Load Distribution During Strength Training for Athletes with Cerebral Palsy

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Masters Thesis

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Declaration

I certify that this thesis does not incorporate without my knowledge any material previously submitted for a degree in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed:

Date:

9/2/2018

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Abstract

For athletes with cerebral palsy (CP), understanding how well they train is extremely important. It is important that when they undergo strength training that their unaffected side isn't compensating for their affected side. The coaches and trainers play a crucial role in monitoring the athletes and ensuring that they are training correctly. However, it is difficult to identify if the athletes are training correctly. Therefore, technology can be used to measure the athletes load distributions during a strength training exercise to guarantee both limbs are being trained equally. Devices such as force plates can be extremely expensive and hard to use, stopping coaches from monitoring their athletes. A possible solution to this is the Nintendo Wii Balance Board (WBB). The WBB is capable of measuring load distributions by manipulating the weight measurements obtained from its 4 strain gauges. The portability and low cost of the Wii Balance Board make it an ideal device.

This report documents the process of using the Wii Balance Board as an alternative force plate capable of measuring the load distribution during a strength training exercise.

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Glossary

CoP	Centre of pressure
CP	Cerebral Palsy
SASI	South Australian Sports Institute
SEBT	Star Balance Excursion Test
WBB	Wii Balance Board

Part I: Introduction

According to Rosenbaum et al., 'Cerebral Palsy (CP) describes a group of permanent disorders of the development of movement and posture causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing or fetal or infant brain' [35]. However, this does not stop many individuals with CP from pursuing their goals and participating in competitive sports. Athletes with CP can experience symptoms such as: muscle weakness, spasticity, asymmetries in balance and unequal load distributions. Strength training is the most common form of physiotherapy used to reduce the symptoms of CP. Athletes with CP generally follow a strength training program similar to an able-bodied athlete. Strength training coaches are essential in ensuring athletes are training with correct technique. During exercises such as double leg press or squats, athletes may have uneven load distributions or asymmetries in their movements. Consequently, this can reduce the effectiveness of training exercises. Determining uneven load distribution can be challenging as athletes and coaches may not realise when the unaffected limb is compensating for the affected limb. The ability to measure load distribution during strength training allows coaches to monitor the athletes, ensuring they are evenly strengthening muscles of the affected and unaffected limbs. Currently on the market, there is a lack of easy to use and affordable devices that allow users to measure their load distribution. Therefore, this project aimed to use a Wii Balance Board as a cheap alternative force plate to measure load distributions during strength training exercises.

In this chapter, the condition of cerebral palsy is introduced and a brief summary of the symptoms associated with each type of CP. As mentioned, strength training is a common form of physiotherapy used to reduce the effects of CP. There are a number of exercises that an athlete can perform based on what muscle they want to strengthen. This thesis will focus on the leg press and squat exercise as they are easy to measure using the Wii Balance Board.

1.1 Cerebral Palsy

Cerebral Palsy (CP) describes a group of permanent disorders of the development of movement and posture causing activity limitation [35]. Common symptoms of cerebral palsy include lack of balance, weakened muscles, lack of postural control and asymmetries in movement. Cerebral palsy is generally classified by the area of which the body is affected (hemiplegia, diplegia and quadriplegia) and the type of neurologic impairment [1]. Figure 1 shows the four types of neurologic impairment to the motor system used to classify cerebral palsy and the likelihood of an individual having that form of neurologic impairment.

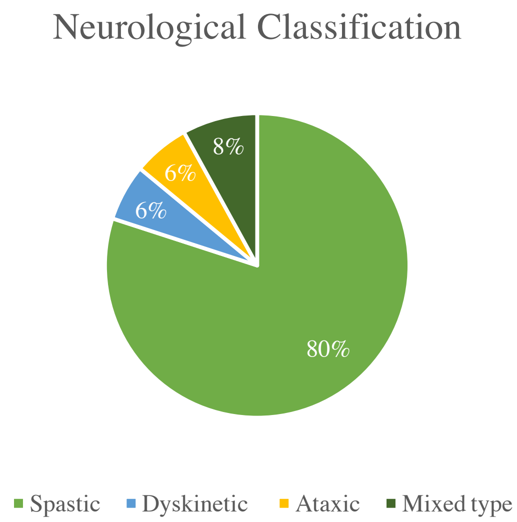


Figure 1: Neurological classification of cerebral palsy [7]

1.1.1 Spastic Cerebral Palsy

Spastic cerebral palsy is the most common form of CP, with 70-80% of individuals having this form [7]. It is caused when the motor cortex is damaged and is characterized by an increase in muscle tone, causing the affected muscles to become stiff and movements to become jerky [10, 11]. Stiffness of the muscle also depends on the speed of the movement. Therefore, when an individual with spastic CP attempts to move quickly, the affected muscle becomes stiffer than if the movement was executed slowly [11]. In lower limbs, spasticity typically causes internal rotation and adduction of the hips, causing flexed posture and a pigeon-toed gait [10]. On the other hand, spasticity of the upper limbs can cause flexion of the elbow, wrist and fingers, making it difficult to lift and grasp objects [11]. It can also affect facial muscles and the tongue, causing slurred and slowed speech [11].

1.1.2 Dyskinesic Cerebral Palsy

Dyskinesia makes up approximately 6% of all CP cases. It occurs when the basal ganglia is damaged. The basal ganglia is responsible for regulating voluntary movements as it interprets messages between the limb and spinal cord [12]. Consequently, damage to this region of the brain can result in involuntary movements of the effected limbs [7,12]. There are three forms of dyskinesia, including dystonia, chorea and athetosis, each with varying affects to the body. Dsytonia causes abnormal postures, slow and repetitive movements due to involuntary muscle contractions [12]. Chorea causes involuntary movements to be abrupt, irregular and unpredictable and finally, athetosis causes slow and continuous movements [12].

1.1.3 Ataxic Cerebral Palsy

Ataxic CP is caused by damage to the cerebellum and makes up approximately 6% of all cases [7, 13]. It is characterized by imprecision and instability, which causes movements to appear unsteady and shaky. Consequently, an individual with ataxic CP will have decreased balance and muscle coordination [13]. In the upper limbs, ataxia causes arms to tremor and overshoot when reaching for objects [13]. For lower limbs, ataxia affects walking, causing individuals to fall. Therefore, to compensate this, a 'wide-base gait' is adapted so that the feet are spread wider than the hips [13].

1.1.4 Mixed Type Cerebral Palsy

In some cases, it is not possible to classify one specific type of CP as an individual may show symptoms of more than one type of CP. The most common form of mixed type CP is dyskinesia with spasticity [10].

1.1.5 Topographical Classification

Cerebral palsy can also be classified by identifying areas of the body that exhibit symptoms. Figure 2 shows the three region-based classifications used to identify areas of the body affected. Hemiplegic CP is the most common, with 39% of individuals having this form of CP [13]. It affects one side of the body and depending on the type of neurological impairment, the symptoms of CP can only be seen on the affected side. Diplegic cerebral palsy is a form of bilateral CP affecting lower limbs of the body. This means that depending on the type of neurological impairment, only the lower limbs exhibit symptoms. Finally, quadriplegic cerebral palsy affects all 4 limbs of the body and symptoms can also affect the facial muscles.

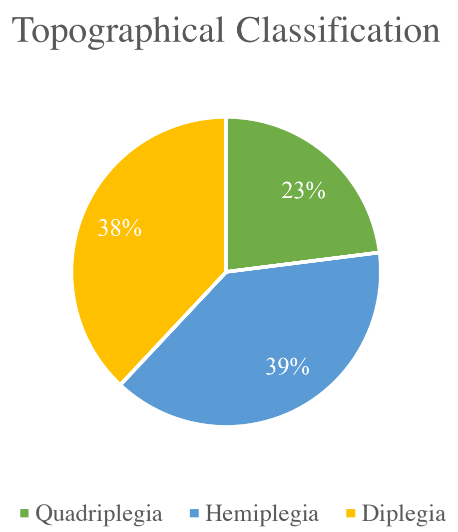


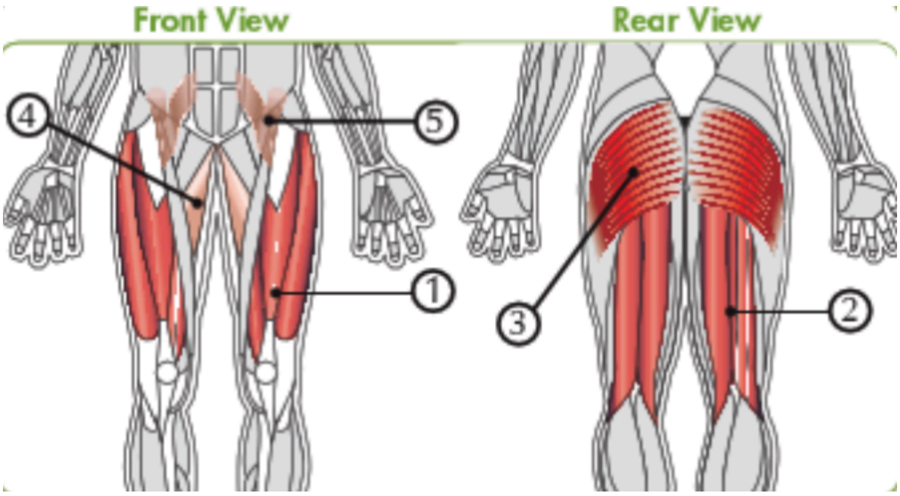
Figure 2: Topographical classification of cerebral palsy [7]

1.2 Strength Training

To improve performance during competition, athletes undergo strength training exercises such as: squats, leg presses and weights [33]. For athletes with cerebral palsy, strengthening exercises are important because it helps reduce spasticity and weakness, allowing for better performance [26]. Therefore, by integrating strength training exercises to an athlete's training program, helps to maintain and improve their performance. Currently, athlete's train with trainers and coaches and follow a training program. These training programs are tailored to suit the needs of the athletes. The two main strength training exercises focused in this study are squat exercises and leg presses as they can be easily measured using a Wii Balance Board.

1.2.1 Squat exercise

The squat is a commonly used strength training exercise that involves most muscles in the lower limbs [33]. The muscles that are activated during a squat include the quadriceps, hamstrings, buttocks, hip flexors and inner thighs. There are two main phases of the squat exercise: the lowering phase and the standing phase. During the lowering phase, the athlete moves from the standing position to a squat position and the muscles will lengthen as they contract, which is also known as eccentric contraction. Following the lowering phase or concentric contraction, muscles will shorten and as a result, the lower limbs and trunk return to the upright position. This is known as the standing phase.



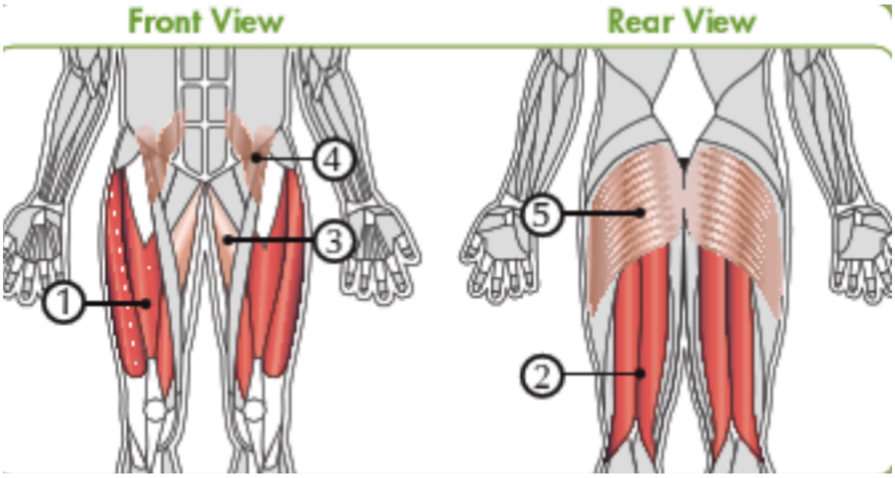
Targeted Muscles:
1. Quadriceps
2. Hamstrings
3. Gluteus Maximus

Additional Muscles:
4. Adductors
5. Hip flexors

Figure 3: Muscles that are targeted during a squat exercise [33]

1.2.2 Leg Press Exercise

The leg press exercise is another common strength training exercise used by athletes to build strength and endurance [33]. The muscles that are targeted during this exercise include the quadriceps and hamstrings. Similar to the squat exercise, there is an eccentric and a concentric phase. Individuals begin in the 'bent-knee' position, which is the starting position [33]. Concentric contraction occurs when the athlete's legs are straightened from the starting position. At the completion of the concentric phase, the legs are extended. The eccentric phase occurs where the legs return from full extension to the starting position. During this eccentric phase, the quadriceps's will eccentrically contract and causing muscles to lengthen.



Targeted muscles:
1. Quadriceps
2. Hamstrings

Additional muscles:
3. Inner thighs (adductors)
4. Hip flexors
5. Gluteus maximus

Figure 4: Muscles targeted during a leg press exercise [33]

1.3 Wii Balance Board

The Nintendo Wii Balance Board (WBB) was released worldwide in 2008. It is used in conjunction with the Wii Fit game and connected via Bluetooth to the Nintendo Wii console. Nintendo's goal in releasing the WBB was to encourage exercise and for players to become more active. Nintendo designed a number of easy to follow games aimed to encourage users to continue playing daily. The games require users to do a number of actions while the WBB tracks their centre of pressure and load distributions during the game. Once the games are over, the player is given a score indicating their fitness level.

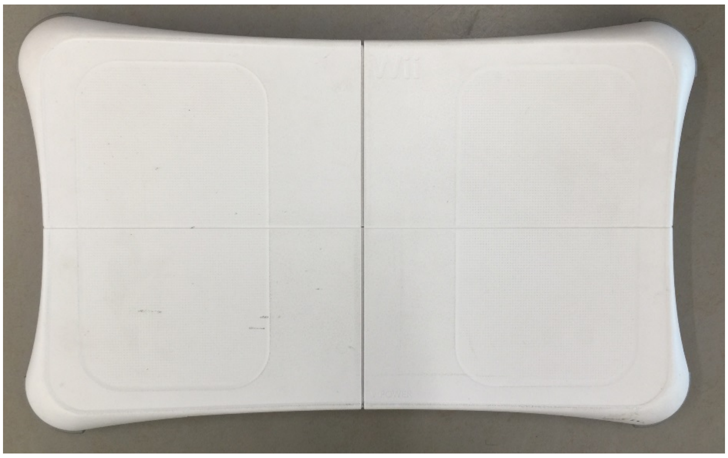


Figure 5: Wii Balance Board

The development of the Wii balance board has piqued the interest of researchers in a number of fields as an alternative force plate. If modified correctly, the it can measure the centre of pressure and load distributions. The main advantage of using the WBB as an alternative force plate is its low cost. The cost of laboratory grade force plates can range from anywhere between

$5,000-$70,000 USD, which is significantly more expensive than a Wii Balance Board, which can cost anywhere between $15-$100 [8, 18, 20, 24]. Other advantages of using the WBB include its ease of use, compact size and commercial availability [8].

1.4 Summary

There are a total of 7 chapters detailing the process of this project. Chapter 2 is literature review outlining the use of the Wii Balance Board as an alternative force plate. In chapter 3 outlines the process of how the Wii Balance Board is modified in order to measure the load distribution. The chapter also outlines the project aims, the components used and the programming of the Wii Balance Board. Chapter 4 then focuses on the study design and methodology, and results will be presented in chapter 5. Chapter 6, discusses the results obtained and aims to understand the load distributions of the athletes. Finally, chapter 7 will suggest possible future work for the development of the Wii Balance Board as an alternative force plate.

Part II: Literature Review

This chapter provides a brief overview on ways that the Wii balance board can be used to measure load distributions and how it could potentially be an alternative force plate. This chapter also touches on the importance of strength training and current devices used to measure load distributions and asymmetries.

2.1 Current Methods used to Measure Centre of Pressure, Load Distribution and Asymmetries

Individuals with cerebral palsy, undergo strength training to improve their posture, balance and gait. There are several tests used to assess an individual's posture and balance. These tests include the Berg balance scale, timed up and go (TUG) test and the star excursion balance test (SEBT) [8]. The advantage of using these tests is that they do not require additional equipment and are easy to follow [2]. A study by Gribble et al. reviews the usefulness of the SEBT as a clinical tool for quantification of postural control deficits [2]. The test requires the individual to do a series of single-limb squats and reach as far as possible along 8 marked lines on the ground with the opposite leg. These lines are marked in a star configuration with 8 points (Figure 6). If the individual misses the marked line or touches the line heavily, then the test is considered to be incomplete. Gribble et al. found that the SEBT was a reliable test and was able to identify dynamic balance deficits [2]. However, one of the limitations with the SEBT is not knowing what a light or heavy touch is, therefore while the test is easy do, an expert is required to administer the test to obtain valid results.

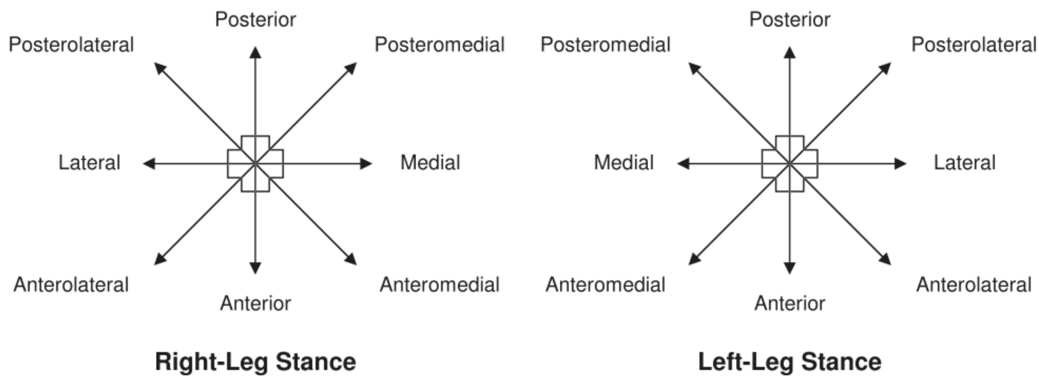


Figure 6: Configuration of the star balance excursion test. These lines are marked on the floor and the participant must reach as far as possible on each of the 8 marked lines [2]

Force plates can be another method of measuring balance and load distributions as they are able to measure postural sway, asymmetries and imbalances [3, 18, 25]. However, the use of force plates to measure balance and load distributions aren't always feasible as they are generally used for individuals who require medical testing to help clinicians assess the individual's movements. For professional athletes, the use of force plates can help coaches assess their movements, in order to better understand load distributions and imbalances when they are training. Monitoring an athlete's movement will allow coaches to assess how well they are performing and how they can further improve their performance. As studies have shown that individuals who are functionally symmetric have an improved athletic performance and are less likely to become injured [17]. However, force plates, are not readily available and have a number of disadvantages that hinder their use in a gym setting [3,18]. One of the main limitations is that they are extremely expensive, ranging from $5,000-$70,000 USD [8, 18, 20, 24]. In addition to this, the coach must be trained to use the force plate and a laboratory setting may be required to ensure the force measurements are accurate [3]. These factors hinder the use of force plates. Therefore, are not used in gyms or by coaches to monitor an athlete.

