The Health Benefits of Trampolining

By

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Abstract

Trampolining is a common recreational activity, that is especially popular amongst children. The body of evidence investigating the health effects of trampolining on human physiology is very limited compared to other common modalities, such as running, rowing or biking. Therefore, the purpose of this series of studies was to expand the amount of literature using trampolining as the modality of choice.

This thesis first comprehensively reviews the literature relating to physiology and trampolining. General methods used in the studies are then discussed. The next five chapters consist of the five studies that were published as a part of completing this thesis. Finally, the findings from each of the studies are summarised in the last chapter.

In the first study, a model was developed which allows energy expenditure, on an app-equipped trampoline, to be calculated using only the input of the user's mass. Participants were required to bounce on a trampoline while wearing a breath by breath analyser. This allowed the model to be validated by comparing the model's estimated energy expenditure to the participant's oxygen consumption, as measured by breath by breath analysis. This allows the intensity of bouncing on a trampoline to be easily calculated and measured. This method was used in every subsequent study, as it was a significant improvement to the quality of life, for the collection of data, for exercise on a trampoline.

In the second study, energy consumption while bouncing on a trampoline was compared to energy consumption while running on a treadmill. Participants wore a breath by breath analyser and blood lactate was collected, while bouncing on a trampoline. Then in a second session, a week later, participants wore a breath by breath analyser and blood lactate was collected while running on a treadmill. This was to build on the findings of a previous study to see if they remained consistent. It was confirmed that trampolining and running had similar exercise profiles and the findings of the previous study were validated.

In the third study, energy expenditure while bouncing on a trampoline was measured while altering the bouncing action. A variety of different bouncing actions were measured and it was discovered that altering the bouncing action did increase the energy expenditure. The model produced in the first study was then updated. This allowed a more accurate estimation of energy expenditure, while using the bouncing actions measured in the study.

In the fourth study, a novel exercise protocol on a trampoline was investigated to assess whether it produced a positive change to various health markers. The novel protocol was designed to be very time efficient. Participants regularly exercised on a trampoline for 8 weeks. The novel protocol appeared to improve the participant's fitness and vertical jump with as little as ten minutes of exercise per week.

The fifth study investigated whether trampolining could be used as a novel treatment to improve body composition, cardiovascular fitness, bone density and stress urinary incontinence amongst parous women. Participants regularly exercised on a trampoline for 12 weeks. The treatment appeared to improve the participant's pelvic floor strength and reduce the impact stress urinary incontinence had on their quality of life.

Keywords:

Trampolining, physiology, oxygen consumption, energy expenditure, model estimation, novel exercise routine, stress urinary incontinence

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Publications

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List of Abbreviations

ATP	Adenosine Triphosphate
BL	Blood Lactate
BMD	Bone Mineral Density
BMI	Body Mass Index
CrP	Creatine Phosphate
DXA	Dual-Energy X-ray Absorptiometry
EE	Energy Expenditure
HDL	High Density Lipoprotein
Hg	Mercury
HIIT	High Intensity Interval Training
HISD	High Intensity Short Duration interval training
HR	Heart Rate
ICIQ	International Consultation on Incontinence Questionnaire
LDL	Low Density Lipoprotein
MET	Metabolic Equivalent of Task
QUID	Questionnaire for female Urinary Incontinence Diagnosis
RHR	Resting Heart Rate
RPE	Rate of Perceived Exertion
SUI	Stress Urinary Incontinence
TGOMA	Take Gaming Outside and Make it Active
UI	Urinary Incontinence
$\dot{V}O_{2\max}$	Volume of Oxygen consumed per minute

1 Introduction

Physical activity is a modifiable risk factor that has been found to reduce all-cause mortality by up to 50% (Myers et al., 2004). The 2020 New Zealand Activity Guidelines recommend at least 2½ hours of moderate or 1¼ hours of vigorous physical activity spread throughout the week (Ministry of Health, 2020). Unfortunately, 49% of New Zealand adults do not complete at least 30 minutes of moderate activity/week and 14% reported doing no activity at all (Ministry of Health, 2019). Trampolining is a common recreational activity that has been promoted, by retailers, as a novel method to improve physical activity rates within the general populace.

The first modern trampolines were created by George Nissen and Larry Griswold in the 1930s. Since then, trampolining has exploded in popularity, both as a recreational activity and a competitive sport and was officially admitted into the Olympic Games schedule in 2000. In 2003, a major improvement to trampoline design was introduced to the market. This improved design is known as a Springfree trampoline. This novel design, for a trampoline, tensioned the mat using cantilevered rods (as opposed to metal springs), which allowed the removal of the hard outer frame. This combined with a strong flexible netting, dramatically improved the safety of use for trampolining.

Trampolining utilises a unique exercise format. Most forms of exercise involve semi-continuous muscle actions (running, rowing, cycling etc,). Whereas, trampolining uses an intermittent form of muscle action, due to the distinct rest time while travelling through the air. This inclusion of a rest time, during a single cycle of the exercise, is unique and so far the exact effect this has on physiology is unclear.

The jumping action of a trampoline consists alternating between a contact period and flight period (Farquharson, 2012). The flight period consists of the time the user is airborne (not in contact with the trampoline mat). During this period, the body position of the user can be altered through manipulation of the user's body. This allows the user to affect the moment of inertia of their body. The user is unable to affect overall momentum of their body while airborne. Therefore, movement during the flight period is limited by the orientation, configuration and angular/linear momenta of the user at the moment of takeoff. To affect these outcomes the user must make adjustments during the contact period.

The contact period can be further separated into two major phases; the depression phase and the recoil phase (Burke, 2015). As the user lands on the trampoline mat, the mat begins to deform. This is due to a transfer of energy from the user's body into the trampoline mat. This is the kinetic and gravitational potential energy of the user being stored as elastic potential energy in the trampoline mat. This is known as the depression phase. Once the trampoline mat is maximally deformed relative to the amount of energy that was transferred, a peak depression is reached. Post this peak depression, the recoil phase begins.

The recoil phase is where the majority of the elastic potential energy in the trampoline mat is transferred back into the user, causing the user to accelerate upwards. During the recoil phase, the user may orientate their body to achieve the desired outcome during the flight period. This is controlled via the hip and knee flexion of the user. Movement while airborne, may be manipulated via alteration of the user's angular momentum (i.e. increasing or decreasing their inertia). Of note is that flexion of the hip/knee will require the absorption of some amount of the kinetic and gravitational potential energy of the user. This will reduce the amount of energy transferred into the trampoline bed and, therefore, the overall height reached during the flight period.

Research concerning trampolines has primarily investigated injury rates relating to their use. Trampoline injuries have increased, proportionally to their use, since their creation in 1936. With the major modes of injury being contact with a hard surface (mat, springs, frame, other users) or ejection from the trampoline. To combat the growing injury rates, safety standards were introduced in New Zealand in 1993. Unfortunately, the reviews of the injury literature concerning the traditional trampoline design found that the improved safety standards have had no effect on injury rates. Conversely, recent investigation of the Springfree trampoline design have found that this design does lower the rate of injury with use.

The use of mini-trampolines, also known as rebounders, are far more popular amongst the literature. Rebounders have been shown to improve outcomes related to body composition (Cugusi et al., 2016; Kamenjašević et al.), balance (Aragão et al., 2011; Miklitsch et al., 2013; Rhouni et al., 2019; Schmid et al., 2012), vertical jump (Atiković et al., 2018; Rhouni et al., 2019), recovery from ankle injury (Kidgell et al., 2007), health outcomes related to obesity (Nuhu & Maharaj, 2017), cardiovascular function (Şahin et al., 2016) and lower body strength (Witassek et al., 2018). It is a normal logical jump to assume that outcomes would be similar between rebounders and trampolines, but there is a debate surrounding this. The jumping action is different between a rebounder and a trampoline and this may affect the outcomes related to exercise using these modalities. Further research is required to examine this phenomenon.

1.1 Thesis Overview

This thesis begins by reviewing the literature relating to trampolining this includes: a brief introduction to the energy systems of the human body, a historical account of the evolution of trampolining from both a recreational and competitive viewpoint, the benefits of physical activity, the jumping action on a trampoline, injury rates associated with recreational trampoline use, physiological effects of trampolining and physiological effects of mini-trampolines (rebounders). The methods that are common amongst multiple studies are then explained in detail. This thesis then contributes to the pool of literature by examining how trampolining affects various health related aspects of human physiology. These outcomes are then presented as the published versions of five studies produced as a part of completing this Doctorate of Philosophy.

1.2 Significance of the Studies

Trampolining is a unique exercise modality that has a distinct rest period in a single cycle of the exercise. This may provide unique benefit to health-related outcomes. The assessment of the physiological effects of trampolining are limited in the current literature pool. In the author's opinion, this is likely due to space constraints related to the storage of full-sized trampolines. A greater amount of research is available for exercise on a rebounder, but it is unclear whether direct comparison can be made between these modalities. Therefore, the purpose of this thesis is to expand the breadth of literature directly investigating the physiological effects of trampolining. This will allow a deeper understanding of the benefits associated with trampolining and how the general populace may benefit from increased trampolining usage. This also provides a framework for where further investigation is necessary.

1.3 Purpose Statement

The purpose of this series of studies was to expand the evidence base regarding physiological and potential health benefits of trampolining. Five different ideas were used as the direction for the studies.

The purpose of the first study was to create a model which could accurately predict energy expenditure during trampolining.

The purpose of the second study was to expand upon the only prior study investigating energy expenditure during trampolining.

The purpose of the third study was to investigate the effect of different bouncing styles on energy expenditure during trampolining.

The purpose of the fourth study was to investigate whether a high intensity, short duration exercise format on a trampoline would have positive outcomes on body composition, lipid profiles, cardiovascular function and vertical jump.

The purpose of the fifth study was to investigate whether a short duration, self-paced, exercise format on a trampoline would provide positive outcomes to; body composition, cardiovascular function, bone density and stress urinary incontinence amongst parous women.

2 Review of the Literature

2.1 Physical Activity

Physical activity can be defined as any bodily movement produced by skeletal muscles which results in energy expenditure (Caspersen et al., 1985). Measuring the volume of physical activity (frequency, duration and intensity of the exercise) is important to the overall promotion of physical health, as it gives guidelines to minimum and maximum dosages for best practise. Two broad methods exist for the measurement of rates of physical activity.

First, is the most common parameter for measurement of physical activity amongst health guidelines, which is time spent active, usually expressed in either minutes or hours per week. The 2020 New Zealand Activity Guidelines recommend at least 2½ hours of moderate or 1¼ hours of vigorous physical activity spread throughout the week (Ministry of Health, 2020). They also recommend, for extra health benefits, to aim for 5 hours of moderate or 2½ hours of vigorous physical activity spread throughout the week and to do muscle strengthening activities on at least two days each week. Unfortunately, it is common that these recommendations are not met. The New Zealand 2018/2019 Ministry of Health Survey reported that 49% of New Zealand adults didn't complete at least 30 minutes of moderate activity/week and 14% reported doing no activity at all (Ministry of Health, 2019).

Second, is measurement through energy expenditure during activity. Early research found regular physical activity (> 8400 kJ/week) increased life expectancy by 1-2 years by age 80 (Paffenbarger Jr et al., 1986). Further investigation showed that an average expenditure of 4200kJ/week is associated with a 20-30% reduction in all-cause mortality (Lee & Skerrett, 2001). Currently, the minimum volume recommended by most health professionals is 4200kJ/week, but it is acknowledged that an increase to this minimum will provide further benefit (Warburton et al., 2006). Emerging research has suggested that as little as 2100 kJ/week of average weekly energy expenditures may provide health benefit (Iwase et al., 2022) and may be of particular benefit to those who are extremely deconditioned or are frail or elderly (Blair et al., 2001).

