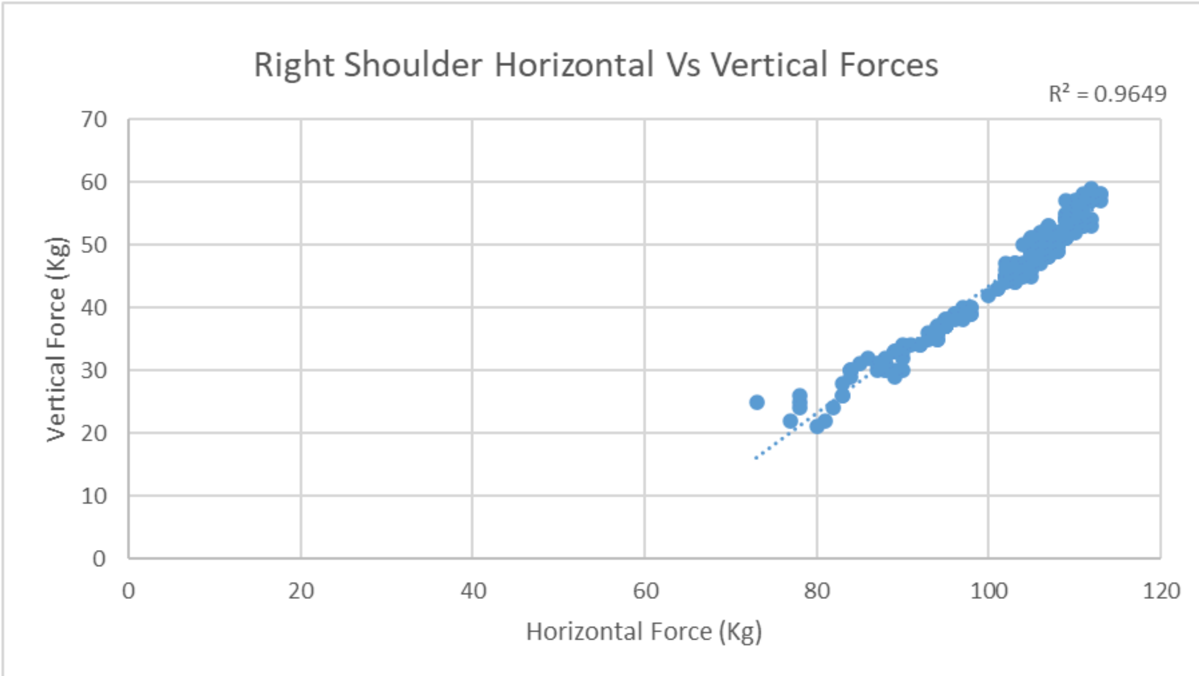

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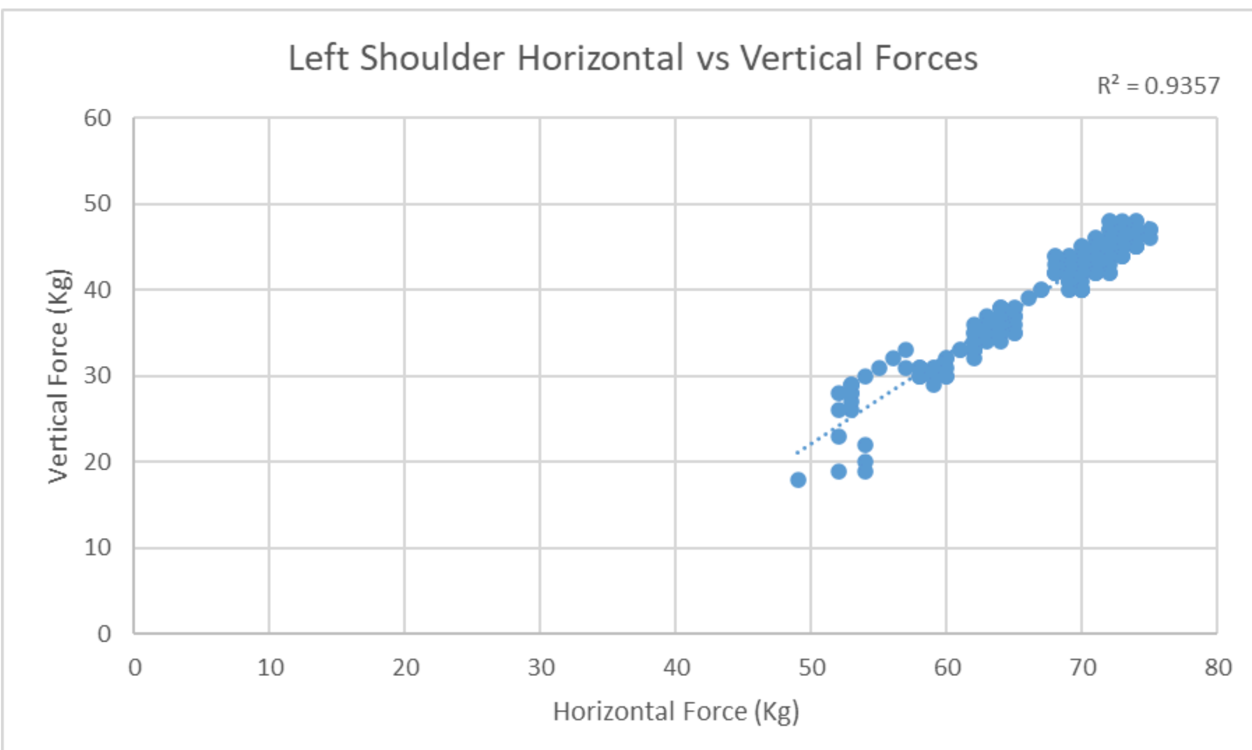

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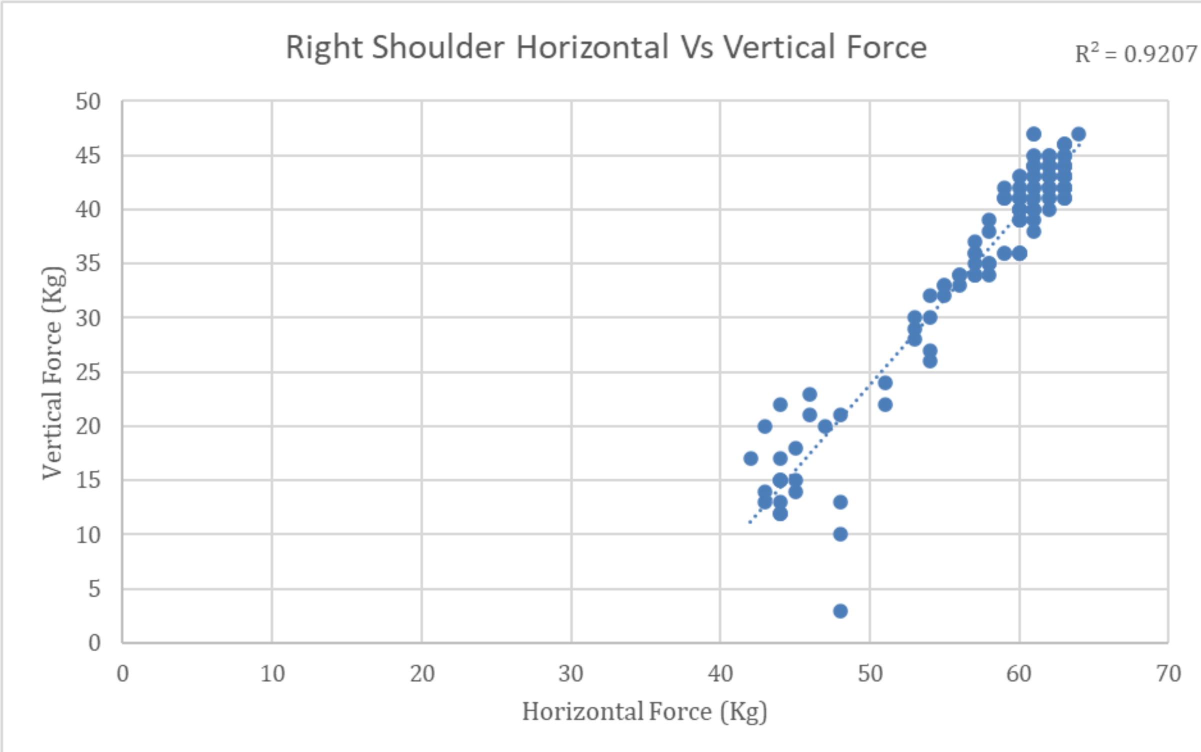

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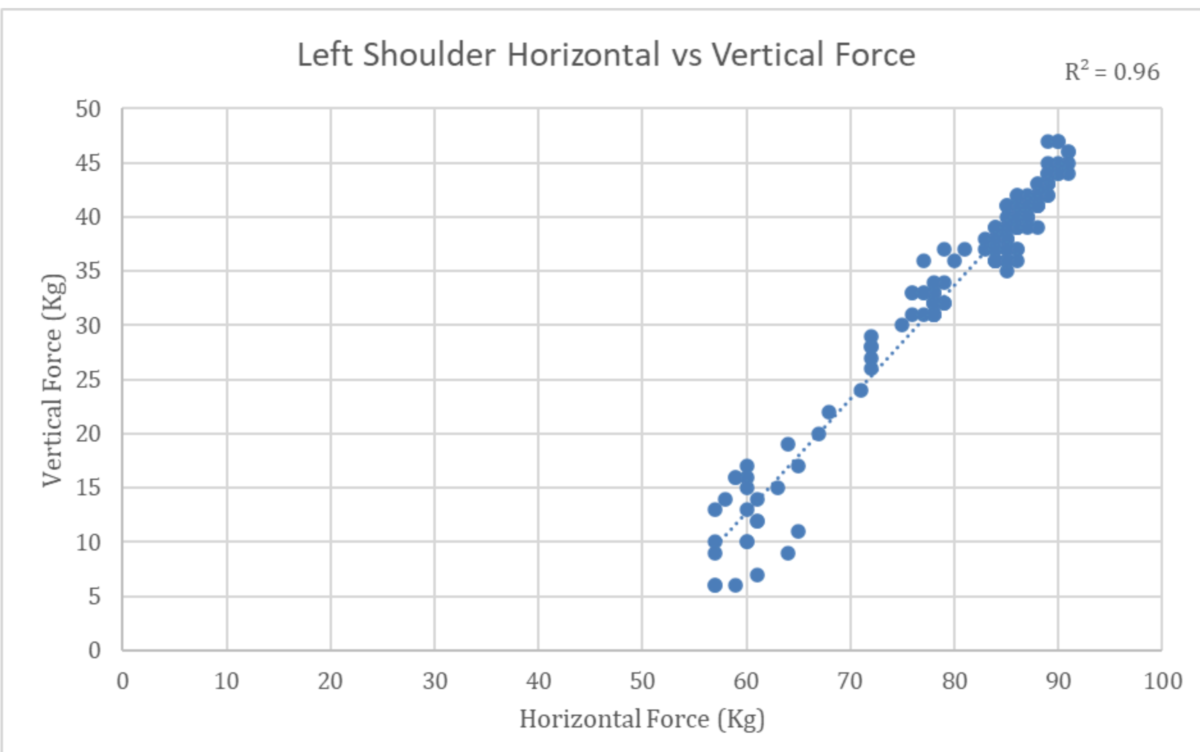

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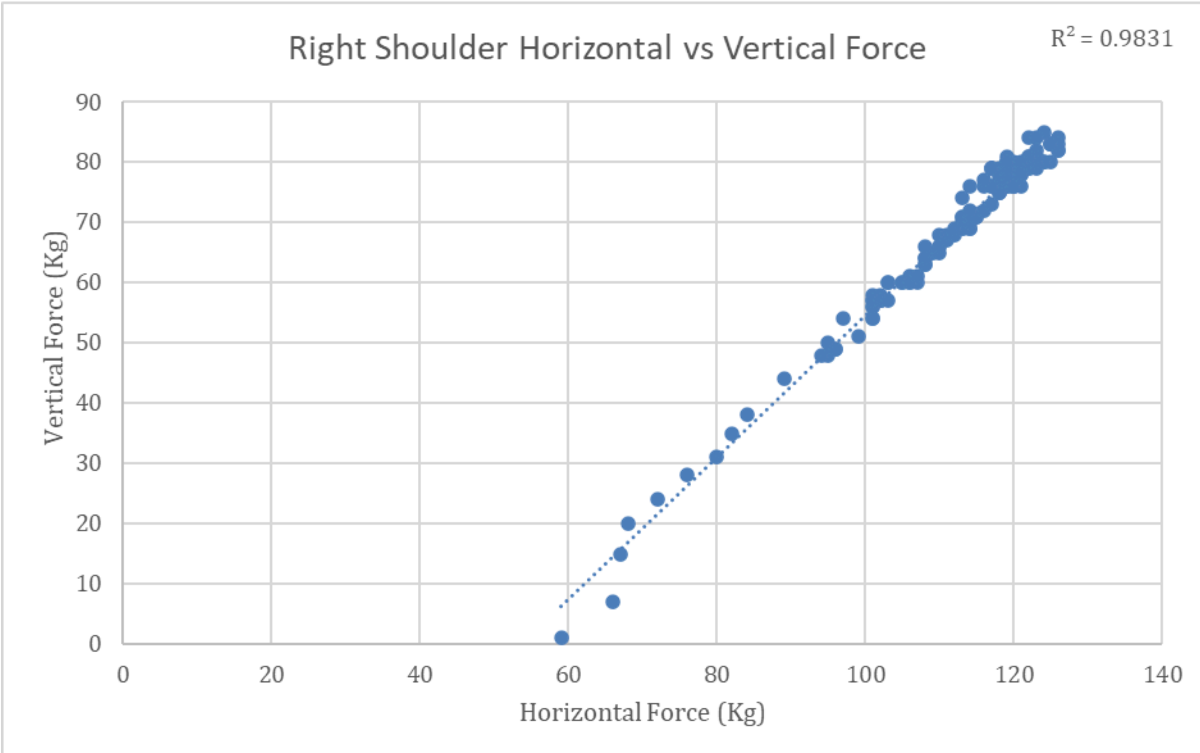

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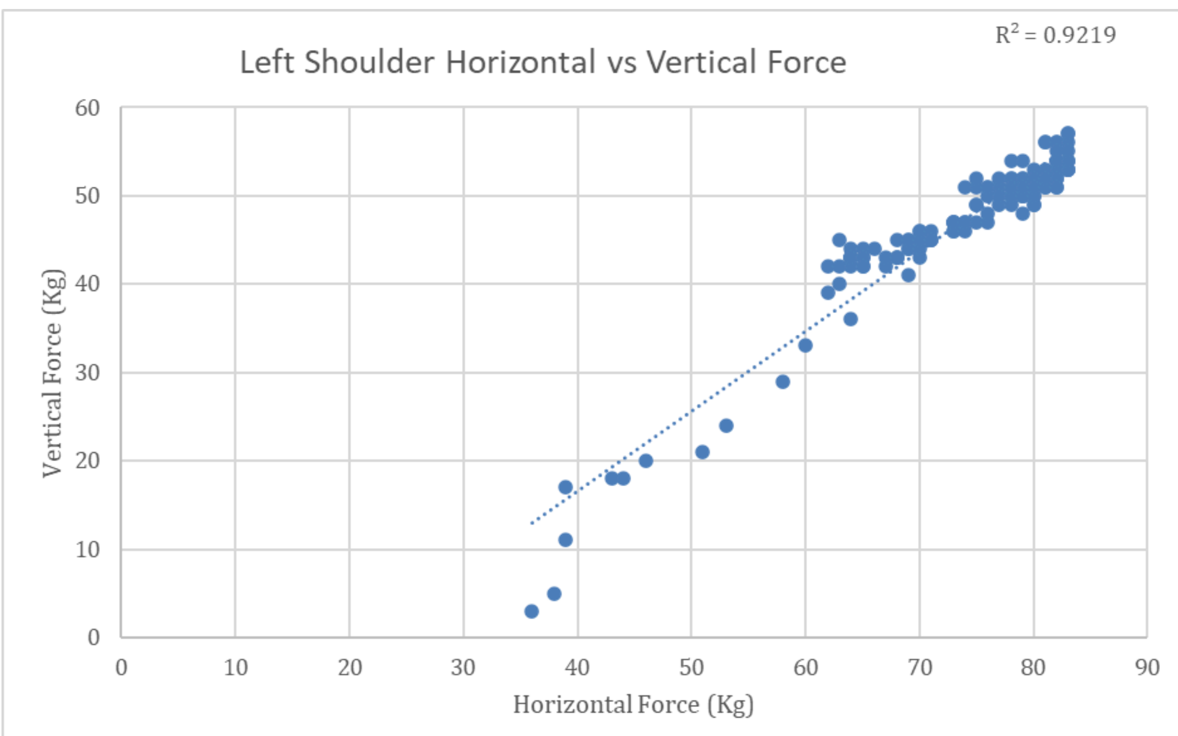

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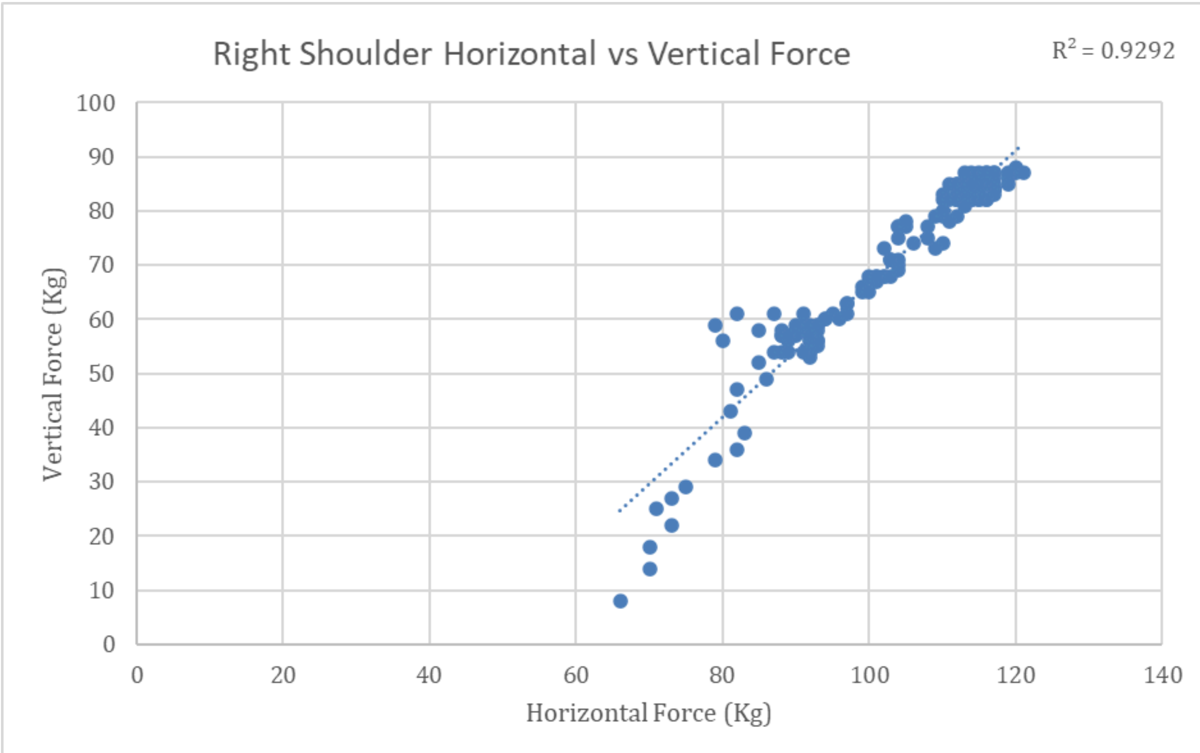

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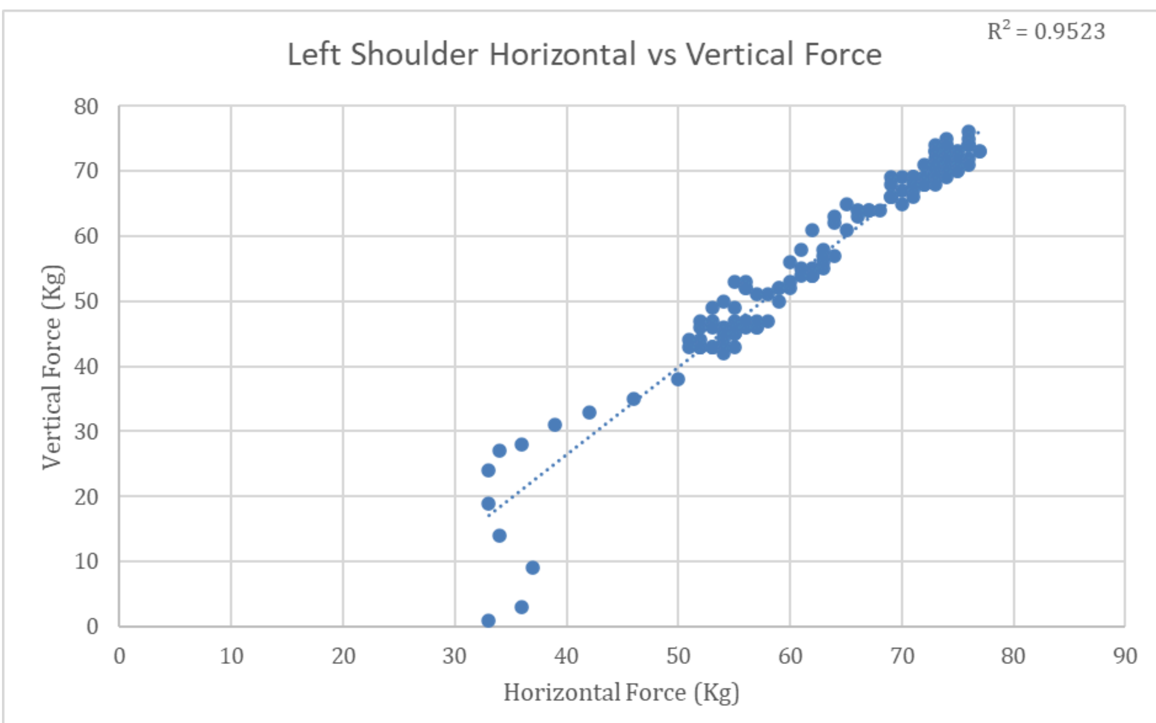

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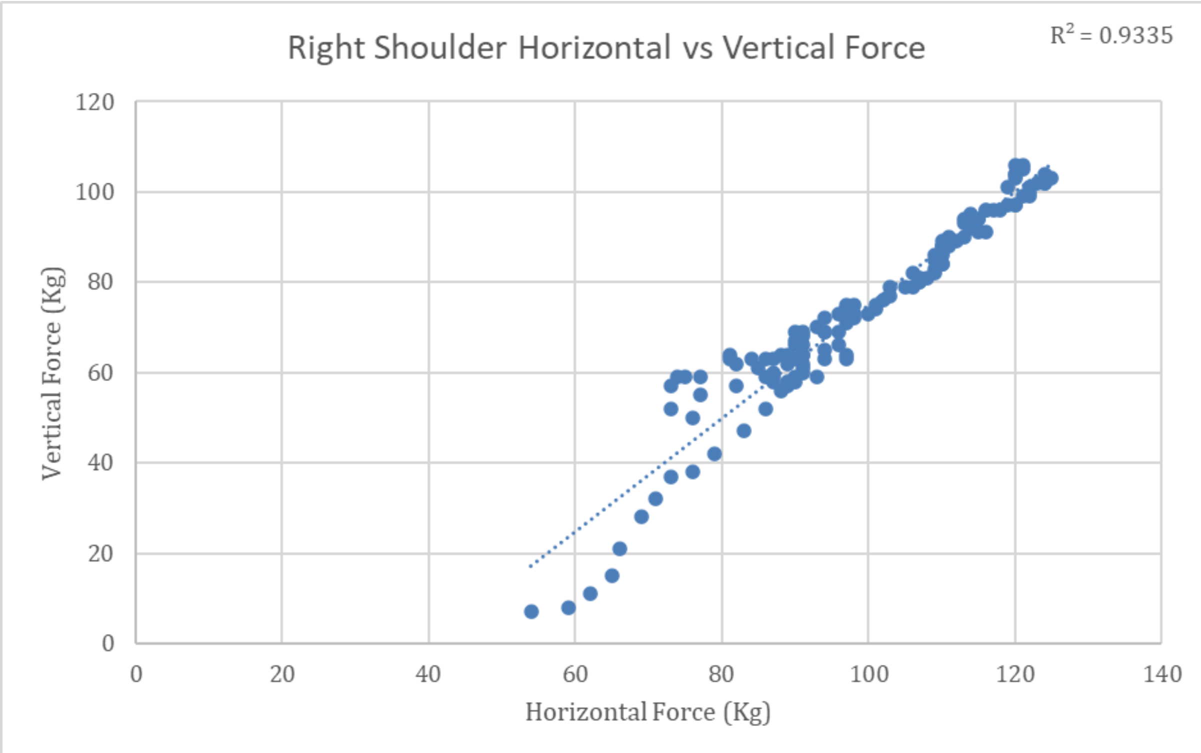