2.2 Wii Balance Board

2.2.1 Accuracy and Reliability of the Wii Balance Board

Wii Balance Boards and force plates are both able to measure force distributions and centre of pressure (CoP). Center of pressure is used to define the point at which the resultant of all the ground reaction forces act. Force plates are considered to be the gold standard in measuring force distributions and CoP. Therefore, it would be extremely difficult for an affordable gaming device to compete with a force plate's accuracy and reliability. However, studies have shown that Wii Balance Boards have several advantages and could potentially be used as an alternative to force plates [8, 20]. However, before WBB can be considered an alternative, the device's accuracy and reliability must be understood.

Bartlett et al., conducted a standard measurement uncertainty analysis, which aimed to quantify the Wii Balance Boards repeatability and accuracy for CoP measurement used in postural sway [3]. They conducted this test using a total of 9 Wii Balance boards, 3 were lightly used and the other 6 were heavily used. Testing with 9 Wii Balance Boards provided a better understanding of how wear affects the accuracy of a centre of pressure measurement and measurement variability. Bartlett et al. developed a protocol that uses 12 calibrated masses, with a range of 0.2-22.5kg, which were placed on the Wii Balance board's 4 sensors. The calibrated masses are placed on the sensor for 0.5 seconds and data is recorded. This step was repeated for each sensor. The authors found that the WBB had a total uncertainty of force measurement to be ±9.1N and a CoP location within ±4.1mm [3]. In addition to this, Bartlett et al. found that wear doesn't affect the CoP measurements and that the Wii Balance Board's internal calibration was very similar to the weighted masses. Overall Bartlett et al. determined that the Wii Balance Board may not be an ideal replacement to a force plate if the measurement was postural sway. However, it was concluded that the Wii Balance Board can be used as an alternative for force and CoP measurements if a lower accuracy was acceptable.

In 2009, Clark et al. examined the Wii Balance Board's validity with a force plate by measuring balance in 30 individuals [18]. This study required each participant to do a series of 4 standing tests on both a Wii Balance Board and a force plate. Statistical analysis was done on both devices and then compared. Intra-class correlation coefficients (ICC), Bland-Altman plots (BAP) and minimum detectable change (MDC) were calculated. The results showed that the Wii Balance Board was able to produce data that was comparable to the force plate for measuring balance. However, Clark et al. stated that the validity of the Wii Balance Board may be reduced if the rapid, high force movements, such as jumping and running, were measured instead [18]. Clark et al. concluded that the Wii Balance Board would be a viable alternative for a force plate as laboratory grade force plates are expensive and not readily available [18].

Similar to Clark et al., Huurnink et al., (2013) measured CoP using the Wii Balance Board and a force plate simultaneously, by placing the Wii board on top of the force plate; allowing subject variability to be eliminated. The study had 14 subjects who were asked to do a series of three balance tests: a single legged stance with their eyes open, single legged stance with their eyes closed and a sideways hop; with each task lasting about 10 seconds [25]. The results show that the instantaneous estimates of CoP between the Wii Balance Board and the force plate were very similar; with a very high Pearson's Correlation coefficient of the CoP trajectories (x: 0.999±0.002; y: 0.998±0.003) [25]. However, Huurnink et al. found that there was an overestimation in the CoP path, which was caused due to noise present in the Wii

Balance Board [25]. Despite these limitations, Huurnink et al. concluded that the WBB is sufficient for measuring CoP.

2.2.2 Uses of the Wii Balance Board

In addition to releasing the Wii Balance Board, Nintendo developed a game called *'Wii Fit'* which is used in conjunction with the Wii Balance Board. The Wii Fit game has a number of interactive mini games that are designed to entertain and encourage players to be active. The player stands on the Wii Balance Board during play and once the mini-game is complete, a score of the players balance is given. Studies have shown that these mini-games are not able to measure and analyse a player's balance and centre of pressure accurately [19]. Wikstrom (2012), conducted a study to test the validity and reliability of the Wii Fit balance scores, which was then compared with data from a force plate. For the study there were 45 participants, and each participant was asked to complete a single-limb-stance task on a force plate, the Star Excursion Balance Test (SEBT) and then 12 Wii Fit balance games. The results show that there was a '*poor concurrent validity relative to CoP outcomes and SEBT reach distances'* [19]. This means that while the Wii Balance Board is able to accurately measure centre of pressure and force, the Wii Fit game is not a good program to present data on balance and CoP.

In order to use the Wii Balance Board to its full potential, custom programs are required to ensure that data presented to the user is correct. There have been several studies that have developed and programmed custom applications to present the data obtained from the Wii Balance Board. Foo et al. (2013) developed a custom program that provided real-time feedback to evaluate and improve weight bearing asymmetry in 20 people with different neurological conditions such as: cerebral palsy, stroke and a traumatic brain injury [20]. Each of the participants were required to perform three trials that consisted of 2 tasks [20]. The Wii Balance Board was used with the customised program, to display visual feedback of their weight bearing asymmetry [20]. This study showed that the program was able to display what the participants saw when they performed static standing and the sit-to-stand task. During the task, if there was equal weight distribution then the left and right bars were green (Figure 7). However, if there was asymmetrical weight bearing, then the bars were orange, indicating that during the task their weight is loaded more to the left [20]. Foo et al. concluded that the Wii

Balance Board provided a positive response from participants during the tasks as it provided real-time feedback that allowed them to correct their weight distribution [20].

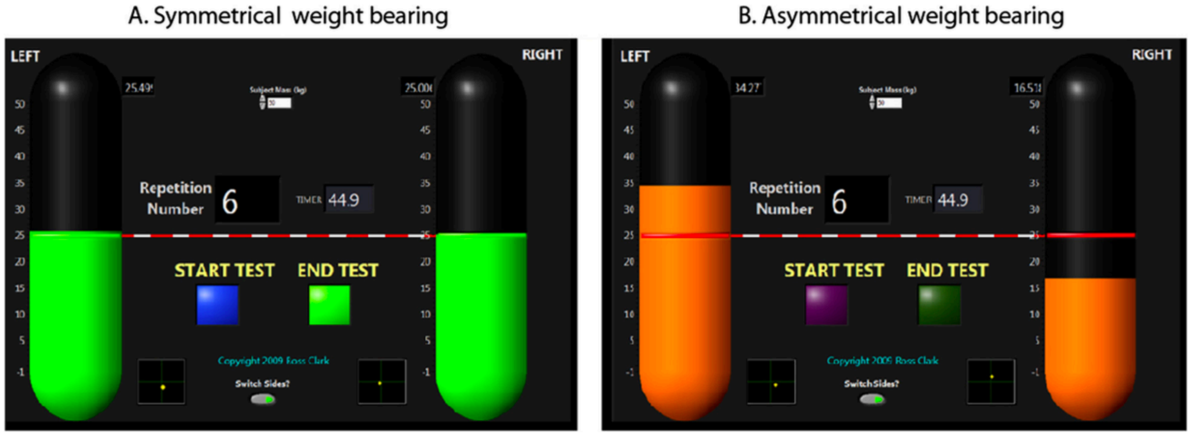


Figure 7: Figure A displays green vertical bars to indicate that there is a symmetrical load distribution between the left and right sides. Figure B displays orange vertical bars when there is asymmetrical weight bearing [20].

A study in 2011 by Kennedy et al. developed software called WeHab, which aimed to measure a stroke patient's center of pressure during a normal rehabilitation exercise [21]. The WeHab system used two Wii Balance Boards that allows for a wider base of support for subjects who are not steady [21]. The WeHab software measured the subject's balance during tasks such as sit-to-stand transition and weight shifting; allowing therapists to objectively measure the subject's performance during these tasks. Over 20 patients were involved in the pilot study, however, only 5 subjects used the WeHab program more than twice. Therefore, it is difficult to identify if the program would be a useful tool [21]. However, the use of the Wii Balance Board as a rehabilitation device was well received by therapists as it provided a more objective diagnosis of subjects [21].

2.3 Importance of Strength training

Common symptoms of cerebral palsy include weakness, spasticity and lack of coordination, affecting an individual's ability to perform tasks such as walking [26]. If an individual does not participate in daily activity, their condition can deteriorate and worsen [27]. For adults living with cerebral palsy, they must maintain a higher level of fitness to offset the decline of function due to their condition [27]. Strength training is a common physiotherapy intervention used by clinicians to help individuals manage their symptoms. An in-depth review by Dodd et al. found that strength training is effective in improving muscle strength, while also improving spasticity [26]. Not only does strength training help reduce the symptoms of cerebral palsy, but it is commonly accepted that undertaking strength training will improve sporting performance. McGuigan et al. found that there is a strong correlation between physical capabilities that are improved through strength training and sport specific skills like speed and agility [33].

2.4 Summary

This literature review shows the need for a cheap, easy to use and assessable force plates. Many studies have shown that the Wii Balance Board can be considered as an alternative force plate as it is able to measure centre of pressure and balance accurately and only costs a fraction of laboratory grade force plates. The low cost of the Wii Balance Board will allow not only athletes but individuals with cerebral palsy, the opportunity to track their centre of pressure to better understand their condition and in order to improve their wellbeing.

Part III: Development of Wii Balance Board

This chapter describes the project aims, requirements and work carried out to design and implement of the Wii Balance Board in order to record load distribution during a strength training exercise. This chapter primarily outlines the components and data recording software used.

3.1 Project Aims

The main goal of this project was to record the load distribution of a strength training exercise using a Wii Balance Board. Currently, there is a lack of affordable devices that can measure load distributions. Therefore, the Wii Balance Board could provide a possible alternative to expensive force plates. Another aim is for the Wii Balance Board to be able to measure the smoothness of movements in real time. Finally, this project also aimed to identify if the data collected using the WBB is useful to trainers.

3.1.1 Project Requirements

Based on the project aims, whilst keeping hardware restrictions in mind, a set of project requirements for the modification of the Wii Balance Board to measure the load distribution were developed. The requirements of the project are:

- Easy to set up
- Be portable and compact allowing it to be used in any setting
- Display load distribution data in real time so that strength training coaches can monitor their athletes
- Be accurate
- Reliable and stay connected when in use

3.2 Hypotheses

- Athletes with cerebral palsy will have more imbalances in load distributions than able bodied athletes
- Unequal load distribution will be more present during a squat exercise than a leg press exercise.

3.3 Wii Balance Board

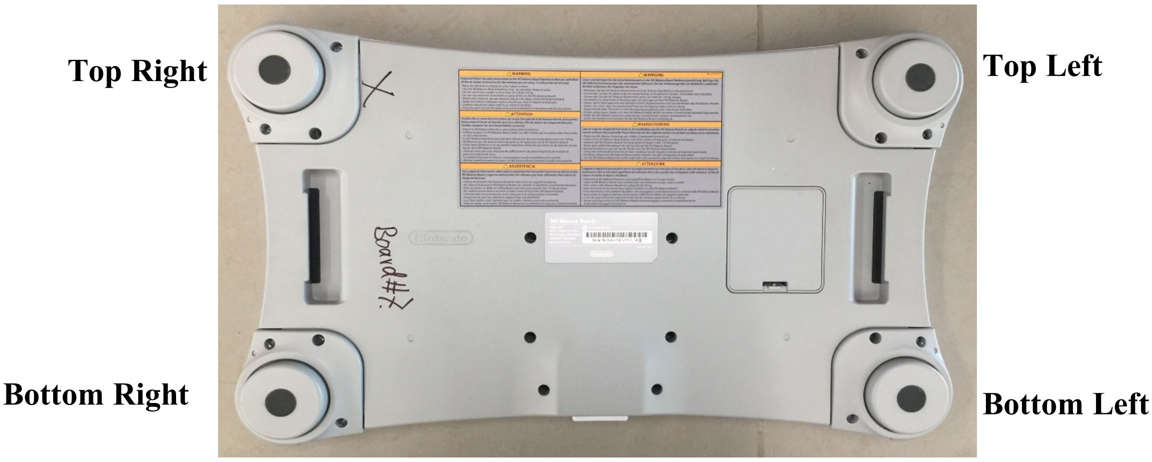


Figure 8: The back view of the Wii Balance Board with the four sensors labelled

The Wii Balance Board has a width of 430 mm and a height of 230 mm and has four load cells, measuring vertical forces, placed on each corner of the board (Figure 8). To obtain reliable measurements of centre of pressure, athletes must place their feet within the Wii Balance Board. Each load cell consists of a cantilevered metal bar with a strain gauge that converts force to a voltage. The data is then transmitted wirelessly via Bluetooth to an interfacing device. The WBB uses Bluetooth HID protocols to send sensor information to a computer. The Wii Balance Board has a recorded sampling frequency of 100Hz, which is higher than the recommended minimum 40Hz required for measuring postural sway [1, 3]. It is powered by four AA batteries (Figure 9), which is able to power the board for roughly 60 hours. It is recommended that only 150 kg should be placed on the WBB, however there are studies that have reported using higher weights [3]. The Wii Balance Board has a power button located at the bottom edge of the board and a synchro button which is located underneath the battery cover.

Figure 9: Sync button must be pressed in order to connect the Wii Balance Board with the Arduino

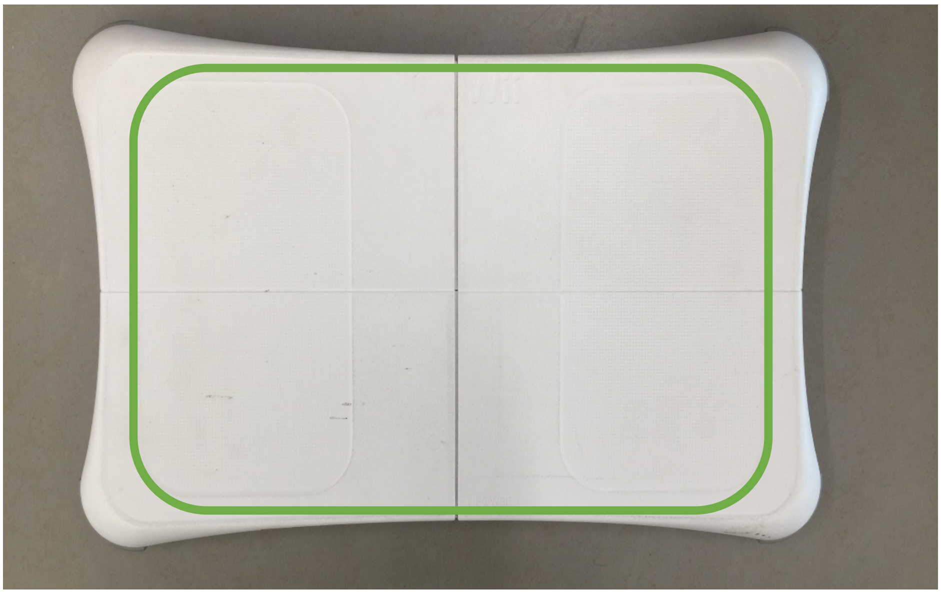


Figure 10: The green rectangle outlines the area in which the athletes should place their feet in

3.4 Hardware

To obtain data from the Wii Balance Board, there are several components required to allow the WBB to interface with the laptop. The Arduino Uno is a microcontroller based on the ATMega328P chip [6]. It is one of the most popular development boards available as it is easy to use and compatible with most shields; making it an extremely versatile board. The Arduino Uno has an operating voltage of 5V and can be powered via an AC-DC adaptor or it can be connected to a computer via a USB-B cable [6]. The Arduino Uno has 14 digital input/output pins and 6 analogue inputs.

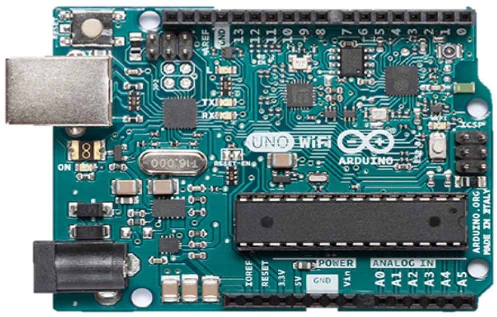


Figure 11: Arduino Uno [6]

The Wii Balance Board has Bluetooth connectivity allowing for easy connection without the need of additional cables to be connected to the laptop. However, the Arduino Uno does not have Bluetooth connectivity. A Bluetooth dongle and a USB host shield were purchased to allow for Bluetooth connectivity between the Wii Balance Board and the laptop. The Bluetooth dongle will be attached to the USB host shield and the USB host shield is then connected to the Arduino UNO.

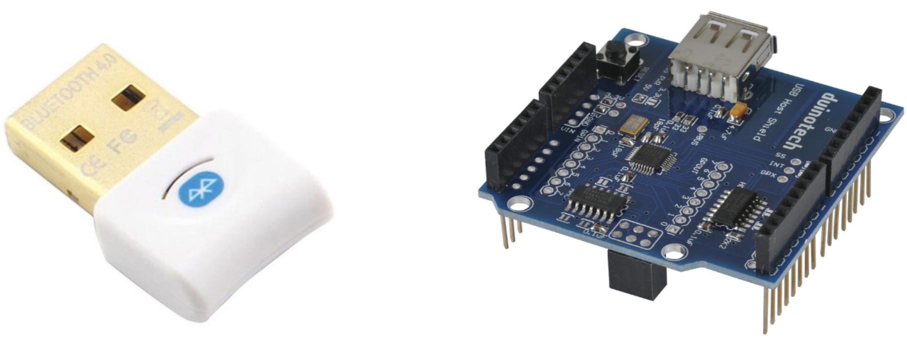


Figure 12: A Bluetooth dongle and a USB host shield was used in order to connect to the Wii Balance Board. The pins of the USB host shield are connected to the Arduino Uno [4, 5].

3.5 Calibration of the Wii Balance Board

As mentioned, the Wii Balance Board was first released in 2008, therefore it has been available on the market for almost 10 years. A total of 10 Wii Balance Boards were purchased for this study. The boards were all purchased second hand from gaming stores so nothing was known about the frequency of use by previous owners. To ensure that the sensors of the Wii Balance Boards were not damaged, testing was carried out to ensure that readings obtained were accurate. Similar to the study conducted by Bartlett et al., a number of calibrated weights were placed on the sensors of the Wii board [3]. Weights of 2-12kg were used and placed on the two left and two right sensors of the board. The program developed displayed the weight measured by the sensor. Figure 13 outlines the process that was used to determine if the Wii Balance Board was acceptable for measuring load distribution.