2.1.1 Physical Fitness

Physical fitness is composed of a number of health and skill related components, such as aerobic fitness, muscular fitness, metabolic fitness and morphological fitness (Draper & Stratton, 2019). Physical fitness is often viewed as a result of recent physical activity, but evidence to support this is lacking, with relatively low associations reported depending on the component of fitness and the measurement methods that were used (Armstrong et al., 2011; Patnode et al., 2011). Each of the aspects of physical fitness are important to overall health, but it is aerobic fitness which is most frequently associated with health and well-being (Ferreira & Twisk, 2017). Maximal $\dot{V}O_2$ is international recognised as the best single measure of adult's aerobic fitness (Draper & Stratton, 2019).

2.2 Demands of Exercise on the Body

Exercise can be defined as any physical activity that is planned, structured repetitive and maintains or improves one or more components of physical fitness (Caspersen et al., 1985). Bouncing on a trampoline is an example of a form of exercise. All muscle contractions, and therefore all forms of exercise, require the breakdown of adenosine triphosphate (ATP) to power the contraction (Glaister, 2005). ATP can be synthesised in the human body using three systems: the phosphagen system, the glycolytic system and mitochondrial respiration. The rates of energy production for each of the energy systems can be seen in Figure 2.1. Historically it was assumed that the energy systems worked independently of each other (i.e. exercise was solely powered by the phosphagen system for the initial 10s, then the glycolytic system for 2-3 minutes, then mitochondrial respiration) (Baker et al., 2010). However, modern research investigating maximal 30s bouts of exercise has found the almost immediate onset of energy production from the glycolytic system, but the rate of energy production does not reach its maximum for 10-15 seconds (Casey et al., 1996). It has been estimated that, during a 30 seconds sprint, the phosphagen system accounts for 23% of energy provision, 49% comes from glycolysis and 28% from mitochondrial respiration. Whereas during a 10-second maximal sprint it has been estimated that energy is provided by 53% phosphagen, 44% glycolysis, and 3% mitochondrial respiration (Van Someren, 2006).

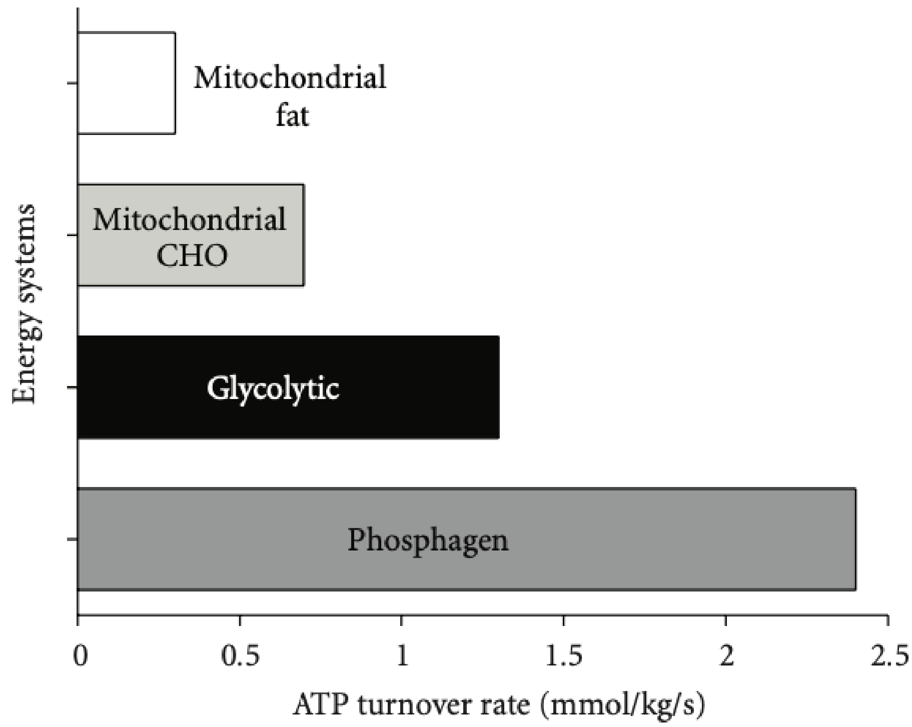

Figure 2.1 *Maximal rates of ATP regeneration from the three broad energy systems. Taken from Baker et al (Baker et al., 2010)*

The phosphagen system generates energy through anaerobic recycling of ATP (Spriet, 1992). The phosphagen system is comprised of three reactions within the muscle cell (see Figure 2.2).

$$CrP + ADP + H^+ \xrightarrow{\text{creatine kinase}} ATP + Cr,$$

$$ADP + ADP \xrightarrow{\text{adenylate kinase}} ATP + AMP,$$

$$AMP + H^+ \xrightarrow{\text{AMP deaminase}} IMP + NH_4{}^+.$$

Figure 2.2 *Illustration of the chemical reactions in the phosphagen system. Taken from Baker et al (Baker et al., 2010).*

The reactions are often referred to by the catalyst of the reaction (the chemical above the arrow). The first reaction (creatine kinase) has the greatest capacity for energy production, due to phosphocreatine (CrP) being present in the muscle cell. The subset reactions (adenylate kinase and AMP deaminase) occur as CrP in the muscle cell is consumed. It is generally accepted that any maximal exercise of up to 6 seconds is sustained primarily by the phosphagen system and may continue up to 10 seconds (Åstrand et al., 2003). Loss of power output after 10 seconds is mostly due to depletion of the CrP in the muscle cells (Bogdanis et al., 1996). Activities that require a high rate of force production (power) are heavily dependent on the phosphagen system (e.g. throwing, sprinting, jumping, weightlifting). Therefore, athletes in these disciplines will benefit from the ability to repeatedly recover their CrP stores. After exhaustive exercise it may take 5-15 minutes depending on the extent of the depletion of the CrP (Forbes et al., 2009).

Glycolysis has the second greatest rate of energy production of the energy systems (see Figure 2.1) and is also primarily anaerobic. When a high intensity of exercise is maintained for longer than 6-10 seconds the glycolytic system becomes the primary energy system through which ATP is generated (Pilegaard et al., 1999). Glycolysis is composed of two broad phases, each containing a multitude of reactions (see Figure 2.3).

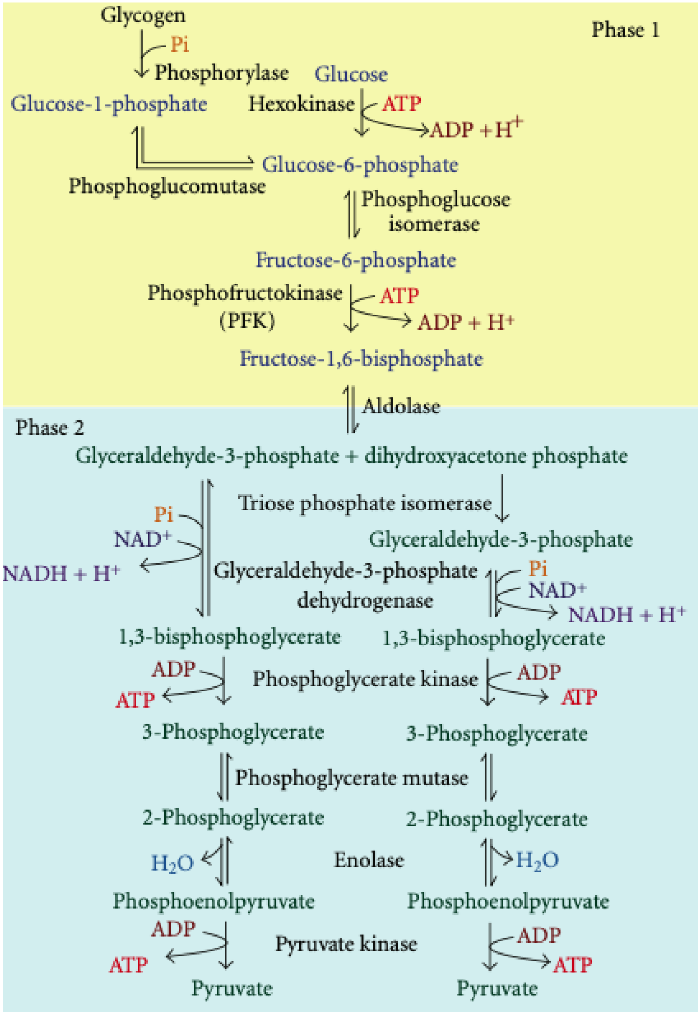

Figure 2.3 *The Glycolytic pathway. Taken from Baker et al.*

The maximum energy production from the glycolytic system is achieved when a work rate above the individual's maximum aerobic capacity is maintained for as long as possible, which for a trained athlete is between 2-3 minutes (Medbo & Tabata, 1989). Glycolysis partially oxidises glycogen to produce ATP. This is because pyruvate is produced at a rate which exceeds the mitochondria's ability to take up pyruvate. Therefore, the remaining pyruvate must be removed from the cell. While some of the pyruvate is exported from the cell, most is converted into lactate (Bigland-Ritchie & Woods, 1984). Lactate was historically considered an unhelpful waste product of glycolysis (Hill & Lupton, 1923), but is now known to be essential for removing pyruvate, and regenerating cytosolic NAD^+ to sustain a high-rate of glycolysis. With Baker et al summarising that “It is fair to state that we could not sustain high-intensity exercise for much longer than 10 to 15 seconds without lactate production.” (Baker et al., 2010).

The final energy system (mitochondrial respiration) resynthesises ATP through the combustion of fuel in the presence of sufficient oxygen (Baker et al., 2010). This fuel can be obtained from both glycogen and free fatty acids. This process is referred to as aerobic energy production. Aerobic energy production has the lowest energy output of the three energy systems, but is the only energy system that can be maintained indefinitely as long as sufficient oxygen and substrates are available. It has been found that, for a maximal exercise bout lasting 75 seconds, energy production will be approximately equal between anaerobic and aerobic sources (Grenhaff, 1998). Therefore, any exercise bout longer than 75 seconds will primarily be supported by aerobic energy production.

Trampolining can utilise any and all of these energy systems, depending on the length of the exercise bout. Short duration (0-10 seconds), high intensity bouts will more strongly utilise the phosphagen system. Medium duration bouts (10 seconds-3 minutes) will more strongly utilise the glycolytic system. Long duration (> 3 minutes) will primarily utilise mitochondrial respiration.

2.3 The History of Trampoline Design

2.3.1 Early Trampoline-like devices

The Inuit people of Alaska may have been the first people to utilise trampolining in some form. They would toss others into the air on a walrus skin, one at a time, during a spring celebration of whale harvest (Spencer, 1959). Another early mention of trampolining came from a 19th century poster for Pablo Fanque's Circus Royal (Dash, 2011). However, the device is thought to have been closer to a springboard, than the fabric and coiled springs design that is now commonly considered to be a trampoline.

2.3.2 The First Modern Trampolines

The first modern trampoline was built by George Nissen and Larry Griswold in 1936 (Hayward, 2010). Nissen was a gymnastics and diving competitor. Griswold was a tumbler on the gymnastics team. Both gentlemen competed for the University of Iowa, United States. They had observed trapeze artists using a tight net to add entertainment value to their performance. They mimicked this idea by stretching a piece of canvas, in which they had inserted grommets along each side, to an angle iron frame by means of coiled springs (Hayward, 2010). This early trampoline was used to train tumblers, but soon became popular as a recreational activity. Nissen stated that the name (trampoline) came from the Spanish word trampolín, meaning a diving board. Nissen had heard the word on a demonstration tour in Mexico in the late 1930s and decided to use an anglicised form as the trademark for the apparatus. In 1942, Griswold and Nissen created the Griswold-Nissen Trampoline & Tumbling Company, and began making trampolines, commercially, in Cedar Rapids, Iowa (Hayward, 2010). At the time, the generic term for the trademarked trampoline was a "rebound tumbler" and the sport began as "rebound tumbling" (Nissen, 1945). The trademark has since expired and "trampoline" has become the generic name for the product.