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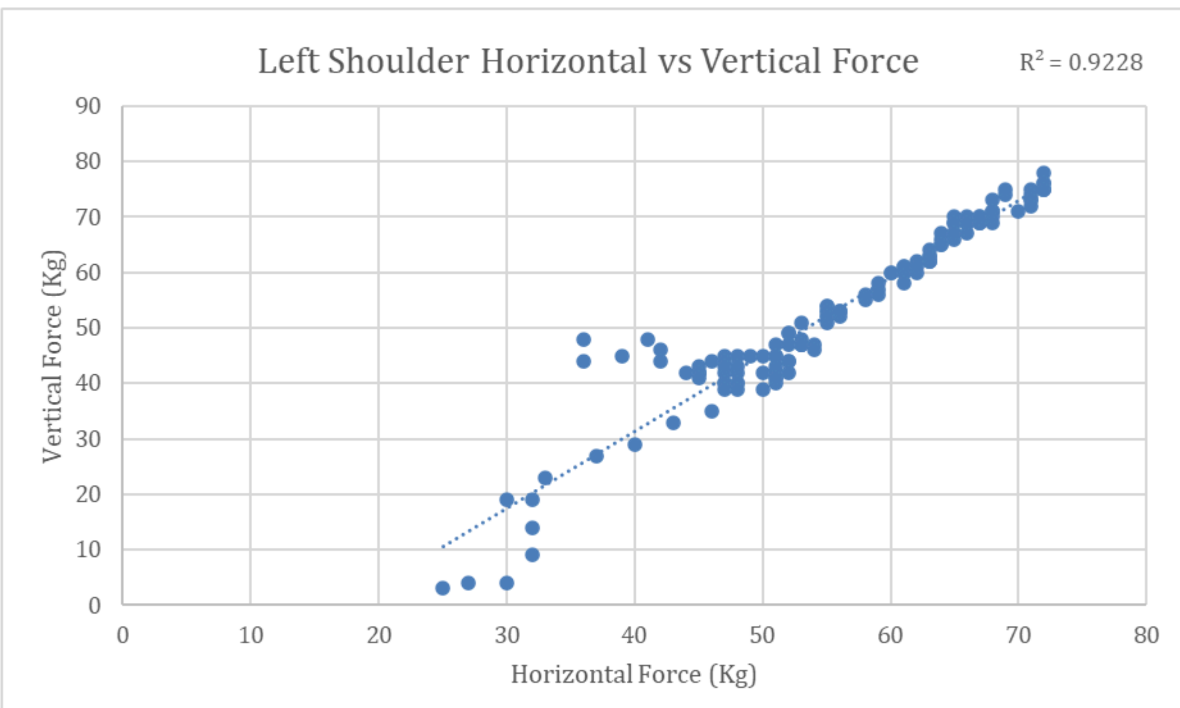

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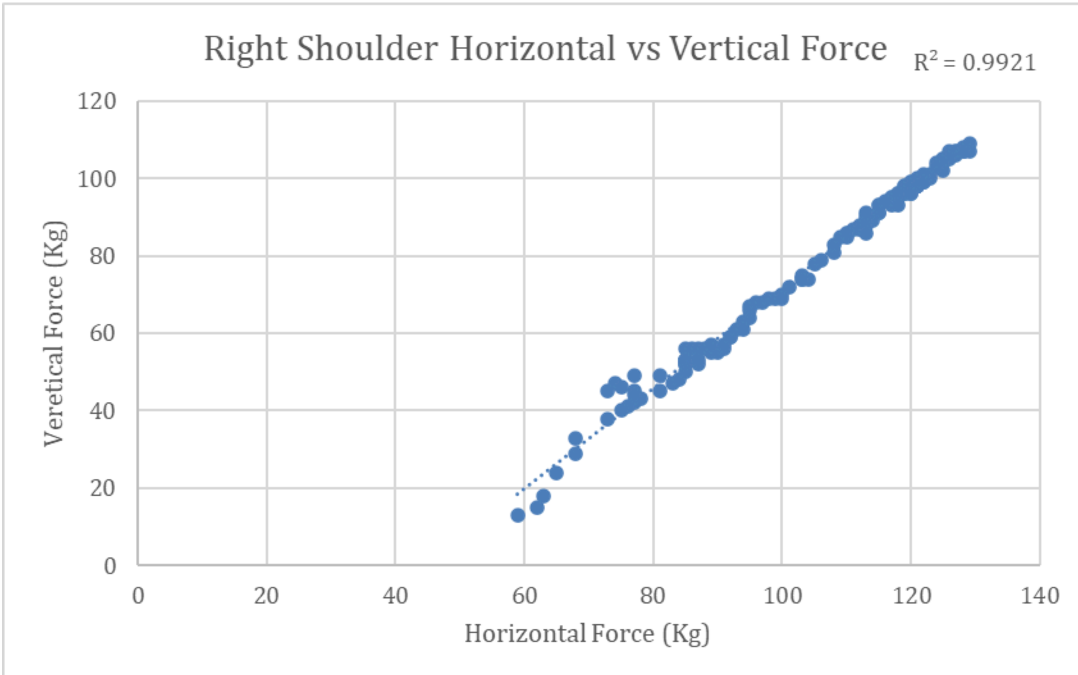

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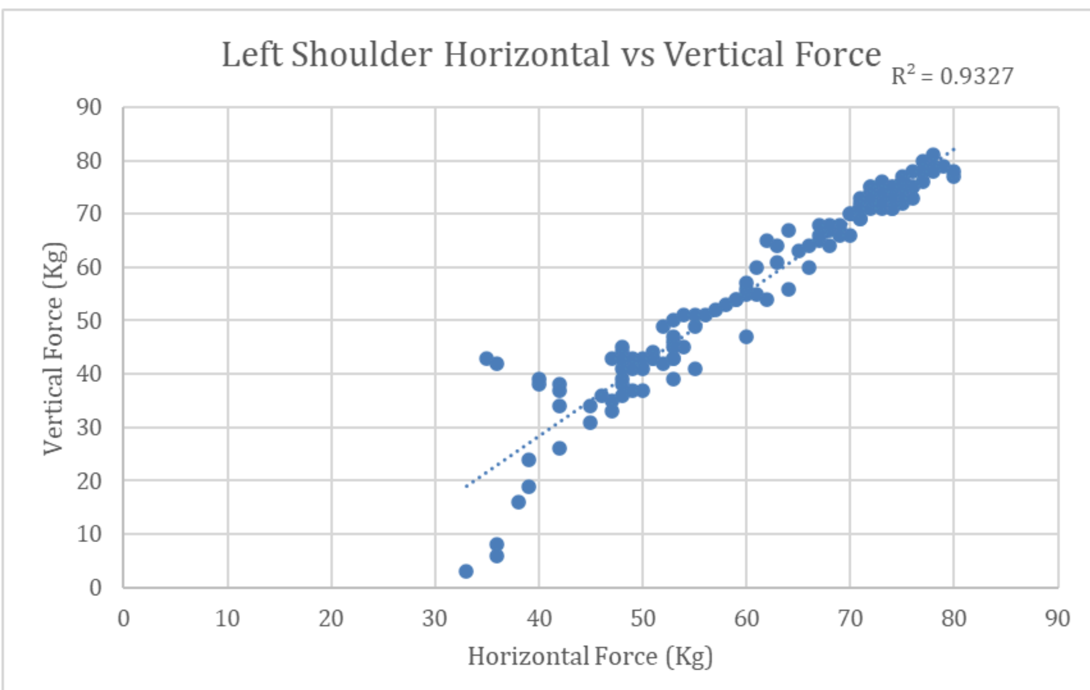

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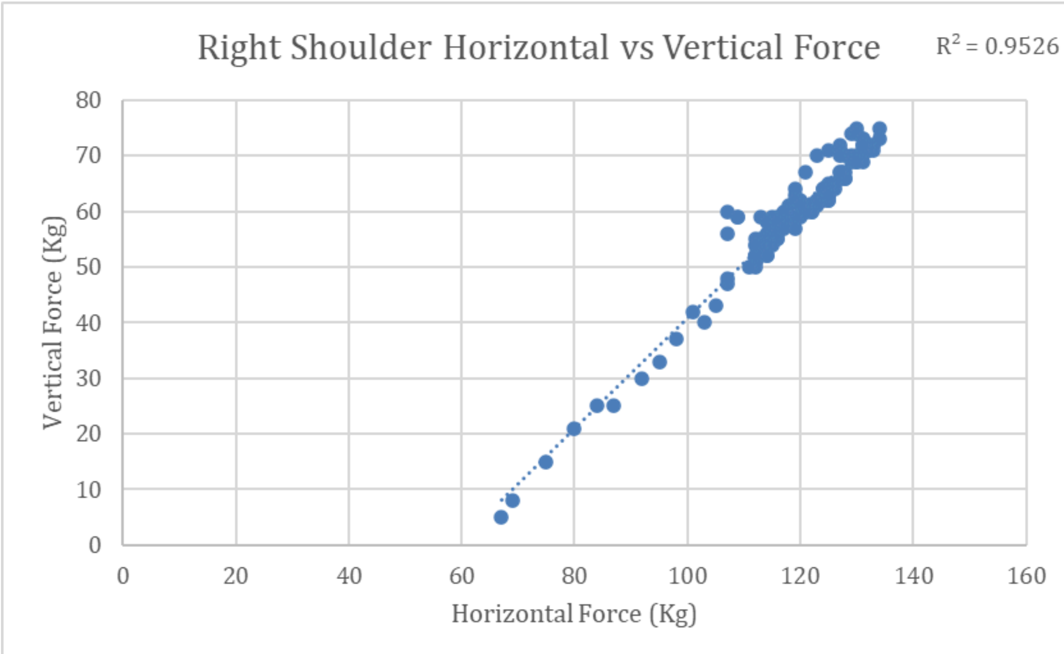

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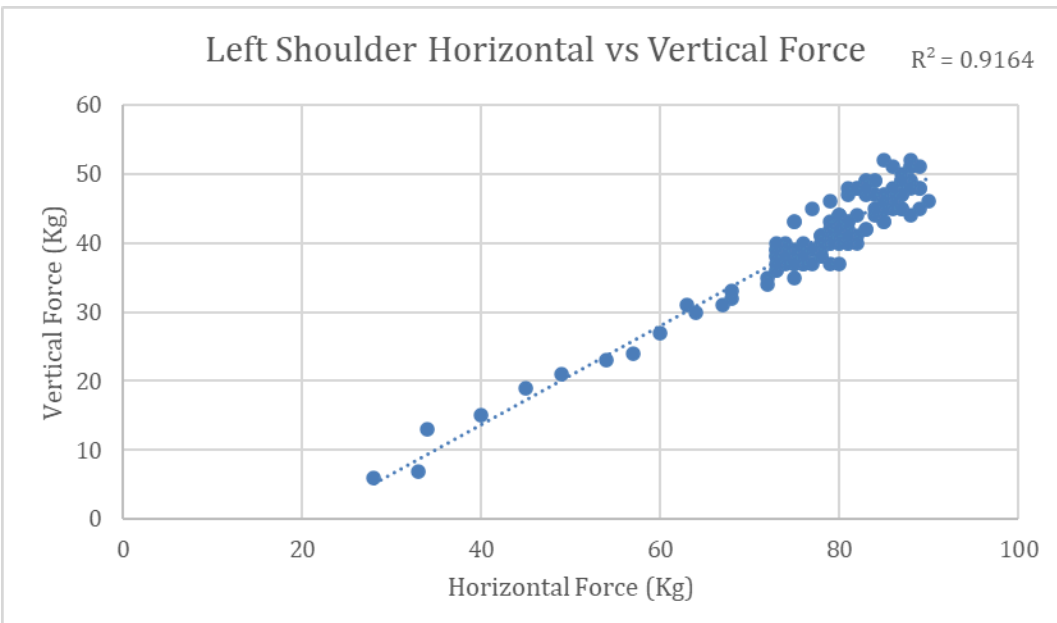

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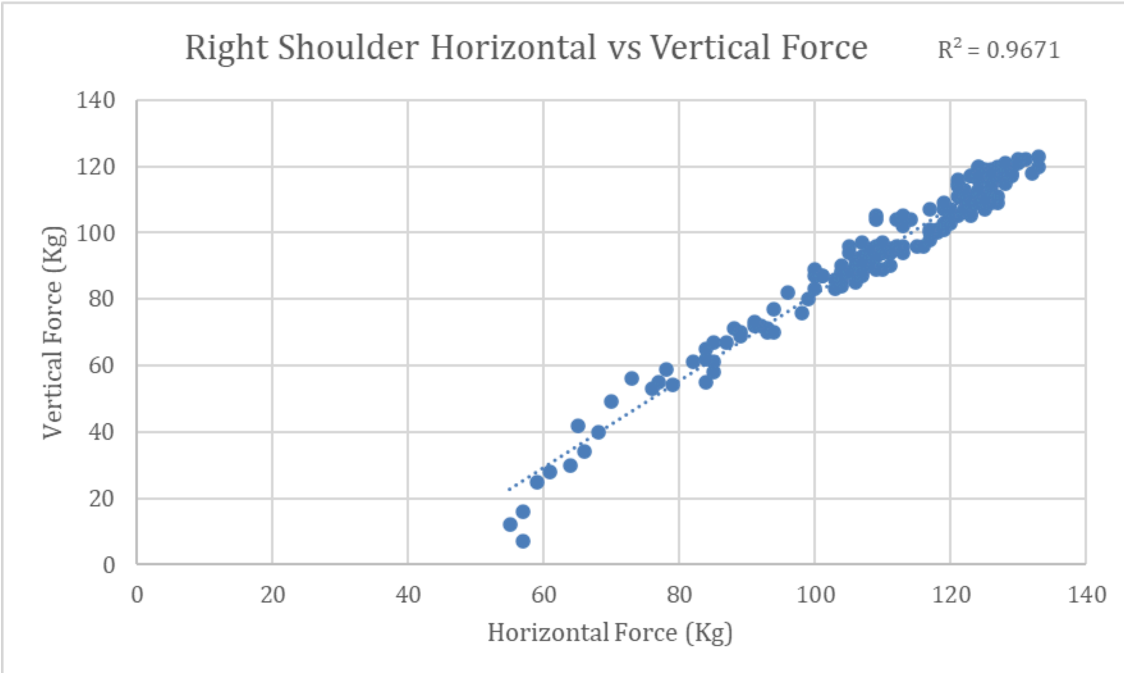

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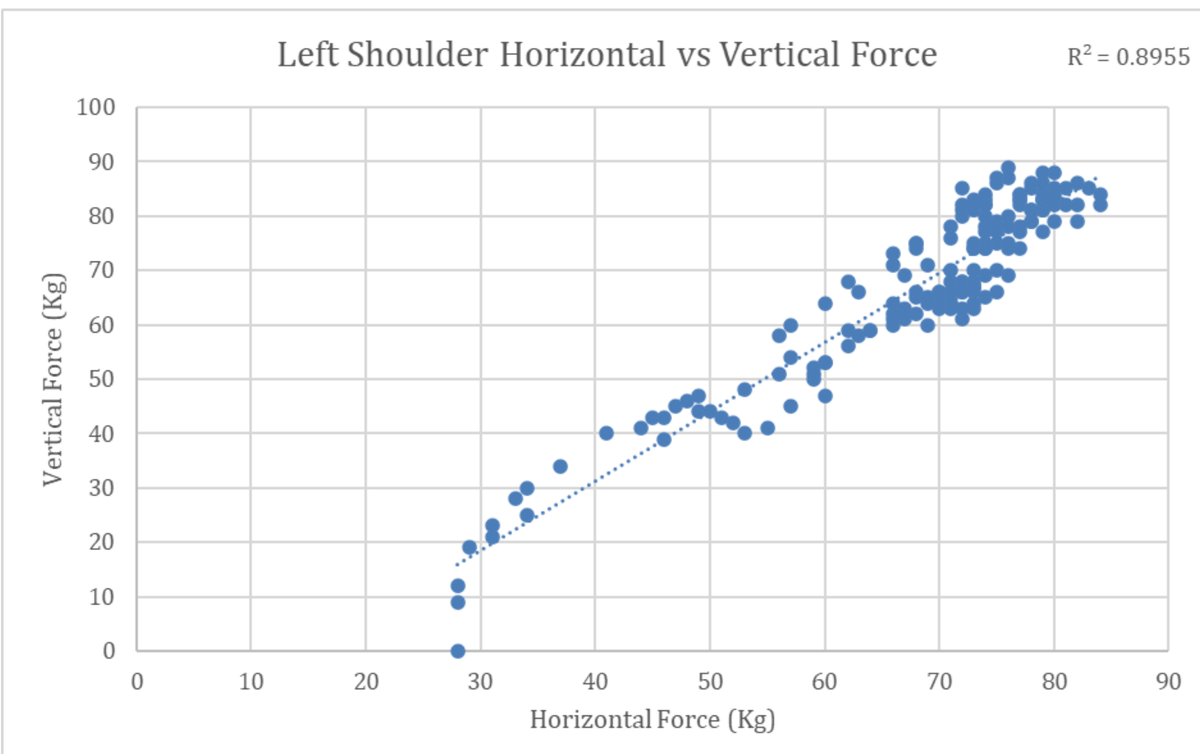

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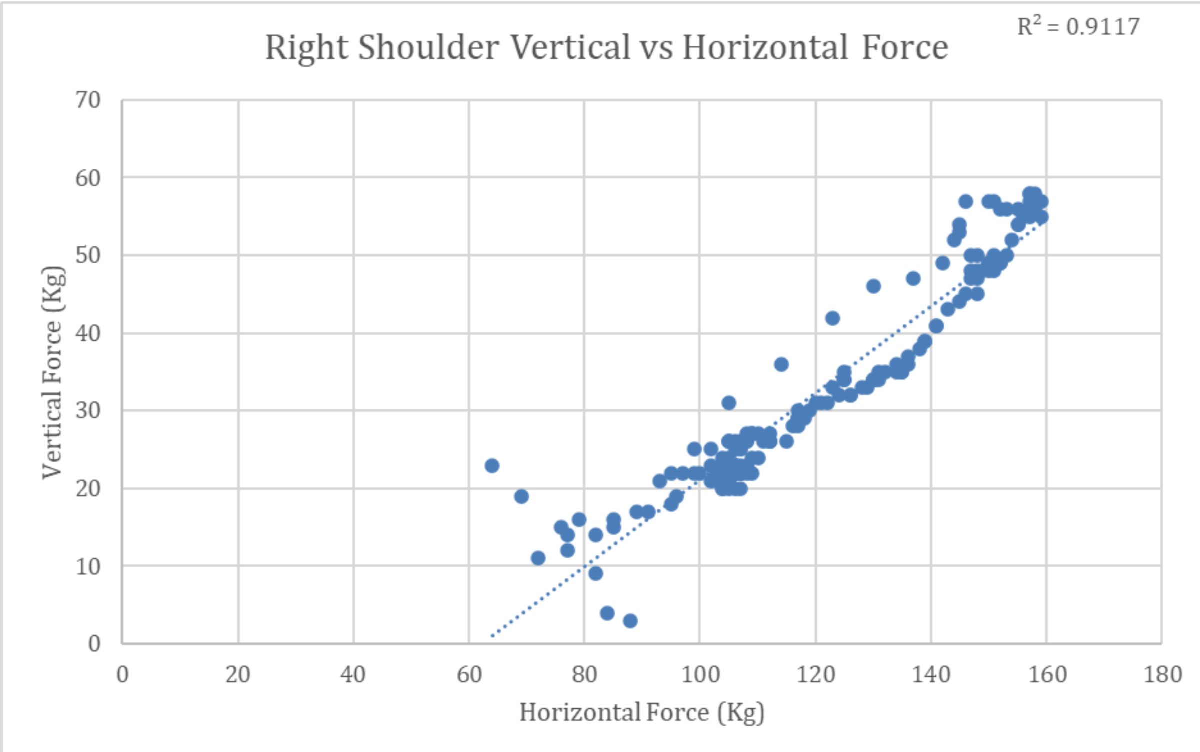

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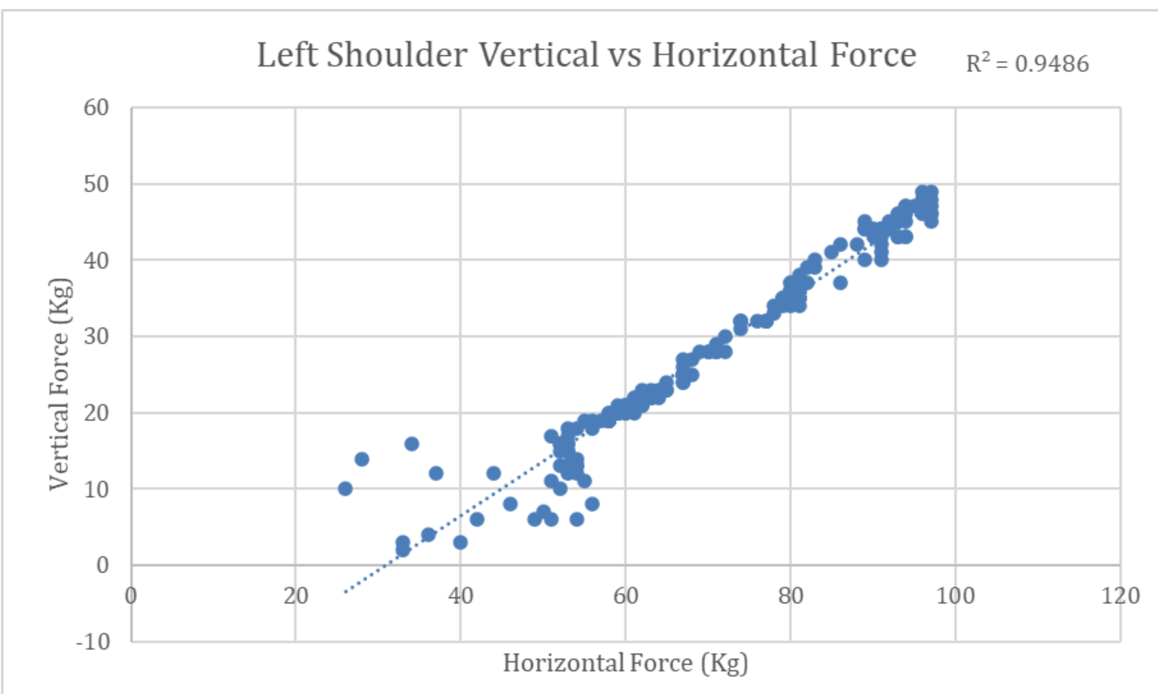

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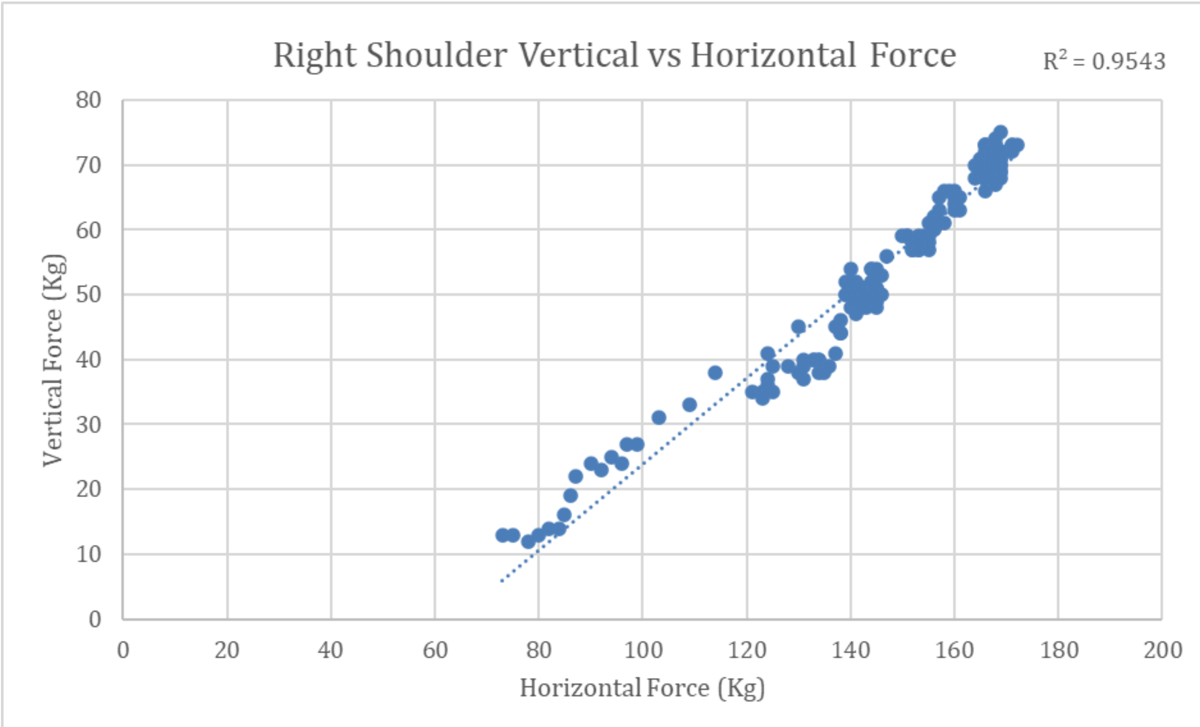