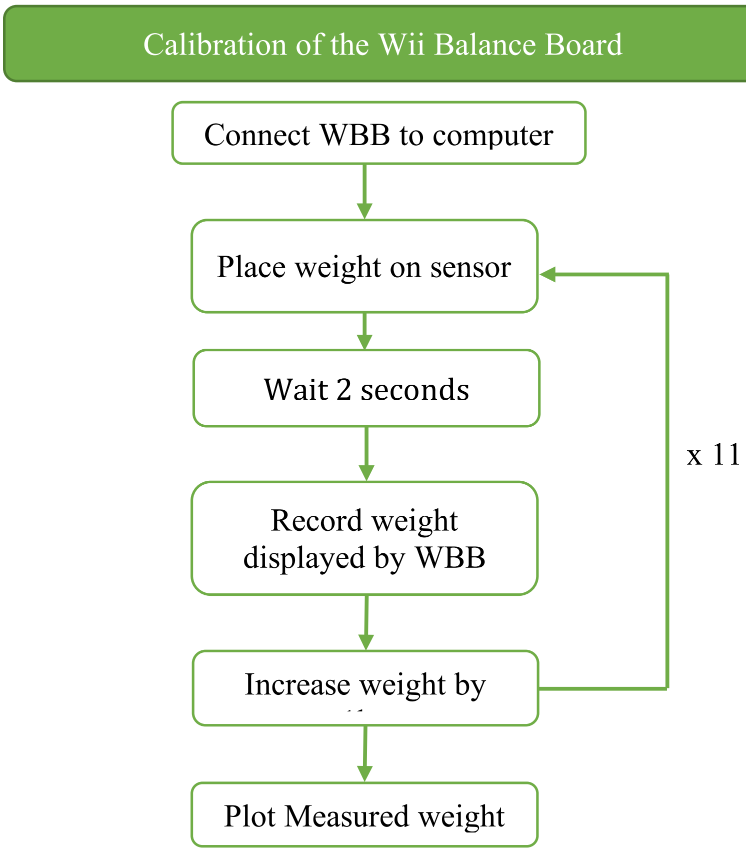


Figure 13:Flow chart outlining testing protocol of the sensors of the Wii Balance Board

Of the 10 boards purchased, only 4 boards were usable and further tested, the remaining 6 boards were not tested as a value was recorded without a weight being placed on the sensor. Out of the 4 boards that were tested, 2 boards produced measurements that were similar to the calibrated weight, Figure 16 and Figure 17. Similar to Young et al., each board was tested 3 times and the average weight was calculated and plotted to find the correlation between the actual weight placed on the sensor and the weight measured by the sensor [30]. Figure 14 shows the two left sensors being tested with a total calibrated weight of 4 kilograms. The calibrated weights are placed directly on the sensors allowing for better measurement from the Wii Balance Board.

Figure 14: 4kg are placed on the left sensors of the Wii Balance Board

Figure 15: 6 kg are placed on the right sensors of the Wii Balance Board

The Figure 16 and Figure 17 show the average value recorded by the Wii Boards. The boards have a high correlation between the calibrated weight and the weight recorded by the Wii Balance Board.

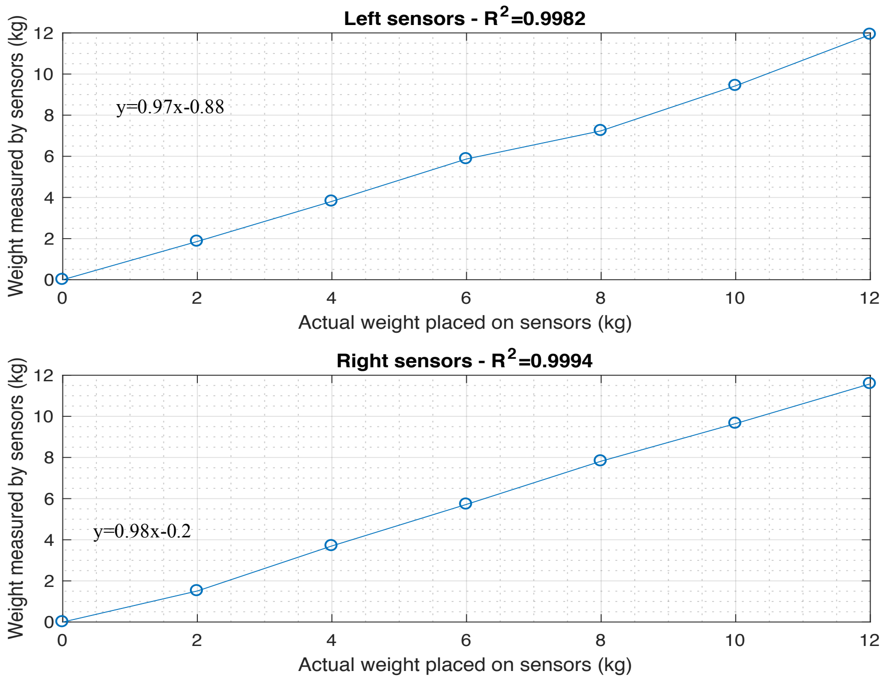


Figure 16: A line graph displaying the weight placed on the left and right sensors and the measured weight from the Wii Balance Board 1

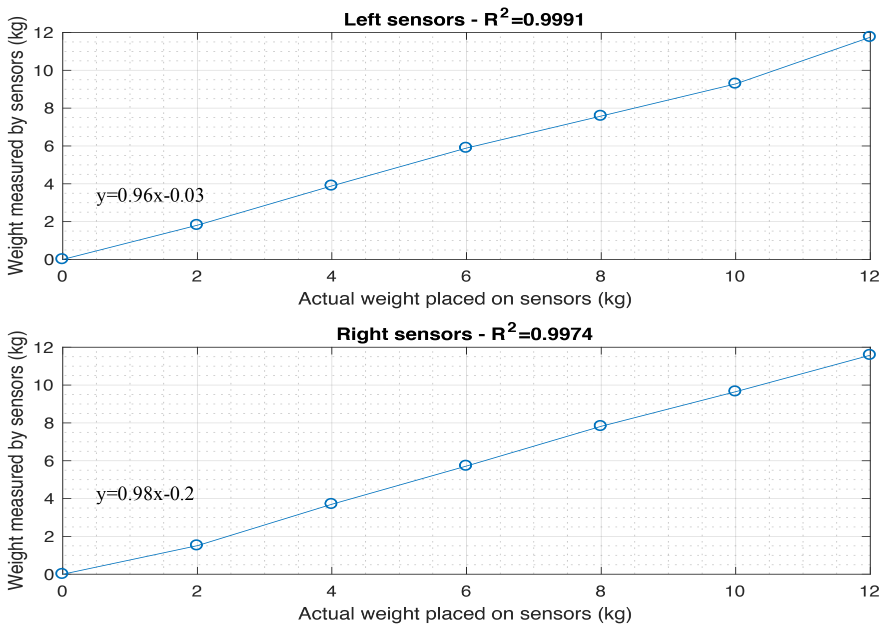


Figure 17: A line graph displaying the weight placed on the left and right sensors and the measured weight from the Wii Balance Board 2

3.6 Software and Code

The Arduino Uno requires the Arduino IDE to program and upload the code. The serial monitor on the Arduino IDE displays data from the sensors and the left and right load distributions. However, saving data straight from the Arduino IDE is not possible, therefore, another program was required. CoolTerm is a freely available serial port terminal application that can be used with the Arduino [29]. It has data logging capabilities that do not require additional hardware. Once the Arduino code was uploaded to the Arduino Uno, the Arduino was connected to the laptop via USB which enables a connection to CoolTerm. The baud rate of the Arduino Uno and CoolTerm are both set to 1153200.

3.6.1 Load Distribution Calculation

To measure the load distribution between left and right side of the body, the Wii Balance Board was divided into left and right sides. The equations below calculate the left and right load distribution percentages. For example, to determine the load distribution percentage of the left side, the weight recorded by both left sensors are added together and divided by the total weight measured by all four sensors; this will produce a percentage value. Therefore, if more weight is measured by the left sensors, this indicates that the left leg is bearing more of the load and there will be a higher left load distribution percentage during the exercise.

$$Load\ distribtion\ left\ (\%) = \frac{top\ left\ weight + bottom\ left\ weight}{Total\ weight} \times 100$$

$$Load\ distribution\ right\ (\%) = \frac{top\ right\ weight + bottom\ right\ weight}{Total\ weight} \times 100$$

3.6.2 Load Distribution Code

The Wii Balance board is considered to be a Human Interface Device (HID) and has protocols that need to be established in order to connect to the WBB via Bluetooth. Lau et al. developed protocols that allow for the sensor values to be used and displayed on the computer [31]. By manipulating the code, load distributions were measured and recorded. The code used can be found in Appendix G.

The code displays the weights measured by the four sensors. Based on what each sensor measured, the load distribution for the left and right sides were calculated which was also displayed on the serial monitor.

3.7 Summary

To obtain valid and reliable results from the Wii Balance Board the correct hardware and software need to be used. Once the data from the Wii Balance Board can be displayed on the computer, it was important to calibrate the Wii Balance Boards. Through calibration, only 2 of the 10 boards were used in testing.

Part IV: Study Design and Methodology

This chapter details the process in which data was collected and analysed. The objective of performing clinical trials with athletes was to determine whether the Wii Balance Board can be considered an alternative to a force plate, while also measuring and understanding load distributions present in athletes with cerebral palsy in comparison to able-bodied athletes.

4.1 Study Inclusion Criteria

- For the participants to be considered an athlete, they must competitively participate in any sporting event.
- All of the athletes participating in the study were to be over 18 years of age. The reasoning for this was that the study focuses on professional adult athletes.
- In order to participate in this study, the athlete must have a confirmed diagnosis of cerebral palsy and for the athlete to be considered an able-bodied athlete they must not have any pre-existing conditions. The reason that both athletes living with cerebral palsy and able-bodied athletes are required for this study is to have a control. Load distributions are also unknown within athletes without a physical disability. Therefore, to determine if there is a significant unequal load distribution for athletes with cerebral palsy, the load distributions of able-bodied athletes are needed.
- The athletes are required to do a leg press exercise and squats; therefore, the athlete must be able to control both lower limbs.

4.2 Ethical Considerations

In order to conduct clinical trials, ethical approval was required from the Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC). As the athletes who participated in the study compete in competitive sports, it was important that they weren't injured during testing. The weight limit of the leg press was set to a maximum of 100kg and after every 2 repetitions of each exercise, the athletes were required to take a short break.

4.3 Method of Recruitment

Once ethical approval was granted, testing began and athletes were recruited. Athletes were recruited at the South Australian Sports Institute (SASI) and Keren Faulkner, a senior physiotherapist who works at SASI, assessed which athletes would be suitable for the study. An information sheet was given to the athletes, approved by the SA HREC which outlined what is expected of the athletes during testing. A consent form (Appendix B) was given to the athletes which they were required to sign. This allowed data to be collected and analysed for the study. A questionnaire (Appendix C) was also given to each athlete to provide additional information on what kind of condition they have.

4.4 Participants

A total of 6 athletes participated in the study. Of these participants, 5 athletes had cerebral palsy and one participant was considered to be abled-bodied. The able-bodied participant was not a professional athlete but was active and did not have any physical disabilities, therefore he will be considered as an able-bodied athlete. Due to time constraints caused by the late approval of ethics and scheduling of testing with athletes, only a small number of tests were conducted. All athletes that participated in the study had a different type of cerebral palsy. Table 1 provides a general overview of each athlete's condition. One of the questions explicitly asked what type of cerebral palsy the athlete had, and surprisingly some were not sure. However, they were able to mention which side they felt was weaker and which area of the body was affected.

Table 1: Participant information

Athlete number	**Age**	**Gender**	**Main sport**	**Condition**	**Additional notes**
1	20	M	Cycling	CP	Everywhere, but more on the left side
2	27	F	Cycling	CP	-
3	22	M	-	Able bodied	-
4	30	M	Tennis	CP	Legs are mainly affected
5	20	M	Badminton	CP	Left side
6	36	M	Hand cycling	CP	-

4.5 Protocol

To obtain load distribution data, athletes were required to do two types of strength training exercises: leg presses and squats. The following flow diagram demonstrates the main steps involved in testing. The athletes were required to do a 10-minute warm up. During that time, the testing equipment was set up. Once the warm up was complete, the athletes were able to start testing. After every second repetition of either exercise, the athlete took a short break to ensure they were not fatigued. This was repeated four times to collect eight sets of data for each exercise. The overall time required from each athlete to complete testing was about 30 minutes, including the warm up time.

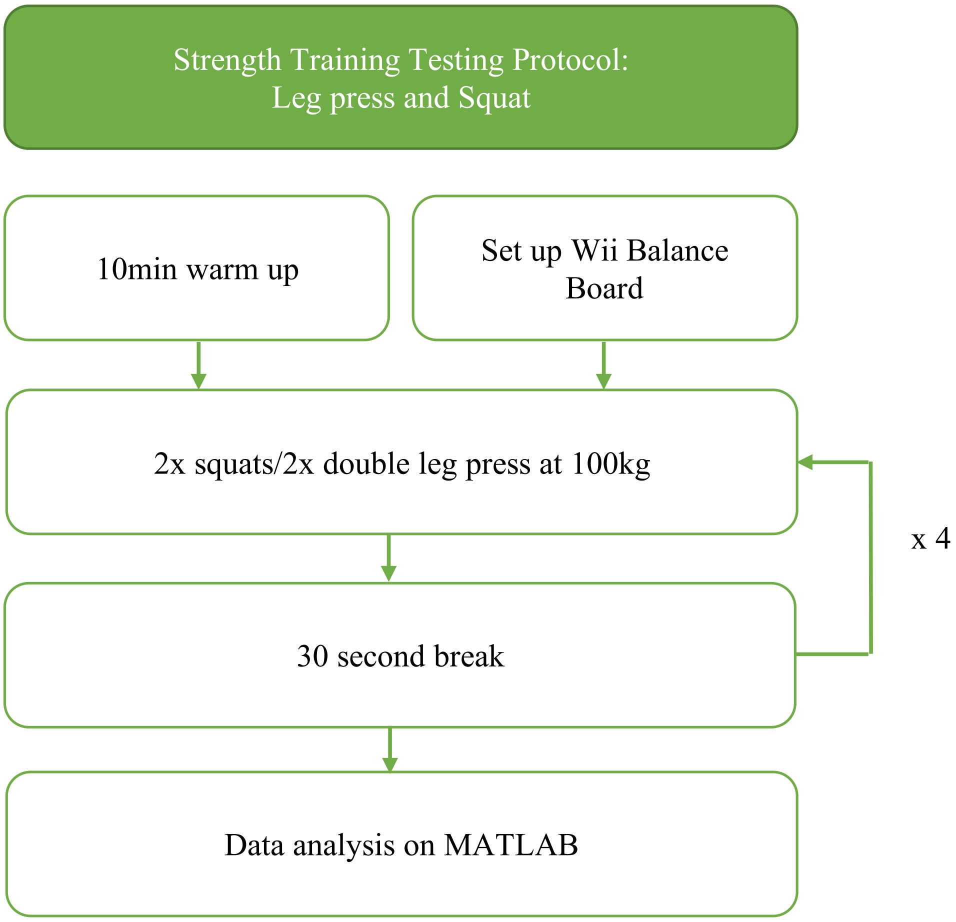


Figure 18: Testing Protocol. Between every second exercise, the athlete is to take a 30 second break.

4.5.1 Testing Set Up

Testing was conducted at the SASI gym. There were three leg press machines available and an area where athletes could perform their squat exercise.

4.5.2 Mounting of the Wii Board on the Leg Press Machine

To measure the load distribution during a leg press, the Wii Balance Board was mounted on the leg press machine. An attachment was created so that the Wii Balance Board could be safely secured to the leg press machine. An important aspect to consider in developing the leg press mount was that it would not cause any compressive forces on the Wii Balance Board therefore testing was conducted before the athletes were able to participate in the test.

Figure 19: Left: front view of the Wii Balance Board mounted on the leg press machine. Right: side view of the Wii Balance Board mounted on the leg press machine.

Figure 20:An athlete using the leg press machine with the Wii Board mounted on the leg press machine

The parts required for the mounting of the Wii Balance Board to the leg press machine were two pieces of 90mm x 12mm x 1.2 m wood and mounting tape. The two pieces of wood were cut in 6 smaller pieces, 2 pieces at 32cm, 2 pieces at 30cm and 2 pieces at 50cm. The pieces of wood where then taped to make a frame, this can be seen in Figure 22. The mount was then attached to the leg press plate using tie down straps.

Figure 21: View of the Wii Balance sensor attached to the mounting frame

Figure 22: Back view of the mounting frame used to attach the Wii Balance Board to the leg press machine

4.6 Data analysis

4.6.1 Raw Data

Information from the four strain gauges was recorded. Based on the weight placed on the sensors, the left and right load distribution percentage were calculated and measured. Table 2 displays 0.5 seconds worth of raw data and demonstrates how it was displayed on CoolTerm during testing. There was a total of 6 columns with each column displaying data of each sensor and the last two columns represented the load distribution of both the left and right side of the body. Sensor 1 represents the top right sensor, sensor 2 represents the bottom right sensor, sensor 3 represents the top left sensor and sensor 4 represents the bottom left sensor. The weights measured by each sensor and the left and right load distributions were displayed.

Table 2: Sample of raw data during an exercise

Sensor 1	Sensor 2	Sensor 3	Sensor 4	Left %	Right %
15.13	20.81	13.52	19.44	47.83	52.17
15.13	20.81	13.52	19.44	47.83	52.17
15.13	20.81	13.52	19.44	47.83	52.17
15.13	20.81	13.52	19.44	47.83	52.17
15.04	20.68	13.45	19.07	47.65	52.35
15.04	20.68	13.45	19.07	47.65	52.35
14.96	20.38	13.48	18.71	47.66	52.34
14.96	20.38	13.48	18.71	47.66	52.34
14.96	20.38	13.48	18.71	47.66	52.34
14.96	20.38	13.48	18.71	47.66	52.34
15.04	20.28	13.63	18.42	47.57	52.43
15.04	20.28	13.63	18.42	47.57	52.43
15.04	20.28	13.63	18.42	47.57	52.43
15.08	20.14	13.55	18.12	47.34	52.66
14.91	19.65	13.49	17.81	47.52	52.48
14.91	19.65	13.49	17.81	47.52	52.48
14.91	19.65	13.49	17.81	47.52	52.48
14.91	19.65	13.49	17.81	47.52	52.48
14.57	18.75	13.66	17.41	48.25	51.75
14.11	17.46	13.77	17.14	49.47	50.53
14.11	17.46	13.77	17.14	49.47	50.53
14.11	17.46	13.77	17.14	49.47	50.53
14.11	17.46	13.77	17.14	49.47	50.53

4.6.2 Data Processing

For each athlete, 16 sets of data were collected, measuring their load distributions in leg press and squat exercises. MATLAB was used to read and process data that was collected during the clinical trials (Appendix D).