2.3.3 Recreational Trampoline Design

Traditional, recreational, trampoline design consists of various shapes, though most are circular, octagonal or rectangular. The fabric is usually a waterproof canvas or woven polypropylene material and the trampoline is tensioned using coiled, steel springs to provide the rebounding force. To prevent injury, padded covers for the springs and nets may be seen on some models.

In 2003, a new design for recreational trampolines was produced by Keith Alexander. Originally, Dr Alexander had wanted a trampoline for his children, but after investigating the research concerning safety of use of traditional trampolines he realised there was a need for an improved design. He went through a number of different design iterations including inflatable options (see Figure 2.4).

Figure 2.4 *Early trampoline prototypes.*

These inflatable designs were good for children and had no hard surfaces which the user could contact, but they had poor bounciness and always leaked air. Therefore designs using springs under the trampoline were explored (see Figure 2.5).

Figure 2.5 *Early prototypes using springs underneath the mat.*

This design also had poor bounciness and were too expensive to produce. The final design utilised rods (instead of springs) to tension the mat (see Figure 2.6).

Figure 2.6 Springfree design using cantilevered rods.

This new design was dubbed a Springfree trampoline. Springfree trampolines tension the mat using cantilevered rods, rather than coiled springs, which remove the need for an outer frame. The Springfree design removes the need for a hard external frame. This dramatically improves the safety of use, compared to the traditional trampoline design. Further, the safety netting design patented in the late 1990's was updated by using the same cantilevered rods used to tension the trampoline, to erect the netting. Traditionally, safety nets were erected using metal poles, which became another hazard that the user could collide with. The poles used on a Springfree trampoline are flexible and, therefore, lower the risk of collision with a hard object while using the trampoline.

2.3.4 Competitive Trampoline Design

Trampolines, for competitive purposes, use a standard design as laid out in the International Gymnastics Federation (FIG) Apparatus Norms (Fédération Internationale de Gymnastique, 2009). This is necessary for practical reasons, competition fairness and safety. The frame of a competitive trampoline is made of steel and can be made to fold up for transportation to competition venues. The trampoline bed is 4.28m by 2.14m in size, fitted into the 5.05m by 2.91m frame. Around 110 steel springs are used (the actual number may vary by manufacturer) to tension the bed. The bed is made of a strong fabric, usually a webbing of nylon. This webbing ranges from 25mm to 4mm wide, with the spacing of the webbing affecting the stiffness of the bed. The springs, which tension the trampoline bed, have a natural length of approximately 35cm and hook into brackets found on both the bed and the frame.

2.4 The History of Gymnastic Trampolining

After trampolines were patented by Nissen and Griswald, they quickly grew in popularity throughout the United States. This led to competitions being held, initially, in colleges and schools in the United States, then across Europe (Kingaby, 2008). At first there was no defined format for routines, with performances often being lengthy and athletes even remounting the trampoline if they were ejected (Kingaby, 2008). Gradually, competitions became more codified, such that, by the 1950s the 10-bounce routine was the norm, thereby paving the way for the first World Championships which were organized by Ted Blake of Nissen, and held in London in 1964 (Gymnastics New South Wales, 2019). In 1965, the International Trampoline Federation was formally recognized as the international governing body for the sport. World Championships were held annually until 1969. This was then changed to be bi-annual until 2009. The World Championships are now held annually. Trampolining became an Olympic Sport at the 2000 games in Sydney, Australia, with a men’s and women’s contest. Trampoline Gymnastics have appeared at every Olympics since, with the number of events remaining the same (two) (International Olympic Commitee, 2019).

2.5 Early Trampoline Literature

The first literature regarding trampolining was mostly the observations and opinions of coaches, who did not support their arguments with objective data. The books focussed on the methods and progressions for trampolining skills (Horne, 1968; LaDue, 1956; Walker, 1983) with some discussion on the details of technique (Phelps & Phelps, 1990). Later texts then investigated the effect of impulse on momentum in trampolining

(Shvartz, 1967) and the force-depression relationship of the trampoline bed (Lephart, 1972).

2.6 Mechanics of Bouncing on a Trampoline

2.6.1 Contact Period

While bouncing on a trampoline, the period during which the user is in contact with the trampoline mat is known as the contact period (Burke, 2015). This contact period can be broken into five distinct elements; the moment of touchdown, the depression phase, the moment of maximal depression, the recoil phase and the moment of takeoff. During the entire contact period, the user is able to adjust the orientation of their body to affect the outcome of the bounce. While the user is airborne, they are unable to affect their overall momentum, only the speed of rotation around their centre of mass can be altered.

2.6.2 Height of the Bounce

Height while bouncing on a trampoline is the simplest measure of intensity of the exercise bout. Studies investigating jumping on a compliant surface (such as trampolines or diving boards) have found that maximal depression of the elastic surface relates to maximal jump heights in both theoretical (Cheng & Hubbard, 2004) and experimental work (Shvartz, 1967). The takeoff velocity has been shown to be the primary factor in improving jump height (Feltner et al., 1999; Sanders & Wilson, 1992). Takeoff velocity, while bouncing on a compliant surface, correlates with landing velocity (Miller & Munro, 1984). Increased landing velocity allows more energy to be stored in the trampoline mat, which results in a greater takeoff velocity (Sanders & Wilson, 1988). However, on a trampoline, the depression of the mat is limited by the height of the frame and strength of construction.

To optimise takeoff velocity, certain movement strategies can be used. These movement strategies are associated with an increased reaction force (Sanders & Wilson, 1992) and impulse (Shvartz, 1967). The first movement strategy is the maximal extension of the lower body during the depression phase. At touchdown, flexion of the lower body should occur (hips, knees, ankles) to allow maximum range for the extension (Sanders & Wilson, 1988). During the depression phase, the extension begins, but the extension should not occur in a proximal to distal sequence (hips then knees then ankles) (Bobbert & van Ingen Schenau, 1988). Rather, the optimal strategy is beginning with extension of the knee, followed by simultaneous extension of the hip and ankle (Cheng & Hubbard, 2004; Sanders & Allen, 1993; Selbie & Caldwell, 1996). The sequence doesn't follow the proximal to distal order due to the need to reorientate the centre of mass, prior to propulsion (Selbie & Caldwell, 1996).

The second movement strategy is the use of flexion of the arms to apply maximal force into the trampoline mat, during the contact phase (Cheng & Hubbard, 2008; Lees et al., 2004). Then, extension of the whole body during the recoil phase (Cheng & Hubbard, 2004).

2.7 Injury Rates while Trampolining

Trampolines have been a popular recreational activity since their creation in 1936. Since then, injury rates related to trampolining have grown proportionately to trampolining's popularity (Ashby et al., 2015). The five main modes of injury while using a trampoline were found to be; contact with the trampolining mat (43%), ejection from the trampoline (27%), contact with the frame or springs of the trampoline (19%), contact with another person (10%) or getting on and off the trampoline (2.5%) (Ashby et al., 2015). Other investigations into the risks of trampolining concluded that trampolining presented a significant health risk (Black & Amadeo, 2003; Nysted & Drogset, 2006;

Smith, 1998). In New Zealand, from 1979-1988, the incidence rate of hospitalisations, due to trampolining, increased from 3.1 per 100,000 per year to 9.3 per 100,000 per year (Chalmers et al., 1994). This led to the creation of the New Zealand Trampoline Safety Standard (Standards Association of New Zealand, 1993), which was a revised version of the American Standard (ASTM F381) (American Society for Testing and Materials, 1984). Since the standards were implemented, it was assumed that injury rates would fall in the following years. To date, multiple studies have found no significant alteration to injury rates for traditional trampoline designs (Alexander et al., 2010; Linakis et al., 2007). Currently, no consensus exists on why improvements to safety standards haven't improved injury rates.

Recent improvements to the design of recreational trampolines (see heading 2.4.3) have aimed to improve the safety profile of trampoline use. An initial response to the high injury rate was the inclusion of foam pads over the springs and a safety net. In 2003, a new design for recreational trampolines was introduced to the commercial market. These trampolines tension the mat using cantilevered rods, rather than coiled springs, which remove the need for an outer frame. This theoretically, would significantly improve the safety profile of the trampoline, as there are less hard surfaces for a user to contact. Eager et al investigated whether the Springfree design had improved trampoline injury rates across the period 2007-2010 (Eager et al., 2012). They found the Springfree design reduced injuries related to ejection from the trampoline and collisions with hard objects. These injury modalities were the most severe for traditional trampolines. This indicates that the rate of injury on trampolines may be significantly reduced by updating the trampoline safety standards to make soft edged trampolines mandatory for recreational use.

2.8 Physiological Effects of Trampolining

Using full-sized trampolines (mat diameter of >1.5m) as an exercise modality for investigation is rare amongst research studies. In the author's opinion, this is likely due to the difficult nature of storing such a large piece of equipment. Below is a summary of the major findings in the literature.

The first study investigated how trampolining affected human physiology, in a now famous study, conducted by the National Aeronautics and Space Administration (NASA). They investigated how trampolining and treadmill running differed in terms of acceleration experienced by the body and oxygen consumption ($\dot{V}O_2$) for a given work rate (n=8) (Bhattacharya et al., 1980). This was to assess the viability of trampolining as a method to mitigate the effect of deconditioning in space brought about by zero gravity. They found that $\dot{V}O_2$ (0.8-3 L/min) was similar between the exercise modalities, but significantly greater acceleration forces were experienced while trampolining (0.5 G/kg vs 0.8G/kg). They concluded that trampolining provided a more appropriate stimulus to mitigate the effect of space de-conditioning and suggested that trampolining should be utilised by NASA as a part of their astronaut programme. This paper was the first piece of evidence that trampolining could provide novel stimulus above and beyond the more traditional forms of aerobic exercise.

Sovelius et al compared strength training to trampolining for the purpose of assessing reduced cervical spine strain amongst fighter pilots (n=16) (Sovelius et al., 2006). During air combat, the performance of modern combat aircraft may exceed the pilot's capability to tolerate high acceleration. High acceleration load, with high onset rate, may cause the pilot neck pain and more serious ailments (Hämäläinen et al., 1994). Strength training and trampolining, were both explored as modalities for improving cervical spine muscle strength and, therefore, lowering the rate of cervical spine injury. They found that both modalities were valuable to the reduction of cervical spine strains (no significant difference between the modalities) and recommended the continued use of both for the physical education programmes of fighter pilots.

Sovelius et al produced a further study investigating how wearing a flight helmet during trampoline training affected the forces experienced, specifically, across the musculature of the cervical spine (n=14) (Sovelius et al., 2008). The flight helmet is a mounting platform for various pieces of equipment and increases the load experienced by the pilot's cervical spine. The helmet had, traditionally, not been worn during the trampoline training. The authors hypothesised that wearing the helmet increased the load experienced, which then may alter the outcomes of the trampoline training. They found that greater cervical spine load was experienced while wearing the flight helmet. This increased load led to adaption in the muscles reducing the rate of muscle strain (sternocleidomastoid (50%), cervical erector spinae (3%), trapezius (4%) and thoracic erector spinae (8%). Therefore, the authors summarised that, bouncing on the trampoline while wearing a flight helmet may have some benefit to the physical education programmes of fighter pilots.

Atilgan, investigated the effect of chronic trampolining on jump height, leg strength and the static and dynamic balance of young males (age 9-11) (n=28, 15 intervention, 13 control) (Atilgan, 2013). The boys were required to complete a trampolining intervention involving bouncing on the trampoline for 1.5 hours, two times per week for a duration of 12 weeks. The study saw improvement to vertical jump (+3cm), static balance (-200mm) and leg strength (+3.2kg) amongst the boys. These results indicate trampolining is a viable modality for the improvement of vertical jump height, static balance and leg strength amongst young males.

Aalizadeh et al, investigated a similar topic (Aalizadeh et al., 2016). This study required that adolescent males (age = 12.6 $\pm$ 2.1 years) bounced on a trampoline for 1.5 hours, four times per week for a duration of 20 weeks (n=28, 14 intervention, 14 control). They found decreased body fat (-2.18kg), increased calf girth (+0.02m) and vertical jump (+0.19m) amongst the young males. From these results the authors postulated that trampolining may be a valuable tool for sport educators wishing to improve the balance, vertical jump and anthropometric measures of children.