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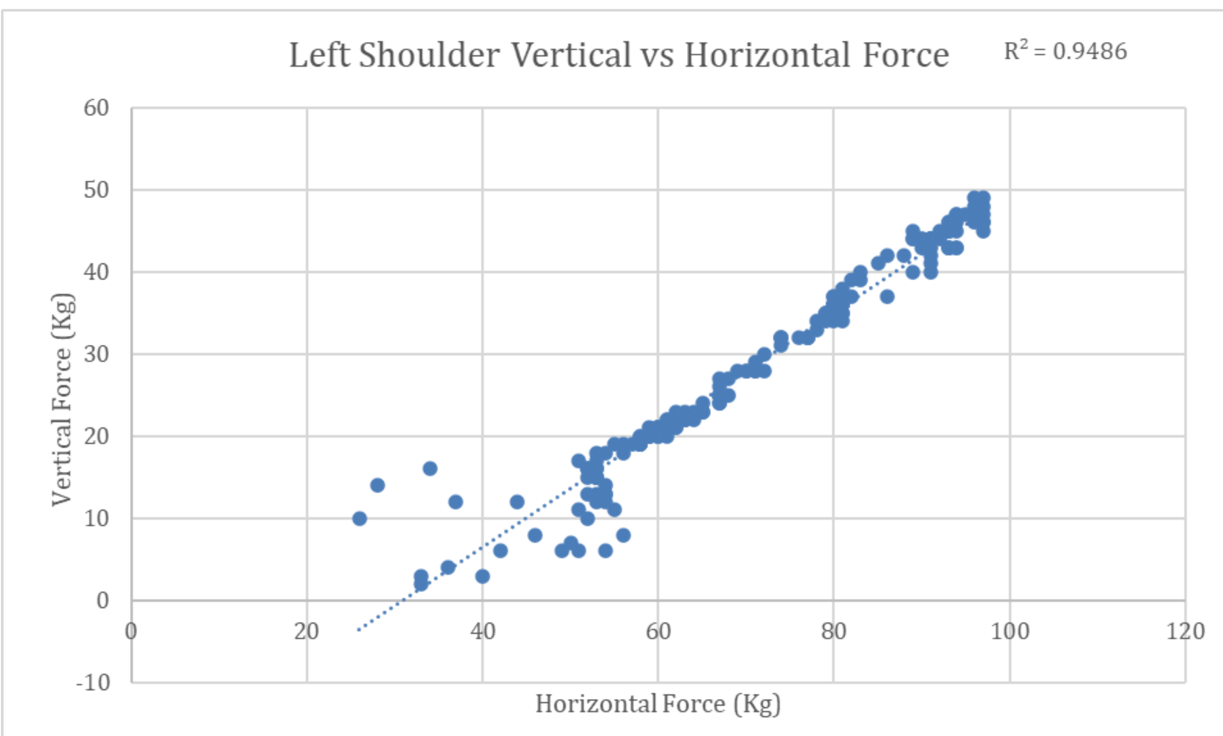

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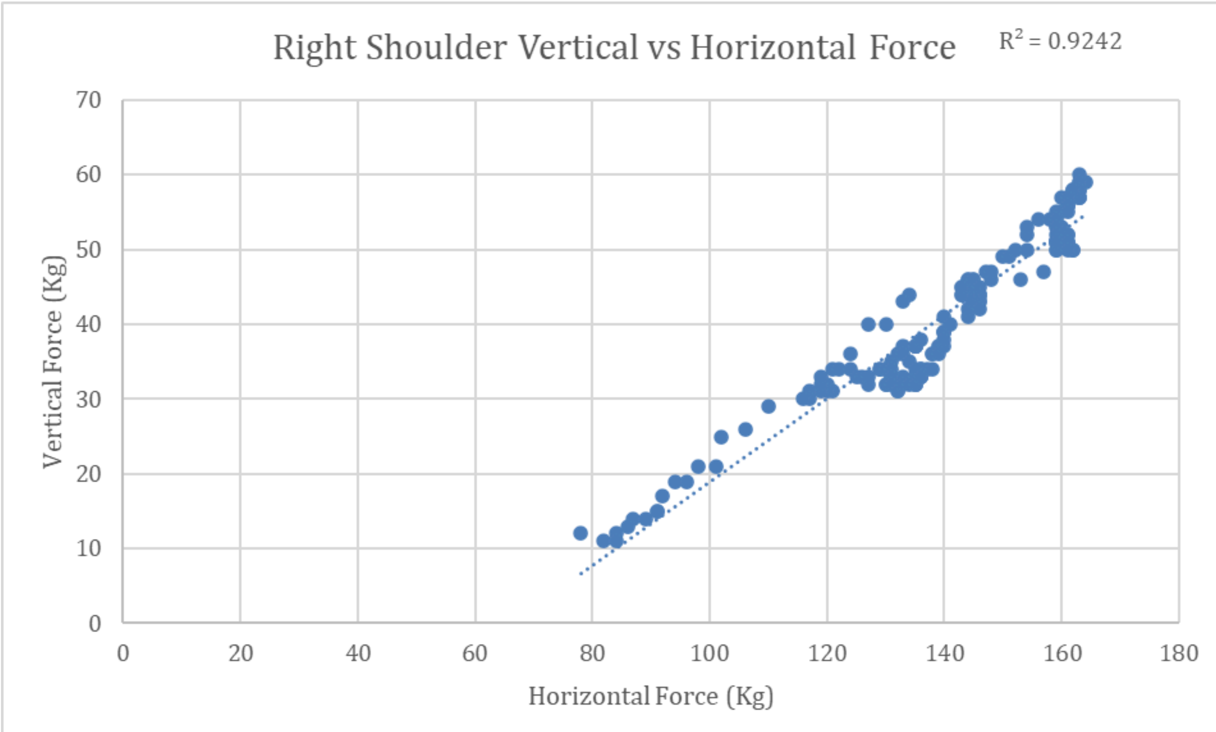

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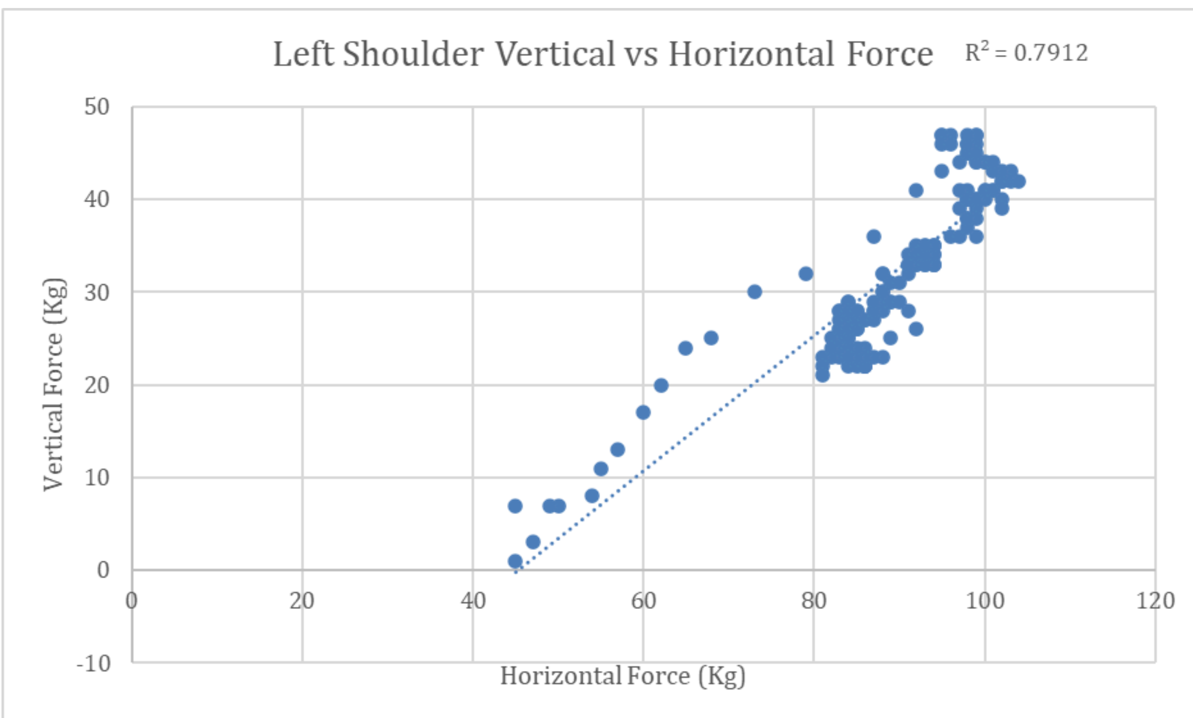

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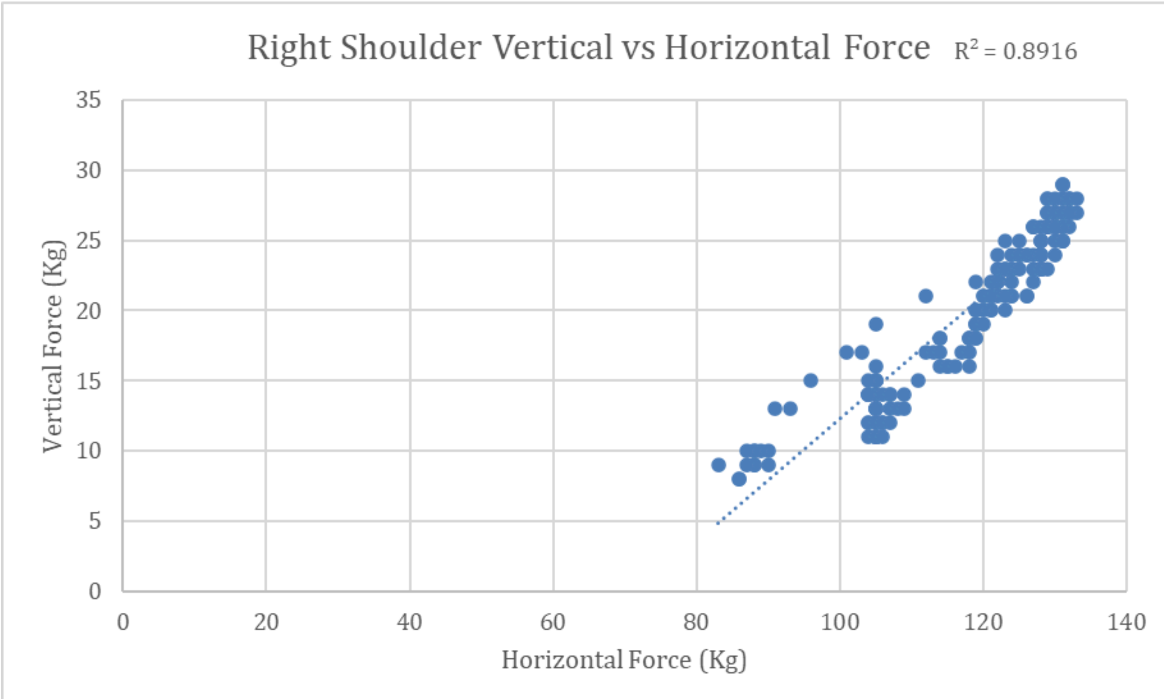

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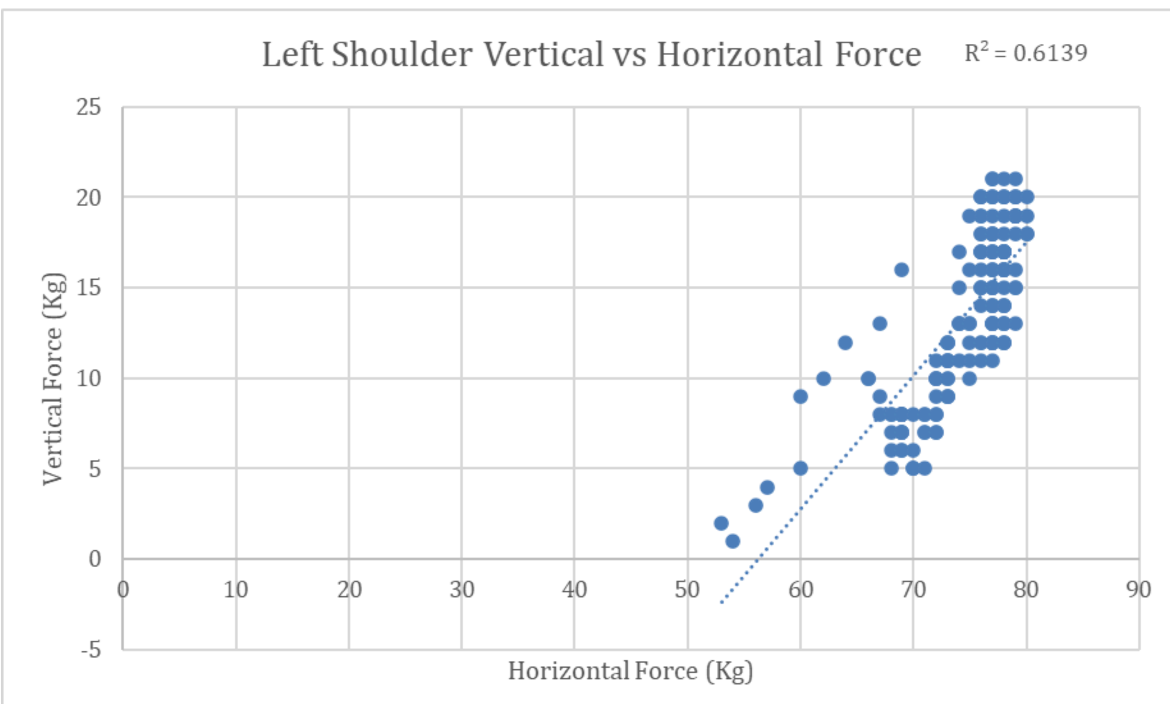

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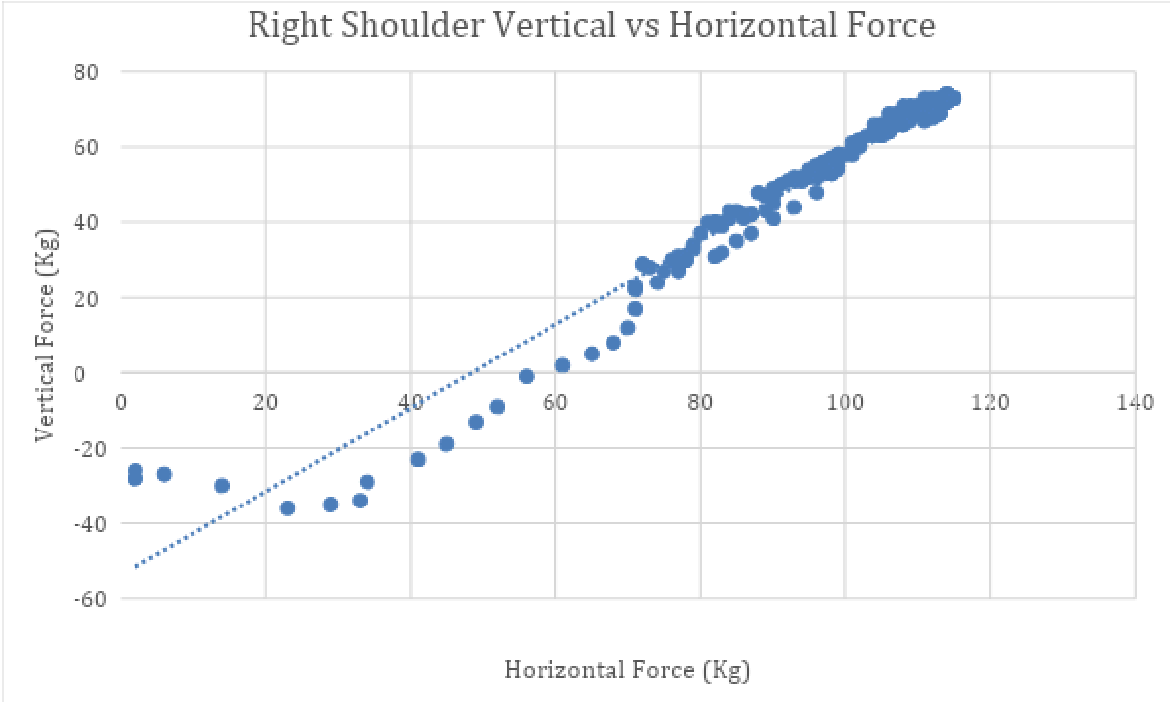

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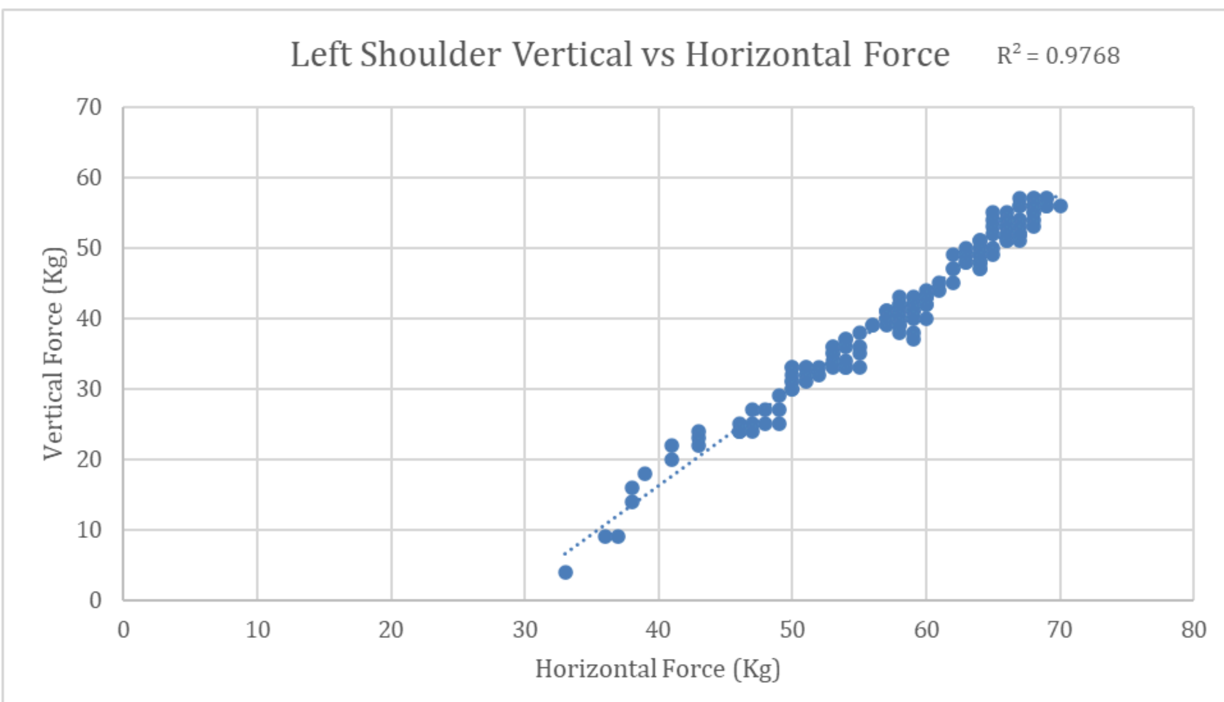

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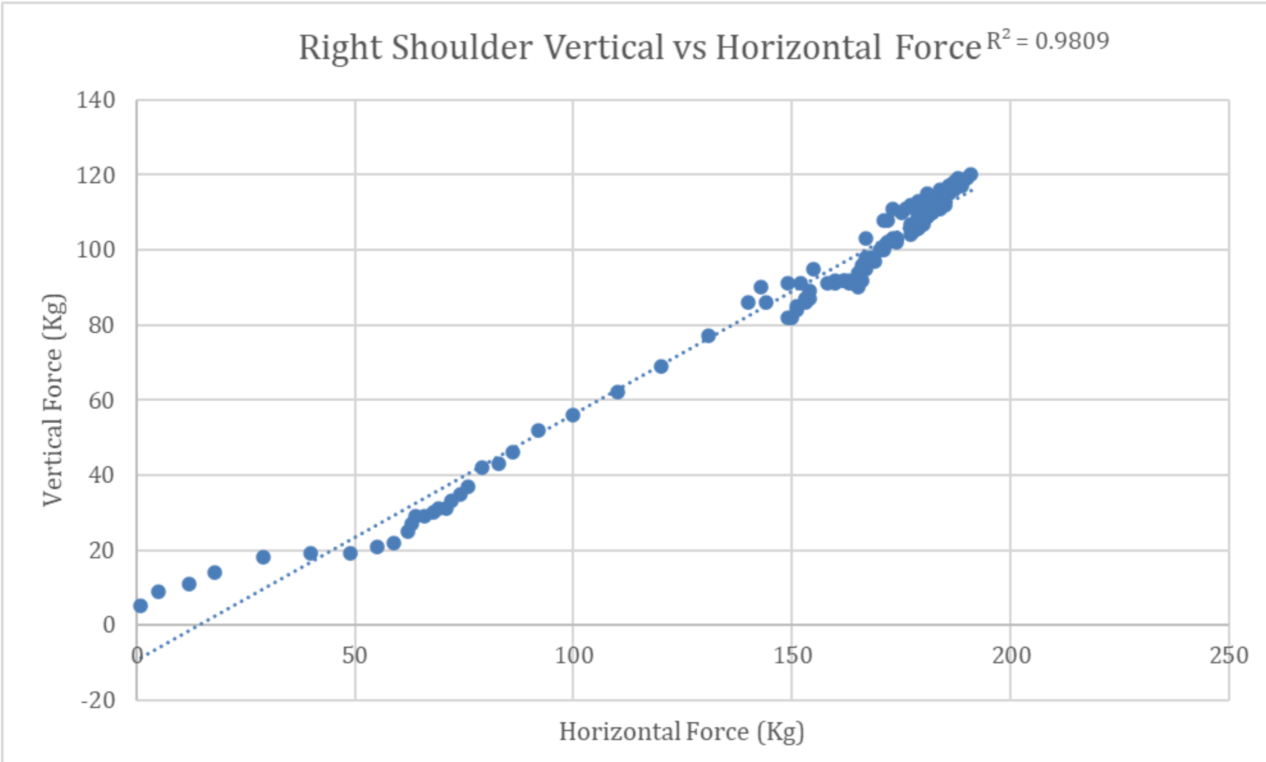

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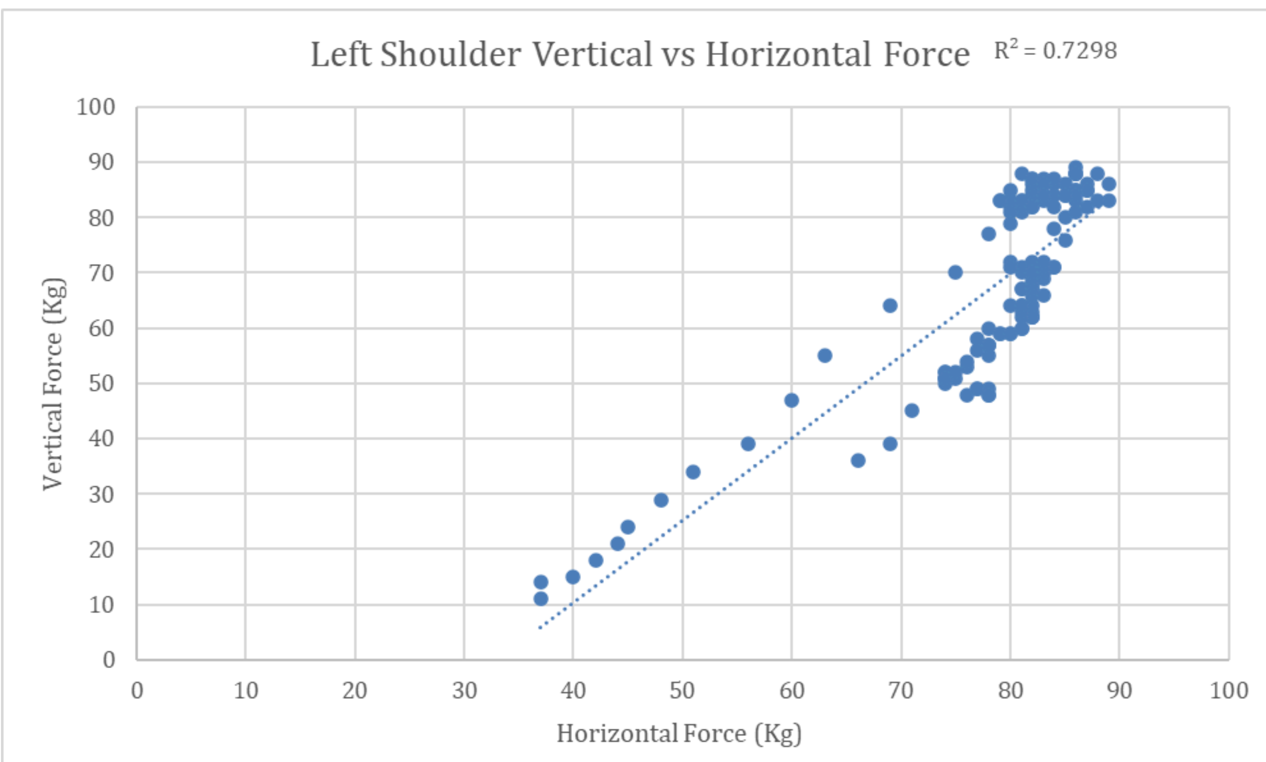