Upon examination of the data, it was noted that the left and right load distribution does not provide useful information about what is happening during the exercise. Therefore, each exercise was split into concentric and eccentric phases. Providing trainers with information on which phase of the exercise was experiencing an imbalance. Concentric exercise refers to when a muscle shortens, while eccentric exercise is when a muscle lengthens.

Each set of data contains information for one repetition during the testing. To plot the eccentric and the concentric phases, the MATLAB code must be able to identify when the athlete changes between concentric and eccentric phases. It was assumed that the phase change occurs when the total weight measured by the Wii Balance Board peaks. For example, during a leg press, the maximum weight will be measured at the point where the athlete starts to extend their legs and push forward. The point where the athlete extends their legs will be considered the eccentric phase and at this point, the total weight measured on the Wii Balance Board should be the highest. The MATLAB code also accounts for errors during the start and stop of data recording. Therefore, the first 20% and last 20% of values were disregarded. Once the phases were identified and placed into a matrix, the left and right eccentric and concentric phases were plotted for each trial and each exercise. This provides an overall average of what the load distributions are each trial. By dividing one repetition into two phases, it becomes difficult to visualise what the load distribution is relative to time. Therefore, an additional graph was produced to see which side the load was distributed on during any point of the repetition and the smoothness of the movement. The stronger side applies more force on the Wii Balance Board, however, the weaker side following will slowly apply more force. This will cause changes to the load distribution as the load will slowly be transferred to the other leg.

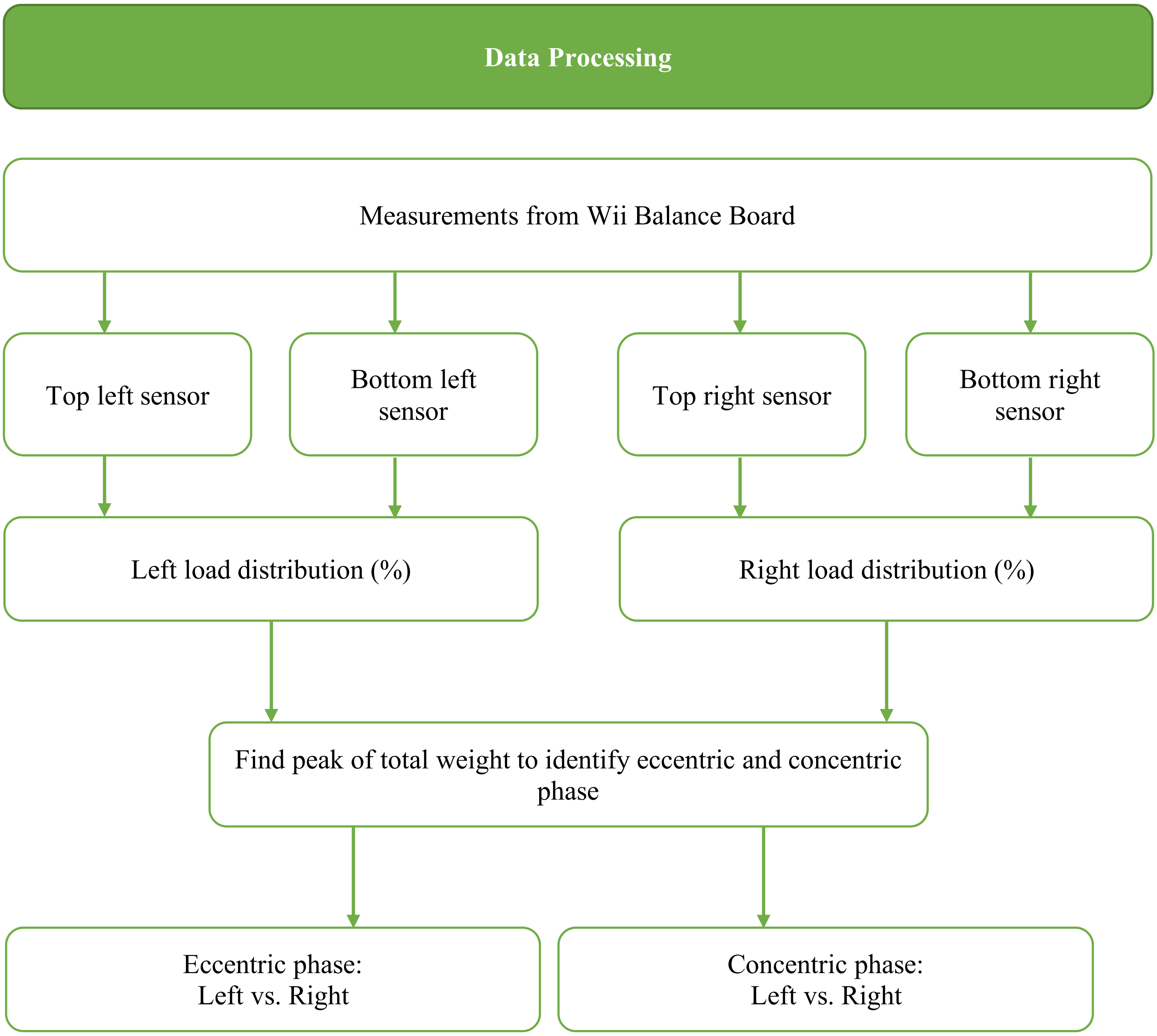


Figure 23: Flow diagram of how data will be processed.

Part V: Results

This chapter presents the results that were obtained during the clinical trials. By implementing the protocol discussed in the previous chapter, results of load distribution during a strength training exercise were recorded and processed in MATLAB.

The graphs presented below represent an athlete with cerebral palsy who is weaker on their left side and an able-bodied athlete. The data for the remaining athletes can be found in Appendix E.

5.1 Load Distributed for Eccentric and Concentric Phases

The following graphs represent the load distributions during a leg press exercise and a squat exercise. The tables provide the numerical interpretation of the graphs. The graphs are broken down into the eccentric and concentric phases and represent how the left and right legs bear the load.

5.1.1 Athlete 3 – Able-Bodied Athlete

Athlete 3 is the able-bodied athlete. Figure 24 and Table 3 represent the load distribution during a squat exercise.

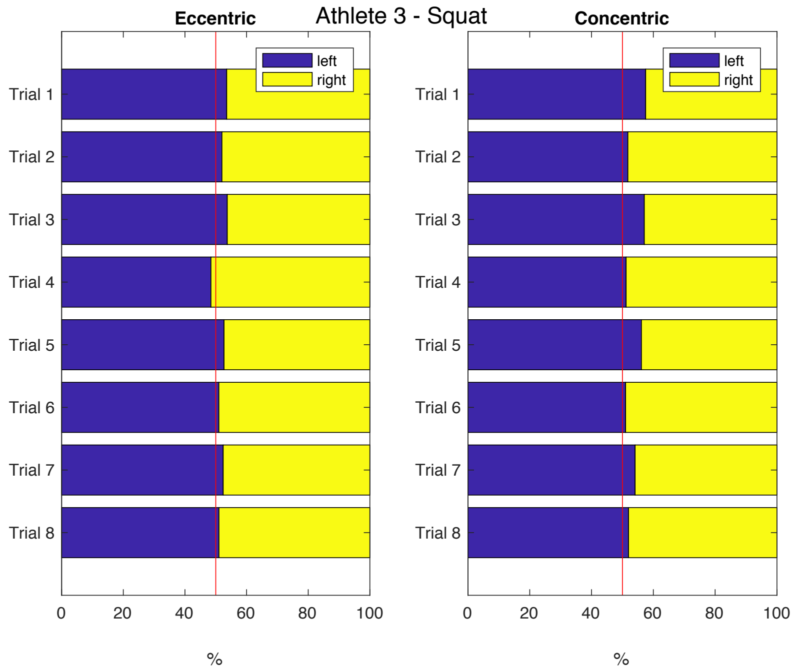


Figure 24: Athlete 3 - load distributions for squat exercise

Table 3: Athlete 3 - load distributions for squat exercise. These are the average percentage values measured for each trial

	Athlete 3 – Squat			
Trial number	**Eccentric**		**Concentric**	
	Left	**Right**	**Left**	**Right**
1	53.55	46.45	57.52	42.48
2	52.00	48.00	51.76	48.24
3	53.73	46.27	57.08	42.92
4	48.43	51.57	51.19	48.81
5	52.68	47.32	56.15	43.85
6	51.01	48.99	51.03	48.97
7	52.41	47.59	54.11	45.89
8	51.03	48.97	51.98	48.02
Average	51.86	48.14	53.85	46.15

Figure 25 and Table 4 represent the load distribution during a leg press exercise.

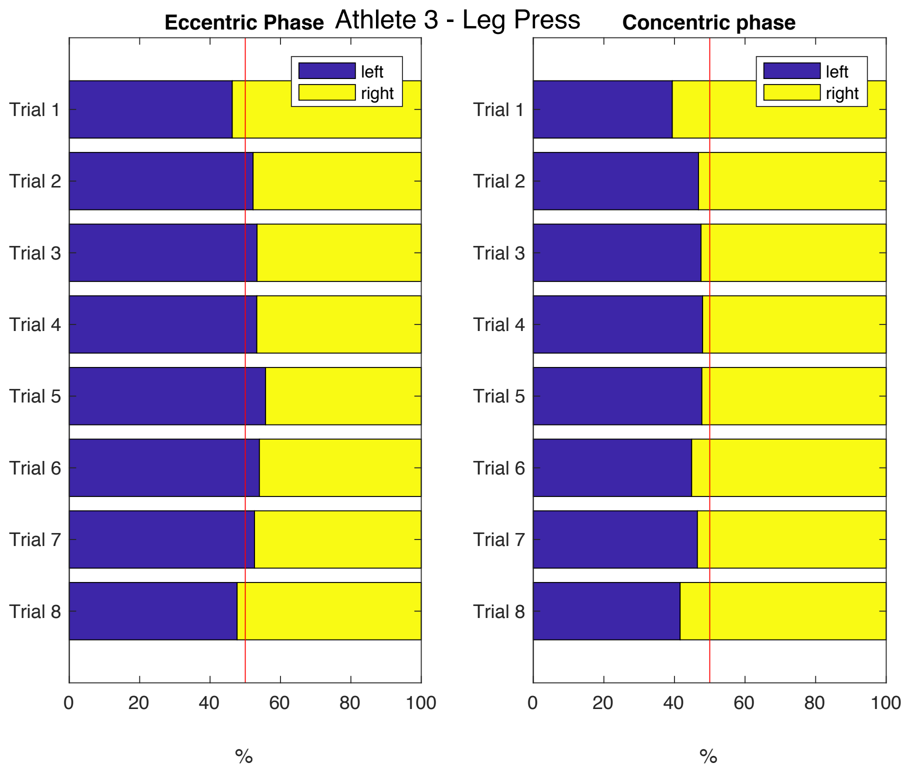


Figure 25:Load distributed between left and right legs during a leg press exercise for athlete 3

Table 4: Percentage of total load distributed for each trial for athlete 3 during leg press exercises

Athlete 3 – Leg press				
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left	**Right**	**Left**	**Right**
1	46.30	53.70	39.39	60.61
2	52.22	47.78	46.81	53.19
3	53.34	46.65	47.53	52.47
4	53.28	46.72	47.97	52.03
5	55.77	44.23	47.77	52.23
6	54.02	45.98	44.88	55.12
7	52.63	47.37	46.50	53.50
8	47.69	52.31	41.61	58.39
Average	51.91	48.09	45.31	54.69

5.1.2 Athlete 5 – Athlete with Cerebral Palsy

Figure 26 and Table 5 represents the load distribution during a squat exercise.

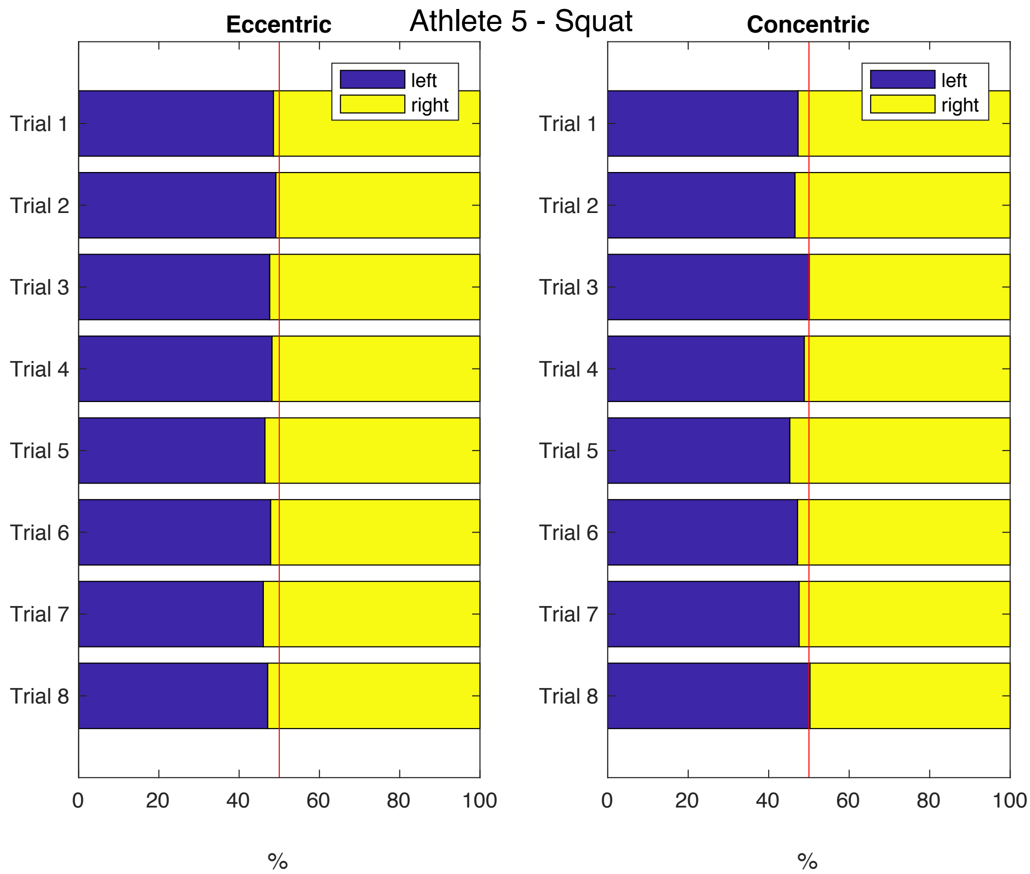


Figure 26: Athlete 5 - load distributions between left and right legs for squat exercise

Table 5: Athlete 5 - percentage of the total load distributed for each trial during a leg press exercise

	Athlete 5 – Squat			
Trial number	**Eccentric phase**		**Concentric Phase**	
	Left	**Right**	**Left**	**Right**
1	48.55	51.45	47.30	52.70
2	49.16	50.84	46.54	53.46
3	47.63	52.37	50.10	49.90
4	48.20	51.80	48.85	51.15
5	46.44	53.56	45.26	54.74
6	47.86	52.14	47.18	52.82
7	46.03	53.97	47.58	52.42
8	47.12	52.88	50.27	49.73
Average	47.62	52.38	47.89	52.11

Figure 27 and Table 6 represent the load distribution during a leg press exercise of an able-bodied athlete.

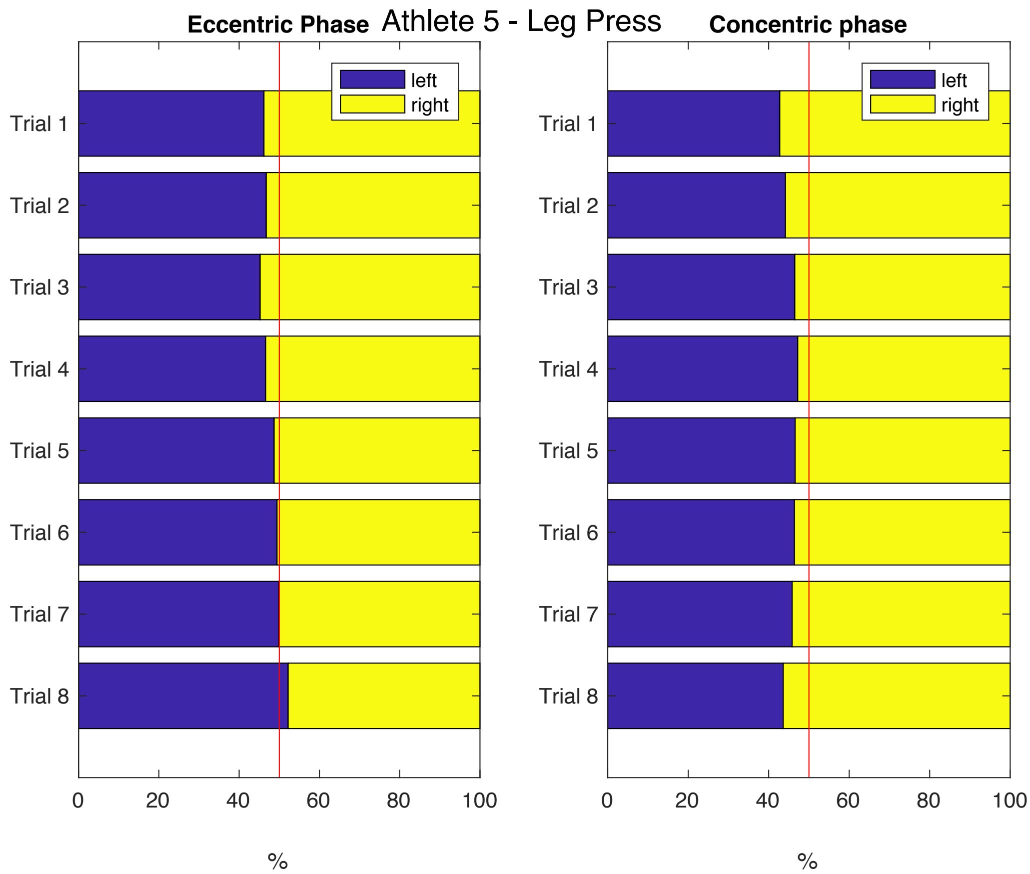


Figure 27: Load distributed between left and right legs during a leg press exercise for athlete 5

Table 6:Percentage of total load distributed for each trial for athlete 5 during leg press exercises

Athlete 5 – Leg press				
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left (%)	**Right (%)**	**Left (%)**	**Right (%)**
1	46.18	53.82	42.76	57.24
2	46.75	53.25	44.17	55.83
3	45.23	54.77	46.49	53.51
4	46.61	53.39	47.22	52.78
5	48.72	51.28	46.57	53.43
6	49.44	50.56	46.40	53.60
7	49.88	50.12	45.82	54.18
8	52.21	47.79	43.60	56.40
Average	48.13	51.87	45.38	54.62

5.1.3 Other Athletes

The following tables show the average load distributions during squat and leg press exercises for each athlete.