Giagazoglou et al, investigated the effect of trampoline exercise on balance and motor performance amongst children (age = 10.3 $\pm$ 1.6 years) with intellectual disabilities (n=18, 8 intervention, 8 control) (Giagazoglou et al., 2013). This study required that the children complete, daily (while at school) a 20-minute trampoline session, for a duration of 12 weeks. They found improvement to vertical jump (+6cm), broad jump (+30cm), sit and reach test (p =0.001) and balance (p = 0.001). They concluded that trampolining is a viable alternative for physical activity programming.

Jensen et al, investigated the physiological response to a simulated trampoline gymnastics competition (Jensen et al., 2013). The participants completed 3 (approximately 40 second) routines, with a 25-minute gap between the first and second routine. Then, an hour gap between the second and third routines. This protocol was used to closely mimic how the events would happen during an actual competition. The authors saw an increase (p <0.05) to heart rate, muscle temperature, blood lactate and creatine kinase, post the routines. The increased concentration of creatine kinase (p <0.05) suggests that muscle damage had occurred from the bout. This was reaffirmed by a decrease in jump height (-4.2%), assessed by counter-movement jump, both immediately post and 24 hours post intervention. Both creatine kinase concentration and jump height had returned to baseline levels after 48 hours. The authors concluded that the high number of explosive jumps that occur during a trampoline gymnastics competition elicit high aerobic and anaerobic energy demands. This results in fatigue both during the competition and up to 48 hours post-competition.

Finally, a 2015 study, by Mohammed & Joshi, investigated how a 20-bounce gymnastic trampoline routine affected various physiological responses (Mohammed & Joshi, 2015). They found a significant (p >0.001) acute response to heart rate, systolic and diastolic blood pressure, core temperature and $\dot{V}O_2$ following trampoline exercise. Concluding that, a gymnastic trampoline bout did affect acute physiological responses.

In summary, it appears that trampolining: has a similar oxygen consumption profile to running, can reduce the rate of muscle strain when used as an exercise modality for fighter pilots, is efficacious at improving balance and vertical jump and decreasing body fat amongst children and has an acute effect to heart rate, muscle temperature, blood lactate, creatine kinase, systolic and diastolic blood pressure, core temperature and $\dot{V}O_2$.

2.9 Mini-Trampolines (Rebounders)

The literature pool investigating mini-trampolines (also known as rebounders) (mat diameter <1.2m) is greater than the literature pool for trampolining. This is likely due to the convenience of storage and transport for a rebounder versus a trampoline.

Though the two exercise modes appear similar, there are some fundamental differences. Bouncing on a trampoline results in larger vertical jump heights than bouncing on a rebounder (McGlone et al., 2002). This is because, on a rebounder, the bounce is often focused on a downward push into the mat, rather than generating an upwards movement. This difference in bounce height is due to a mixture of rebounders having a greater average stiffness (the force per unit deflection) than a trampoline and the trampolines having a greater mat height off the ground. Allowing a greater amount of mat deflection on a trampoline. This high stiffness and low mat height, can make vertical jumping on a rebounder uncomfortable and potentially dangerous, due to the resultant high forces and risk of contact with the ground.

Exercise on a rebounder is often more focussed on a downwards push into the mat, resulting in a “running on the spot” modality. The potential differences between these two bouncing actions haven’t been investigated at this time. Therefore, the conclusions from the following studies may or may not be applicable to trampolining as well. Further research is necessary in this area.

2.9.1 History of Rebounders

The first rebounder was created by Ed Russell in 1938, but it wasn't patented until 1975 (Green, 1975). Rebounders became popular as a recreational activity and exercise modality. Their usage as an exercise modality led to a the effect of rebounding as an exercise therapy being investigated in the literature.

2.9.2 Acute Effects of Rebounding

The acute effects of rebounder use on human physiology are varied.
The heart rate of participants was recorded while stepping on a rebounder at step rates between 100-200 step/minute (Weston, 2001). The recorded heart rate values were then matched to a max effort test while running on a treadmill. Average $\dot{V}O_{2max}$ for the participants was found to be 52.2 mL/kg/min. $\dot{V}O_2$ relative to HR was significantly lower on the rebounder for all intensities (27-68% $\dot{V}O_{2max}$) (p = 0.001). The authors concluded that, using heart rate as an indicator of exercise intensity while bouncing on a rebounder should be used with caution.

A similar study compared various exercises (two legged bouncing, alternating heel lifts, weight shifting, lunge jump, twist jump, high knee running) on a rebounder to a $\dot{V}O_{2\mathrm{peak}}$ on a stationary bike, for both a population of endurance trained athletes and a population of overweight/obese subjects (Höchsmann et al., 2018). $\dot{V}O_{2\mathrm{peak}}$ was found to be 53 mL/kg/min for the endurance trained athletes and 29 mL/kg/min for the overweight subjects. The $\dot{V}O_2$ values for the exercises on the rebounder were between 35-69% of the $\dot{V}O_{2\mathrm{peak}}$ for the endurance athletes and between 48-71% for the overweight subjects. A point to note for this study is that, none of the rebounder exercises were performed at maximum intensity. The authors concluded from their findings that, even though $\dot{V}O_2$ was significantly lower on the rebounder than on the stationary bike, it still provided a sufficient level of stimulus for the development of aerobic capacity. Therefore, the authors promoted rebounding as a suitable alternative to other conventional aerobic activities such as running, jogging or cycling. They also emphasized the joint-friendly, low-impact nature of rebounding and suggested rebounding may have crucial advantage, compared to other high impact forms of aerobic exercise, for overweight users and those with joint troubles.

Gerberich et al, investigated how stepping (105-205 steps/minute) on a rebounder affected $\dot{V}O_2$ compared to bouncing (90-140 bounces/minute) on a rebounder (Gerberich et al., 1990). These values were compared to a $\dot{V}O_{2max}$ assessed on a treadmill. Average $\dot{V}O_{2max}$ was found to be 33.1 mL/kg/min for the participants. Jogging was defined as one foot contacting the mat surface at a time. Whereas, bouncing was defined as both feet contacting simultaneously. They found that $\dot{V}O_2$ while bouncing on the rebounder reached 76% of $\dot{V}O_{2max}$. Whereas, jogging on a rebounder reached 80% of $\dot{V}O_{2max}$. They concluded that mode of activity on the rebounder elicited substantially different physiological responses. Therefore, it is important to note the activity type during exercise on a rebounder.

Energy expenditure (EE) during a rebounder session has been investigated for overweight women and found to average 6.9 ± 0.8 kcal/min or 6.0 METs (Cugusi et al., 2017). EE while jogging on a rebounder has also been investigated and averaged 5.9 ± 1.9 kcal/min or 5.2 METs (Katch et al., 1981). Metabolic equivalent of task (MET) is a unit used to compare the EE rate of different exercise types. 1 MET is approximately the same amount of energy used by a human while at rest (Ainsworth et al., 1993). The MET values found for both rebounding bouncing and rebounding jogging are approximately the same as jogging 6-7km/hr (Ainsworth et al., 2011). Therefore, this level of energy expenditure would classify activity on a rebounder as a “moderate” activity level (McIntyre, 2015).

In summary, rebounding acutely affects: heart rate, $\dot{V}O_2$ and energy expenditure. If compared to running, exercise on a rebounder produces a lower $\dot{V}O_2$ for a matched heart rate and exercise on a rebounder can be classified as a moderate activity level.

2.9.3 Chronic Effects of Rebounding

Using rebounding as a treatment has been investigated for a variety of ailments.

Adequate balance is defined as maintaining, attaining, or correcting the centre of mass in relation to the base of support (Alexander, 1994). Developing adequate dynamic and static balance is a critical skill for children (Bushnell & Boudreau, 1993). The type of sport played during childhood affects the development of balance, with some sports improving balance to a greater degree (Sirmen et al., 2008). Rebounding, as a mode of activity to develop balance, has been investigated by Arabatzi (Arabatzi, 2018) and Kamenjašević et al (Kamenjašević et al.). Arabatzi had the children use a rebounder for 45 minutes, three times per week for 4 weeks. Whereas, Kamenjašević et al had the children use the rebounder for 45 minutes, two times per week for 15 weeks. Both authors saw improvement ($p < 0.05$) to the children's balance and concluded that rebounding was a valuable tool for the development of balance amongst children.

Lack of balance during locomotion is a risk factor for a variety of populations; the elderly (Masud & Morris, 2001), those with mental disabilities (Baranek, 2002) and stroke patients (Schmid et al., 2012). For each of these populaces, rebounding has been investigated as an intervention to aid recovery. For the elderly, Aragão et al, utilized a 14 week rebounder intervention (Aragão et al., 2011). The participants completed two sessions per week. Each session was approximately 90 minutes. The authors found the participant's ability to recover balance during forward falls improved ($p < 0.05$) after the intervention. This improvement was attributed to the higher rate of hip moment generation (4.9 Nm/kg to 5.6 Nm/kg). They concluded that rebounding was an appropriate intervention for the enhancement of the mechanisms by which dynamic balance is maintained.

Lourenço et al, investigated rebounding as a method of improving dynamic balance amongst children with autism spectrum disorders (Lourenço et al., 2015). The intervention involved a single, 45 minute session per week, for 32 weeks. They found improvement to motor proficiency ($p < 0.05$), they also noted that all other measures improved but didn’t reach significance. The authors recommended rebounder training as a valuable modality for children with autism spectrum disorder. They also noted that rebounding had a valuable playful component.

For stroke patients, rebounder interventions have been used to improve balance related to falls (Hahn et al., 2015; Miklitsch et al., 2013). They saw significant improvement in balance ($p < 0.05$), compared to a control group, who completed group balance training at a similar frequency and volume. The authors also noted that, although not statistically significant, the rebounder training group showed increased improvement in mobility and activities of daily living. The authors believed this change would have been significant if a larger sample size was used. They concluded that rebounding was shown to be a feasible and safe method for the improvement of postural control. They recommended, further studies could investigate whether a rebounding training programme could be a feasible, affordable and beneficial home self-training programme for stroke patients.

Lateral ankle sprains often result in the development of instability at the ankle joint (Konradsen, 2002). This instability may be a major factor in the high recurrence rate of lateral ankle sprains. With some research suggesting that, secondary injury after a lateral ankle sprain may occur in as many as 80% of cases (Hertel, 2002). Kidgell et al, compared whether balance training on either a dura disk or a rebounder was more effective at improving postural sway (Kidgell et al., 2007). The participants completed exercises, aimed at mobilizing the talocrural and subtalar joints, on either a dura disk or rebounder, 3 times per week for 6 weeks. Both groups saw improvement ($p < 0.05$) to the control of postural sway, but there was no difference between the groups. The authors concluded that the two treatments were equally effective.

Obesity is associated with an increased rate of mortality (Harrington et al., 2009). Therefore, any intervention which encourages maintenance of a healthy bodyweight is of value to an overweight populace. Rebounding has been investigated as a means to lose body fat by two different studies. Cugusi et al investigated what effect a 12 week (1 hour, 3 times per week) training program would have on the health of overweight women (Cugusi et al., 2016). They saw improvement to body composition (circumferences , fat mass and muscle mass), a decrease in systolic and diastolic blood pressure values (from 128/81 to 123/71 mmHg, p <0.05), an increase in work capacity (from 104 to 123 Watts, p =0.003) and $\dot{V}O_{2\max}$ (from 15.4 to 16.9 mL/kg/min, p =0.04) improvement to the participant's perception of their overall wellbeing (p <0.05). They concluded that rebounding appeared to be a viable modality for the improvement of overall health in overweight women.