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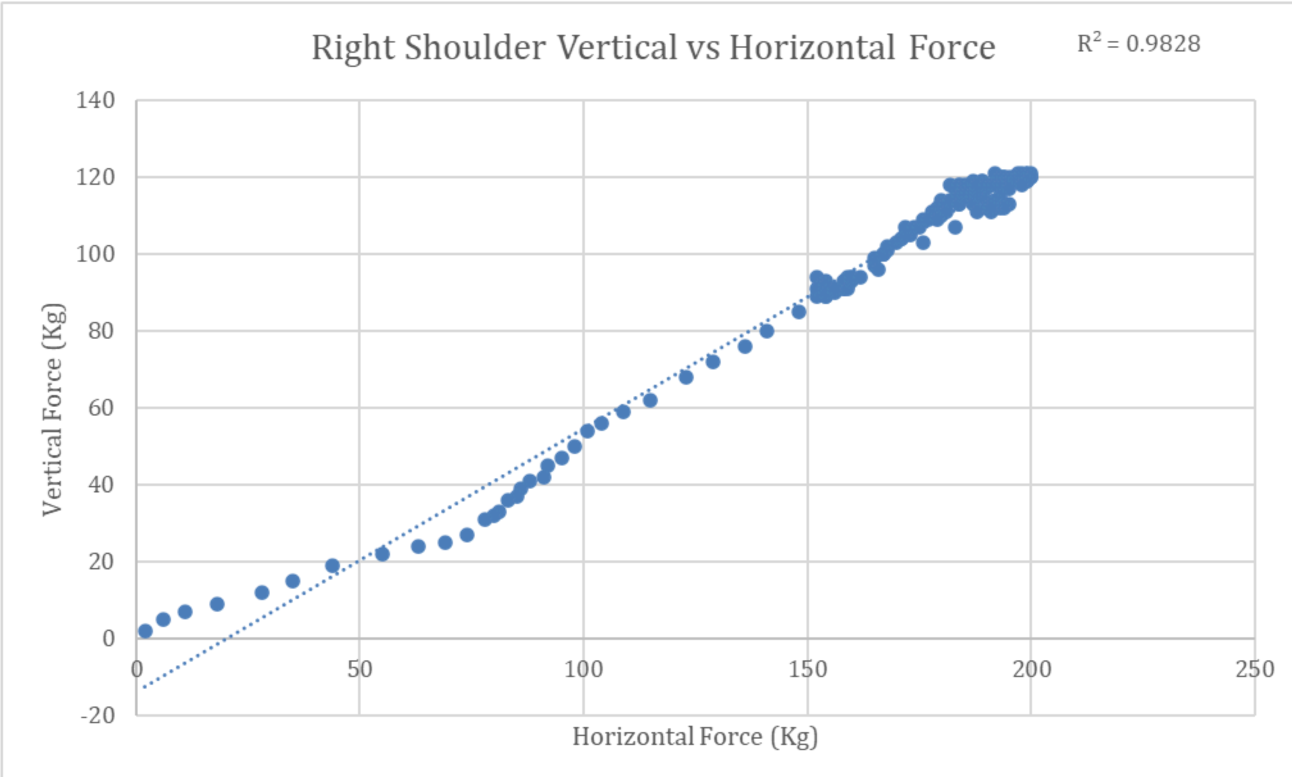

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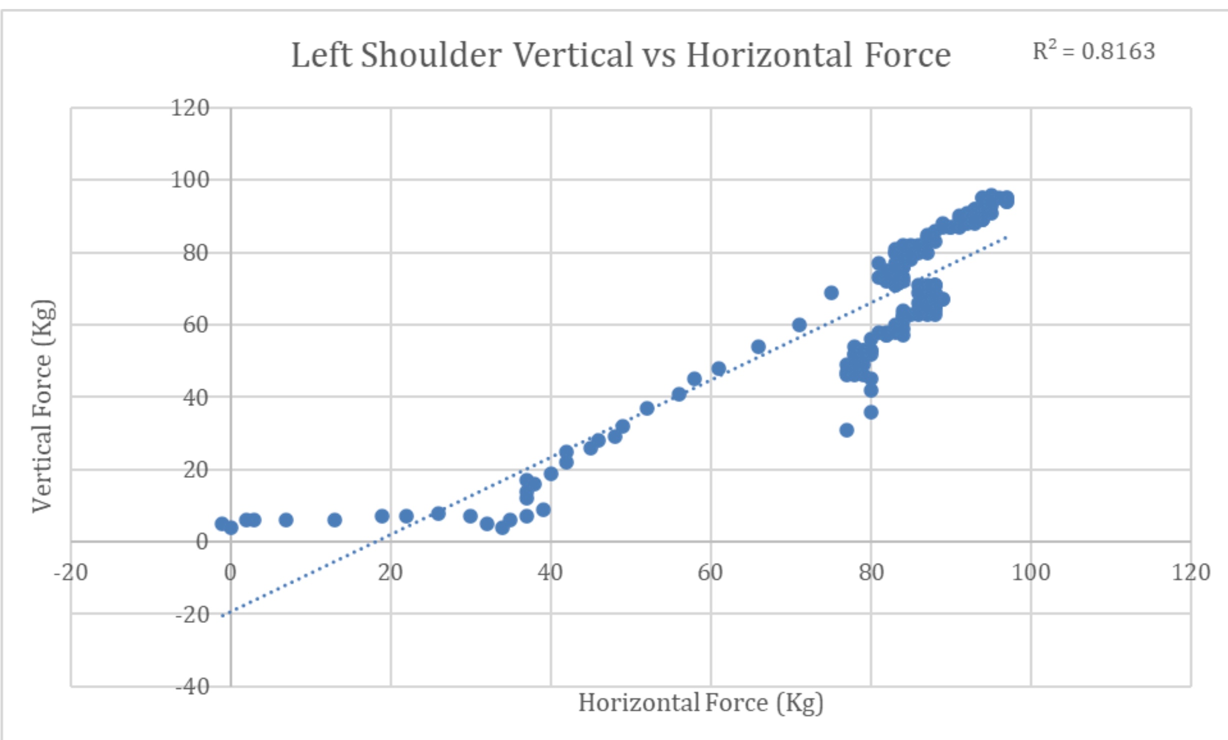

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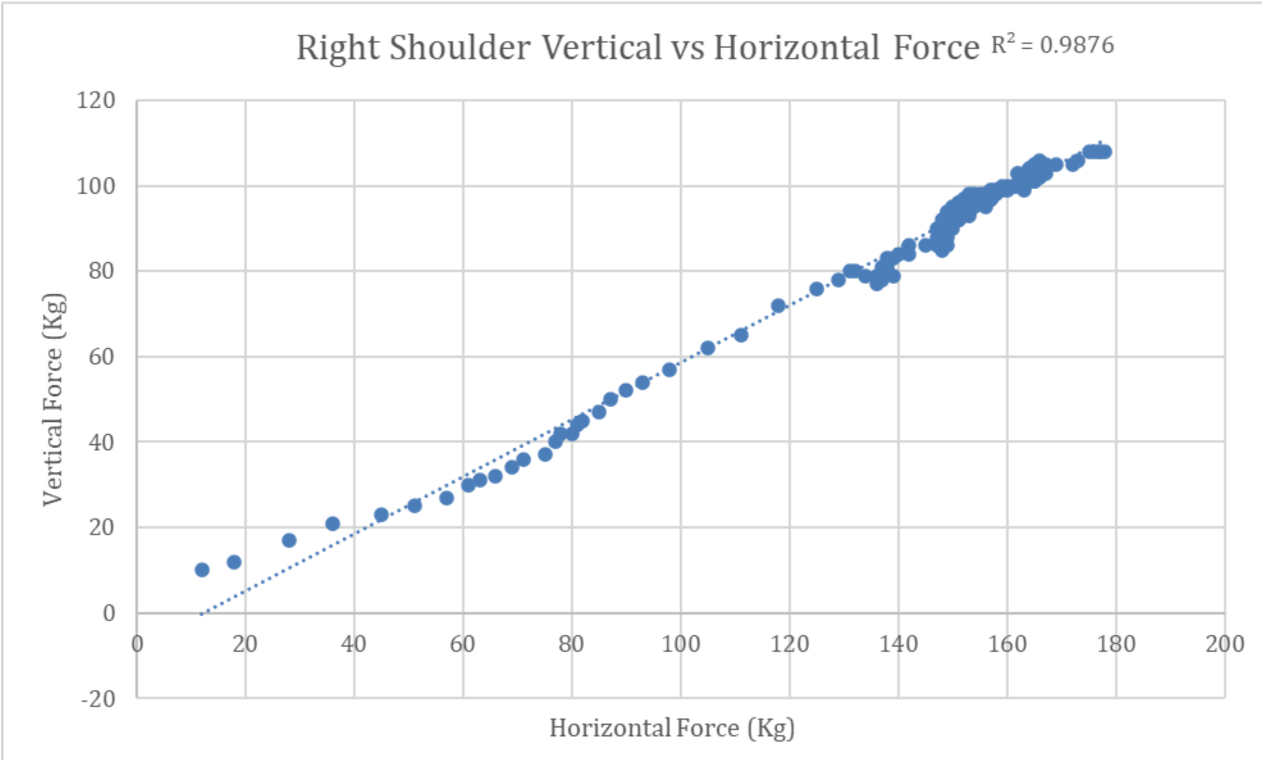

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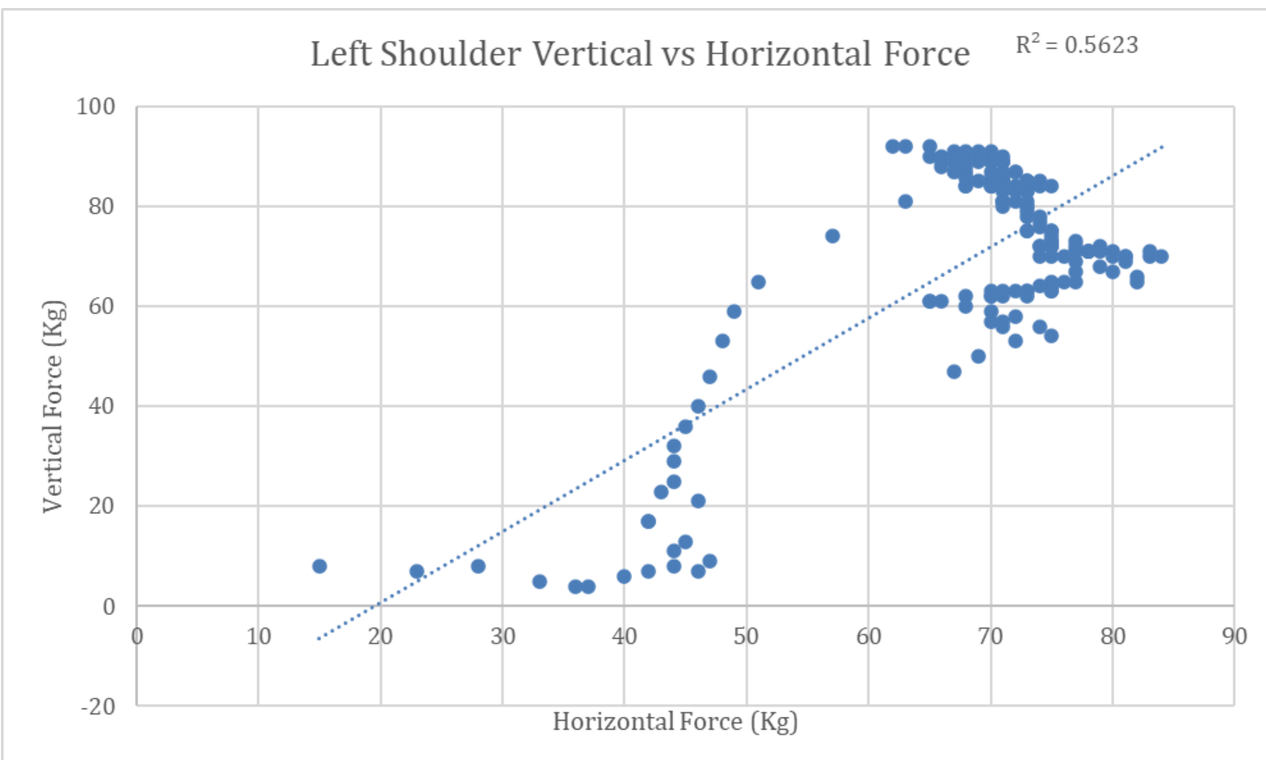

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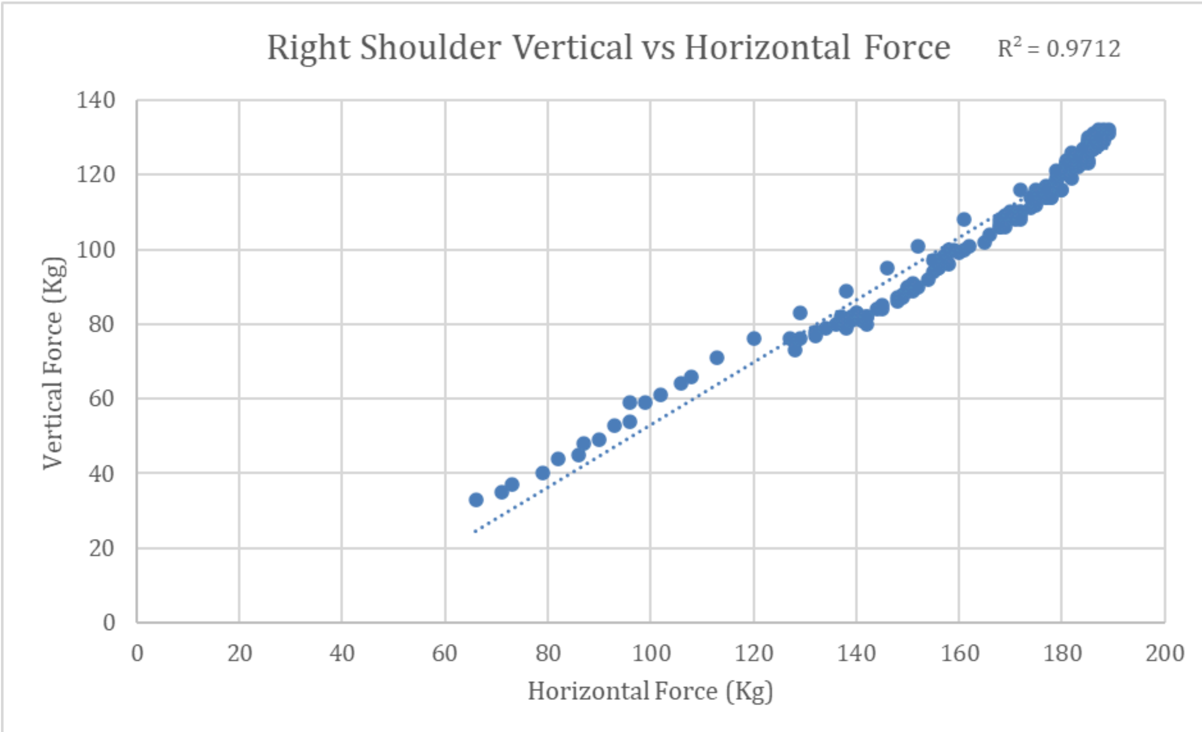

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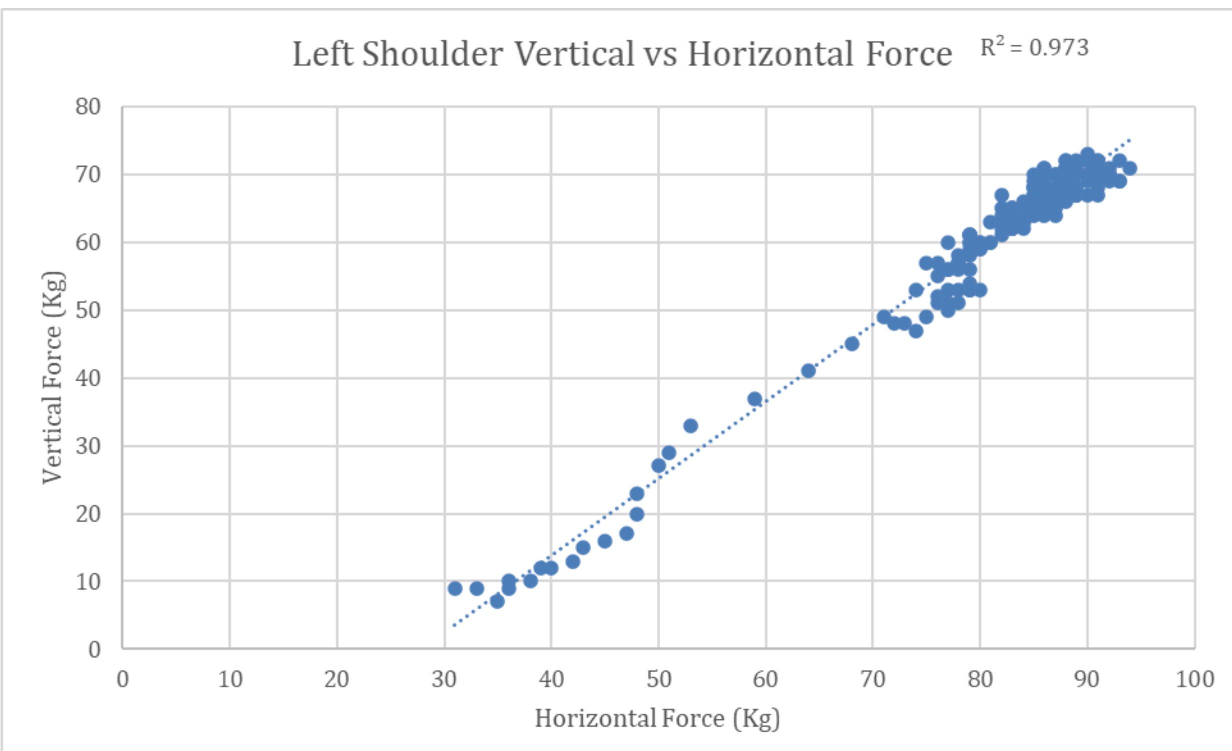
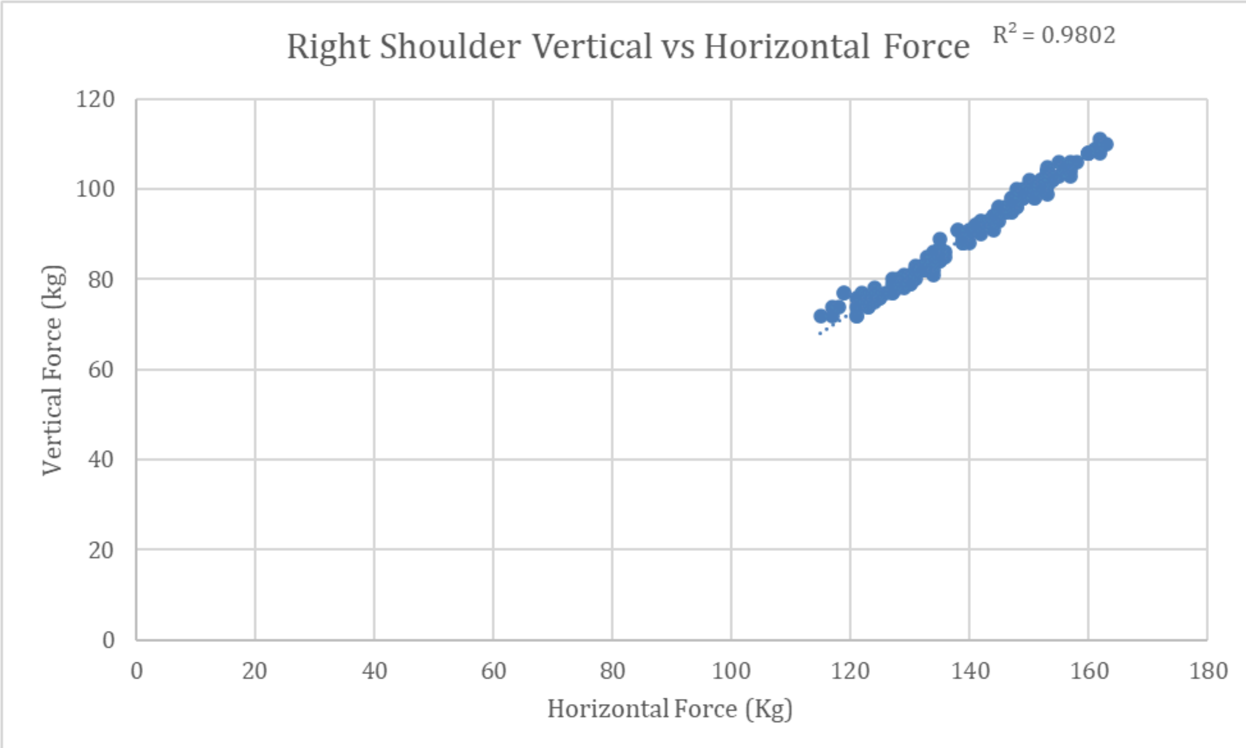
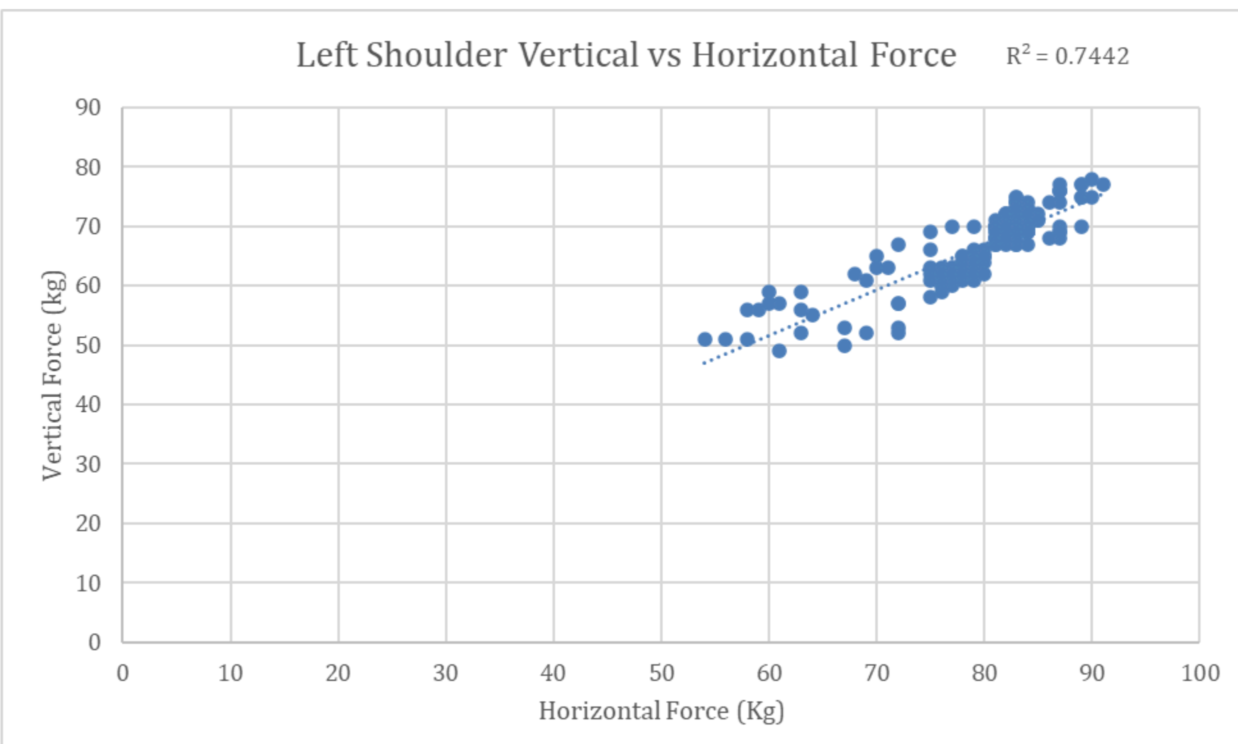