Table 7: Average load distributions for each athlete during a squat exercise

Athlete Number		Eccentric		Concentric	
		Left (%)	Right (%)	Left (%)	Right (%)
1	CP	48.48	51.52	45.81	54.18
2	CP	49.64	50.36	46.13	53.87
3	Able	51.86	48.11	53.85	46.15
4	CP	46.36	53.64	47.38	52.62
5	CP	47.62	52.38	47.89	52.11
6	CP	52.47	47.53	55.08	44.92

Table 8: Average load distributions for each athlete during a leg press exercise

Athlete Number		Eccentric		Concentric	
		Left (%)	Right (%)	Left (%)	Right (%)
1	CP	43.62	56.38	42.41	57.59
2	CP	47.74	52.26	50.93	49.07
3	Able	51.91	48.09	45.31	54.69
4	CP	45.05	54.95	43.84	56.16
5	CP	48.13	51.87	45.38	54.62
6	CP	50.01	49.99	50.28	49.72

5.2 Load Distribution Relative to Time

The load distribution was plotted against time to see how the load is transferred between the left and right sides. The y-axis of each graph refers to the percentage of the load being lifted by each side. If the % value is less than 50 then the left side is stronger and if the percentage is higher than 50% then the right side is stronger.

5.2.1 Athlete 3 – Able bodied Athlete

Figure 28 represent the load distribution during a squat exercise with respects to time.

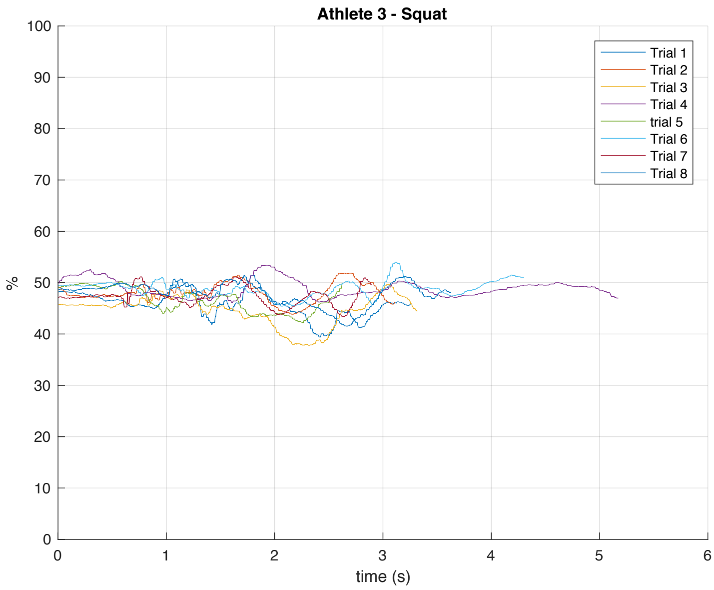


Figure 28: Load distributed for a squat exercise relative to time for athlete 3

Figure 29 represents the load distribution during a leg press exercise with respect to time.

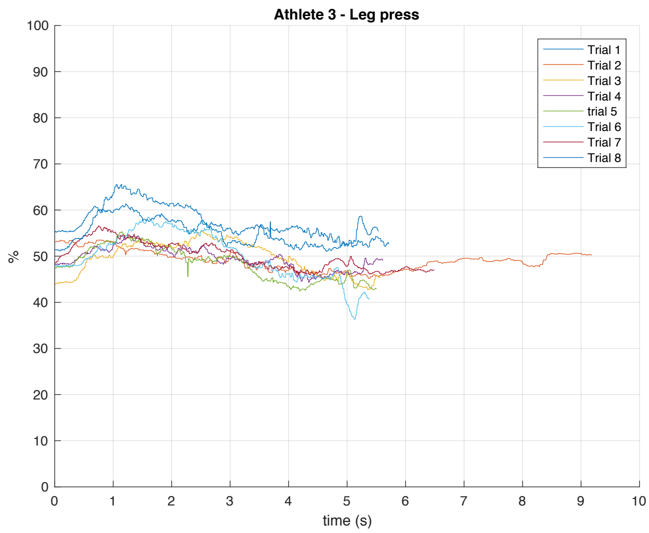


Figure 29: Load distributed during a leg press exercise relative to time for athlete 3

5.2.2 Athlete 5 – Athlete with Cerebral Palsy

Figure 30 represent the load distribution during a squat exercise with respect to time.

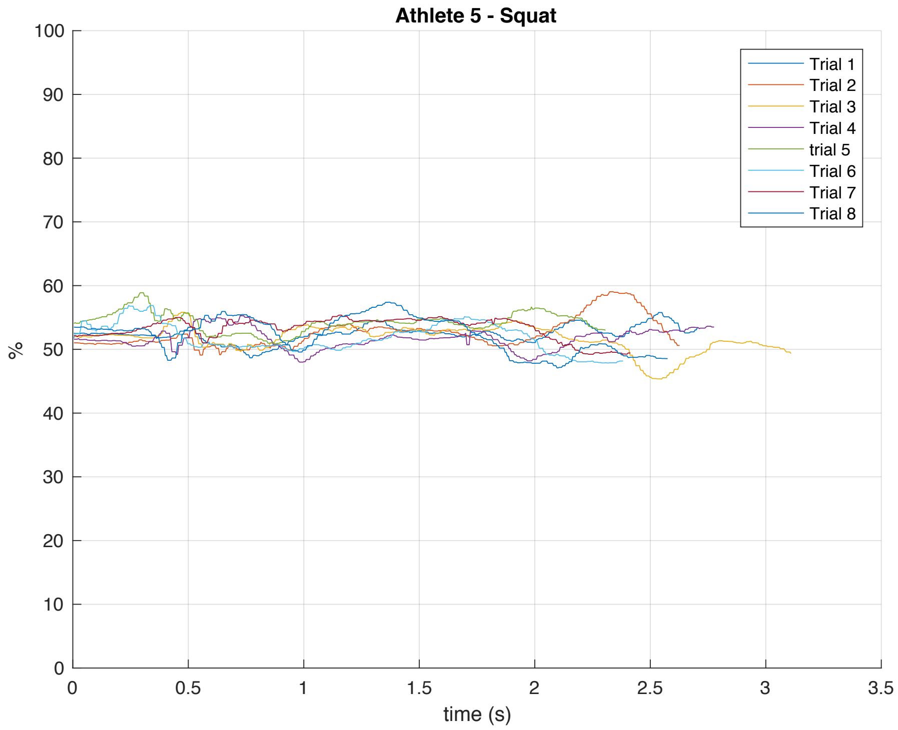


Figure 30:Load distributed during a squat exercise relative to time for athlete 5

Figure 31 represent the load distribution during a squat exercise with respect to time.

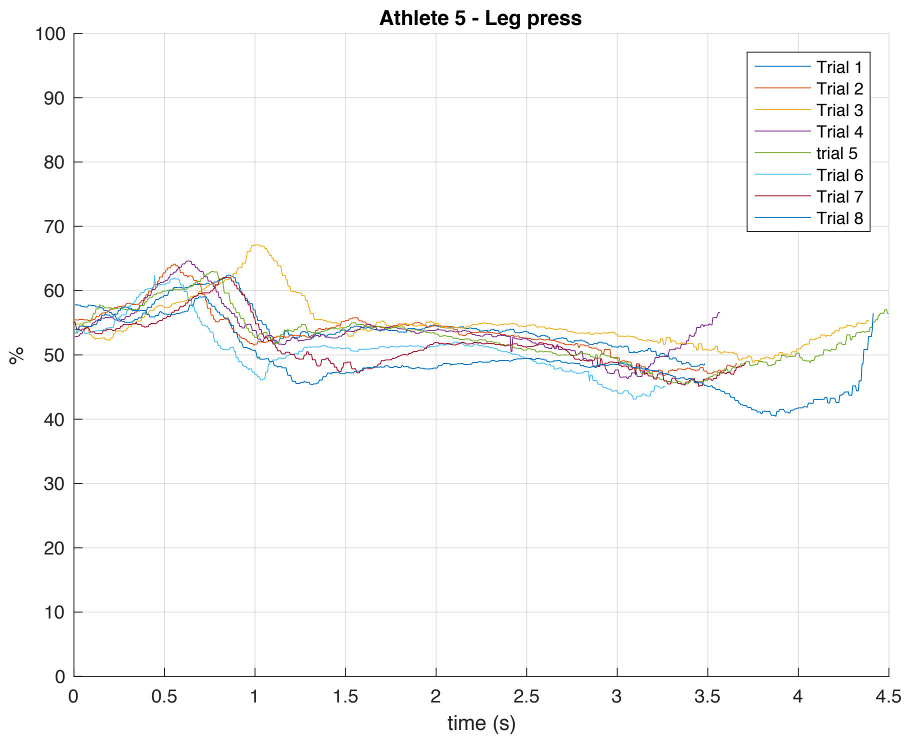


Figure 31: Load distributed during a leg press exercise relative to time for athlete

Part VI: Discussion

This chapter discusses the results obtained in the previous chapter and aims to understand and analyse the load distributions of athletes with cerebral palsy and able-bodied athletes. This chapter also discusses the assumptions made about the results obtained and the limitations of the study.

6.1 Data Analysis

The aim of this study was to measure load distribution between the left and right side of the body, to ensure that athletes are training both legs equally. The Wii Balance Board is programmed to measure how much weight the athlete is placed on the sensors, which will give an indication of which side is stronger and is bearing more of the load. If the athletes are balanced and have an equal load distribution, 50% of the total load will be measured on each side. The Wii Balance Board will measure imbalances and quantify this, which would help athletes know whether they need to train more on the affected side to reach a balanced load distribution.

It is assumed that able bodied athletes will be more balanced and that the load is distributed equally between both legs. However, little is known on what the load distributions are for athletes with cerebral palsy and if it varies more than able bodied athletes. This made it difficult to determine whether the results obtained are valid, as there were no results from previous studies to compare with.

6.2 Load Distribution for Eccentric and Concentric Phases

6.2.1 Athlete 3 – Able Bodied Athlete

From the results during the squat exercise, Athlete 3 seemed to be bearing more of the load on the left side, meaning overall, the left side is stronger. During the eccentric phase, where the athlete from the starting position moves to the squat positon, 51.91% of their weight was loaded on the left side. For the concentric phase, where the athlete returns to the standing position from the squat position, 53.85% of their weight was also loaded on their left side. Therefore, overall during a squat exercise their left side is stronger.

The leg press exercise shows that during the concentric phase, where the leg is extended from the bent-knee position, 54.69% of the load is being lifted by the right side. When the athlete returns to the starting position, the eccentric phase, the load is then transferred to the left with 51.905%.

6.2.2 Athlete 5 – Athlete with cerebral palsy

Athlete 5 has cerebral palsy and mentioned that he was, weaker on the left side of his body. Based on the results measured by the WBB, this was confirmed.

For the squat exercise, during both phases, the left side is weaker therefore the right-side bears more of the athlete's weight, with 48.13% for the left and 51.87% right side, during the eccentric phase and 45.38% for the left side and 54.62% for the right side. What is interesting to note about this is that for both the eccentric and concentric phase the load distribution was kept relatively constant, when the athlete changes from one phase to the other (Figure 26).

The leg press exercise further confirms that athlete 5 is weaker on the left side. During the concentric phase, 54.62 % of the load was lifted by the right side. When the athlete moved to the eccentric phase, legs returning to the start position, 51.87% of the load was lifted by the right side. It seems like the athlete was able to control the weight better during the downwards phase and because the left side was weaker, the right side had to compensate by exerting more force.

6.2.3 Other Athletes

The results of the remaining athletes can be found in Appendix E. All of the other athletes have cerebral palsy and all have imbalances. Each athlete has a different form of cerebral palsy and not just hemiplegia cerebral palsy. Therefore, the effects of cerebral palsy would have affected each athlete differently. Only two athletes mentioned what side was weaker and the Wii Balance Board was able verify that. Table 7 and Table 8 show the average load distribution based on the 8 repetitions. When comparing the type of exercise, the load distribution for the squat exercise seems to be more balanced. For the leg press exercise, the difference between the left and right sides seem to be larger.

6.3 Load Distribution Relative to Time

The load distribution was also plot relative to time. The purpose of displaying the load distribution relative to time was to get a representation of what was happening during one repetition and the smoothness of the movement. If the athlete was weaker on the left, more of the load would be held by the right side, then the graph will indicate this by having a higher percentage value. Ideally the load should be evenly distributed throughout the exercise, therefore the graph should be a smooth line, straight line. If the athlete is weaker on one side, the line would have small peaks that indicate the unequal load distribution.

6.3.1 Athlete 3 – Able-Bodied Athlete

During the squat exercise, it was difficult to identify whether the athlete is evenly distributing his weight. Figure 29 shows that there is a lot of variation in his balance. The lines showed that his movements aren't smooth, as the line plotted for each repetition isn't straight. However, towards the end of each repetition, his form and balance seemly become worse.

For the leg press exercise, there was a trend in the load being distributed between the left and right sides. The load seems to be shifted to the right and as the athlete reaches the end of the leg press exercise, the load becomes evenly distributed between both limbs. Figure 29 shows this change in load being shifted as the lines plotted for each repetition slopes downwards. This result correlates to the averages that were calculated above, where during the concentric phase the load is more distributed to the right and as he moves to the concentric phase the load is more even distributed.

6.3.2 Athlete 5 – Athlete with Cerebral Palsy

As mentioned, athlete 5 has cerebral palsy and mentioned that he was weaker on the left side. For the squat exercise, the load doesn't shift much between the left and right sides. However, the results do show that the right-side bears more of the load as the graph is shifted higher. There is a definite trend of the load being distributed between the limbs during the leg press exercise. During a leg press, the upwards phase occurs first, which is considered to be the concentric phase. There is an increase in slope of the curve that occurs before the first second of all of the repetitions. After the first second, the weight slowly becomes more evenly distributed showing a decrease in the slope. This could indicate that the right side is faster in lifting the weight and the decrease in the slope can indicate the left side following just after. After that initial peak the load is distributed relatively evenly for the rest of the repetition.

6.3.3 Other Athletes

For the time graphs, there is a lot of variation in the shape of the curves generated. Therefore, it was difficult to identify a trend. This could because each athlete had a different type of cerebral palsy and were all affected differently. It was also difficult to identify the difference between the load distribution based on the type of exercise.

6.4 Summary of Results

Based on the results, all of the athletes had unequal load distributions for both strength training exercises. It seemed that athletes were able to have a more equal load distribution during the squat exercise, which does not confirm the hypothesis. Due to such a small sample size, it is not possible to confirm that able-bodied athletes have a more equal load distribution.

6.5 Limitations of Study

This study aimed to measure load distributions during a strength training exercise of athletes with cerebral palsy using a Wii Balance Board as a cheaper alternative to a force plate. Clinical trials were conducted with athletes with cerebral palsy and able-bodied athletes. However, there were several limitations that need to be considered for future work in order to obtain results that better represented what happens during a strength training exercise.

6.5.1 Limitations of the Wii Balance Board

- The sampling frequency of the Wii Balance Board in the literature is mentioned to be at 100Hz, [1] which is ideal in providing reliable data. However, the sampling frequency was less than 100Hz and varied when the measurements were conducted. This affected the graphs that were plotted against time.
- The size of the Wii Balance Board is another limitation of the study as it was too small. The size of the WBB is 230mm x 430mm and during testing athletes were required to place both feet on the board without their feet hanging off the edge. For

some athletes, this distance was too small for them to comfortably perform the squat exercise as their feet are usually further spread apart.

- The Wii Balance Board is connected to the computer via Bluetooth, allowing for easy connection and reduces the need of additional wires. However, there were times when the Bluetooth connectivity was unreliable which meant that data collection stopped while testing was being conducted.
- A total of 10 Wii Balance Boards were purchased and the accuracy of the board was measured to test whether further calibration was required. Out of the 10 boards that were tested only 4 boards didn't have damaged sensors and out of the four boards, only 2 were able to provide measurements that were close to calibrated masses used.
- Nintendo recommends that only a maximum of 150kgs be placed on the Wii Balance Board, however studies have shown that the Wii Balance Board is capable of measuring up to 300kg [1]. The 100kg used for the leg press machine was within the recommended weight limit, however if higher weights were used, further calibration would be required.

6.5.2 Limitations of the Methodology

- When seeking ethical approval to conduct clinical trials, it was explicitly stated that the maximum weight that could be used during a leg press exercise was 100kg. However, through filling out the questionnaire given to each athlete prior to testing, most athletes stated that for a double leg press they were able to press over 200kg. The maximum weight limit of 100kg used in the study could have been too easy for the athletes and the measurements obtained might not be able to represent what actually happens during their strength training sessions.

6.5.3 Limitations of Study Size

- Due to time constraints, only 6 athletes were able to participate in the study and of these six athletes only one was an able-bodied athlete. Therefore, it was difficult to determine whether the unequal load distributions of athletes with cerebral palsy was significant. A larger sample size of both athletes with cerebral palsy and able-bodied would help determine if athletes with cerebral palsy had a larger imbalance of load distributions compared to able-bodied athletes.

6.6 Overall Cost of Project

A major advantage of using the Wii Balance Board as an alternative force plate is the cost. It would be desirable to keep costs of the parts and equipment used for testing to be as low as possible. Table 9 outlines the costs of the parts used in the project. For the project, a total budget of $600 was given and the total cost of the materials purchased is $339.70. This overall cost is a tiny fraction of the price of a force plate, further proving that the use of the Wii Balance Board is cost effective, making it a desirable alternative to a force plate.

Table 9:Total Costs of Parts

Part	Quantity	Cost	Total
Wii Balance Boards	10	$6	$60
Arduino Uno	1	$61.45	$61.45
DuinoTech Classic	1	$29.95	$29.95
USB Host Shield	2	$39.95	$79.90
Bluetooth Dongle	2	$8	$16
Mounting Equipment	1	$92.40	$92.40
Total Overall Cost:			$339.70

Part VII: Conclusion and Recommendations

7.1 Future Work

The use of a Wii Balance Board in research has been conducted for almost 10 years. The WBB allows for measurements to be made in real time and displays the load distributions as the athlete is performing the exercise. Through clinical trials with professional athletes, a small glimpse on how weight bearing is affected is understood. However, through testing and data analysis, there were several areas to be considered for future work to further develop and improve the study.

During the squat exercise, one balance board was used, which hindered the athlete's ability to have a more natural stance. Therefore, future work in this area would benefit from using two Wii boards – one for each foot. This will enable participants to have a more natural stance and spread their feet to a position that would more closely replicate conditions of a squat during strength training.

During testing, the data was measured in real time, however it is displayed as 6 columns of numbers, changing depending on the weight placed on the board. These numbers on the screen have little context if the coach didn't know what each column means and it is extremely difficult to read. An application that displays the load distribution as a bar displaying left and right percentage would be extremely useful. It would provide a visual representation of what is happening during the exercise but might be useful for athletes as they can use the program during strength training exercises to ensure they are bearing their weight evenly.