Şahin et al investigated a similar topic, looking at whether an 8 week (30 minutes, 3 times per week) training programme, using either running or a rebounder, was more effective at improving the health of young men (Şahin et al., 2016). Intensity during the sessions was assessed based on percentage of maximum heart rate (measured using a heart rate monitor). The authors found a change to $\dot{V}O_{2max}$ (p =0.02), body fat percentage (p =0.02) and vertical jump distance (p =0.00) compared to the control. They also found that $\dot{V}O_{2max}$ and vertical jump height was higher for the rebounder group, compared to the running group (50cm vs 47cm). They concluded that rebounding is a superior modality for the improvement of $\dot{V}O_{2max}$ and vertical jump. Of note, is that, a critical flaw was observed in the methodology for this study. The authors chose to set the intensity for the running group at 60% of the participant's maximum heart rate. Whereas, the intensity for the rebounder group was targeted at 75% of maximum heart rate. Intensity of exercise heavily influences the subsequent adaptions, with more vigorous exercise causing greater adaption (Gebel et al., 2015). Therefore, because one group utilized a higher intensity, it should be assumed that a greater degree of adaption would occur in this group. This brings into question whether it is fair to compare these two groups.

Minimizing insulin resistance is critical for populations that struggle with the regulation of blood glucose (Cheng, 2005). Chronically elevated blood glucose (hyperglycaemia) can cause a variety of symptoms including (but not limited to); cardiovascular disease, nerve damage, kidney damage or kidney failure, blindness, ulcerations and in some severe cases amputation (Martin et al., 1992). Maintaining an optimal blood lipid profile is also of importance. Chronically elevated low-density lipoprotein (LDL) is a risk factor associated with an increased risk of heart disease (Manninen et al., 1992). Nuhu et al investigated the effect of rebounding on patients who had type 2 diabetes (Nuhu & Maharaj, 2017). The patients were instructed to complete exercise sessions on a rebounder, 3 times per week (20-30mins), for 12 weeks. The authors found improvements to insulin resistance, lipid profile and waist circumference in the intervention group, when compared to the control ($p < 0.05$). They concluded that rebounding is beneficial for individuals with type 2 diabetes and can serve as a useful exercise approach in the management of cardiovascular risk in diabetes.

In summary, it appears that exercise on rebounders is efficacious for the improvement of: balance for the general population, children, overweight individual and stroke patients, return from injury after lateral ankle sprains, body composition for overweight individuals, cardiovascular output, blood lipid profiles and vertical jump.

3 General Methods

The following chapter provides an overview of the shared methods and procedures presented in chapters 4, 5, 6, 7 and 8. Referred to as Study 1, Study 2, Study 3, Study 4 and Study 5. This chapter is divided into three sections. The first section is concerned with the recruitment and description of the participants for the studies. The second section details the objective and subjective measures used, during the studies, to assess change to physiological markers measured during the interventions. The third section briefly describes the data and statistical analysis methods used to interpret the outcomes of the interventions.

3.1 Participants

3.1.1 Recruitment

For all the studies, participants were recruited from the community of Christchurch, New Zealand. Studies 1-4 were advertised locally around the University of Canterbury using word of mouth, posters and advertisements on the University of Canterbury social media pages. All contact with participants was made directly; no third parties were involved. For Studies 1-4, participation was sought voluntarily and no enticement was offered for taking part. Study Five used voluntary participation, but renumeration was offered of 50-75% off the cost of a Springfree trampoline for completing the study.

All participants were over the age of 18 and reported being capable of safely participating in vigorous exercise. Inclusion criteria for each of the studies is set out in Table 3.1.

Table 3.1 Participant Recruitment Requirements Notes: ♀Female; ♂Male.

STUDY TITLE	SEX	AGE (YEARS)	TOTAL NUMBER OF PARTICIPANTS RECRUITED	NOTES
Developing a Mathematical Model to Predict Energy Expenditure While Bouncing on a Trampoline (Study 1)	♀ or ♂	18-70	23	Two testing sessions (one week apart).
The Physiological Demands of Trampolining Across Different Intensities (Study 2)	♀ or ♂	18-70	23	Two testing sessions (one week apart).
Investigating the Effect of Bouncing Type on the Energy Expenditure of Trampolining (Study 3)	♀ or ♂	18-70	28	Single testing session.
The Effect of High Intensity, Short Duration Trampolining markers related to health, across an 8-week intervention (Study 4)	♀ or ♂	18-70	25	Three testing sessions (pre, 4 weeks and post). Intervention: x4/week for 8 weeks.
The Effect of Trampolining on Body Composition, Cardiovascular Fitness, Bone Density And Stress Urinary Incontinence (Study 5)	♀ only	18-70	22	Two testing sessions (pre/post). Intervention: x5/week for 12 weeks.

For each study the participant received a detailed verbal explanation of the procedure and were given an opportunity to ask any questions they may have. They were then provided with an information and consent sheet to sign. No deception was used for any of the studies. Participants had the right to withdraw from any of the studies, at any time, for any reason. The participant's data was kept securely until after data collection was complete. At this stage, all identifying traits were removed from the data. Participants were informed that this data may be published in journals in addition to within this thesis.

For all of the studies, the participants were asked to refrain from participating in vigorous exercise for 24 hours prior to the testing sessions. For Study 4 & 5, participants were asked to maintain the amount of weekly exercise (minutes per week) they performed prior to the beginning of the intervention. For Study 4, the participants were asked to fast the morning prior to the testing session (testing sessions were conducted between 6am and 10am, depending on participant availability). For Studies 4 & 5, participants were also instructed to avoid making changes to their diet during the intervention. The understanding of these instructions was checked upon recruitment and adherence was confirmed on each testing day.

As with any form of exercise, there was a small, but potentially significant, risk of injury during the performance of the procedures. This was fully explained on the information sheet and the participants were made aware of this verbally. As well as being able to withdraw at any time, the participants were supervised at all times during the testing. If at any time the participant's safety was at risk, the testing was stopped immediately and appropriate measures were taken. For each of the studies, participants were screened for health conditions that may put them at higher risk during exercise. If they failed this screen they were excluded from the study.

3.1.2 Ethics Approval

Ethical approval was granted for Study 1-4 by the University of Canterbury Ethics Committee (see Table 3.2). Ethical approval for Study 5 was granted, both, by the Health and Disabilities Ethics Committee and the Australia, New Zealand Clinical Trials Registry (ACTRN12619001770156p) (see Table 3.2).

Table 3.2 *Details of the Ethical Approval for each of the studies.*

STUDY TITLE	REF NUMBER	DATE GRANTED
Developing a Mathematical Model to Predict Energy Expenditure While Bouncing on a Trampoline (Study 1)	HEC 2017/27	23/5/2017
The Physiological Demands of Trampolining Across Different Intensities (Study 2)	HEC 2017/27	23/5/2017
The Effect of Bouncing Type on the Energy Expenditure of Trampolining (Study 3)	HEC 2018/15	8/5/2018
The Effect of High Intensity, Short Duration Trampolining markers related to health, across an 8-week intervention (Study 4)	HEC 2018/22	10/8/2018
The Effect of Trampolining on Body Composition, Cardiovascular Fitness, Bone Density And Stress Urinary Incontinence Amongst Parous Woman (Study 5)	19/NTA/187	11/3/2020

Note: The same dataset/ethics application was used for Study 1 & 2

3.1.3 Data Protection and Confidentiality

The participant's confidentiality and anonymity were maintained and their personal privacy was protected. The collection, storage, disclosure and use of research data complied with the Data Protection Act (1998). The data was held securely on private, password protected computers and was only accessible by Tāne Clement. Once data collection was complete, all data was anonymised. Participant's identity will never be made public. All data was published anonymously. All datasets will remain stored on Tāne Clement's personal computer for a maximum of ten years from the completion of the individual studies. After ten years the data will be destroyed.

3.2 Health Related Measures

3.2.1 Anthropometric Data Collection

Anthropometric data was collected for each participant during each testing session, which comprised of age (years), height (cm), body mass (kg), muscle mass (kg) and fat mass (kg). Height was measured using a stadiometer. The participants were asked to remove their shoes and stand with their feet together, while touching the wall with their heels. The participant was then instructed to stand as "tall" as possible. Next, the headboard was lowered until it met firm resistance. Height readings were rounded to the nearest centimetre. Body mass, muscle mass and fat mass were measured using a digital bio-impendence analysis scale (InBody 230, InBody, Seoul, Korea). Participants were asked to remove as much clothing as they felt comfortable with. The participants were asked to note the amount of clothing they wore during the first assessment. This amount of clothing was then kept similar for each subsequent testing session. So, for example, if the participant wore a t-shirt and shorts during the first session. They were measured in a t-shirt and shorts for all subsequent testing. Shoes and socks were always removed. The participant was then asked to align their feet with the foot panels and to hold the thumb panels on the device. The participant's sex, age and height were then input into the device.

The device then measured the participant's muscle mass and fat mass by transmitting an electric charge between both the hand and the feet panels. The amount of time it took for the charge to be registered at the other panels was noted by the machine. These times were then compared to normal values, stored in the machine, which gave guidelines to the charge transfer rate, based on the type of tissue between the two points. More fat mass would cause the transfer rate to be slower, while more muscle mass would cause the transfer rate to be faster. For more information on this process see the InBody User Manual (InBody, 2019). The participant was asked to remain still during this process until the device had completed all the measurements. Once the measurement was complete, the participant was asked to put back on all removed clothing. Mass, muscle mass and fat mass were all recorded to the nearest 0.1kg.

3.2.2 Heart Rate

Measurement of heart rate is commonly used as a means of assessing the intensity of an exercise bout (Achten & Jeukendrup, 2003). For Studies 1-5, heart rate data was collected using a chest mounted heart rate monitor (K5, COSMED, Rome, Italy). First, the band of the heart rate monitor was moistened to aid conductivity. The participant was then asked to place the monitor underneath their clothing, against their skin, roughly in line with the bottom of their sternum. It was confirmed with the participant that the fit was comfortable. The device was then checked to confirm that data was being recorded. Data collection began at the commencement of the test.

3.2.3 Oxygen Capacity ($\dot{V}O_2$)

$\dot{V}O_2$ is a measure of the rate of oxygen consumption at the time of measurement (Perez-Suarez et al., 2018). $\dot{V}O_{2\mathrm{max}}$ is the highest value of $\dot{V}O_2$, that is achievable for a particular individual. $\dot{V}O_{2\mathrm{max}}$ is the most common assessment, amongst exercise literature, for determining whether an intervention affected the fitness of the participant (Bassett Jr & Howley, 2000).

For the assessment of $\dot{V}O_{2max}$ a breath by breath gas analyser (K5, COSMED, Rome, Italy) was used. The equipment was calibrated prior to each testing session. The procedure for calibration can be found in the K5 User Manual (COSMED, 2017). The K5 unit was then assembled to be ready for testing. The K5 unit (including the heart rate monitor) was then placed on the participant. It was confirmed with the participant that the fit was comfortable. The device was then checked to confirm that data was being recorded. Data collection began at the commencement of the test.

The Modified Bruce Protocol is a maximal effort test used for the measurement of $\dot{V}O_{2max}$ (McInnis et al., 1992). The Modified Bruce Protocol was used during Study 2 and Study 4 as a means of assessing change to the cardiorespiratory fitness of the participant. Prior to the session, the participant was briefed on the protocol for the Modified Bruce Test. This included the procedure for the test and strongly emphasised that the participant could stop at any stage, for any reason. The K5 unit was used to assess $\dot{V}O_{2max}$ for this test. The brief was repeated once the participant was equipped with the K5 unit.

The modified Bruce protocol involves the participant completing a maximum effort run on a treadmill (Excite Run 1000, Technogym, Cesena, Italy). The bout began at a walking pace (6-8km/hr). The participant was instructed to remain on the treadmill at this speed for a minute. 15 seconds prior to the completion of the minute, the participant was asked whether they were comfortable with the treadmill speed being increased. They were instructed to indicate their intention using a “thumbs up” as an affirmative and “thumbs down” as a negative. The treadmill speed was increased by 1km/hr, every minute, until the participant indicated they were no longer comfortable with the speed increasing (thumbs down). At this stage, the incline of the treadmill was increased at the top of every minute (1 degree per minute) until the participant could no longer continue. At the completion of the test, the participant was instructed to rest until they felt fully recovered.