Run 9: Left Shoulder

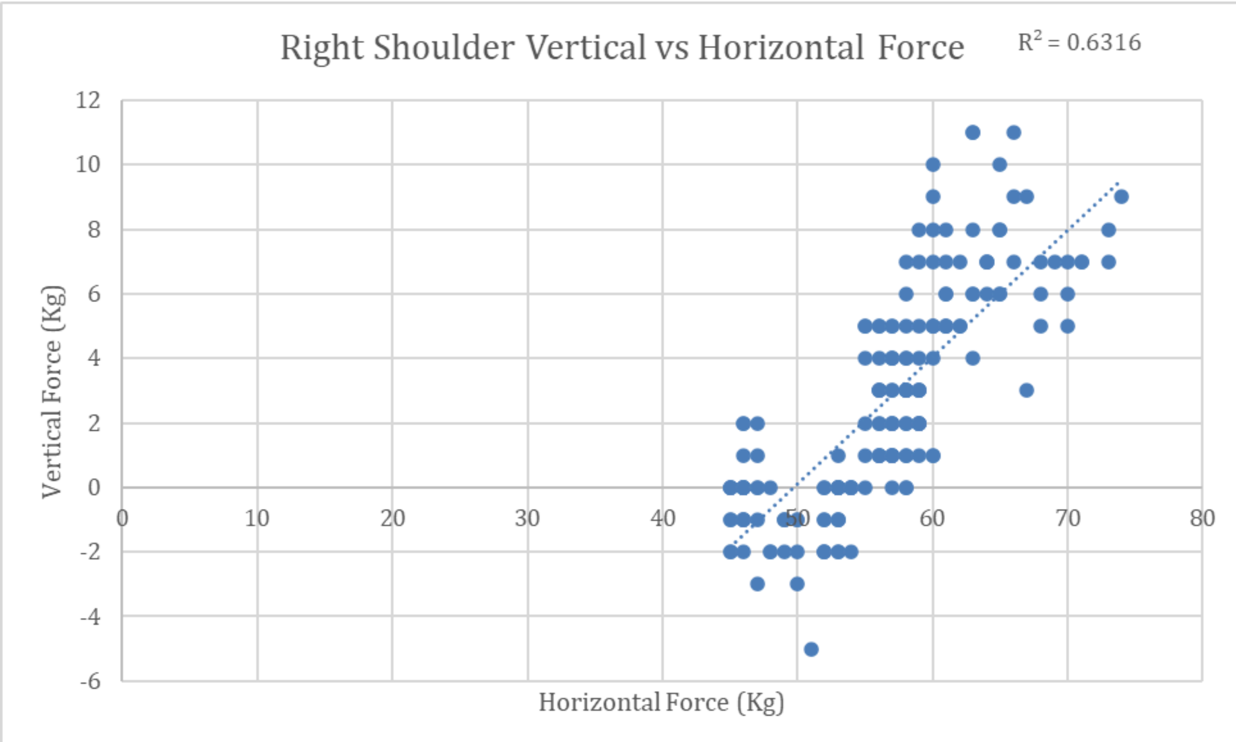


Run 10: Right Shoulder

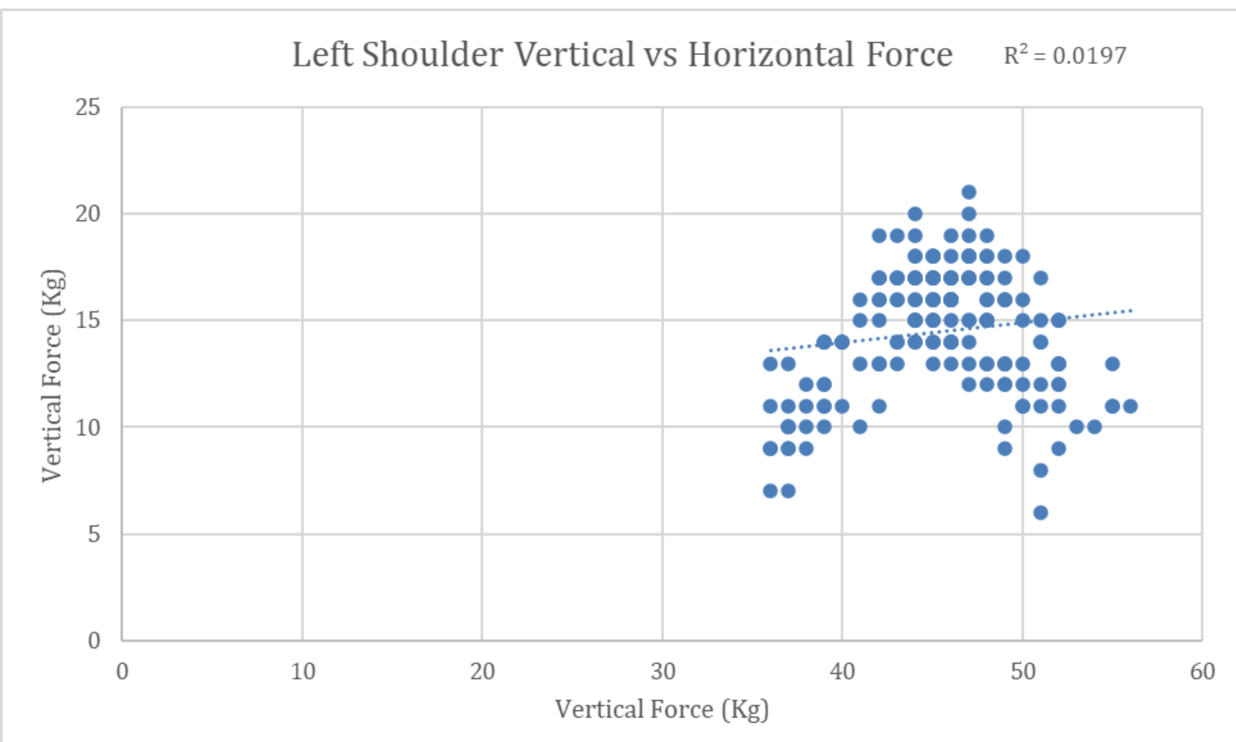


Run 10: Left Shoulder

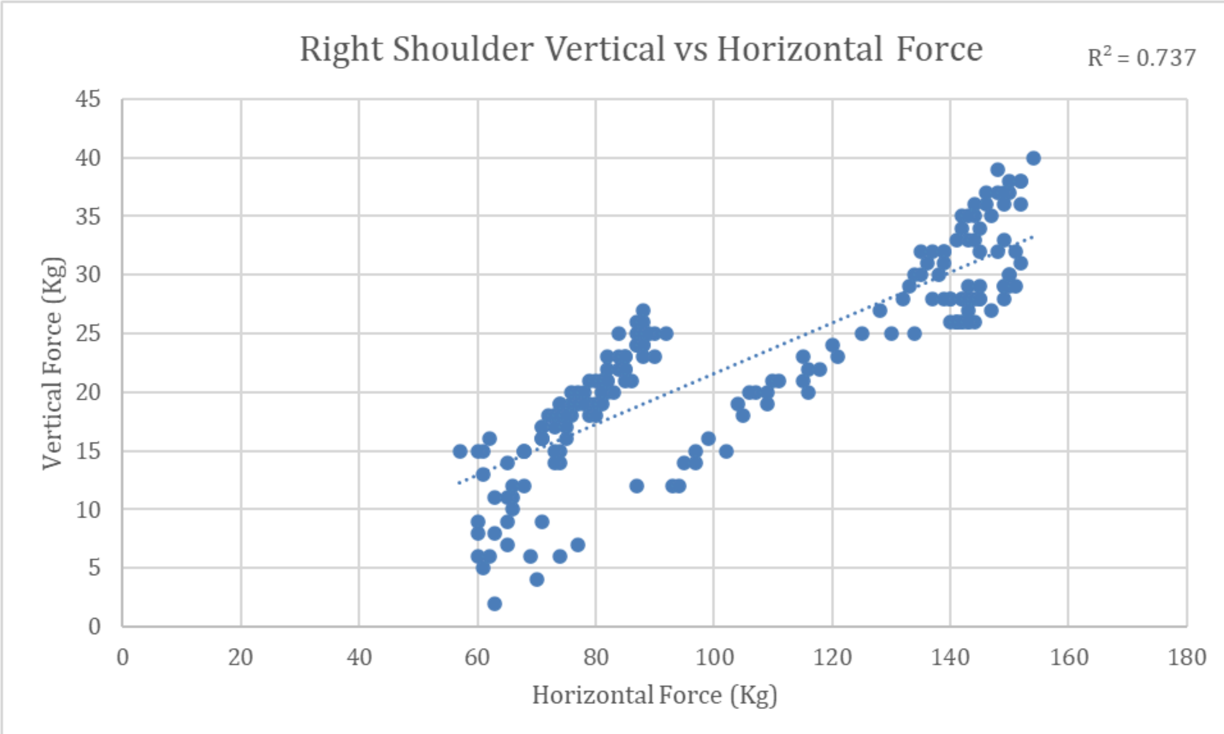
Data Set 3 (Participant 3):