One of the aims of the project was to measure the load distribution to provide useful data for coaches on how well an athlete is training. To determine if the results were useful, clinical testing would have needed to be conducted multiple times. The idea of this aim was to conduct clinical trials with the same athletes using the WBB and tell them that their athlete is weaker on a particular side. Based on the information given, the coach would focus on improving the athlete's weaker side in order to reach an equal load distribution. After a few weeks of training, testing would be conducted again to see if the load distribution had improved. However, due to the time constraints it was not possible to determine if the information was useful for both coaches and athletes. Therefore, in the future, testing would need to be conducted earlier to allow for multiple testing sessions with the same athlete.

From the small number of athletes who were able to participate in the study, it was difficult to identify if the load distributed between left and right sides for athletes with cerebral palsy was significant. From the results obtained, the differences in load distribution between each limb seemed to vary within a 50±7% range, depending on which limb was weaker. It is difficult to determine if this range was valid with such a small number of participants. Therefore, more testing with both abled-bodied athletes and athletes with cerebral palsy is needed. To improve the results obtained from the Wii Balance Board, better signal processing should be applied to remove the noise present. From the time graphs, it would have made visualising the smoothness of the movement easier if filtering was used.

To better understand if the results obtained from the Wii Balance Board are useful, it would be beneficial to have follow up testing sessions. The results obtained suggest that athletes had a slight imbalance during the strength training exercises. Knowing this information would be useful for coaches as they can focus training the side that is affected by balance. If time had permitted, it would have been interesting to have follow up testing sessions to see if the athletes load distributions had reduced.

Further testing and calibration of the Wii Balance Board would also be beneficial to obtain reliable results. A total of 10 boards were purchased however only 2 were used. The remaining 8 Wii Balance Boards could be recalibrated and then retested to also be used.

7.2 Conclusions

The Wii Balance Board has been adapted in many studies as an alternative force plate, allowing researchers to obtain measurements of load distribution, postural sway and centre of pressure. The cost, ease of use, portability and accessibility has made the Wii Balance Board a very popular device for researchers. This study focuses on measuring load distributions during strength training for athletes with cerebral palsy. The results show that while each athlete has imbalances during each repetition, with such a small sample size and having only one able bodied athlete, it is difficult to conclude if these imbalances are significant. Hopefully, this study piques interest for further research on what the imbalances are for athletes with cerebral palsy.

The main goal of this project was to record the load distribution of a strength training exercise using a Wii Balance Board. Currently, there isn’t an affordable device that is able to measure load distributions. Therefore, looking at the many advantages of the Wii Balance Board, it could provide a possible alternative to expensive force plates. The second aim was for the Wii Balance Board to measure the smoothness of movements in real time. Finally, the last aim was to identify if the data collected using the WBB is useful to trainers and athletes. While the first two aims were reached, due to time constraints multiple clinical trials were not possible. Overall, this study was able to provide a small insight on the load distributions of athlete with cerebral palsy by using the Wii Balance Board as a cheaper alternative force plate.

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Appendix A

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Government of South Australia
SA Health
Southern Adelaide Local Health Network

Final Approval for Ethics Application

24 August 2017

Prof Mark Taylor

Dear Prof Mark Taylor

OFR Number:	151.17
HREC reference number:	HREC/17/SAC/238
Project title:	Load Distribution during Strength Training for athletes with cerebral Palsy
Chief Investigator:	Prof Mark Taylor
Ethics Approval Period:	22 August 2017 – 22 August 2018

The Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC EC00188) have reviewed and provided approval for this application which appears to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007).*

You are reminded that this letter constitutes **Ethics** approval only. **Ethics approval is one aspect of the research governance process.**

You must not commence this research project at any SA Health sites listed in the application until a Site Specific Assessment (SSA), or Access Request for data or tissue form, has been approved by the Chief Executive or delegate of each site.

The below documents have been reviewed and approved:

- Cover letter dated 06 June 2017
- Low and Negligible Risk (LNR) Research form dated 12 July 2017
- Protocol v2 dated 29 June 2017
- Letter of support from Prof Ian Menz, Dean (People and Resources) dated 10 July 2017
- Participant Information Sheet/Consent Form v2 dated 29 June 2017
- Questionnaire v2 dated 29 June 2017

Noted:
Articles:
- Using the Star Excursion Balance Test to Assess Dynamic Postural-Control Deficits and Outcomes in Lower Extremity Injury: A Literature and Systematic Review
- Using the Wii Fit as a tool for balance assessment and neurorehabilitation: the first half decade of "Wii-search"
- Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance

Terms And Conditions Of Ethics Approval:

As part of the Institution's responsibilities in monitoring research and complying with audit requirements, it is essential that researchers adhere to the conditions below and with the *National Statement chapter 5.5.*

Final ethics approval is granted subject to the researcher agreeing to meet the following terms and conditions:

1. The approval only covers the science and ethics component of the application. A SSA will need to be submitted and authorised before this research project can commence at any of the approved sites identified in the application.
2. If University personnel are involved in this project, the Principal Investigator should notify the University before commencing their research to ensure compliance with University requirements including any insurance and indemnification requirements.
3. Compliance with the *National Statement on Ethical Conduct in Human Research* (2007) & the *Australian Code for the Responsible Conduct of Research* (2007).
4. To immediately report to SAC HREC anything that may change the ethics or scientific integrity of the project.
5. Report Significant Adverse events (SAE's) as per SAE requirements available at our website.
6. Submit an annual report on each anniversary of the date of final approval and in the correct template from the SAC HREC website.
7. Confidentiality of research participants MUST be maintained at all times.
8. A copy of the signed consent form must be given to the participant unless the project is an audit.
9. Any reports or publications derived from the research should be submitted to the Committee at the completion of the project.
10. All requests for access to medical records at any SALHN site must be accompanied by this approval email.
11. To regularly review the SAC HREC website and comply with all submission requirements, as they change from time to time.
12. Once your research project has concluded, any new product/procedure/intervention cannot be conducted in the SALHN as standard practice without the approval of the SALHN New Medical Products and Standardisation Committee or the SALHN New Health Technology and Clinical Practice Innovation Committee (as applicable). Please refer to the relevant committee link on the SALHN intranet for further information.

For any queries about this matter, please contact the Office for Research on (08) 8204 7433 or via email to Health.SALHNOfficeforResearch@sa.gov.au.

Yours sincerely

A/Professor Bernadette Richards
Chair, SAC HREC

Appendix B

Consent Form - Adult providing own consent

Title	Load distribution during strength training for Athletes with Cerebral Palsy
Short Title	Load distribution during strength training
Protocol Number	[Protocol Number]
Project Sponsor	Flinders University and South Australian Sports Institute
Coordinating Principal Investigator/ Principal Investigator	Mark Taylor
Location (where CPI/PI will recruit)	South Australian Sports Institute

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project without affecting my future health care.

I understand that I will be given a signed copy of this document to keep.

Optional paragraph:
I understand that, if I decide to discontinue the research project treatment, I may be asked to attend follow-up visits to allow collection of information regarding my status.

Name of Participant (please print)	______________________
Signature ______________________	Date ______________________

Declaration by Study Doctor/Senior Researcher[†]

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Name of Study Doctor/ Senior Researcher[†] (please print)	______________________
Signature ______________________	Date ______________________

[†] A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature

Appendix C

Load distribution during strength training for athletes with cerebral palsy.

Thank you for participating in this experiment. Please fill out the following questions, this information will be kept confidential. .

Information about you:

1. What is your age? ________
2. What is your gender?

   ☐ Female
   ☐ Male
   ☐ Other

3. What sport do you mainly participate in? __________________
4. What is your 1 Rep Max for incline leg press? _____________
5. What is your 3 Rep Max for incline leg press? _____________
6. Do you have cerebral palsy?

   ☐ Yes. Please go to question 7
   ☐ No. Please go to question 9

7. What type of cerebral palsy do you have? _______________
8. What part of the body does CP effect you? ______________
9. How many days in a week do you undergo strength training? ______________

Appendix D

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Data analysis
% created on:
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clearvars -except averageLPEccentric averageLPConcentric averageSquatEccentric averageSquatConcentric

for i=6 % Athlete number

  cd(['/Users/michellepham-nguyen/Documents/MATLAB/Data/' num2str(i)])
  fname = dir([num2str(i) '_*']);

  for j=1:16 %number of trials
    readtable(fname(j).name);
    counter=1;
    p=1;
    totalWeight=[];
    time=[];

    %Formating time column
    for k=1:length(ans.Var1)
      new(k)=string(ans.Var1(k));
      temp=strsplit(new(k),':');
      time(k,:)=(temp(1,3));
    end

    %
    names={'Time','Sensor1', 'Sensor2', 'Sensor3', 'Sensor4', 'Left', 'Right'};
     athlete{i}=table(time(1:end-1),ans.Var2(1:end-1),ans.Var4(1:end-1),ans.Var6(1:end-1),ans.Var8(1:end-1),ans.Var12(1:end-1),ans.Var14(1:end-
1),'VariableNames',names);


    % Calculating total weight to find the peak
    totalWeight=athlete{1,i}.Sensor1+athlete{1,i}.Sensor2+athlete{1,i}.Sensor3+athlete{1,i}.Sensor4;
    [peak,index]=max(totalWeight);

     % determining when concentric and eccentric phases occur by using
     % the peak value determined
    concentric=mean(athlete{i}.Right(ceil(0.2*index):ceil(0.8*index)));
    eccentric=mean(athlete{i}.Right(ceil(index+0.2*(length(totalWeight)-index)):ceil(index+0.8*(length(totalWeight)-index))));

    t=max(athlete{i}.Time)/length(athlete{i}.Time):max(athlete{i}.Time)/length(athlete{i}.Time):max(athlete{i}.Time);

   %% Identifying which file to graph
      if j<9
        LPLeft{j}(:,2)=athlete{i}.Left; % leg press informnation for left side
        LPLeft{j}(:,1)=t;
        LPRight{j}(:,2)=athlete{i}.Right; % leg press information for right side
        LPRight{j}(:,1)=t;
        legPressEccentric(i,j)=eccentric;
        legPressConcentric(i,j)=concentric;

      else
        SQLeft{j-8}(:,2)=athlete{i}.Left;
        SQLeft{j-8}(:,1)=t;
        SQRight{j-8}(:,2)=athlete{i}.Right;
        SQRight{j-8}(:,1)=t;
        squatEccentric(i,j-8)=eccentric;
        squatConcentric(i,j-8)=concentric;

      end

  end


  %% Load distributed over time of a leg press exercise
  figure(1)
  hold on

  for j=1:8 % the number of trials
    hold on
    plot(LPLeft{j}(:,1),LPLeft{j}(:,2));
    hold off

  end
```

```
    legend('Trial 1','Trial 2','Trial 3', 'Trial 4','trial 5','Trial 6','Trial 7','Trial 8');
    title('Athlete 6 - Leg press');
    xlabel({'time (s)'});
    ylabel({'%'});
    ylim([0 100]);
    grid on;


%% Load distributed over time of a squat exercise
figure(2)
hold on

for j=1:8 % the number of trials
    hold on
     plot(SQLeft{j}(:,1),SQLeft{j}(:,2));
    hold off
end


    legend('Trial 1','Trial 2','Trial 3', 'Trial 4','trial 5','Trial 6','Trial 7','Trial 8');
    title('Athlete 6 - Squat');
    xlabel({'time (s)'});
    ylabel({'%'});
    ylim([0 100]);
    grid on;

%% average of each trial
        averageLPEccentric(i)=abs(mean((50-legPressEccentric(i,:))));
        averageLPConcentric(i)=abs(mean((50-legPressConcentric(i,:))));

        averageSquatEccentric(i)=abs(mean((50-squatEccentric(i,:))));
        averageSquatConcentric(i)=abs(mean((50-squatConcentric(i,:))));

%% Leg press trials

    figure(3);
    suptitle('Athlete 6 - Leg Press');
    hold on;

   for k=1:8
        w(k,:)=([legPressEccentric(i,k) 100-legPressEccentric(i,k)]);
        x(k,:)=([legPressConcentric(i,k) 100-legPressConcentric(i,k)]);
   end

    subplot(1,2,1)
    barh(w,'stacked');
    hold on
    plot([50 50],ylim,'r')
    hold off;
    set(gca, 'YTickLabel', {'Trial 1' 'Trial 2' 'Trial 3' 'Trial 4' 'Trial 5' 'Trial 6' 'Trial 7' 'Trial 8'},'Ydir','reverse')
    xlim=get(gca,'xlim');
    title('Eccentric Phase');
    legend('left','right');
    xlabel({' ','%'});

    subplot(1,2,2)
    barh(x,'stacked');
    hold on
    plot([50 50],ylim,'r')
    hold off;
    title('Concentric phase');
    set(gca, 'YTickLabel', {'Trial 1' 'Trial 2' 'Trial 3' 'Trial 4' 'Trial 5' 'Trial 6' 'Trial 7' 'Trial 8'},'Ydir', 'reverse')
    xlim=get(gca,'xlim');
    legend('left','right');
    xlabel({' ','%'});

%% Squat trials
    figure(4);
    suptitle('Athlete 6 - Squat');

   for m=1:8
       y(m,:)=([squatEccentric(i,m) 100-squatEccentric(i,m)]);
       z(m,:)=([squatConcentric(i,m) 100-squatConcentric(i,m)]);
   end

    subplot(1,2,1);
    barh(y,'stacked');
    hold on
    plot([50 50],ylim,'r')
```

```
    hold off;
    set(gca, 'YTickLabel', { 'Trial 1' 'Trial 2' 'Trial 3' 'Trial 4' 'Trial 5' 'Trial 6' 'Trial 7' 'Trial 8'},'Ydir','reverse')
    xlim=get(gca,'xlim');
    title('Eccentric');
    legend('left','right');
    xlabel({' ','%'});


    subplot(1,2,2);
    barh(z,'stacked');
    hold on
    plot([50 50],ylim,'r')
    hold off;
    set(gca, 'YTickLabel', { 'Trial 1' 'Trial 2' 'Trial 3' 'Trial 4' 'Trial 5' 'Trial 6' 'Trial 7' 'Trial 8'}, 'Ydir', 'reverse')
    xlim=get(gca,'xlim');
    title('Concentric');
    legend('left','right');
    xlabel({' ','%'});