3.3 Statistical Analysis

Experimental design, methods, data analysis and statistical analysis that are unique to each of the studies are presented in their respective chapters. For every study, data was analysed using Excel (Version 2016, Microsoft, Redmond, Washington, USA) and SPSS

(Version 24, IBM Corp, Armonk, NY, USA). This involved, first, compiling all the data into one spreadsheet for each participant. These participant spreadsheets were then compiled into a master spreadsheet, where all the data was anonymised. These master sheets were then exported into SPSS to perform the required statistical analysis for that investigation.

For each study the data was first inspected to assess whether any significant outliers existed using box plots. If outliers were found, they were removed. Next, each dataset was assessed for normality using a Shapiro-Wilk test. All datasets were found to follow an approximately normal distribution. Finally, sphericity was assessed for each dataset using Mauchly's test of sphericity, only one dataset failed this test (Study 3), so a Greenhouse-Geisser correction was used for the multivariate analysis of this study. From this point the studies used individualised approaches to the multivariate analysis and post hoc tests. Descriptions of these tests can be seen in the statistical analysis section of each paper.

4 Study 1: Developing a Mathematical Model to Predict Energy Expenditure while Bouncing on a Trampoline.

4.1 Project Background

This series of studies was initiated by Springfree, a trampoline sales and manufacturing company, to expand the evidence base concerning the health benefits of trampolining. At the first meetings, where the direction for the research was generated. Springfree suggested that trampolining has potential benefits to the general populace, due to its novelty, compared to other forms of aerobic exercise. At the time, little research existed surrounding the physiological response (both acute and chronic) associated with trampolining. To assess physiological response, the bounce height while using the trampoline must be collected, to quantify intensity in a meaningful way. Traditionally, measuring bounce height, while trampolining, required technical and time intensive processes. Prior to the project, Springfree had patented a new intellectual property, Take Gaming Outside and Make it Active (TGOMA). TGOMA is a series of tri-axial accelerometers, built into the trampoline mat, which enabled the calculation of both airtime and jump location on the trampoline mat. Using this technology, a new method for calculating bounce height on the trampoline became possible. This method involved calculating the energy absorbed by the trampoline, based on the amount of time the participant was airborne. Though, before jump height could be accurately quantified, first, a model needed to be created which could take all the known inputs (mass of the participants, the stiffness of the trampoline mat, time spent airborne) and use these values to produce both an energy expenditure and a jump height in real time. The following chapter is the process by which this model was developed.

4.2 Introduction

Regular physical activity is a crucial component of a healthy lifestyle, providing benefit to muscle mass (Rogers & Evans, 1993), bone density (Marques et al., 2012), cardiovascular function (Berthouze et al., 1995) and mental health (Lawlor & Hopker, 2001). Regular physical activity is defined as any bodily movement, produced by the skeletal muscles, that raises energy expenditure above resting level. It may be general movement or more planned, structured and repetitive movement, such as exercise (McIntyre, 2015). The current guidelines for physical activity recommend either 2.5 hours of moderate or 1.25 hours of vigorous activity per week (McIntyre, 2015). Unfortunately, not all New Zealanders meet these guidelines. Mason et al, found that, 49% of New Zealanders did less than 30 minutes of moderate activity per week and 14% did little to no activity at all (Mason et al., 2012). This presents a problem, as lack of physical activity is strongly correlated with an increase in all-cause mortality (Nocon et al., 2008). In New Zealand, 12.7% of all deaths can be attributed to a lack of physical activity (Lee et al., 2012). Worldwide, lack of physical activity is the fourth greatest risk factor for non-communicable diseases, which is estimated to cause 3.2-5 million deaths per year (McIntyre, 2015). Therefore, both, because of the cost to the healthcare system and in the interest of having a healthy and vibrant populace, it is in the best interest of a government to work to promote, and improve, rates of physical activity.

One of the biggest issues with engaging the population in regular physical activity is a lack of adherence, as approximately 50% of people who begin an exercise regime will drop out within 6 months (Dishman, 2001; McAuley et al., 1994). Improving adherence to exercise is a complicated task due to the complexity of the issue (Prasad & Cerny, 2002). However, it has been suggested that enjoyment may be a strong determinant of exercise adherence (Ekkekakis et al., 2011; Wankel, 1993; White et al., 2005). Enjoyment of exercise is not only influenced by psycho-sociological factors, but also the mode, intensity and duration of the exercise (Raedeke, 2007). Keeping physical activity novel by utilizing different modes of movement has been found to increase enjoyment of an aerobic exercise regime (Glaros & Janelle, 2001; Miller et al., 2005; Szabo et al., 1998).

Domestic trampolines are well recognized as play equipment for children, but some manufacturers have promoted them as an alternative exercise modality for adults. While trampolining may offer a viable training stimulus, prior to our study, it was not possible to quantify work rate on a trampoline, in a manner similar to other popular exercise modes. Research supports that the intensity of the exercise matters, with vigorous exercise providing more benefit than moderate exercise and moderate more than light (Gebel et al., 2015). Due to a lack of the ability to assess intensity, currently, it is difficult to predict the outcomes of a training bout on a trampoline.

Many methods exist through which intensity during exercise may be tracked, but a common form utilized during aerobic exercise, is the measurement of the EE during the bout. This is commonly expressed as a MET, where one MET represents a resting EE (Ainsworth et al., 1993). Light physical activity has been defined as 1.5-2.9 METs, moderate physical activity as 3-5.9 METs and vigorous physical activity as >6 METs (McIntyre, 2015). Prior to this study, it wasn't known whether trampolining would meet the standard to be classified as moderate or vigorous exercise.

A variety of MET scores have been reported for trampolining, with the values differing widely. The Compendium of Physical Activities lists the MET of recreational trampolining at 3.5 METs and competitive trampolining at 4.5 METs, though it is acknowledged in the text that these are estimates only (Ainsworth et al., 2011). Arvidsson et al, conducted a piece of research comparing the accuracy of different sensors (Arvidsson et al., 2009). As a part of the research, they recorded EE during a five-minute bout on a trampoline. They found a value of 6.9 METs, which is nearly twice the MET level suggested by the Compendium of Physical Activities. Cugusi et al, looked at energy consumption during a rebounder exercise session in overweight women (Cugusi et al., 2016). They found an average energy expenditure of 6.9 ± 0.8 kcal/min. The average participant mass was 68.5 ± 6.4kg, meaning the average MET for the participant was approximately 6 METs. Of note, this MET value may not be useful for comparison to trampolining, as there is a difference in the bouncing action between rebounders and conventional trampolining. The differences in the size of the jumping bed not only results in greater forces acting on the jumper, but caused the bouncing mechanism to fundamentally differ (McGlone et al., 2002). Though each of the previous studies investigated EE on a trampoline in some way, they also each include some systematic flaw which reduces the confidence that these MET values accurately reflect the correct EE. To quantify EE during trampolining, a model which calculates EE during the trampolining bout is needed.

Having a real-time display of EE is standard for almost every piece of commercial exercise equipment. The exercise equipment usually calculates energy expended during the bout in real time and will track it throughout the exercise session. The models to calculate EE during the use of popular pieces of exercise equipment such as; treadmills, rowing ergometers and stationary bikes, have been developed and validated (Hagen et al., 1980; Steinacker et al., 1986; Van Ingen Schenau et al., 1990). Some investigation has been made into modelling activity on a trampoline. Srinivasan et al, modelled how energy may be transferred between two masses on a trampoline (Srinivasan et al., 2013). Pendrill et al, modelled how acceleration and force are exerted on a trampoline (Pendrill & Eager, 2014). Neither of these models are capable of calculating EE in real time.

Using TGOMA (Take Gaming Outside and Make it Active), a set of tri-axial accelerometers built into the trampoline, it is now possible to easily assess flight time while on a trampoline (Howe, 2017). Using this feature, it is now possible to develop a model which could predict EE while bouncing on a trampoline. Therefore, the aim of this study was to develop a mathematical model for the calculation of energy expenditure while trampolining.

4.2.1 Hypothesis

- A model can be developed to calculate the energy expenditure of a person bouncing on a trampoline, if their weight and jump height is known.

4.2.2 Strengths of the Study

- The study is the first of its kind, in that, no other study has attempted to form a model to predict energy expenditure while bouncing on a trampoline.
- No other researchers have had TGOMA software available for the collection of bounce height during the trampolining bout.

4.2.3 Delimitations

- Energy expenditure is the average of the recorded values across the final 30 seconds of the bout.

4.2.4 Assumptions

- -All participants reached a steady state of energy expenditure by the conclusion of each bout.
- Energy lost to the trampoline will be similar for similar masses.

4.2.5 Limitations

- Participants were mostly young adults (18-24), therefore findings may not be applicable to children and the elderly.
- Participants were recruited, solely, from the University of Canterbury population. Therefore findings may be less applicable to other populations.
- The model does not account for energy expended that doesn't relate to vertical jump height (lateral movement, angular movement, flipping, twisting, spinning movement of the arms and legs, etc.).

4.3 Methods

The process for creating the model by which EE could be calculated, while jumping on a trampoline, required two stages. The first was developing the equation which is used to calculate EE. This is covered in stage one. Stage two is the process by which the efficiency of energy conversion during trampolining is found.

4.3.1 Developing the Model

If a weight, such as a ball, is dropped from a given height on to a trampoline, the energy lost to the trampoline can be directly calculated as the difference between the original height and the rebound height, multiplied by the weight of the ball. The ratio of the rebound height to the original height is often represented as a coefficient, C.

The assumption is made that, for a given fall height, the energy lost to the trampoline will be identical for a person of the same weight, falling from the same height. Therefore, once the jump height of the person is known, the energy absorbed by the trampoline, can be calculated using the coefficient (C). By extension, for a series of jumps, the average energy absorbed by the trampoline, per unit time, can be calculated. For the jumper to maintain the same height, they must counteract this energy loss by putting in the equivalent amount of energy per unit time. For the development of C, it is found that the fall height has to include the static deflection of the trampoline mat (S), under the load (W) and the mass of the jumper in question. Then, for a given jump height (h) above the mat, the potential energy (PE) of the jumper is weight times gravity times the full fall height, including S:

$$PE = W\ g\ (h + S)$$

Equation 4.1 *Calculating potential energy of the jumper.*

The fraction of PE lost in each rebound is 1-C. So, the energy absorbed by the trampoline $PE_{absorbed}$ for a single drop from a given jump height above the mat is:

$$PE_{absorbed} = (1 - C)\ W\ g\ (h + S)$$

Equation 4.2 *Calculating the potential energy absorbed by the trampoline.*

From this equation, the amount of energy a jumper is expending to maintain their jump height is the same as the amount of energy being absorbed by the trampoline. Therefore, the mechanical energy output by the participant is equivalent to $PE_{absorbed}$.

4.3.2 Calculating the Coefficient of Restitution

The trampoline used in the jump tests (SF90, Springfree, Christchurch, New Zealand) was tested by dropping the FIG standard trampoline test ball (IGF, 2016) at three weights (30kg, 60kg and 90kg) from a height of 1.5 m above the mat. Then, measuring the rebound height of all subsequent bounces. To measure the fall and rebound height of the ball, video-graphic methods were used, measuring against a scale on the wall behind the trampoline. Parallax error was corrected for by using calculations involving the dimensions from the wall, to the camera, the wall to the ball, and the camera height. From the results of the drop test the coefficient of restitution could be found, where the coefficient of restitution (C) was defined as the ratio of the rebound height to the previous fall height.