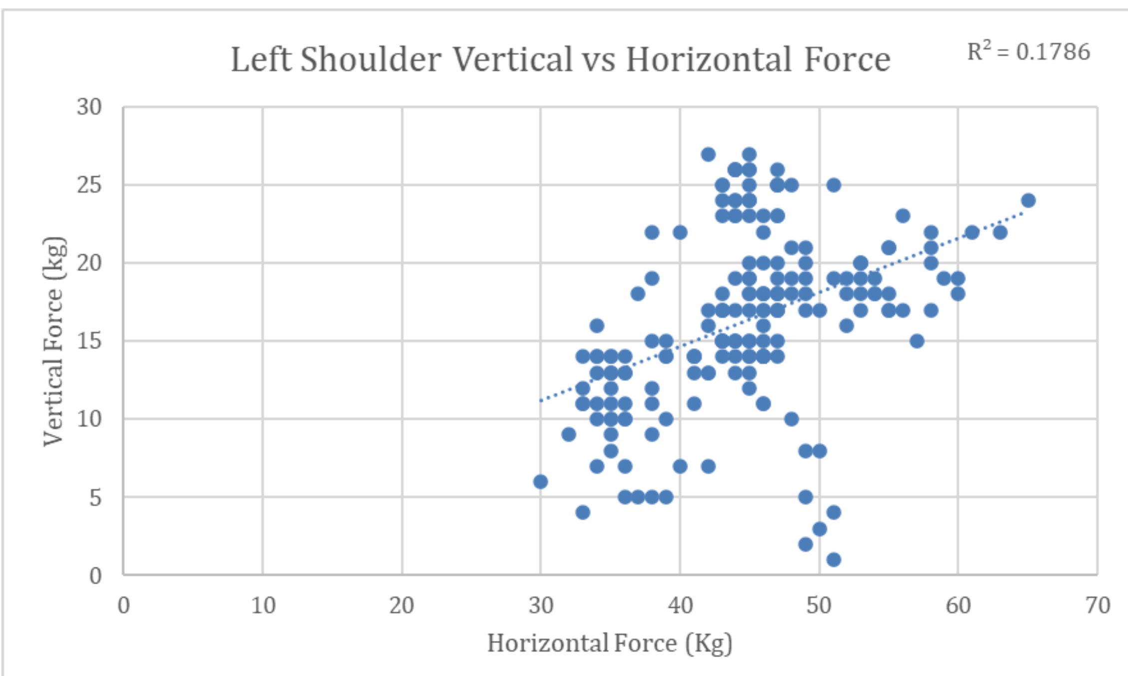
Run 1: Right Shoulder



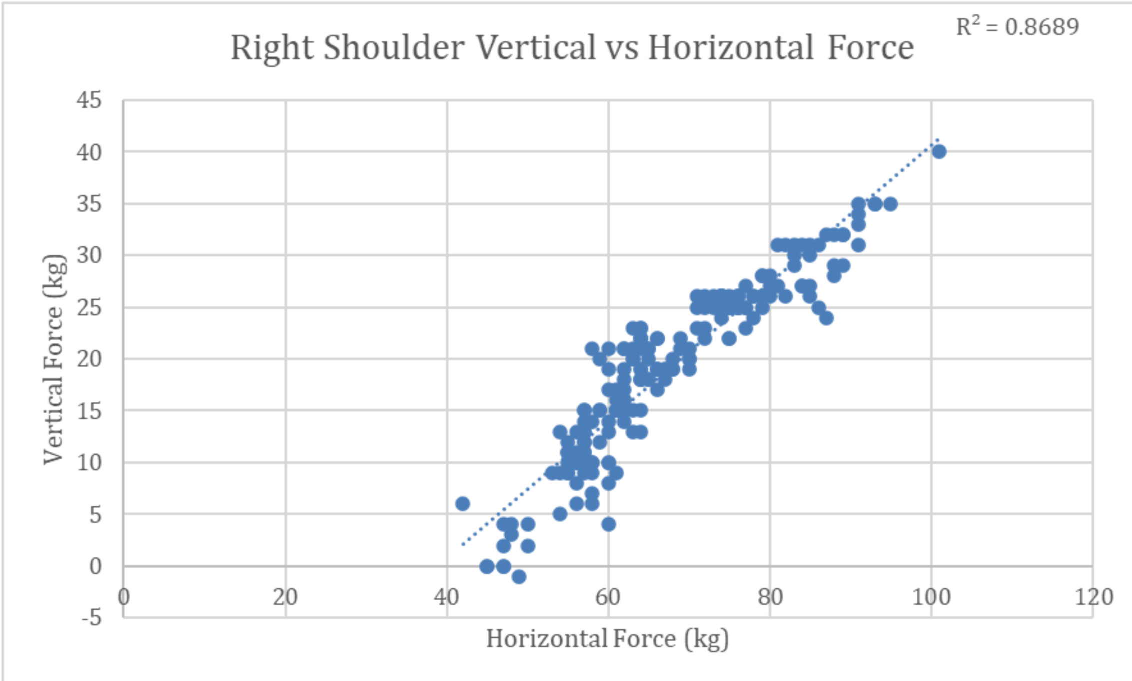
Run 1: Left Shoulder



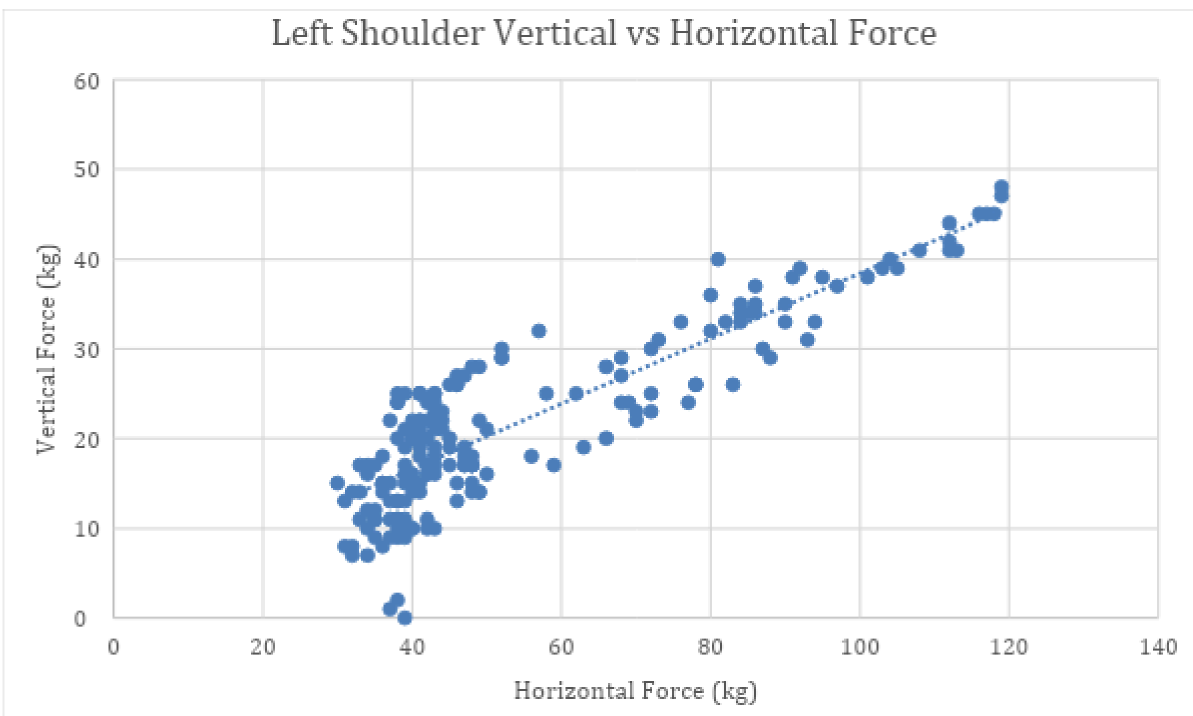
Run 2: Right Shoulder



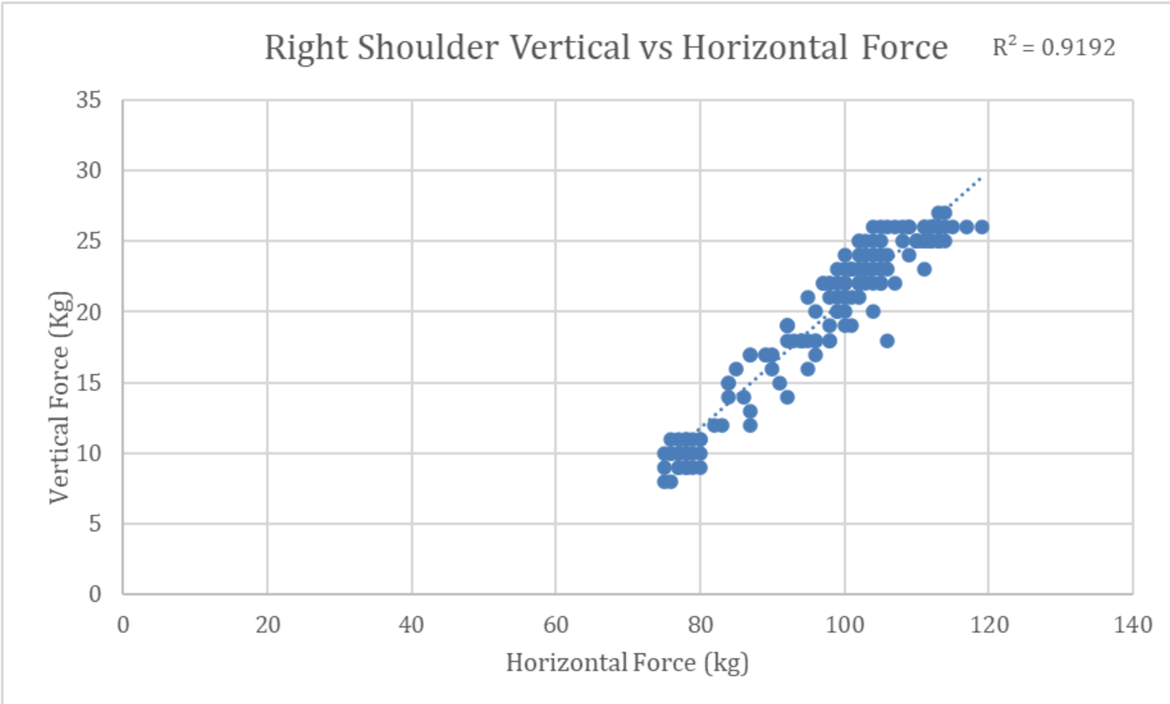
Run 2: Left Shoulder



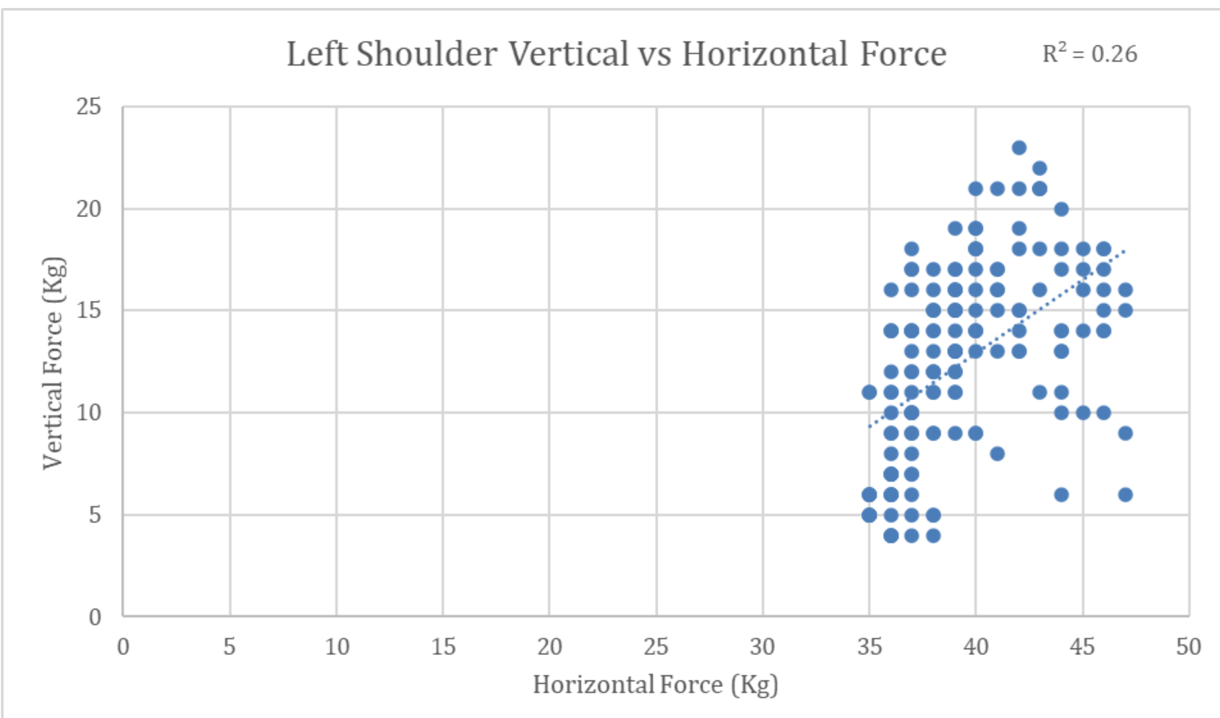
Run 3: Right Shoulder



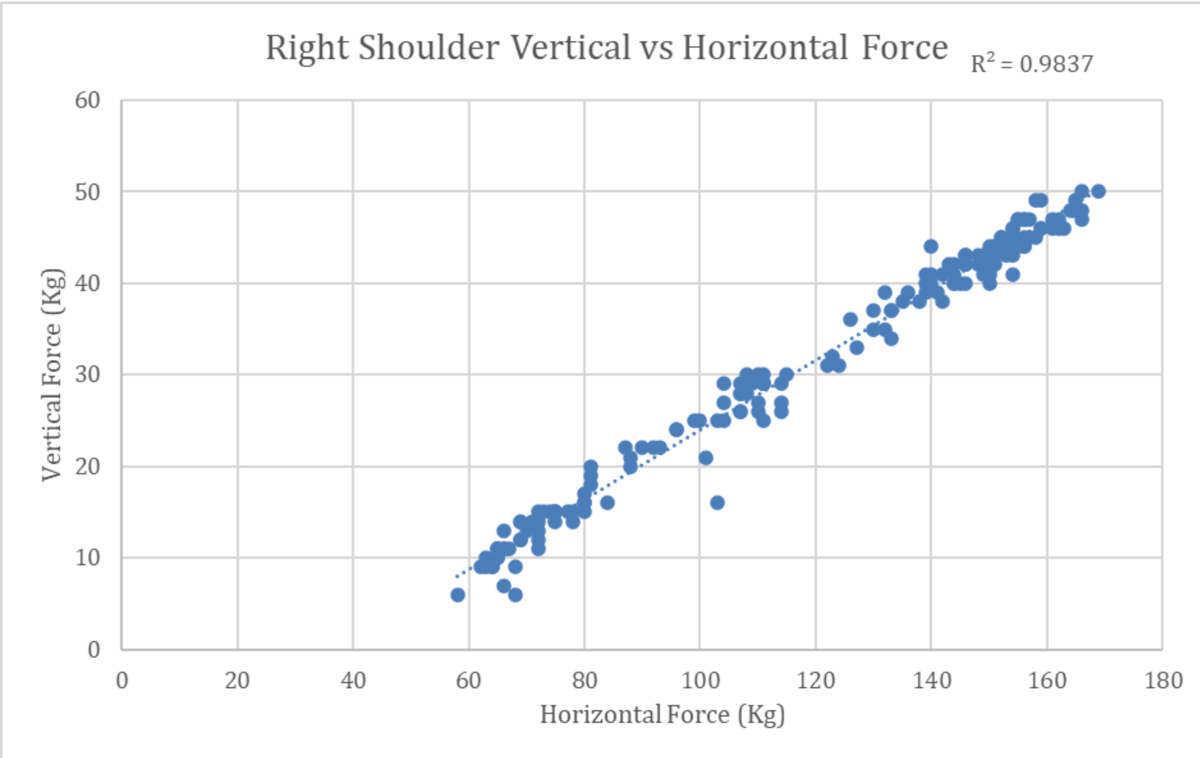
Run 3: Left Shoulder



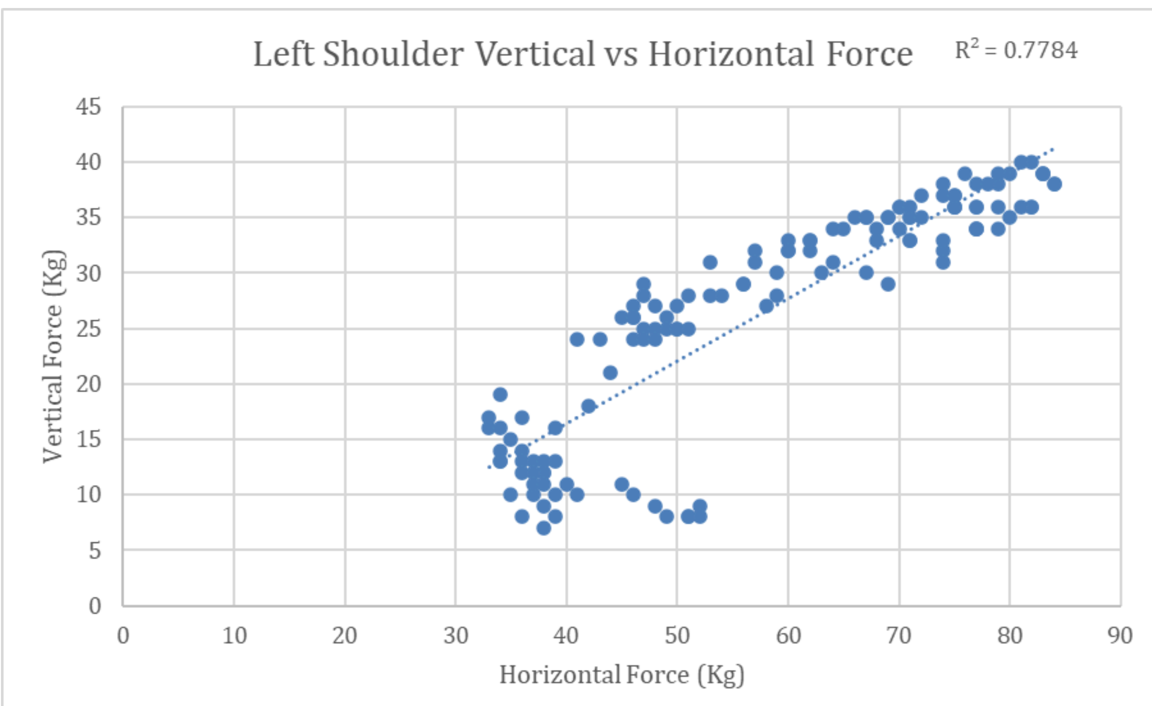
Run 4: Right Shoulder



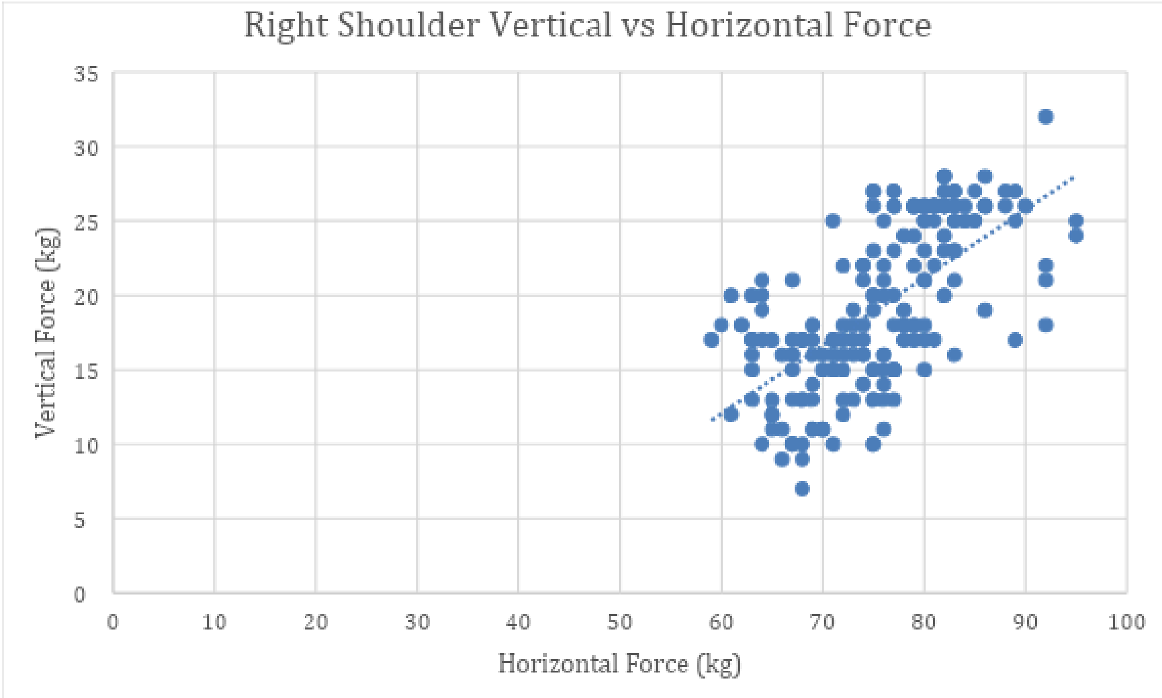
Run 4: Left Shoulder



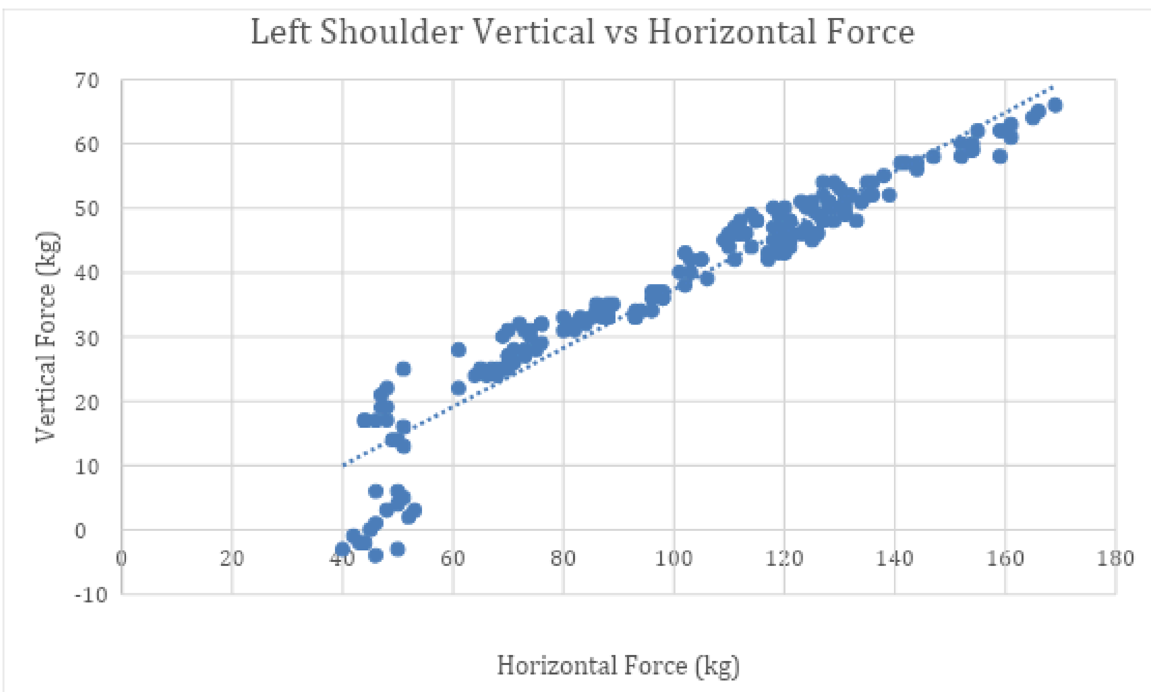
Run 5: Right Shoulder



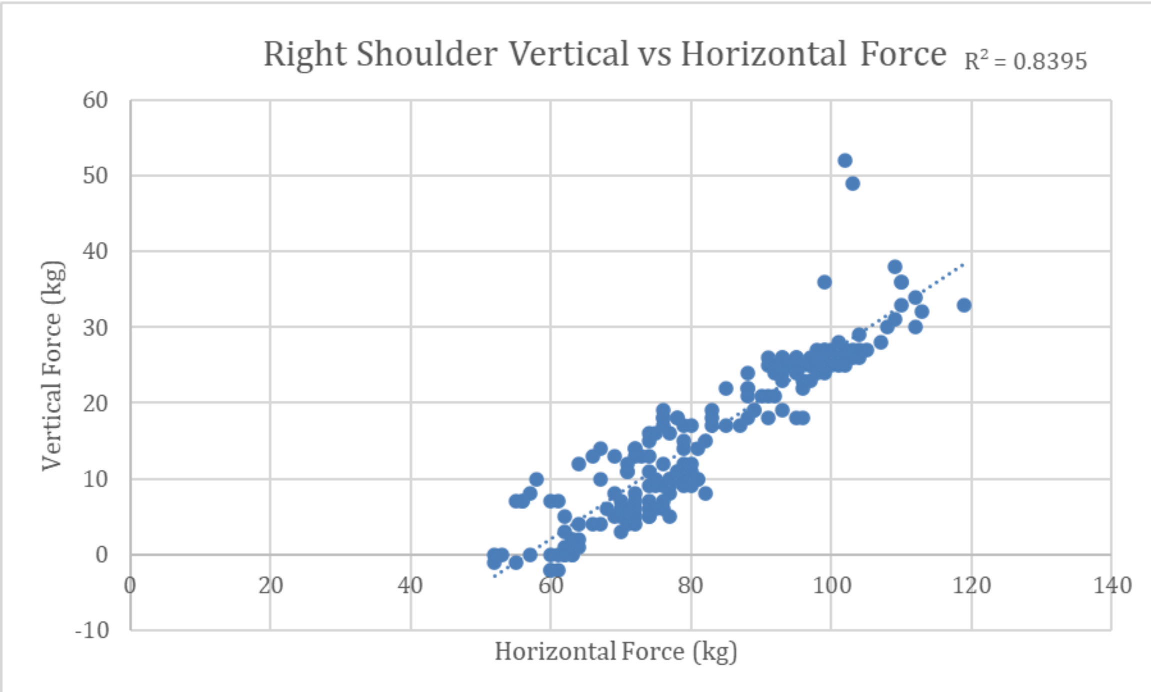
Run 5: Left Shoulder



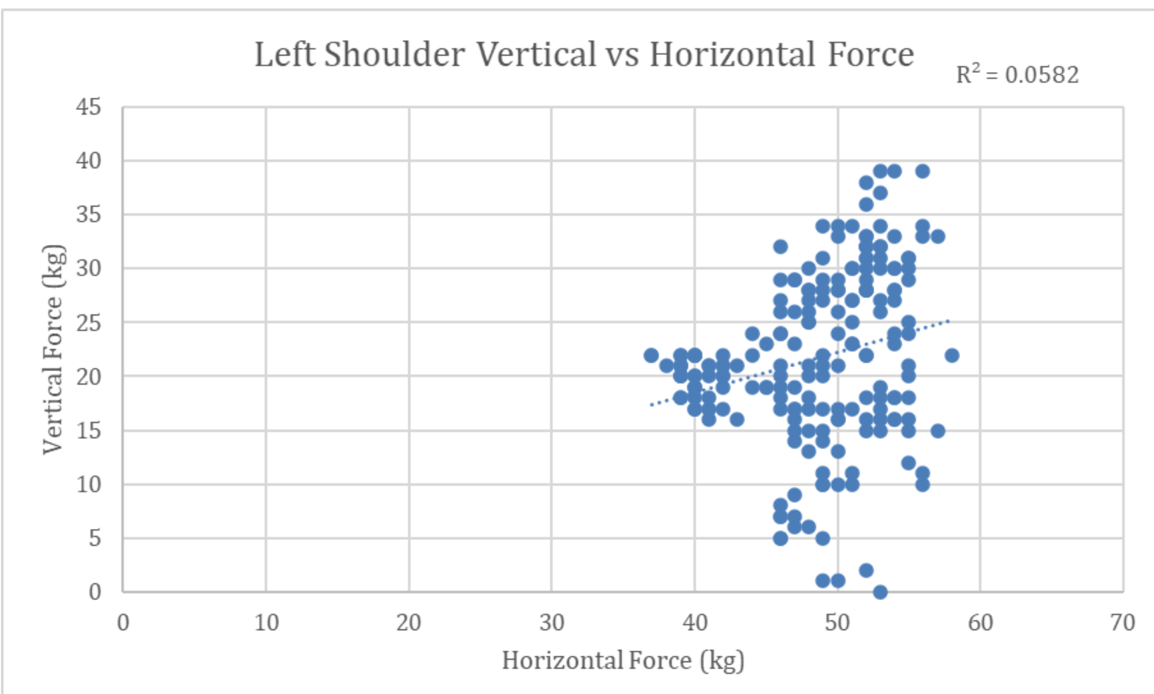
Run 6: Right Shoulder



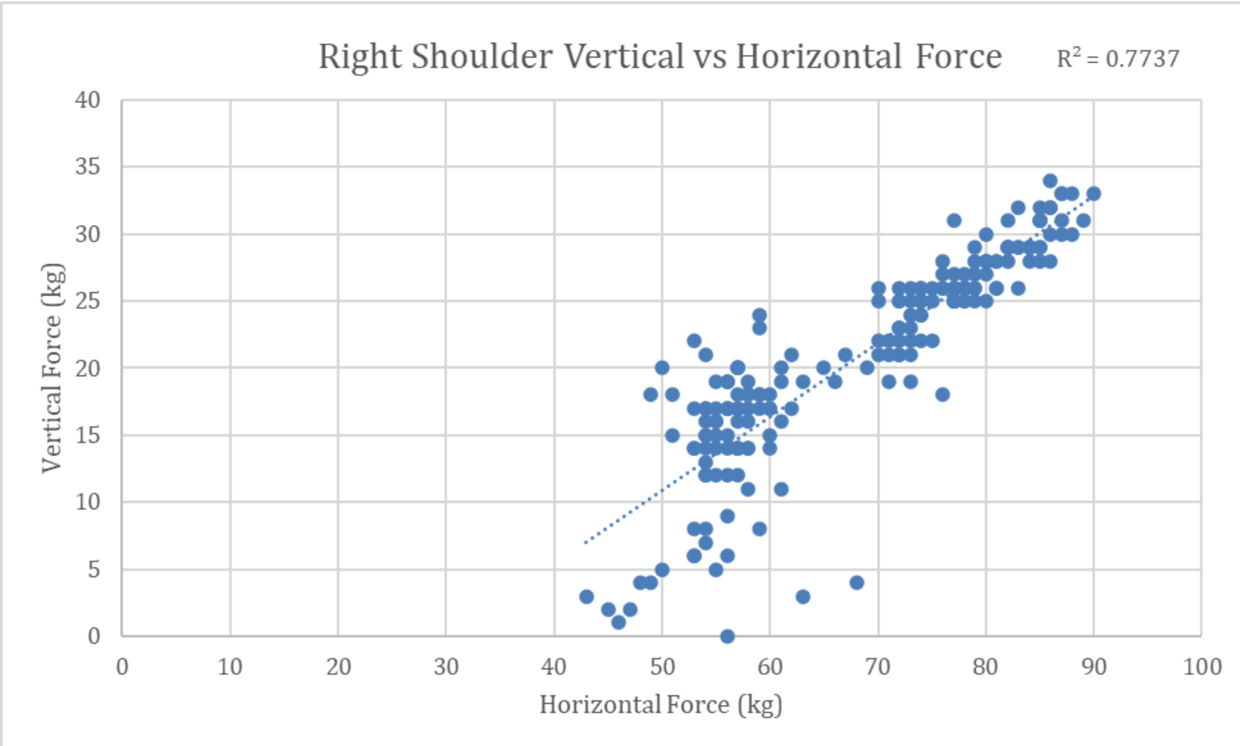
Run 6: Left Shoulder



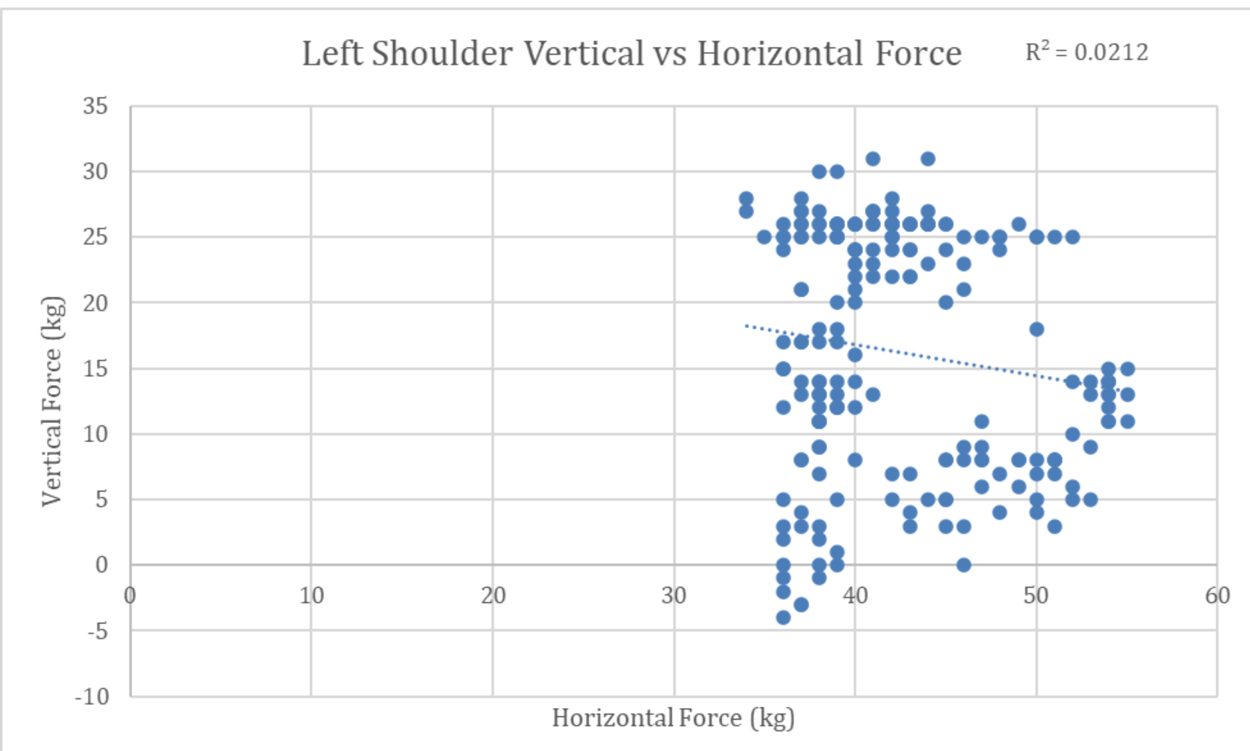
Run 7: Right Shoulder



Run 7: Left Shoulder

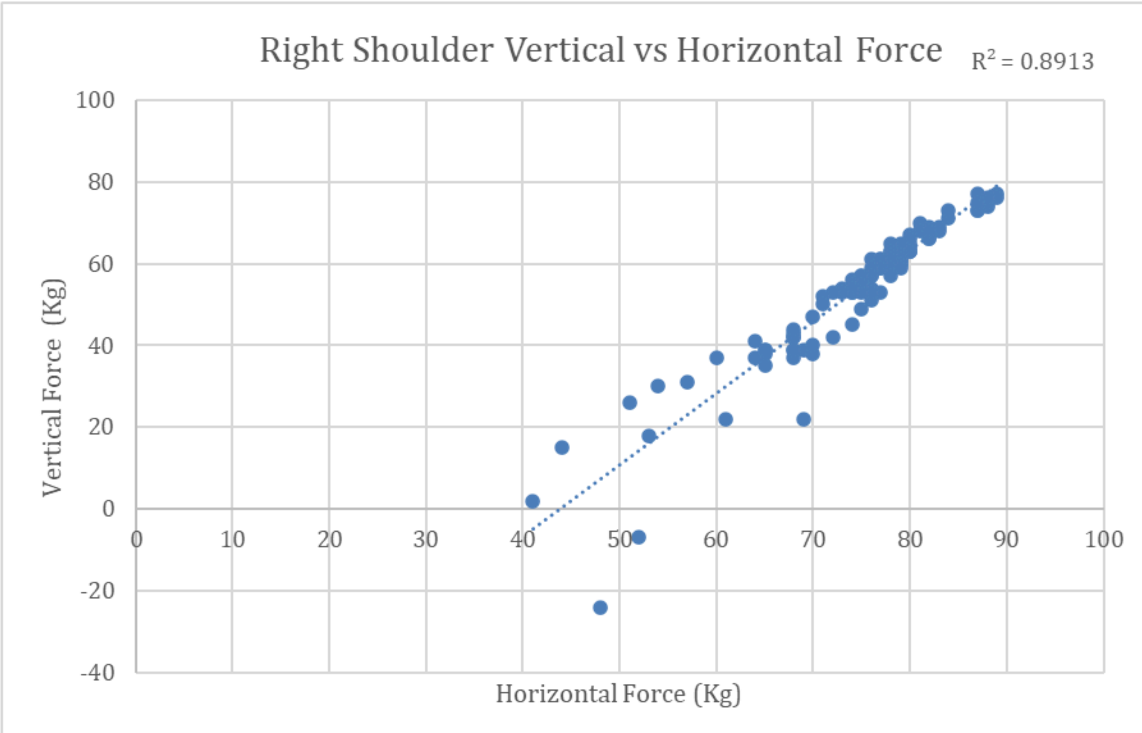


Run 8: Right Shoulder

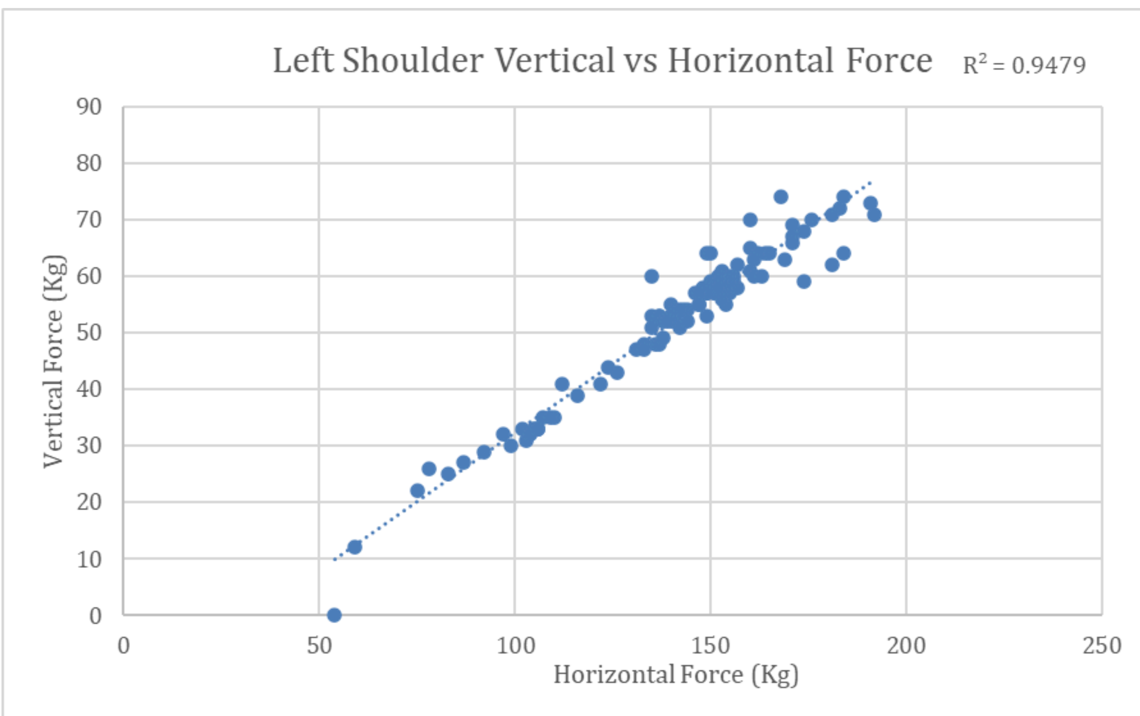


Run 8: Left Shoulder

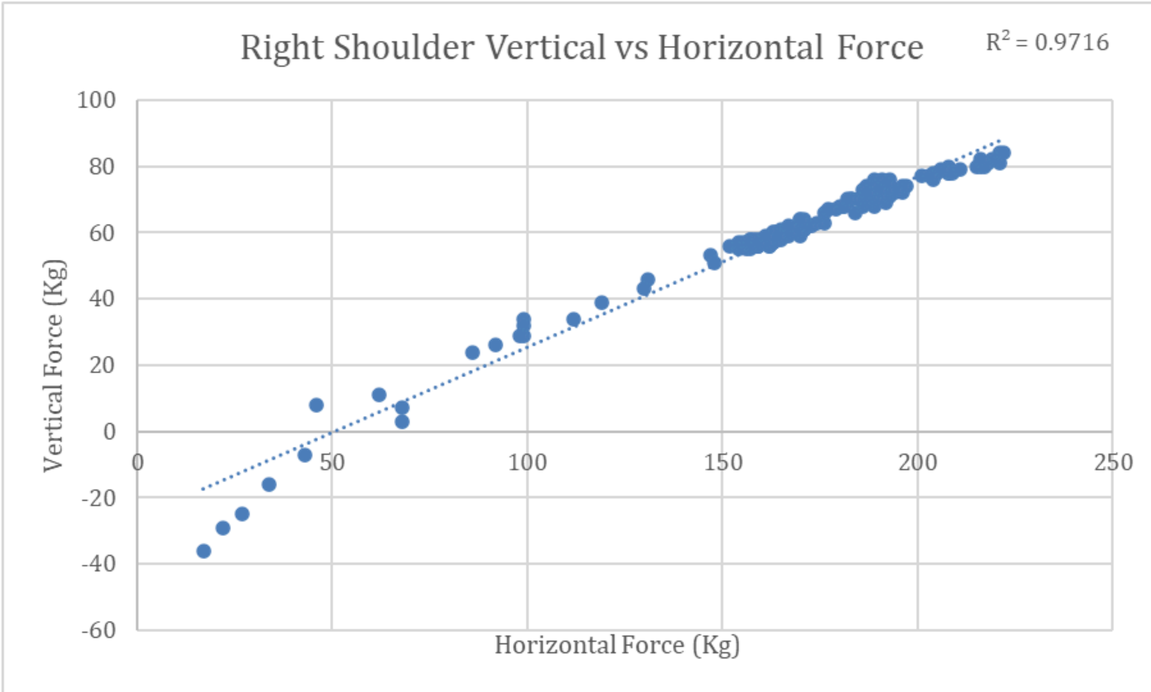
Data Set 4 (Participant 4):