end
```

Appendix E Athlete 1

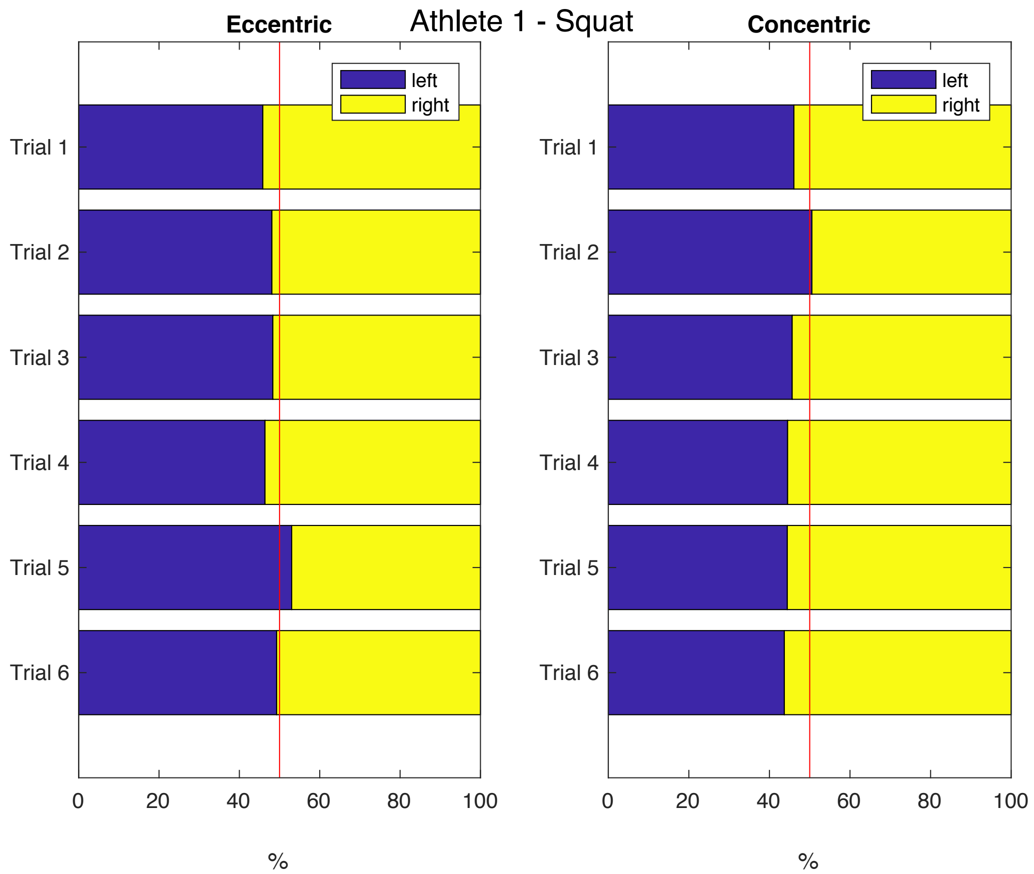

Figure 32: Athlete 1 - load distributions during a squat exercise

Table 10: Athlete 1 Average load distributions for each athlete during a squat exercise

Athlete 1 – Squat Exercise				
Trial number	**Eccentric (%)**		**Concentric(%)**	
	Left	Right	Left	Right
1	45.8298	54.1702	46.0733	53.9267
2	48.0901	51.9099	50.5440	49.4560
3	48.3256	51.6744	45.6441	54.3559
4	46.3743	53.6257	44.5082	55.4918
5	53.0176	46.9824	44.4331	55.5669
6	49.2719	50.7281	43.6959	56.3041
Average	48.48488	51.51511667	45.81643333	54.18356667

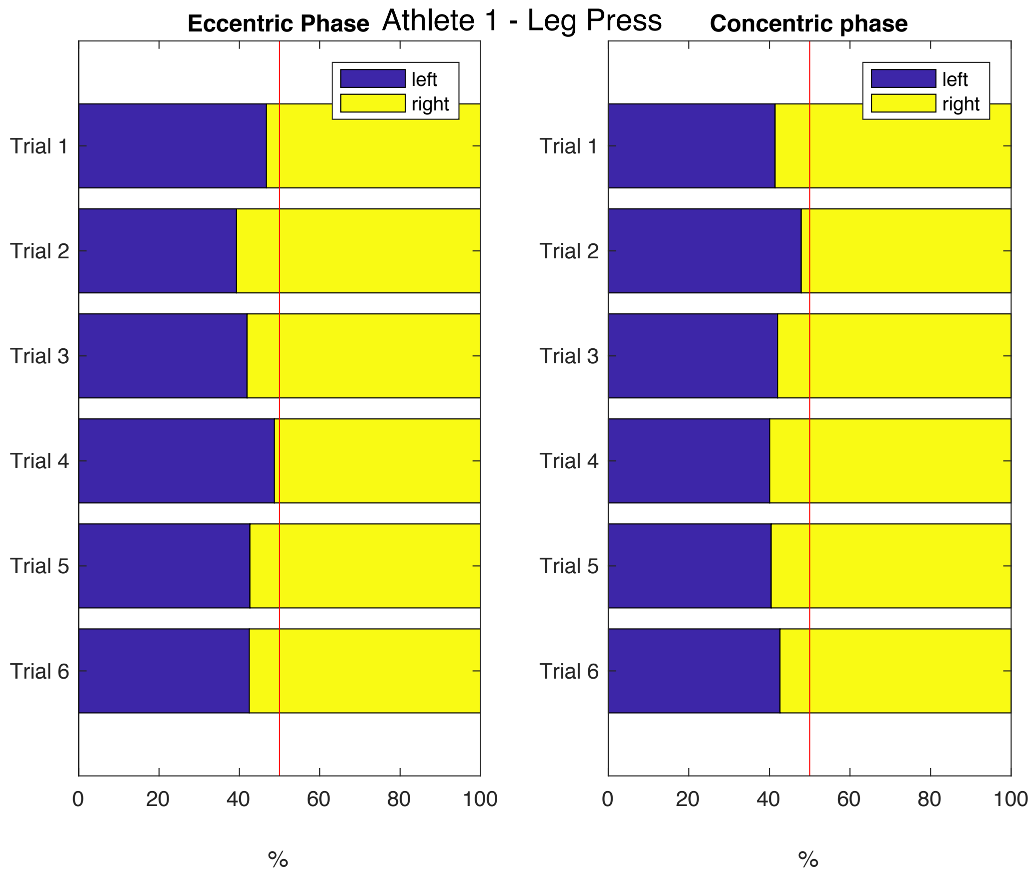

Figure 33: Athlete 1 - load distributions during a leg press exercise

Table 11: Athlete 1 - average load distributions during a leg press exercise

Athlete 1 – Leg press				
Trial number	**Eccentric Phase (%)**		**Concentric Phase (%)**	
	Left	**Right**	**Left**	**Right**
1	46.7313	53.2687	41.4072	58.5928
2	39.2895	60.7105	47.8895	52.1105
3	41.9032	58.0968	42.0326	57.9674
4	48.7075	51.2925	40.0914	59.9086
5	42.6207	57.3793	40.4275	59.5725
6	42.4417	57.5583	42.6248	57.3752
Average	43.61565	56.38435	42.41216667	57.58783333

Athlete 2

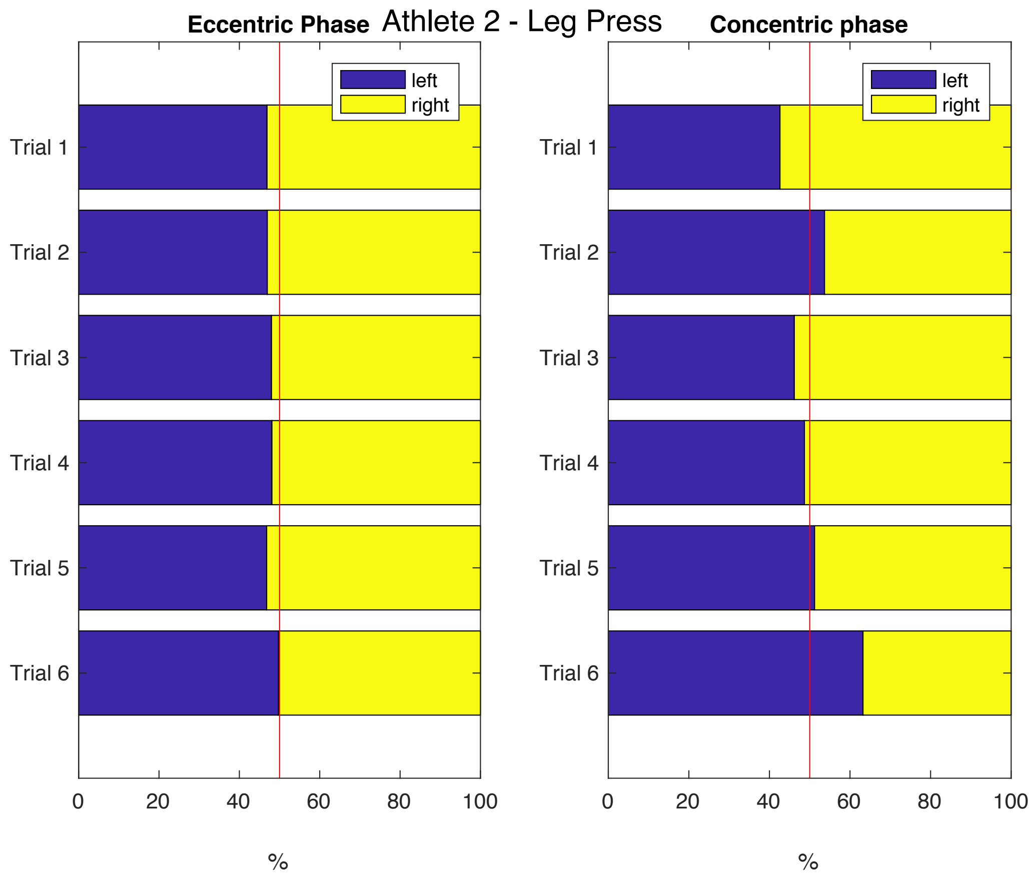

Table 12: Athlete 2 - average load distributions during a leg press exercise

Athlete 2 – Leg press				
Trial number	**Eccentric Phase (%)**		**Concentric Phase (%)**	
	Left	**Right**	**Left**	**Right**
1	46.8786	53.1214	42.6144	57.3856
2	46.9411	53.0589	53.6726	46.3274
3	47.9930	52.0070	46.1684	53.8316
4	48.0983	51.9017	48.6826	51.3174
5	46.7917	53.2083	51.2027	48.7973
6	49.7489	50.2511	63.2195	36.7805
Average	47.74193333	52.25806667	50.9267	49.0733

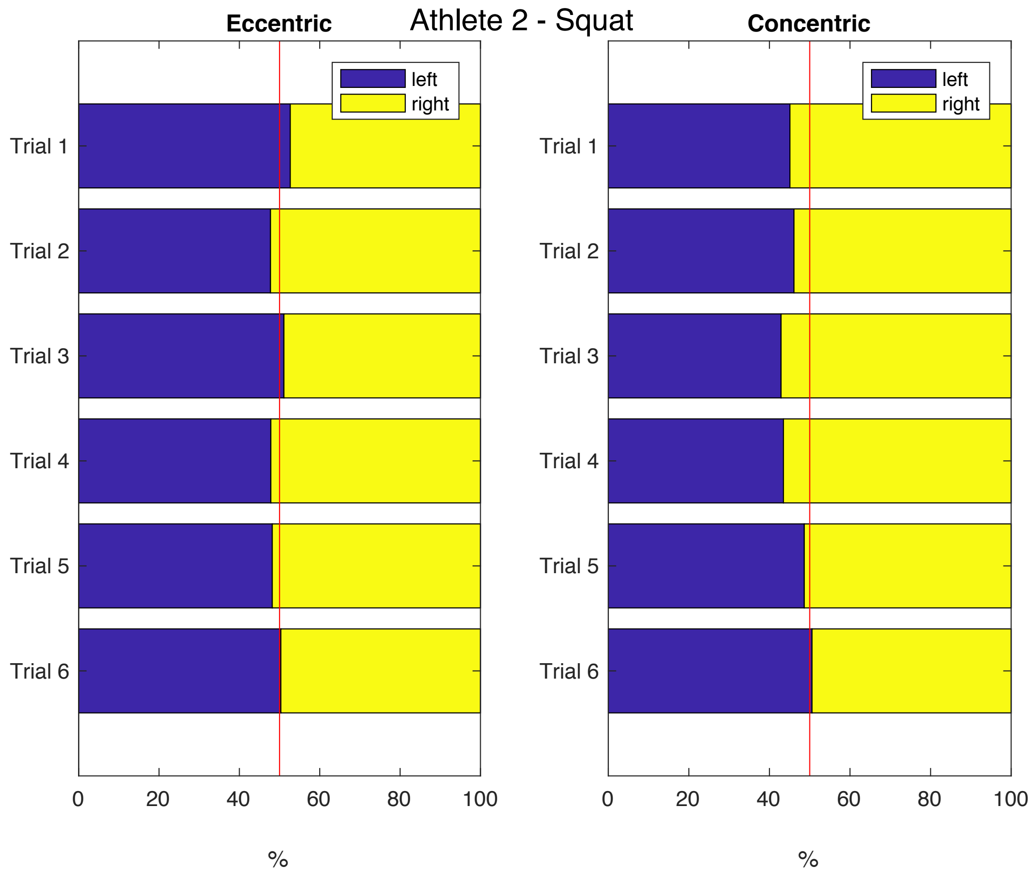

Figure 34: Athlete 2 - load distributions during a squat exercise

Table 13: Athlete 2 - average load distributions during a squat exercise

	Athlete 2 – Squat Exercise			
Trial number	**Eccentric**		**Concentric**	
	Left	**Left**	**Left**	**Right**
1	52.6674	45.0890	45.0890	54.9110
2	47.7477	46.0933	46.0933	53.9067
3	51.0825	42.8865	42.8865	57.1135
4	47.8273	43.4707	43.4707	56.5293
5	48.1841	48.6449	48.6449	51.3551
6	50.3214	50.5740	50.5740	49.4260
Average	49.6384	50.3616	46.1264	53.8736

Athlete 4

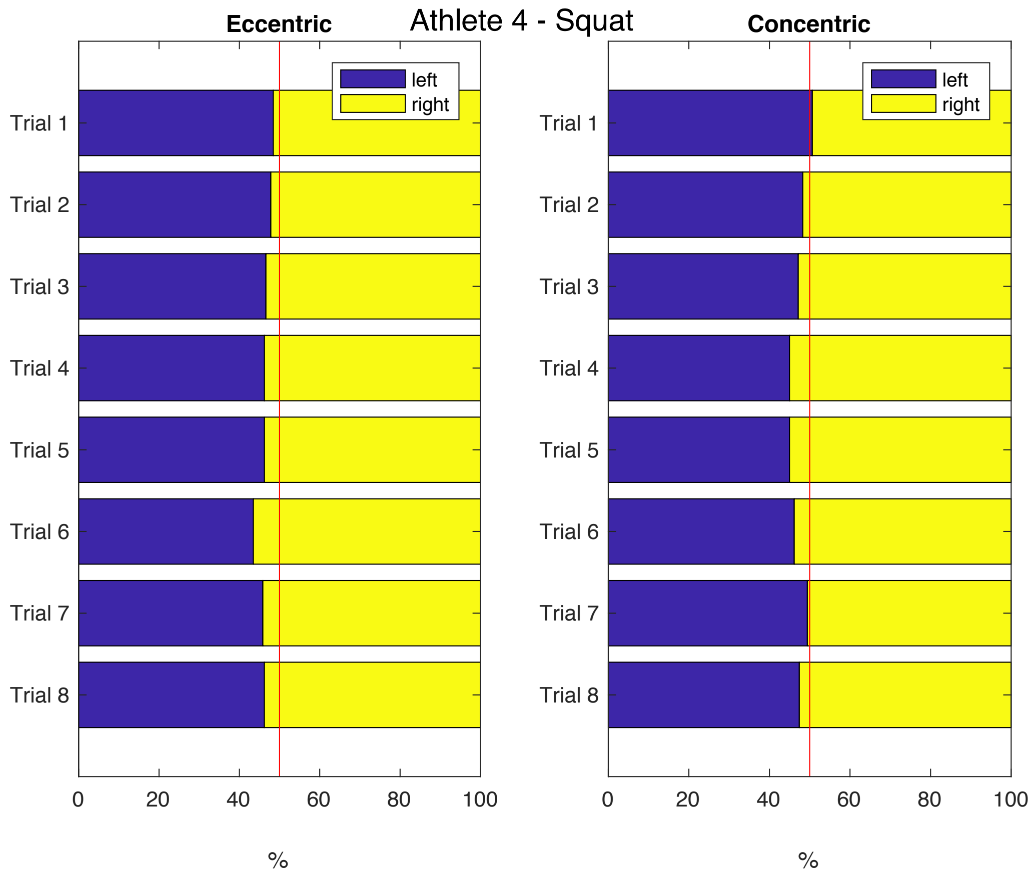

Figure 35: Athlete 4 - load distributions during a squat exercise

Table 14: Athlete 4 - average load distributions during a squat exercise

	Athlete 4 – Squat Exercise			
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left	**Right**	**Left**	**Right**
1	48.4231	51.5769	50.6371	49.3629
2	47.8311	52.1689	48.2913	51.7087
3	46.6083	53.3917	47.1447	52.8553
4	46.2346	53.7654	44.9811	55.0189
5	46.2346	53.7654	44.9811	55.0189
6	43.4718	56.5282	46.1491	53.8509
7	45.8433	54.1567	49.4043	50.5957
8	46.2134	53.7866	47.4116	52.5884
Average	46.357525	53.642475	47.3750375	52.6249625

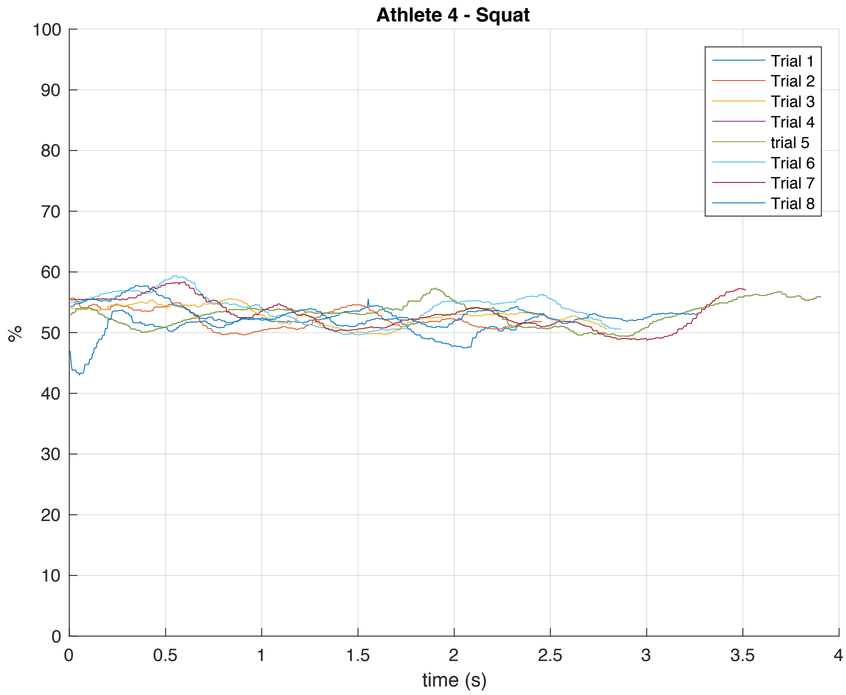

Figure 36: Athlete 4 - load distributed during a squat exercise, relative to time

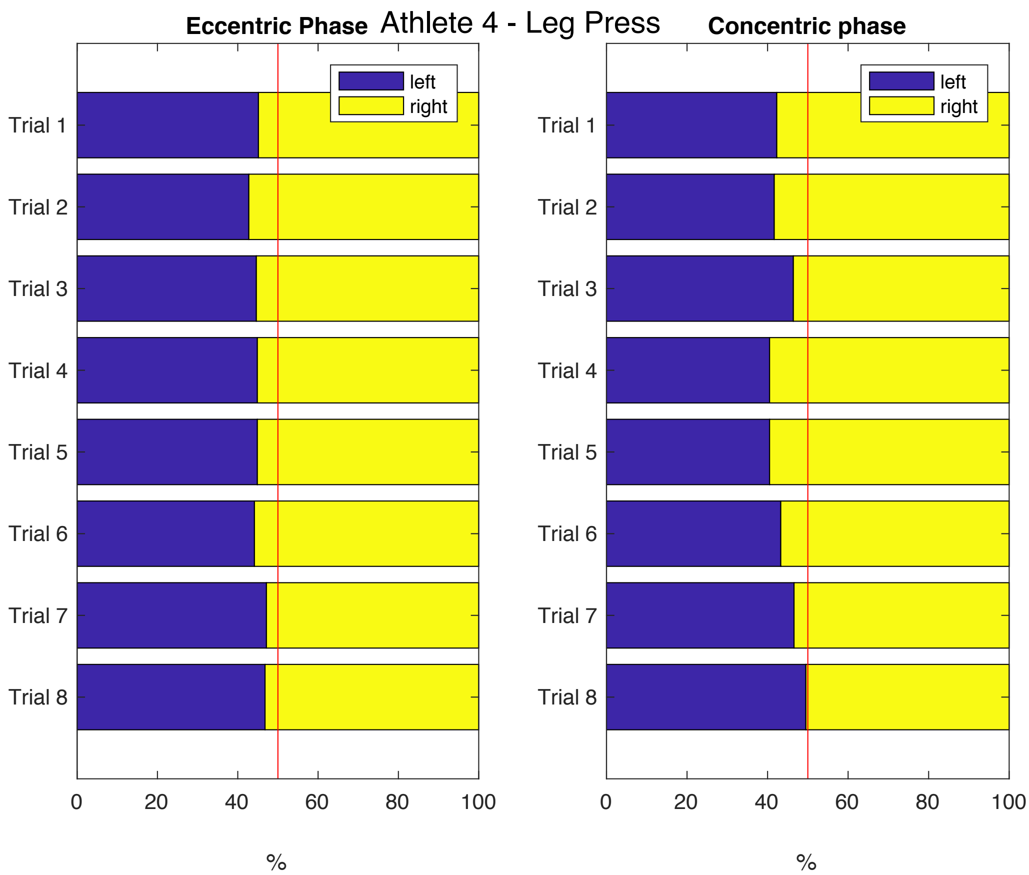

Figure 37: Athlete 4 - load distributions during a leg press exercise

Table 15: Athlete 4 - average load distributions during a leg press exercise

Athlete 4 – Leg press				
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left	**Right**	**Left**	**Right**
1	45.1485	54.8515	42.2841	57.7159
2	42.7536	57.2464	41.6584	58.3416
3	44.6276	55.3724	46.4026	53.5974
4	44.8749	55.125	40.4992	59.5008
5	44.8749	55.1251	40.4992	59.5008
6	44.1519	55.8481	43.2803	56.7197
7	47.1396	52.8604	46.5731	53.4269
8	46.7950	53.2050	49.5120	50.4880
Average	45.04575	54.95425	43.8386125	56.1613875

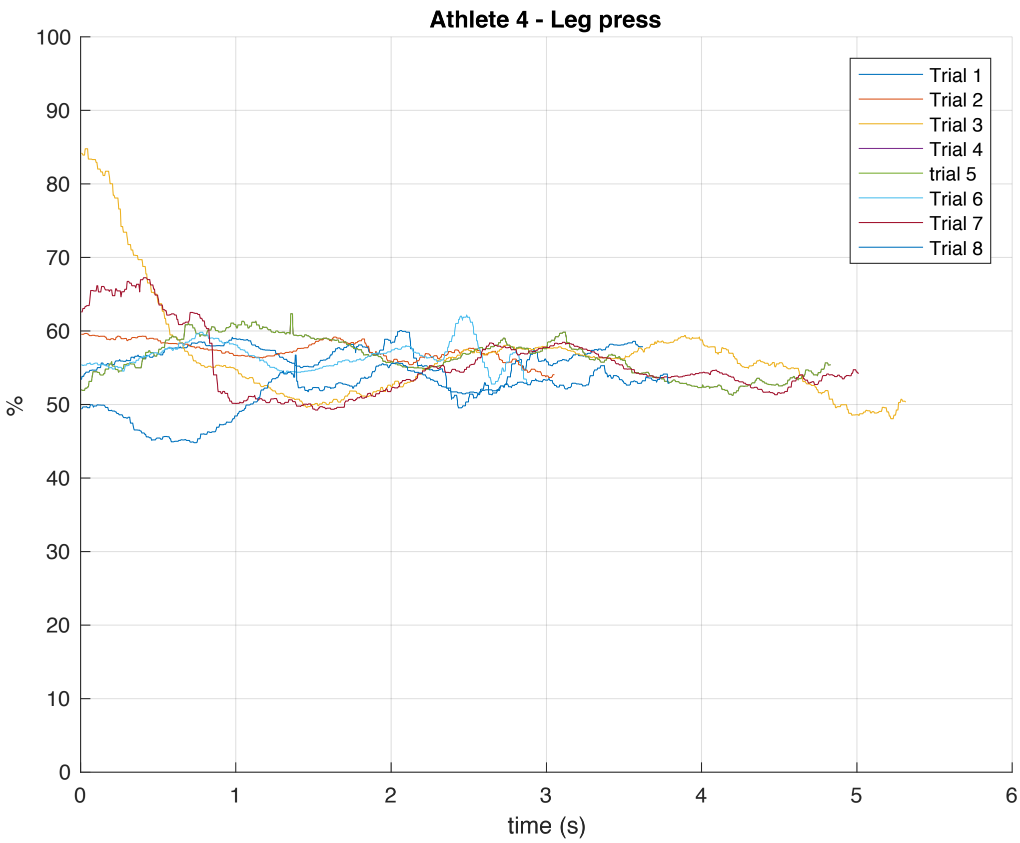

Figure 38: Athlete 4 - load distributed during a squat exercise, relative to time

Athlete 6

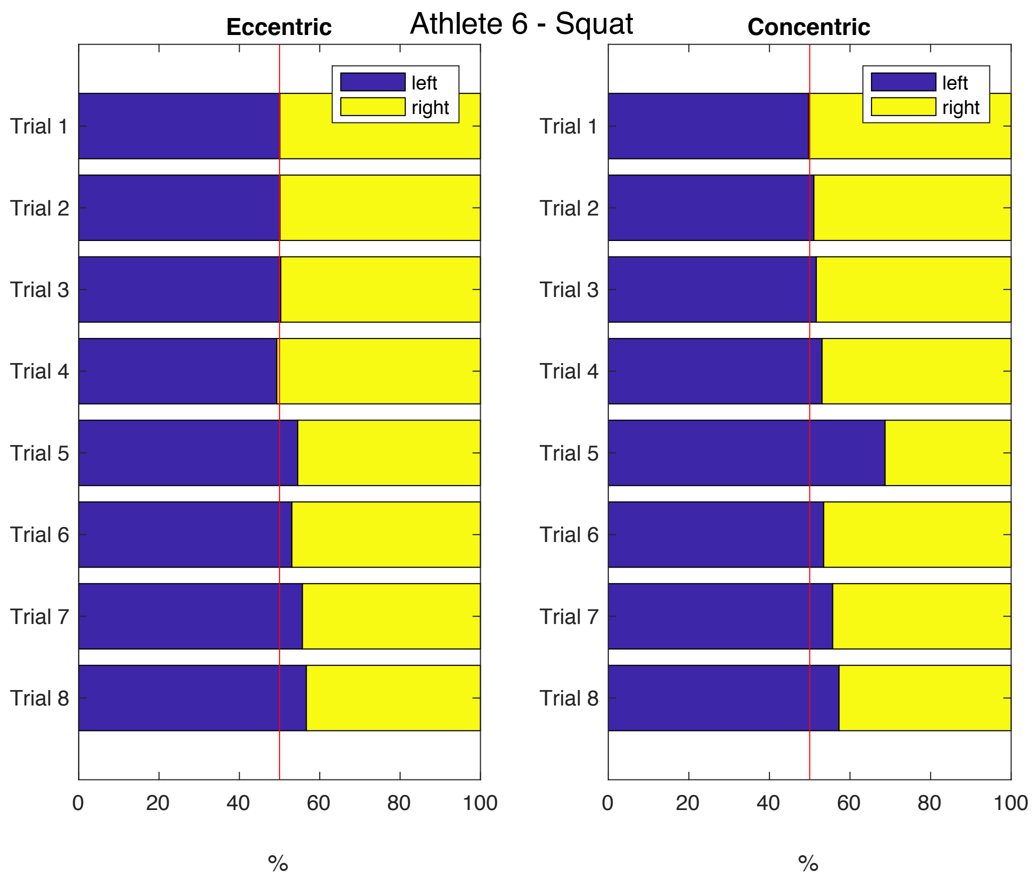

Figure 39: Athlete 6 - load distributed during a squat exercise

Table 16: Athlete 4 - load distributed during a squat exercise

Athlete 6 – Squat Exercise				
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left	**Right**	**Left**	**Right**
1	50.0907	49.9093	49.7298	50.2702
2	50.1151	49.8849	51.0433	48.9567
3	50.2990	49.7010	51.6417	48.3583
4	49.3135	50.6865	53.0709	46.9291
5	54.5250	45.4750	68.7061	31.2939
6	53.0656	46.9344	53.4647	46.5353
7	55.7009	44.2991	55.7044	44.2956
8	56.6787	43.3213	57.2815	42.7185
Average	52.4735625	47.5264375	55.0803	44.9197

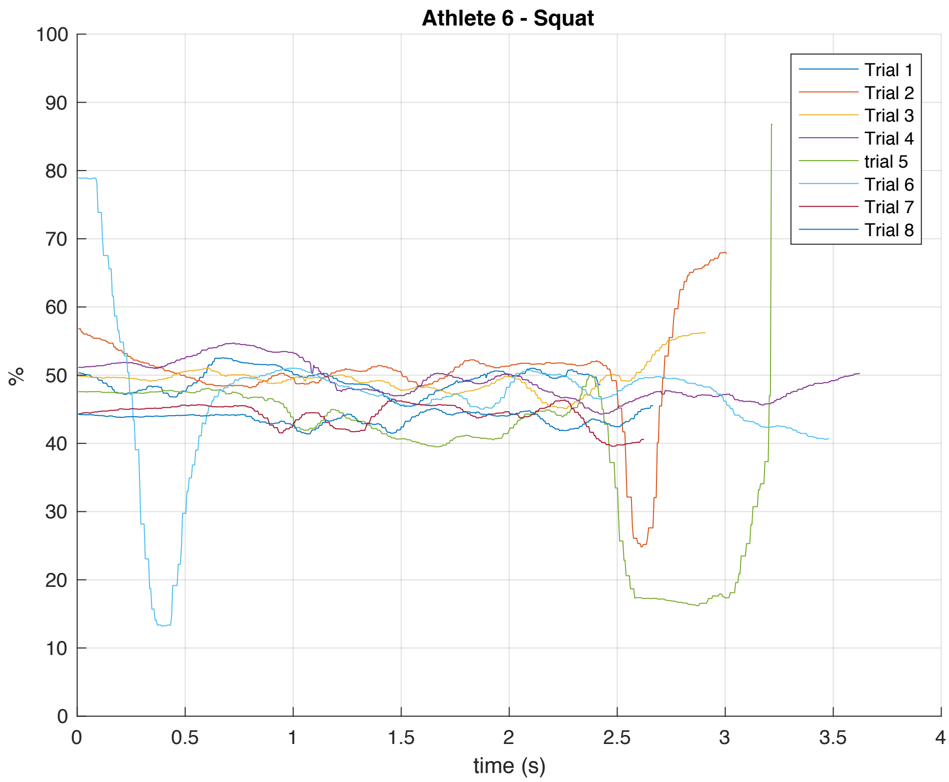

Figure 40: Athlete 6 - load distributed during a squat exercise, relative to time

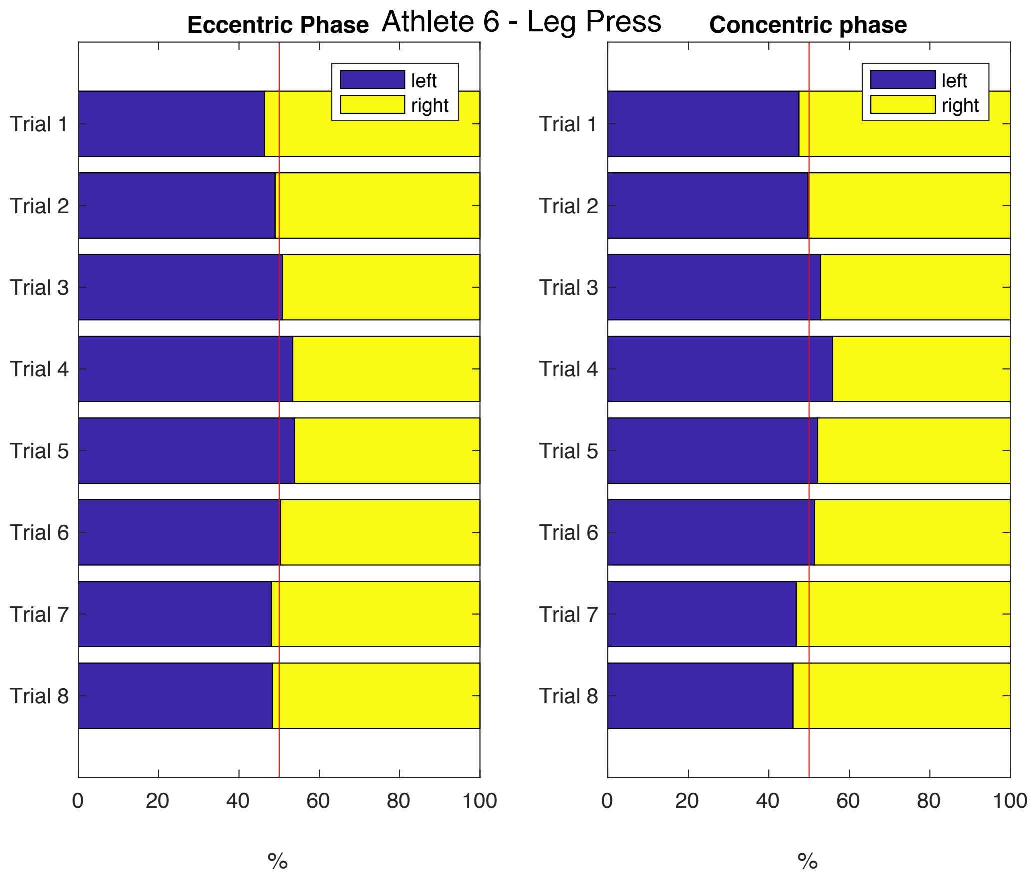

Figure 41: Athlete 6 - load distributed during a leg press exercise

Table 17: Athlete 6 - load distributed during a leg press exercise

Athlete 6 – Leg press				
Trial number	**Eccentric Phase**		**Concentric Phase**	
	Left (%)	**Right (%)**	**Left (%)**	**Right (%)**
1	46.3078	53.6922	47.4890	52.5110
2	48.9984	51.0016	49.7408	50.2592
3	50.7866	49.2134	52.8505	47.1495
4	53.3868	46.6132	55.8700	44.1300
5	53.8702	46.1298	52.1114	47.8886
6	50.3518	49.6482	51.3939	48.6061
7	48.0803	51.9197	46.7964	53.2036
8	48.2794	51.7206	46.0218	53.9782
Average	50.0076625	49.9923375	50.284225	49.715775

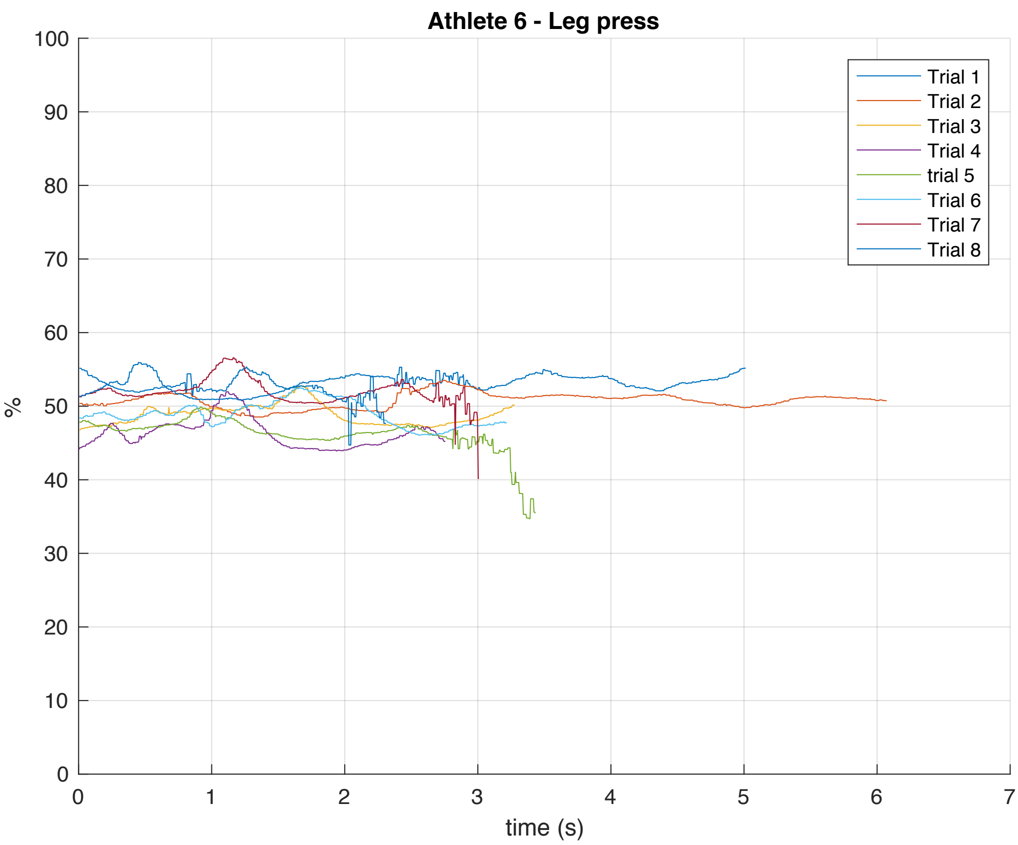

Figure 42: Athlete 6 - load distributed during a leg press exercise, relative to time

Appendix F

Board 1

Table 18: Weights measured by left sensors of board 1

	Weight measured from Wii Balance Board (kg)			
Applied weight (kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
2	1.84	1.87	1.88	1.86
4	3.79	3.86	3.78	3.81
6	5.90	5.85	5.87	5.87
8	7.29	7.20	7.24	7.24
10	9.42	9.38	9.50	9.43
12	11.94	11.89	11.92	11.92

Table 19: Weights measured by right sensors of board 1

	Weight measured from Wii Balance Board			
Applied weight (kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
2	1.49	1.60	1.44	1.51
4	8.84	3.85	3.72	3.8
6	5.72	5.76	5.69	5.72
8	7.81	7.85	7.81	7.82
10	9.69	9.62	9.65	9.65
12	11.86	11.73	11.76	11.78

Board 2

Table 20: Weights measured by left sensors of board 2

	Weight measured from Wii Balance Board (kg)			
Applied weight (kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
2	1.71	1.86	1.87	1.81
4	3.92	3.88	3.87	3.89
6	5.33	5.49	5.48	5.43
8	7.68	7.55	7.51	7.58
10	9.89	9.96	9.94	9.93
12	11.73	11.81	11.72	11.75

Table 21: Weights measured by right sensors of board 2

	Weight measured from Wii Balance Board (kg)			
Applied weight (kg)	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
2	1.53	1.49	1.52	1.51
4	3.62	3.49	3.48	3.53
6	5.79	5.65	5.84	5.76
8	7.85	7.74	7.89	7.83
10	9.75	9.82	9.73	9.75
12	10.88	10.94	10.90	10.91

Appendix G