4.3.3 Calculating the Efficiency of Energy Conversion

To compare the measured physiological EE of a jumper to the mechanical energy output, the energy needs to be expressed in kilojoules per minute (E), so the equation above must be multiplied by the number of drops per minute (N) (or number of jumps per minute) and divided by 1000:

$$E = (1 - C)\, W\, g(h + S)\, N/1000$$

Equation 4.3 *Calculating energy expenditure of the jumper.*

For this to predict the physiological EE of a jumper, it needs to be divided by the efficiency (e) of the conversion of stored energy into mechanical energy by the human machine during jumping. Therefore, the equation that predicts the EE of the jumper, including this efficiency, is:

$$EE = (1 - C)\, W\, g\, (h + S)\, N/1000/e$$

Equation 4.4 *Including efficiency in the calculation.*

If the EE has been measured by gas analysis, then the human efficiency while jumping on a trampoline can be found from:

$$e = (1 - C)\, W\, g\, (h + S)\, N/1000/EE$$

Equation 4.5 *Determining efficiency.*

Consequently, to use Equation 4.5 to determine human efficiency (e) while jumping, a series of tests were needed to measure EE by gas analysis, with a suitable number of participants.

See Table 4.1 for a description of the variables.

Table 4.1 Variables used when forming the equations and their descriptions.

Variable	Description
PE	The gravitational potential energy of the jumper at the top of a bounce (kJ)
$PE_{absorbed}$	The energy absorbed by the trampoline with each bounce (kJ)
C	Coefficient of restitution for the mass of the jumper on the given trampoline
W	Mass of the jumper (kg)
g	Gravity ($9.81 m/s^2$)
h	Average jump height above the undeflected mat surface, over the measurement duration (m)
S	Static mat deflection with the jumper stationary on the mat (m)
E	Energy absorbed by the trampoline (kJ/min)
N	Number of jumps per minute (1/min)
EE	Energy expenditure of a jumper continuously jumping on a trampoline (kJ/min)
e	Efficiency of human energy conversion from stored to mechanical energy while jumping

4.3.4 Testing Procedures

On each of the testing days, the participant's height and mass were measured to allow accurate analysis of oxygen consumption. Mass was obtained using a bio-impedance scale (Inbody 230, Inbody, Seoul, Korea). Body fat and muscle mass were obtained using the same machine by the method of bioelectrical impedance analysis (Lukaski et al., 1985).

4.3.5 Trampolining Intervention

Prior to the testing, the participants were briefed on the protocol and instructed to perform a series of bounces at three intensities; low, medium and maximum intensity. The participant was then allowed a practice bout, during which, they were instructed to bounce at these intensities and adjust accordingly.

The low intensity was a bounce height which was primarily maintained through plantarflexion of the ankle. The medium intensity was a height at which some degree of knee flexion was exhibited. The maximum intensity was the maximum height, the participant believed, they could maintain for 3 minutes. A heart rate monitor (H7, Polar, Kemplele, Finland) and a breath by breath gas analyser (K5, COSMED, Rome, Italy) were then placed on the participant. Resting heart rate (RHR) (while sitting) was recorded. Then, resting blood lactate (BL) was assessed using a portable blood analyser (LT-1730, Arkray, Edina, USA). Participants were then helped into the trampoline (S113, Springfree, Christchurch, New Zealand) and instructed to bounce at the low intensity. Participants were given a 3 second countdown, then instructed to begin. For three minutes; HR, $\dot{V}O_2$ and EE were recorded using the gas analyser. Total jump height and the number of jumps performed were recorded during the bout using an accelerometer built into the trampoline (TGOMA, Springfree, Christchurch, New Zealand). At the end of the bout, the participant was stopped, helped out of the trampoline and asked to sit. BL was then collected. The participant was asked to remain seated until their $\dot{V}O_2$ and HR had returned to resting levels. This protocol was then repeated for the medium and maximum effort intensities.

4.3.6 Participants

The participants consisted of 23 healthy adults (9 male, 14 female). Participants ranged 18-40 years, with a mean age of 25±4 years. Mean values for the anthropometric measures for males and females can be seen in Table 4.2. All participants had prior, recreational, trampolining experience. None had experience trampolining in a competitive or sporting context. The study was completed across two separate sessions, one week apart, between June and August, 2017. Exclusion criteria were health risks that contraindicate exercise testing (American College of Sport Medicine, 2013), diseases that are associated with a loss of balance, as well as the presence of infections, injuries or an existing drug treatment that could potentially limit physical performance. Participants who passed the screening were given detailed information about the study's aim and protocol and gave written consent before participation. This study was approved by the ethics committee of the University of Canterbury (HEC 2017/27).

Table 4.2 *Anthropometric measurements for participants. Mean ±SD.*

	Male	**Female**
Age (years)	26 ±5	24 ±4
Height (cm)	178 ±6cm	165 ±4cm
Mass (kg)	78 ±11kg	69 ±11kg
BMI (kg/m^2)	25 ±4	25 ±4

4.3.7 Statistical Analysis

Statistical analysis was performed using SPSS Statistics for Windows (Version 24, IBM Corp, Armonk, NY, USA). For each of the variables, the data was averaged across the final 30 seconds of each bout. Datasets were first assessed for normality using a Shapiro-Wilks test. All variables, except the blood lactate results, were found to follow a normal distribution. A two-way, repeated measures, MANOVA was used to assess whether differences existed between the means for $\dot{V}O_2$, EE and BL. Equipment type (trampoline, treadmill) and intensity (low, medium and maximum) were used as the independent variables. After finding a difference between the groups ($p < 0.05$), a series of two-way repeated measures ANOVAs were used to identify where the differences existed between the individual variables. A difference was found between the intensities for each of the variables. Paired samples t-tests were then used to determine the degree of the difference between the running and bouncing at each of the different intensities for $\dot{V}O_2$, EE and BL. Effect size (Cohen's d) was then used to interpret the differences.

4.4 Results

4.4.1 Development of the Model

From the results of the drop test, the coefficient of restitution could be found. A summary of C values can be found in Table 4.3. These C values were determined to be sufficiently consistent that the potential energy lost in each fall-rebound pair, for any ball weight in the range from 30 to 90kg, could be predicted using the coefficient, to an accuracy of ±3% for bounces over 50mm above the mat.

However, the TGOMA system could only record airtime to an accuracy of ±22 milliseconds. These two tolerances combined resulted in a participant jump height prediction accuracy that varied from ±24% for a 0.2m jump to ±12% for a 0.8m jump.

Table 4.3 *Results of a drop test on a 12ft trampoline.*

	Drop 1	Drop 2	Drop 3	Drop 4	Drop 5
Fall Height above Mat (mm)	1500	888	525	280	106
Rebound Height above Mat (mm)	888	525	280	106	-7
Coefficient of Restitution	0.64	0.667	0.663	0.639	0.633

Notes: Ball Weight W = 60kg; Static Deflection S = 202mm; SF90 trampoline

Repeating the process with balls of different weights gives the values found in Table 4.4.

__Table 4.4__ Representative values for different ball weights on the Springfree S113 trampoline.

Ball Weight (*W*)	**30kg**	**60kg**	**90kg**
Mat static deflection (*S*)	0.131m	0.204m	0.277m
Coefficient of Restitution (*C*)	0.59	0.692	0.73

4.4.2 Calculating the Efficiency of Energy Conversion

Descriptive statistics for the measured variables can be found in Table 4.5.

__Table 4.5__ Descriptive statistics averaged over all participants, for each of the three intensities while bouncing.

Low Intensity Effort	**Mean ±SD**
Jump Height (m)	0.21 ±0.1
Jump Rate (bounces/m)	61 ±4
Heart Rate (bpm)	118 ±16
Oxygen Consumption (mL/min/kg)	22 ±5
Metabolic Equivalent of Task (kCal/kg/hr)	5.3 ±1.2
Efficiency (%)	29 ±4
Medium Intensity Effort	
Jump Height (m)	0.38 ±0.1
Jump Rate (bounces/m)	56 ±4
Heart Rate (bpm)	145 ±18
Oxygen Consumption (mL/min/kg)	30 ±6
Metabolic Equivalent of Task (kCal/kg/hr)	6.9 ±1.3
Efficiency (%)	28 ±4
Maximum Intensity Effort	
Jump Height (m)	0.78 ±0.2
Jump Rate (bounces/m)	48 ±3
Heart Rate (bpm)	179 ±10
Oxygen Consumption (mL/min/kg)	43 ±8
Metabolic Equivalent of Task (kCal/kg/hr)	9.4 ±1.7
Efficiency (%)	27 ±4

Using Equation 4.5, developed in Stage 2, and the known values for EE from the gas analysis, Figure 4.1 was created.

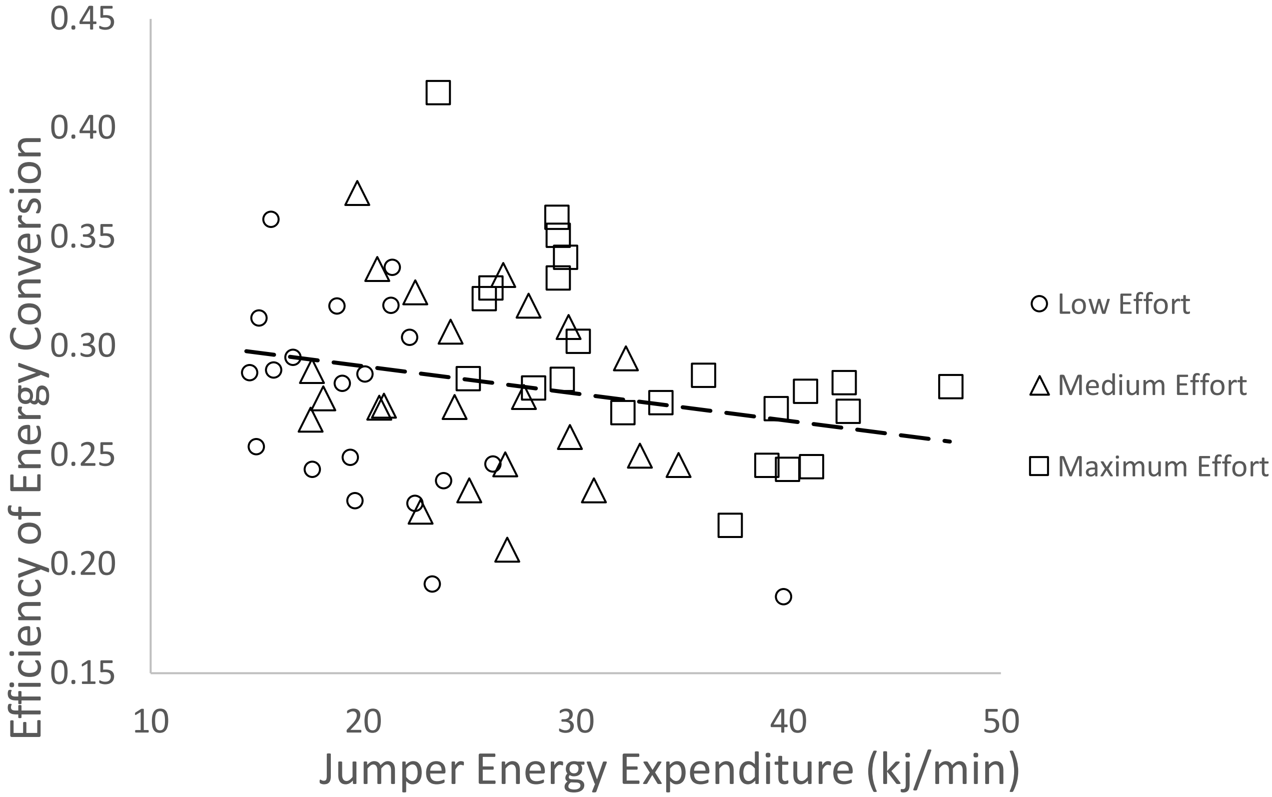

Figure 4.1 *Efficiency of energy conversion for each participant.*

Figure 4.1 indicates that the mean efficiency for the human machine while jumping on a trampoline is approximately 28%, and decreases as EE increases.