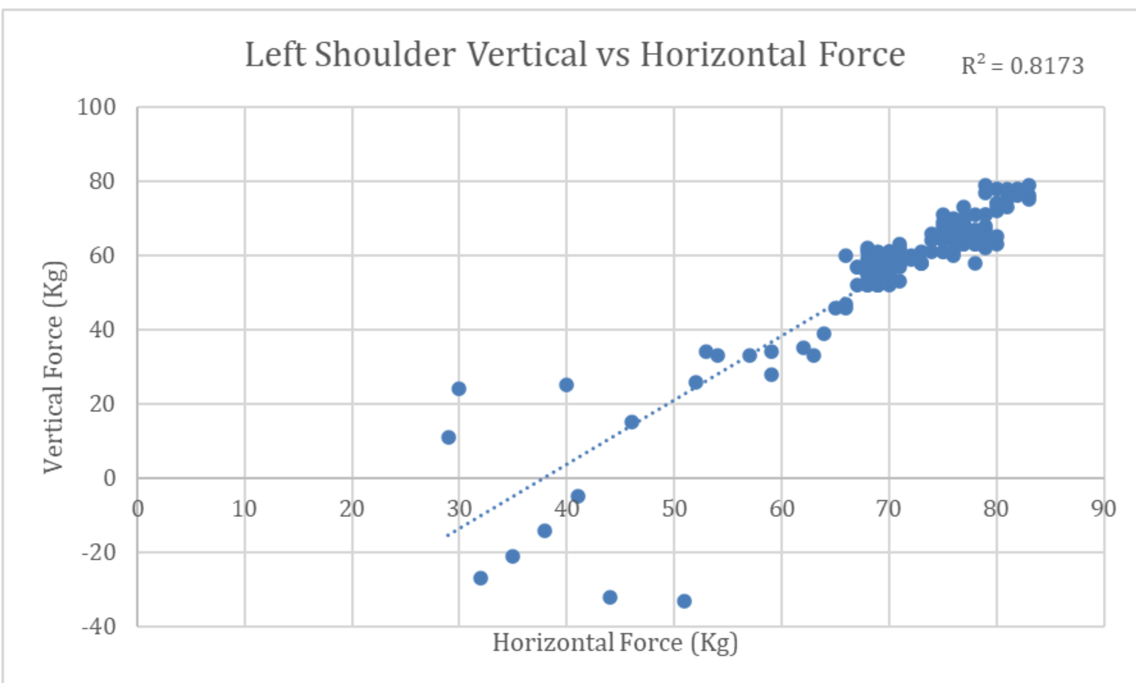
Run 1: Right Shoulder



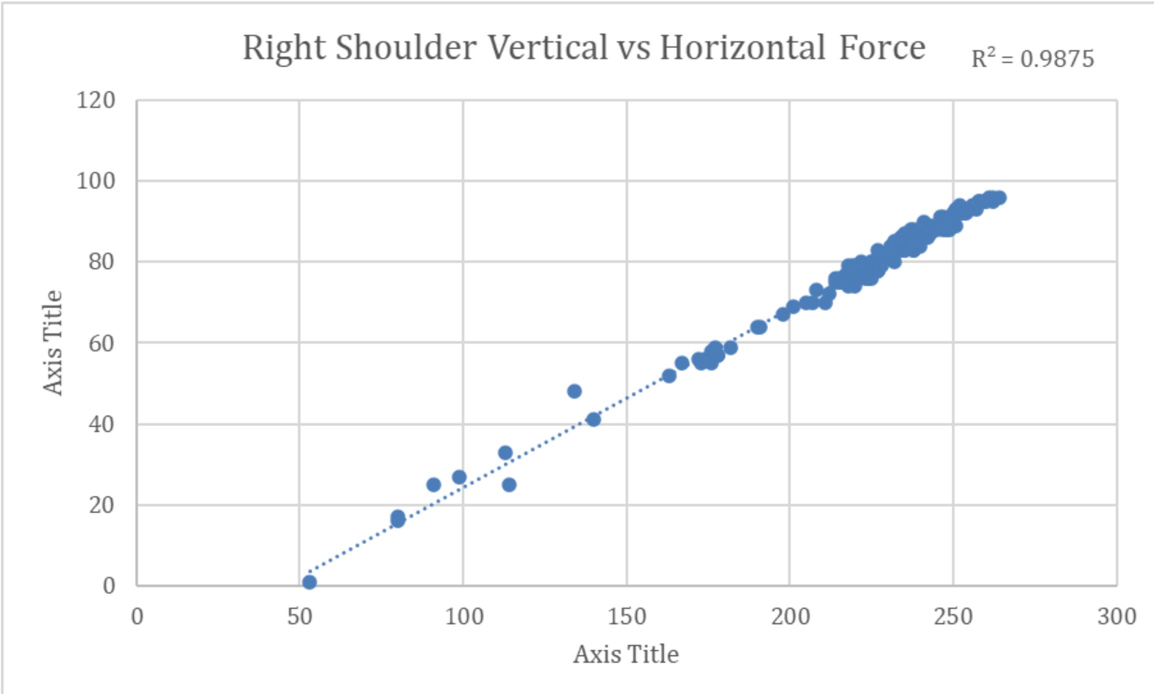
Run 1: Left Shoulder



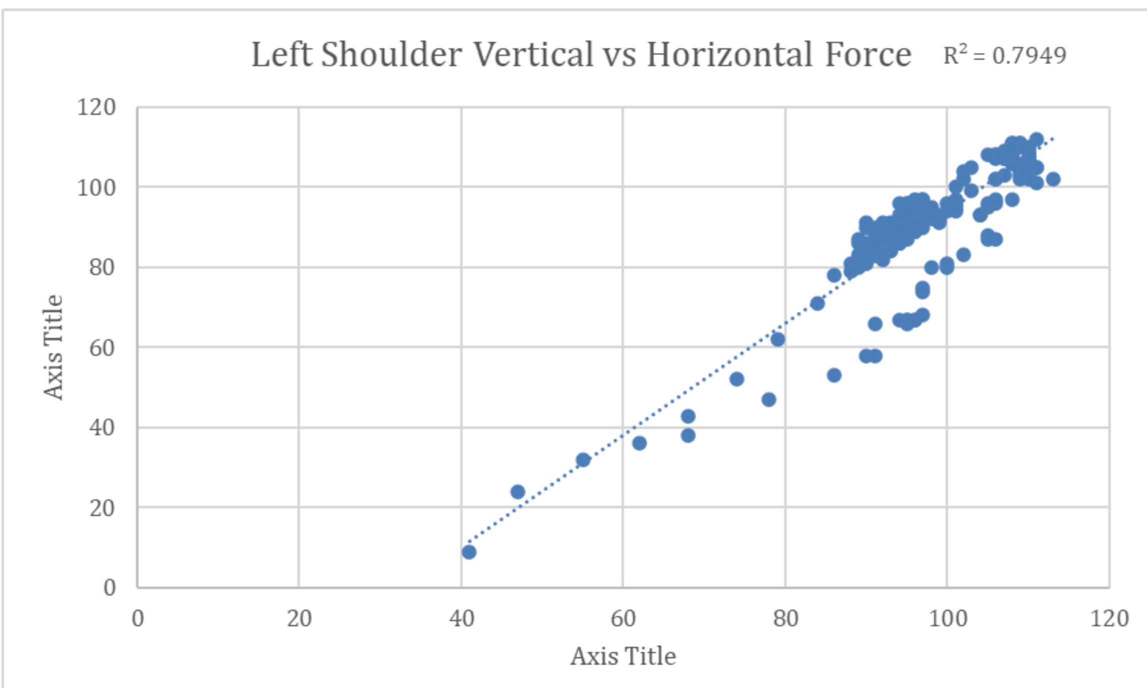
Run 2: Right Shoulder



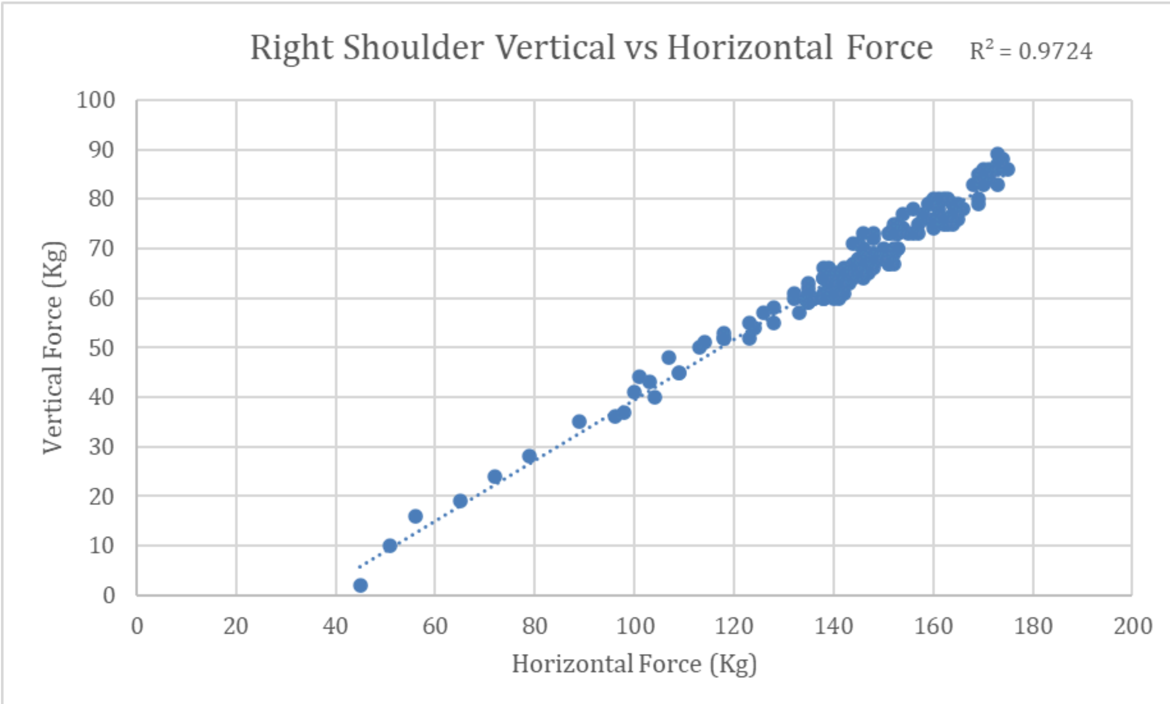
Run 2: Left Shoulder



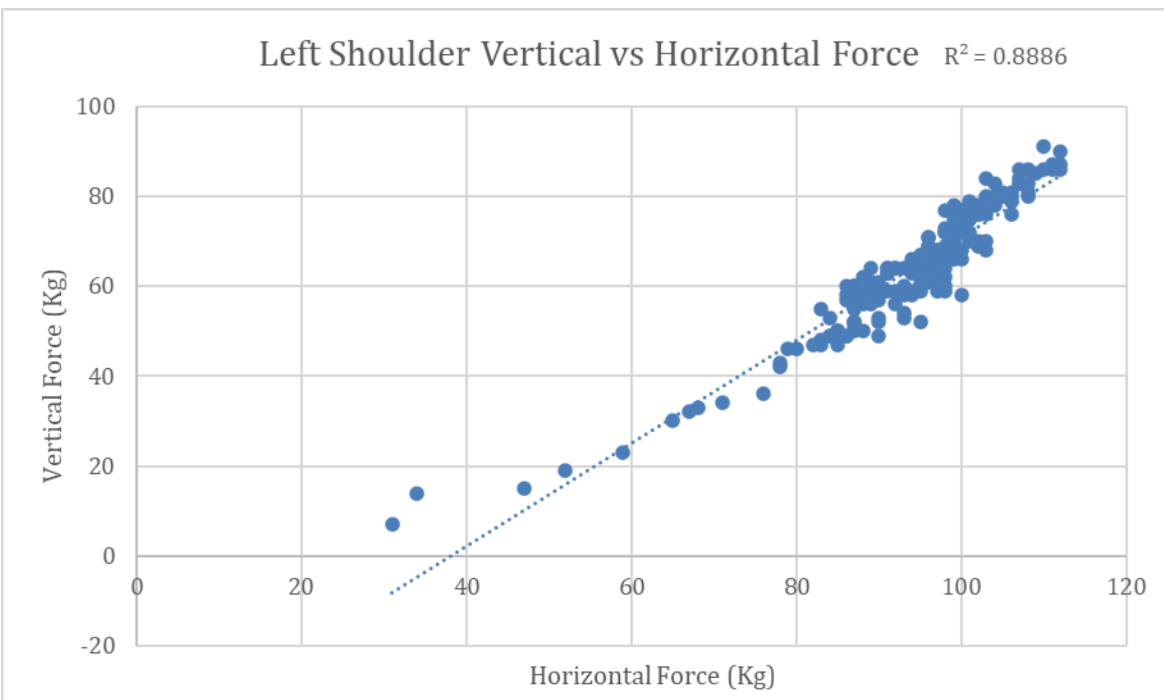
Run 3: Right Shoulder



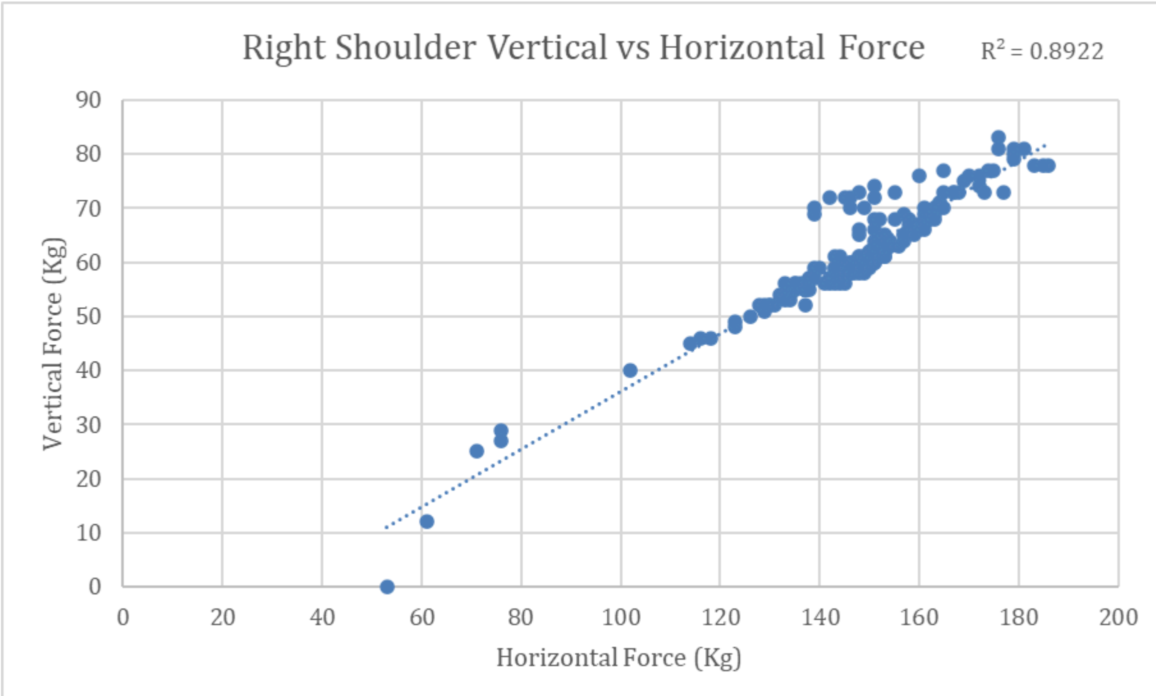
Run 3: Left Shoulder



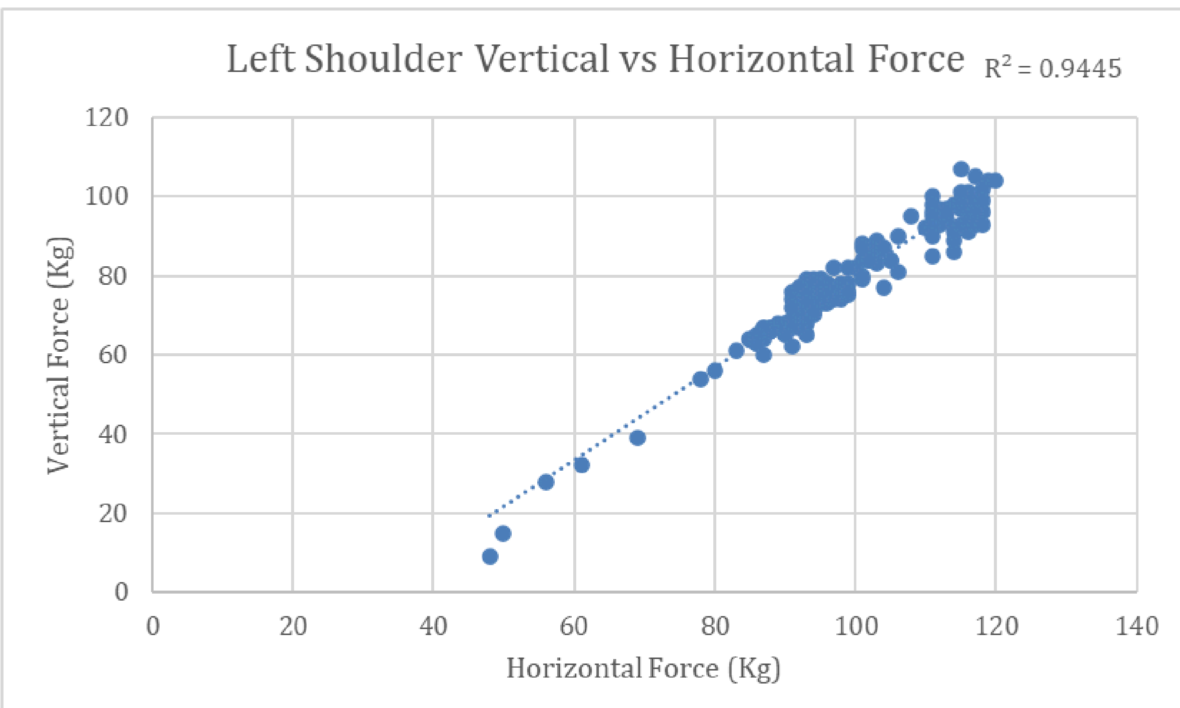
Run 4: Right Shoulder



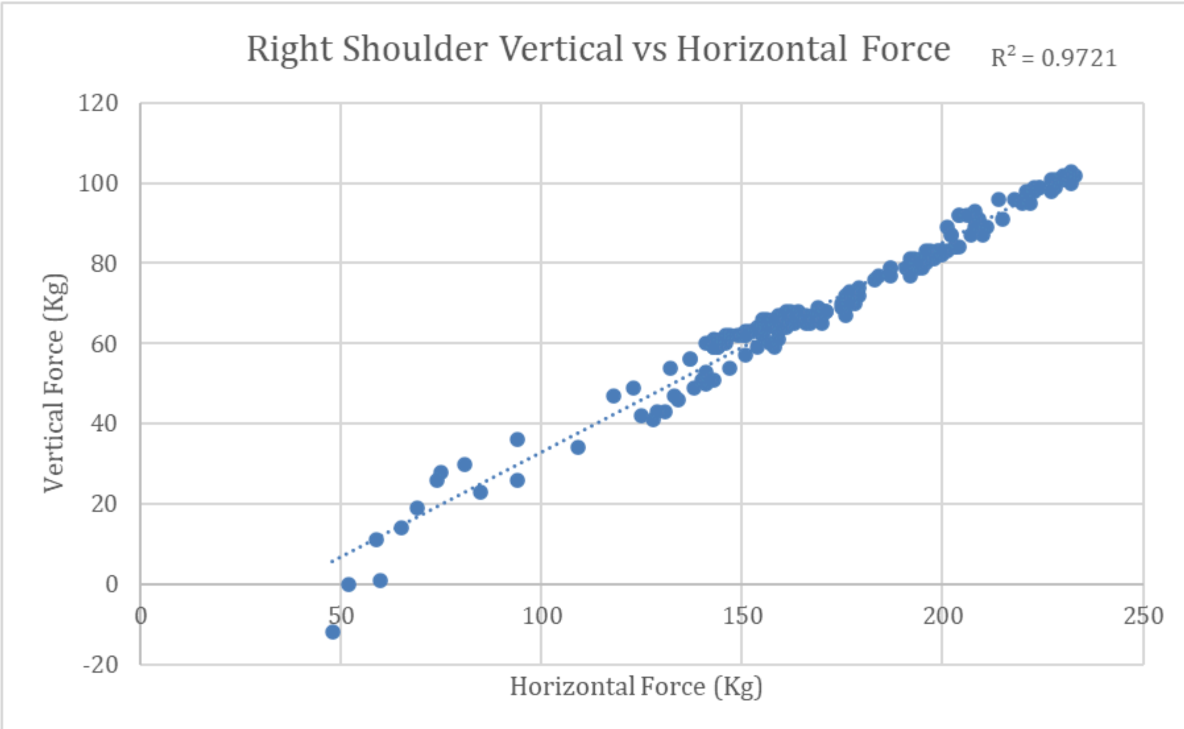
Run 4: Left Shoulder



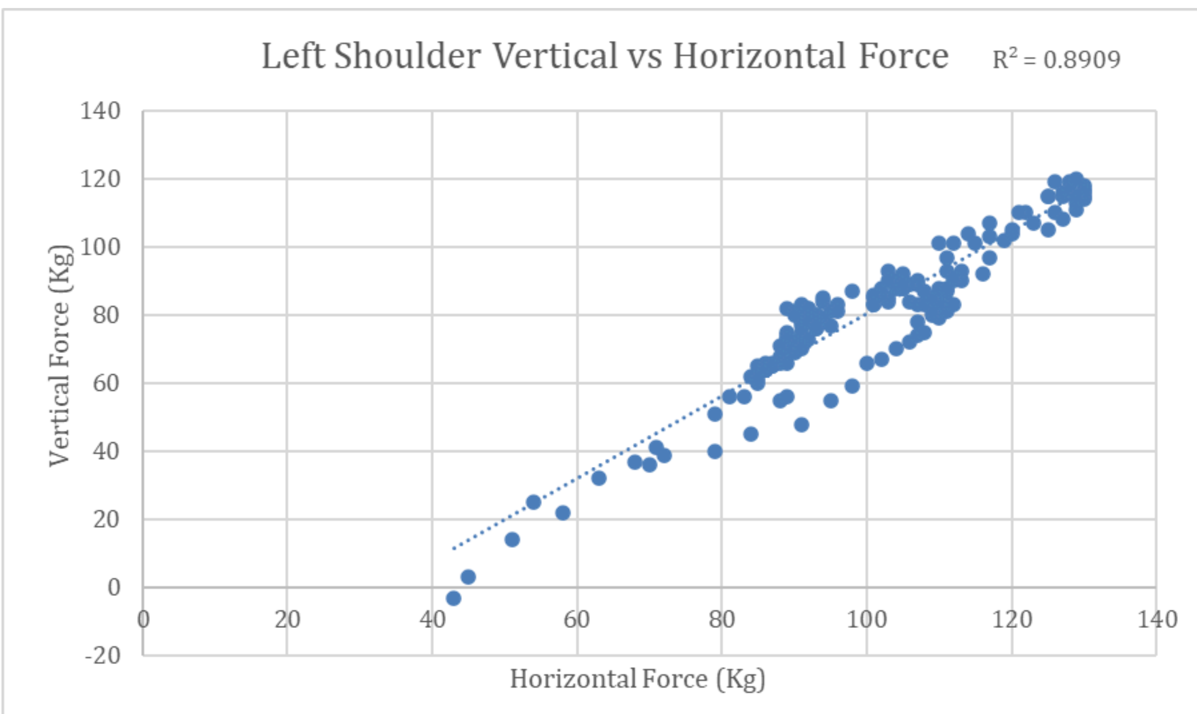
Run 5: Right Shoulder