```
  Created 10th of September 2017
  by Michelle Pham-Nguyen
  Used to establish Bluetooth connection between Wii Balance Board and laptop.
  The load distributions are also
*/

#include <Wii.h>
#include <usbhub.h>
#include <SoftwareSerial.h>

// Satisfy the IDE, which needs to see the include statment in the ino too.
#ifdef dobogusinclude
#include <spi4teensy3.h>
#include <SPI.h>
#endif



USB Usb;
BTD Btd(&Usb); // You have to create the Bluetooth Dongle instance like so
WII Wii(&Btd, PAIR); // This will start an inquiry and then pair with your Wii Balance Board

void setup() {

  Serial.begin(115200); // setting baud rate
#if !defined(__MIPSEL__)
  while (!Serial);
#endif

  if (Usb.Init() == -1) {
    Serial.print(F("\r\nOSC did not start"));
    while (1); //halt
  }
  Serial.print(F("\r\nWii Balance Board Bluetooth Library Started"));
}



void loop() {
  Usb.Task();

  if (Wii.wiiBalanceBoardConnected) {
    Serial.print(F("\r\n"));
    for (uint8_t i = 0; i < 4; i++) { // Displays weight measured for the 4 WBB sensors
      Serial.print(Wii.getWeight((BalanceBoardEnum)i));
```

```
    Serial.print(F("\t"));
   }

     //Left distribution percentage
     Serial.print(F("\t"));
      Serial.print(((Wii.getWeight((BalanceBoardEnum)2)+Wii.getWeight((BalanceBoardEnum)3))/(Wii.getTotalWeight()))
*100);

     //Right distribution percentage
     Serial.print(F("\t"));
      Serial.print(((Wii.getWeight((BalanceBoardEnum)0)+Wii.getWeight((BalanceBoardEnum)1))/(Wii.getTotalWeight()))
*100);


   if (Wii.getButtonClick(A)) { // pressing the button will pause measurement from the WBB

    Serial.print(F("\r\nPAUSE"));

    Wii.disconnect();
   }
  }
}
```