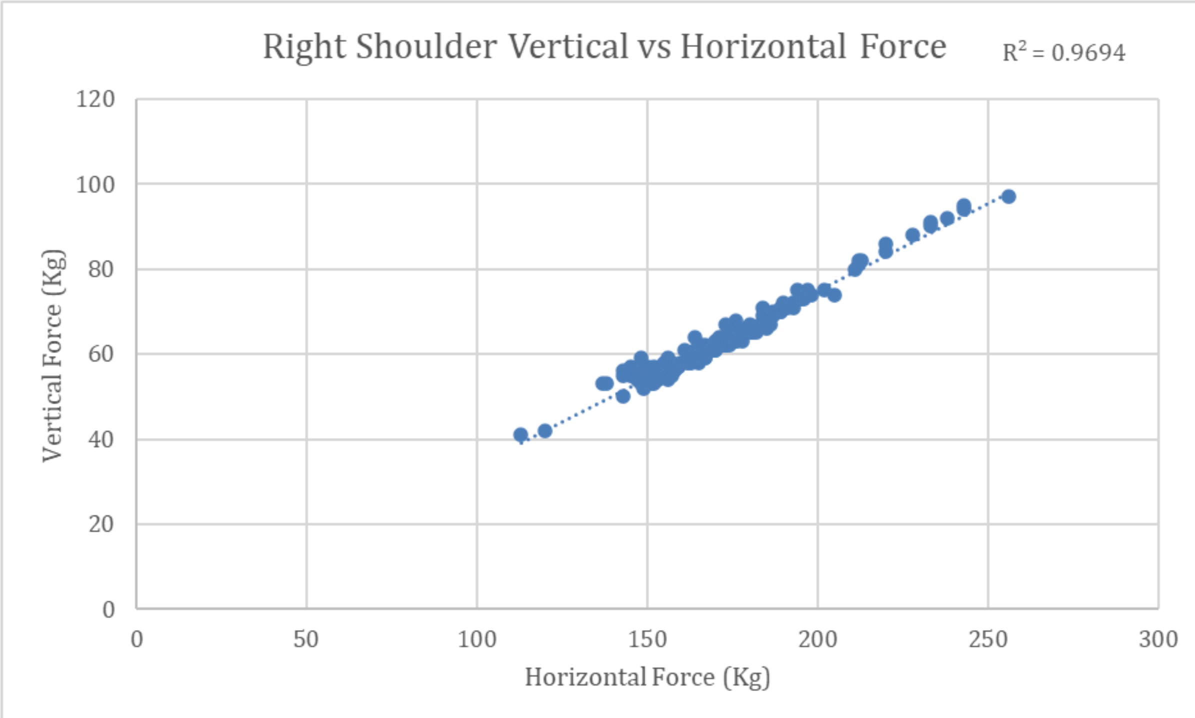
Run 5: Left Shoulder



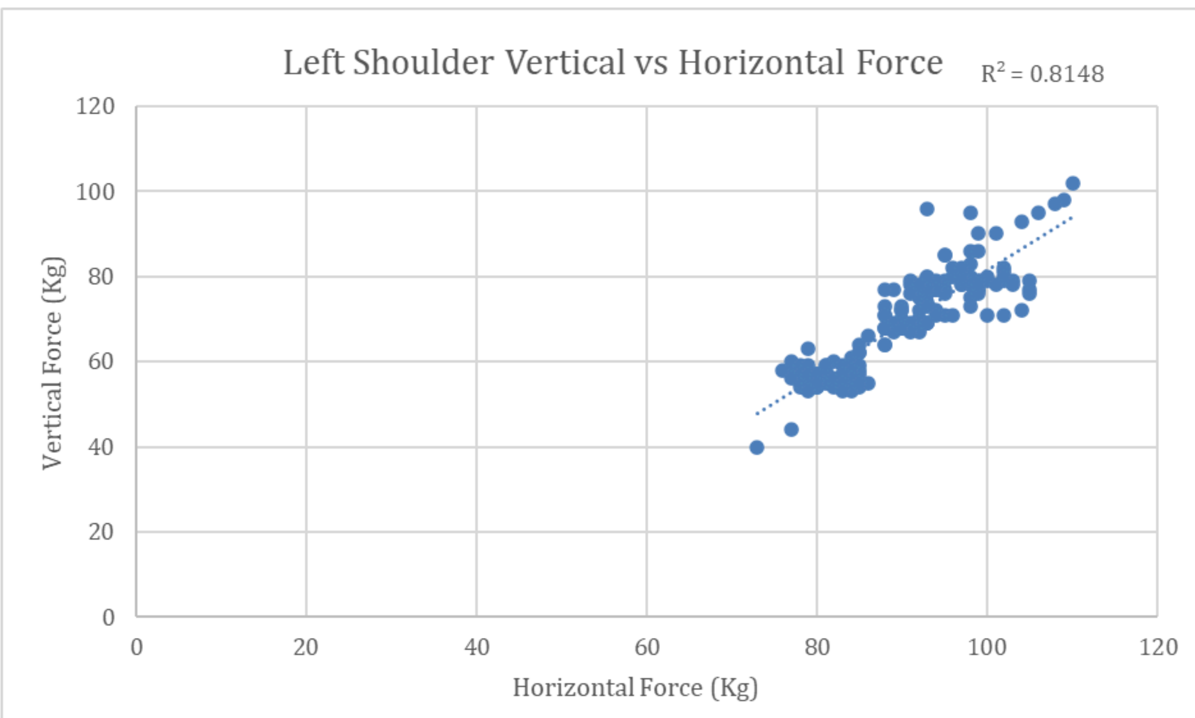
Run 6: Right Shoulder



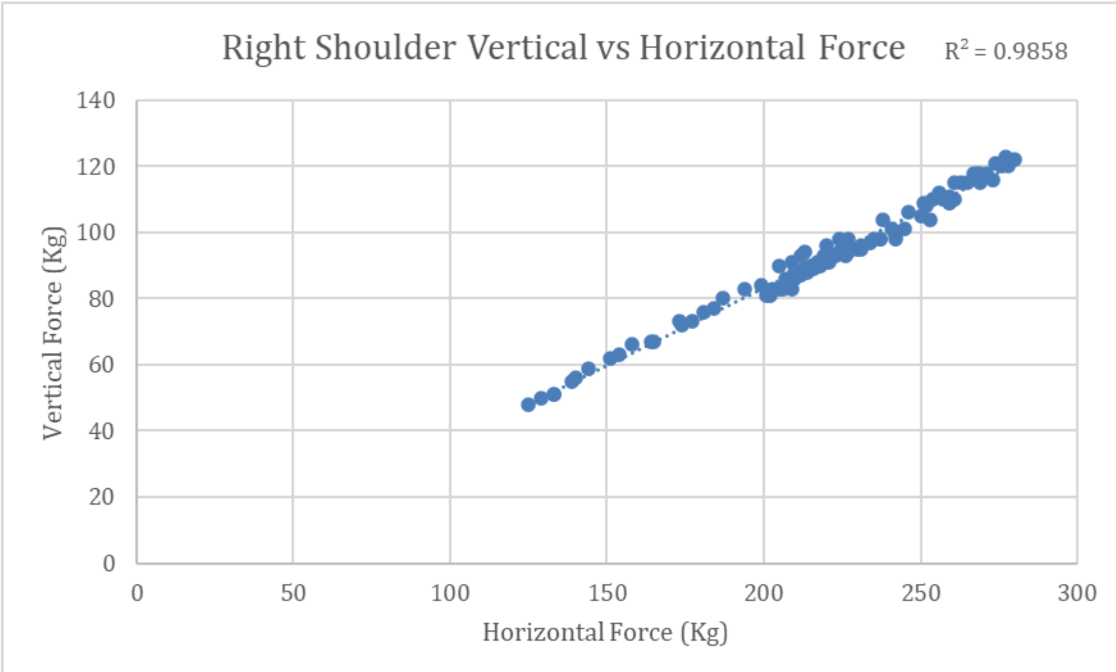
Run 6: Left Shoulder



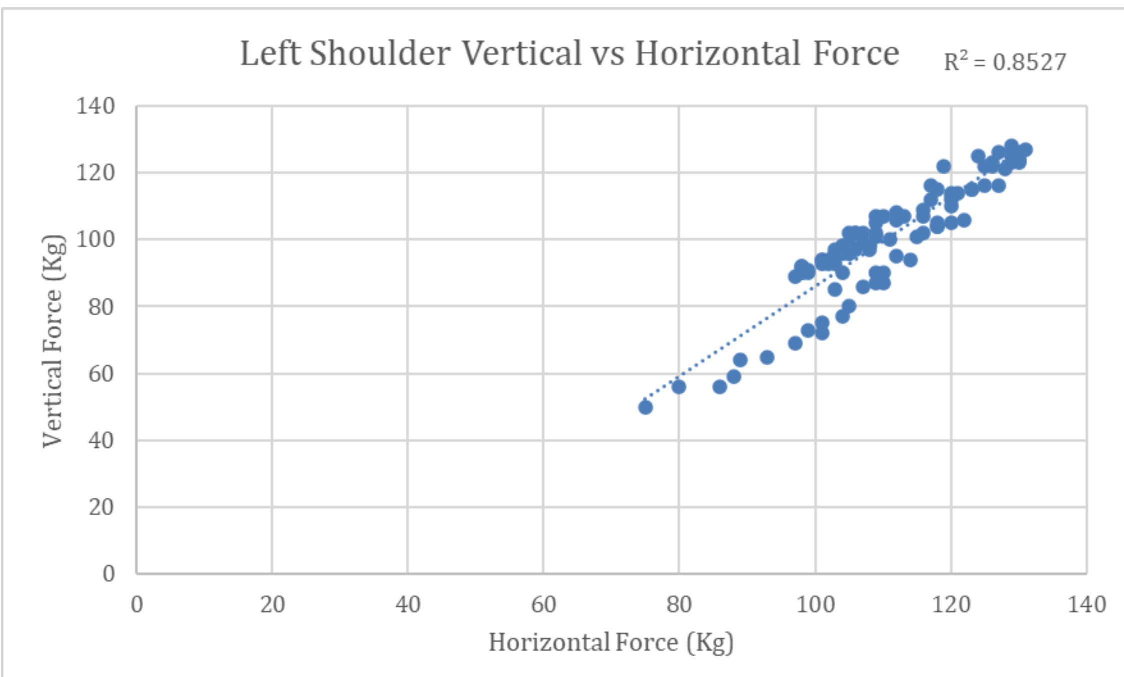
Run 7: Right Shoulder



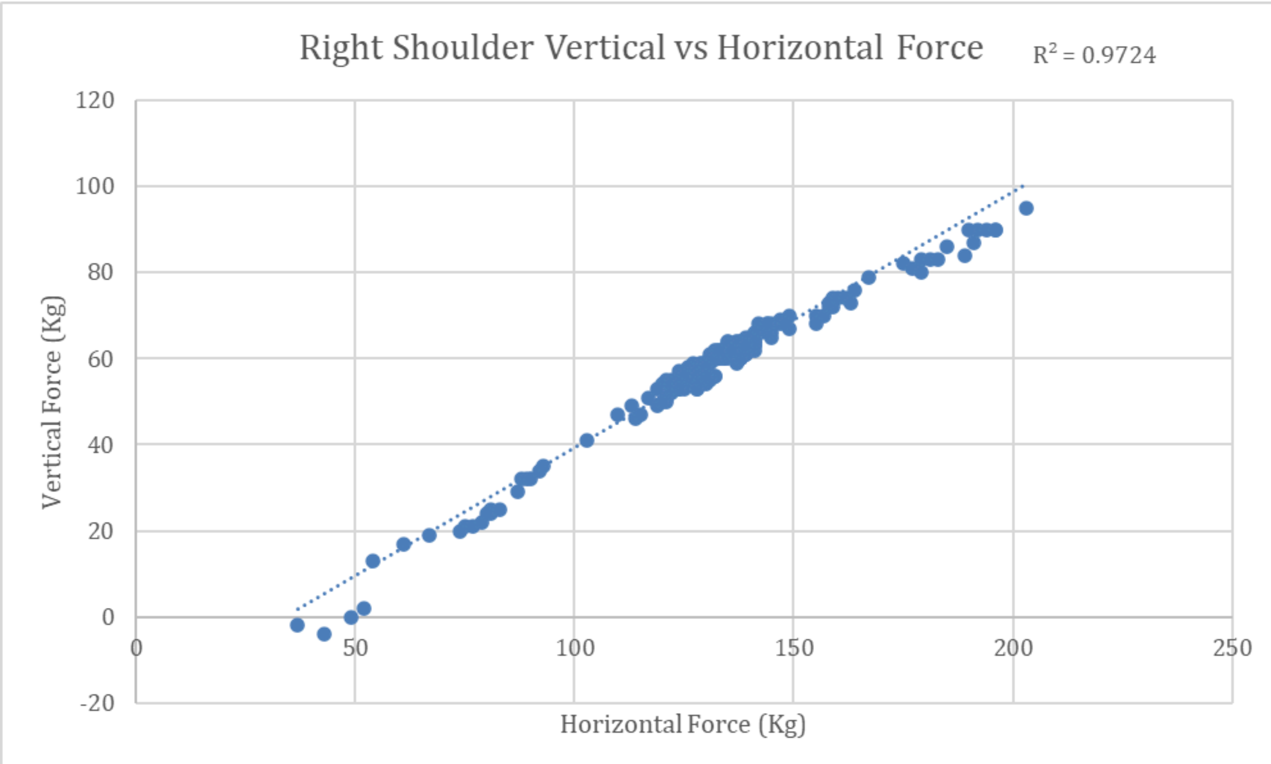
Run 7: Left Shoulder



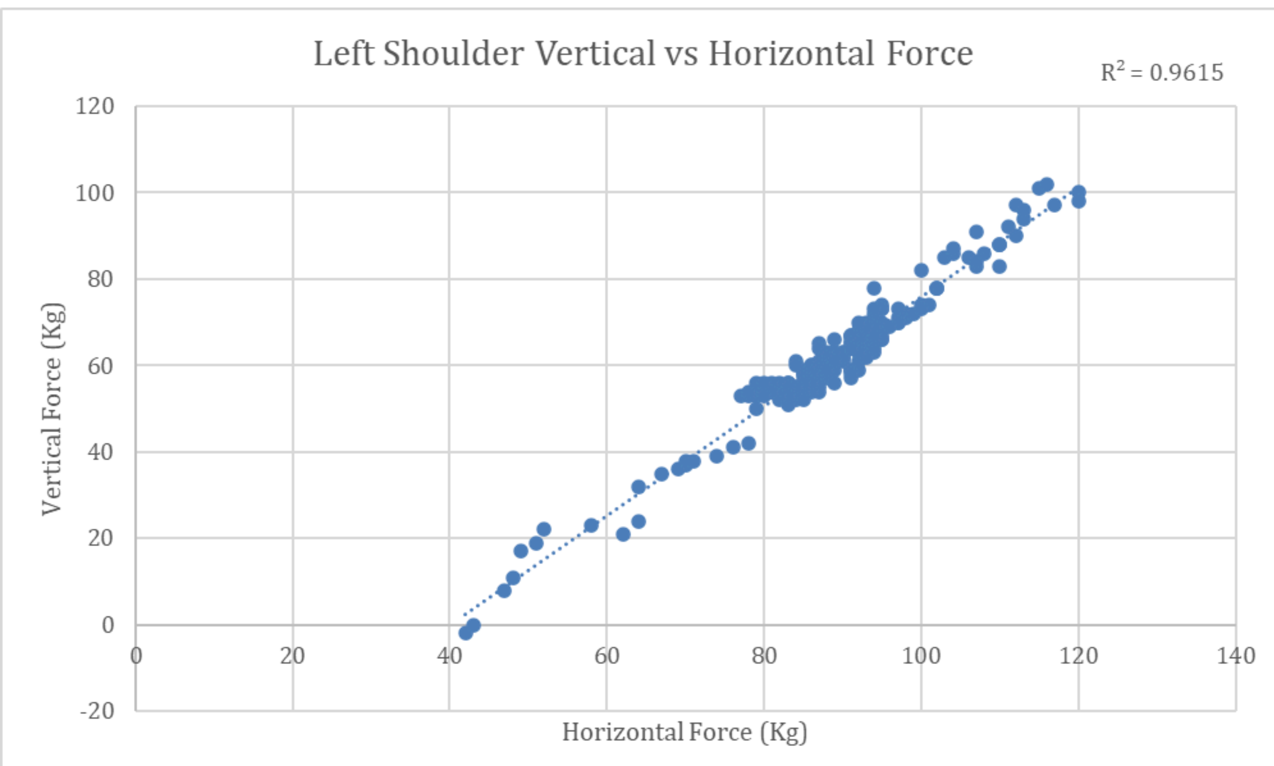
Run 8: Right Shoulder



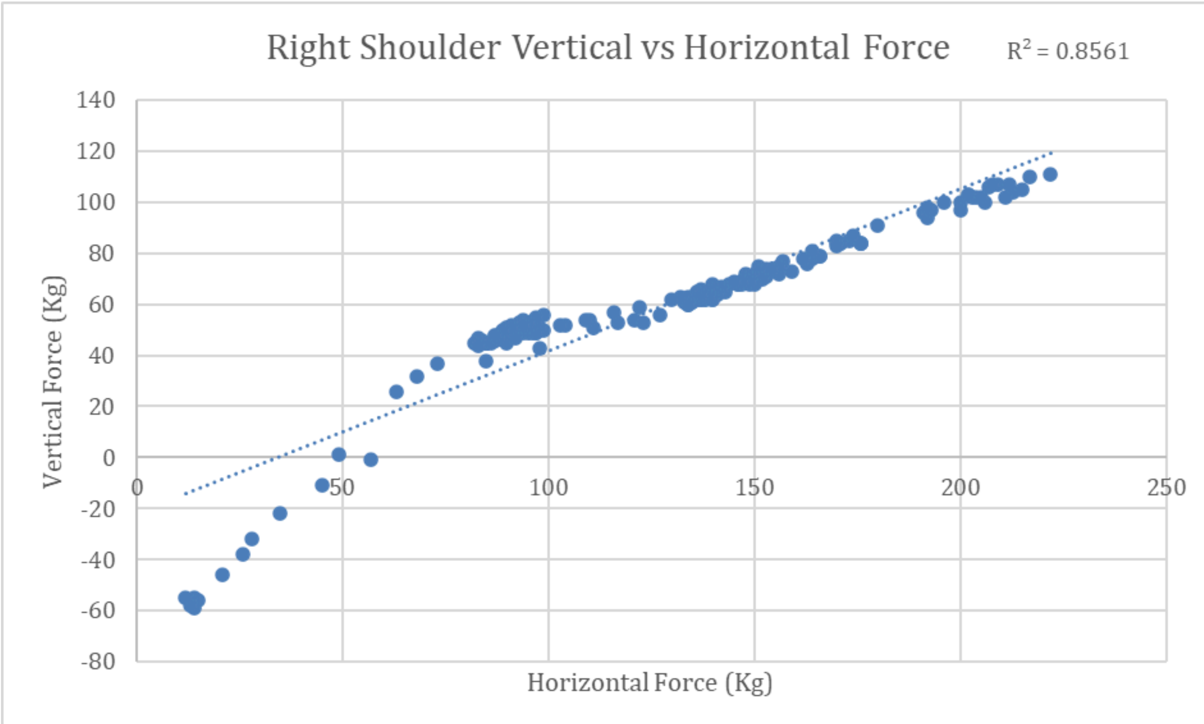
Run 8: Left Shoulder



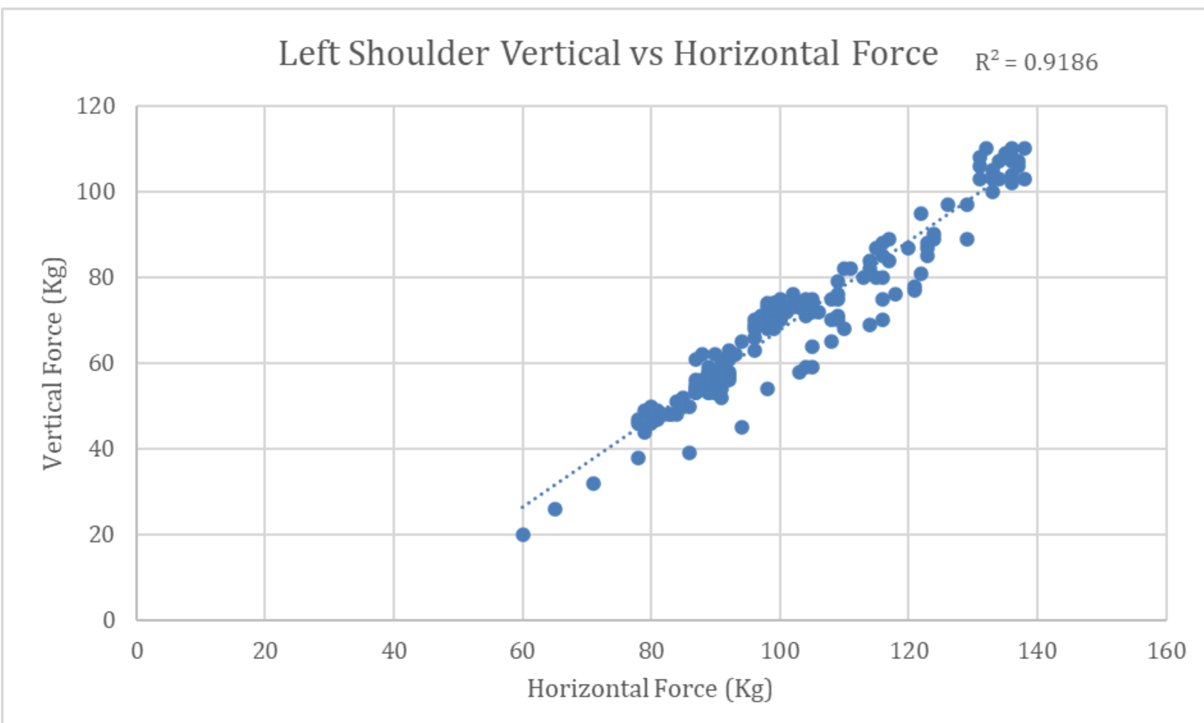
Run 9: Right Shoulder



Run 9: Left Shoulder



Run 10: Right Shoulder



Run 10: Left Shoulder