4.5 Discussion

The aim of this study was to produce a model which could calculate, in real time, the energy expenditure during a trampolining bout. This was done in two stages. In the first stage, the properties of the trampoline were used to determine the energy absorbed by the trampoline when someone is jumping, $PE_{absorbed}$. This resulted in Equation 4.2 and the variables in Table 4.1.

In the second stage, this same energy is reinterpreted as the mechanical energy expended by the jumper. It is described in Equation 4.3. Then e, (the human efficiency while jumping) is included in Equation 4.4. This meant that Equation 4.4 now describes the physiological energy expended by the jumper, as would be determined by gas analysis.

Finally, the energy absorbed by the trampoline and the physiological energy expended by participants (as measured by gas analysis), was used to confirm human energy efficiency while jumping on a trampoline. Through this research, a model has now been produced for use within an algorithm for the TGOMA software package. This model (using the TGOMA package) is capable of producing a real-time calculation of EE with only the trampoline coefficient C, and mass of the jumper as inputs. It is also possible, using TGOMA software, to calculate the bounce height of a participant in real time.

From the results of this study, the average human mechanical efficiency across the intensities on the trampoline was found to be 28 ±4%. This value is in line with previous literature, with the published range for human mechanical efficiency being anywhere from 14-34%, depending on the type of activity (Banks et al., 2015).

In Table 4.1, efficiency trends downward with increased intensity. This result is in line with literature regarding other exercises modalities (i.e. that mechanical efficiency decreases as exercise intensity increases) .The cause of this loss of efficiency still remains speculative, but new research techniques suggest that, during heavy exercise, efficiency losses arise from both contractile and mitochondrial sources (Banks et al., 2015; Cannon et al., 2014). A recent paper has further refined the investigation into this phenomena stating “the results strongly implicate a progressive impairment of mitochondrial function, and the authors suggest an uncoupling-based mechanism, which points the way to the studies which will be needed to pin this down.” (Kemp, 2020).

It is possible to develop a more precise expression for efficiency than is found in Equation 4.3, which would account for changes in the intensity across an exercise bout. This could give a better calculation of EE than is given in Equation 4.4. This change was not included due to adding a significant complication to the equation, while not significantly altering the accuracy of the estimated EE.

In Table 4.5, the MET values for trampolining were higher than what had been reported previously in the literature. The highest MET value recorded in this study was 9.4 METs, whereas the highest value reported previously in the literature was 6.9 METs. This means trampolining has a higher rate of EE than previously thought and increases the viability of trampolining as an alternative exercise modality.

A limitation of this method is that it cannot account for energy spent while the jumper is in the air, for example doing star jumps or tuck jumps. Bouncing on a trampoline may involve a myriad of movements, including: twisting, turning, flipping or some combination of the three. Consequently, the method described in this chapter is most effective when measuring solely vertical jumping. Measuring other forms of jumping exercises requires further refinement of the EE calculation method.

For recreational users with TGOMA or an equivalent app, trampolining has now become a more viable exercise alternative, for which the EE during the bout is known. Another benefit of this research is the capability to include technology into an exercise bout on a trampoline. Recent meta-analyses have found that the inclusion of technology with exercise has a positive effect on adherence rates (Connelly et al., 2013; Valenzuela et al., 2018). It is also known that high variety of exercise helps with adherence to exercise programs (Wankel, 1993). Therefore, this advancement may provide positive benefits to adherence through both the novelty of trampolining as an exercise mode and the inclusion of technology with trampolining for exercise.

In a sporting context, the findings of this chapter are most useful in the ability to calculate bounce height in real time with the TGOMA app. Prior to this research, bounce height was convoluted to calculate. It could be measured by filming the trampoline with a measuring stick in the background, then subsequently manually calculating the bounce height by trigonometric methods. Bounce height could also be measured, approximately, by recording the time spent in the air by the jumper, using a stopwatch or other timing device. These are both time intensive methods and limit the viability of measuring bounce height in real time. This information is useful in a sporting context, specifically for trampoline gymnastics, where the scoring system takes into account total time spent in the air (Gymnastics New Zealand, 2018).

4.6 Conclusion

This study has described a method by which trampoline properties can be used to measure EE of an athlete jumping on a trampoline. This was achieved by, first, developing an equation which calculated the energy absorbed by the trampoline. Next, an equation was developed which included the variable for efficiency during exercise on a trampoline. Once the trampoline model is known, this model now allows real-time assessment of physiological energy expenditure while bouncing on a trampoline using only mass as an input. This furthers the use of trampolining as a relevant exercise modality for health and fitness. The MET value for trampolining was also calculated during the development of this model and was found to be higher than reported in previous literature.

5 Study 2: The Physiological Demands of Trampolining across Different Intensities

5.1 Project Background

The fourth chapter of this thesis described the method by which a model was created, which allowed real time calculation of energy expenditure while bouncing on a trampoline. The creation of this model required the collection of gas analysis data from a range of participants, to confirm the human efficiency of exercise on a trampoline. During one of the meetings for the direction of the research, it was noted that only one study (Bhattacharya et al., 1980) had previously investigated how exercise on a trampoline compared to other exercise modalities. This then raised the question, how much energy does trampolining use? Since data was already being collected, using participants, for the development of the energy expenditure calculation, it was decided that a second study could be developed, by adding a second testing session using a treadmill. So, it was decided that the findings of Bhattacharya et al should be validated using a larger sample size and a wider range of physiological measures.

5.2 Introduction

Regular physical activity is a crucial component of a healthy lifestyle, providing many benefits, such as; increased muscle mass (Rogers & Evans, 1993), increased bone density (Marques et al., 2012), improved cardiovascular function (Berthouze et al., 1995) and mental health benefits (Lawlor & Hopker, 2001). A commonly cited reason for low physical activity is boredom (Marshall & Biddle, 2001). Trampolining is becoming an increasingly popular recreational activity. However, there appears to be a lack of research concerning the physiological demands, and potential benefits of trampolining. A number of studies exist, for related aspects, using mini-trampolines (rebounders). Rebounding has been shown to; increase balance ability (Aragão et al., 2011; de Oliveira et al., 2014; Heitkamp et al., 2001; Kidgell et al., 2007; Miklitsch et al., 2013), leg strength (Heitkamp et al., 2001; Karakollukcu et al., 2015) and jump performance (Karakollukcu et al., 2015). Further, it has been shown that, one rebounding session of moderate to high intensity can temporarily reduce blood glucose concentration in normoglycemic adults (Cunha et al., 2016). Also that several weeks of moderate-intensity rebounding, can induce significant improvements in mean HbA1c and fasting plasma glucose concentration (Maharaj & Nuhu, 2016), as well as insulin resistance (Nuhu & Maharaj, 2017) in individuals with type 2 diabetes mellitus. In addition, it has been found that three 60-minute exercise sessions of moderate to vigorous intensity (5.2 MET) rebounding, increase power output and $\dot{V}O_{2max}$ in middle-aged, overweight women over 12 weeks (Cugusi et al., 2017; Cugusi et al., 2016).

Comparison between the findings for rebounders and trampolines are controversial, due to the differences in the size of the jumping bed. Bouncing on a trampoline not only results in greater forces acting on the jumper, but the bouncing mechanism fundamentally differs (McGlone et al., 2002). On a rebounder, the bounce is often focused on a downward push into the mat, rather than an upward movement. This difference in the bouncing action brings into question whether the findings on a rebounder can be assumed to be the same on a trampoline. Currently, no research has investigated whether the difference in the bouncing action affects the outcomes of an exercise bout using either modality. Further research is necessary to determine this outcome.

The most notable study directly investigating the physiological demands of trampolining, is the 1980 study by Bhattacharya et al (Bhattacharya et al., 1980). While widely cited as a consequence, this study provided data from only 8 young male participants. This study concluded that trampolining had a similar oxygen demand to treadmill running, at the same intensity. Given that only one previous study has investigated the EE of trampolining, it is important that the physiological demands of trampolining, compared to other exercise modalities, be validated. Therefore, the aim of this study was to investigate the EE while trampolining, using a larger sample size and more physiological measures than has been reported in previous research. (Note, this Study (Study 2) uses the same participants as Study 1, but adds an extra testing day.)

5.2.1 Hypothesis

- Trampolining will have a different physiological response when compared to treadmill running, for a given heart rate.

5.2.2 Strengths of the Study

- This study is the largest study, to date, examining energy expenditure while trampolining.
- It is the first study to compare the acute lactate response of trampolining compared to other exercise modalities.

5.2.3 Delimitations

- Energy expenditure is the average of the recorded values across the final 30 seconds of the bout.

5.2.4 Assumptions

- -All participants reached a steady state of energy expenditure by the conclusion of each bout.
- Energy lost to the trampoline will be similar for similar masses.

5.2.5 Limitations

- Participants were mostly young adults (18-24), therefore findings may not be applicable to children and the elderly.
- Participants were recruited, solely, from the University of Canterbury population. Therefore findings may be less applicable to other populations.
- The model does not account for energy expended while in the air (flipping, twisting, spinning etc.).

5.3 Methods

For this study, two separate testing days, one week apart, were used. One for the trampoline, then, a week later, one for the treadmill. On each of the testing days, the participant's height and mass were measured to allow accurate analysis of oxygen consumption. Mass was obtained using a bio-impedance scale (Inbody 230, Inbody, Seoul, Korea). Body fat and muscle mass were obtained using the same machine by the method of bioelectrical impedance analysis (Lukaski et al., 1985).

5.3.1 Trampolining Testing

Prior to the testing, the participants were briefed on the protocol and instructed to perform a series of bounces at three intensities; low, medium and maximum intensity. The participant was then helped into the trampoline (S113, Springfree, Christchurch, New Zealand) for a practice bout, during which, they were instructed to bounce at each of the intensities. The participants were allowed to practise each intensity until they felt comfortable they understood what was required. This took approximately a minute total for all three intensities.

The low intensity was a height which was primarily maintained through plantarflexion of the ankle. The medium intensity was a height at which some degree of knee flexion was exhibited. The maximum intensity was the maximum height the participant believed they could maintain for 3 minutes. A heart rate monitor (H7, Polar, Kemplele, Finland) and a breath by breath gas analyser (K5, COSMED, Rome, Italy) were then placed on the participant. Resting heart rate (RHR) (while sitting) was recorded. Then, resting blood lactate (BL) was assessed using a portable blood analyser (LT-1730, Arkray, Edina, USA).

Blood lactate is a commonly used measure amongst exercise science literature. It can act as a predictor of exercise performance (Billat, 1996; Sjödin & Jacobs, 1981; Wasserman, 1984) or can be used to assess the difficulty of exercise and prescribe a specific difficulty (Lagally et al., 2002). The average concentration of blood lactate is usually 1-2 mmol/L at rest, but can rise to greater than 20 mmol/L during intense exertion (Faude et al., 2009). This study utilised the measurement of blood lactate, as a secondary measure, for the comparison of intensity between two exercise modes. Prior to sampling, gloves, safety goggles and a lab coat were donned by the technician. The participant was then asked to sit on a provided chair. The participant was asked whether they were left or right handed and how much typing they would be completing throughout the rest of their day. Their non-dominant hand was always selected for the sample point. If the participant indicated that they would be completing a significant amount of typing throughout their day, their pinky finger was selected, if not their index finger was used. These questions and the selection of the sampling point were utilised to minimize impact on the participant's regular daily activities.

After selecting the sampling point, the site was cleaned with an alcohol wipe. A spring-loaded blood lancet (Haemolance, HTL Strefa, Marietta, USA) was then used to apply an incision, by which the blood could be sampled. The incision was applied to the most distal pad of the finger, approximately 10mm, laterally, from the centre of the finger. The participant was then given a tissue to hold. They were instructed to lightly apply the tissue to the incision point, to contain the blood flow. A portable lactate analyser (Lactate Pro 2, ARKRAY, Kyoto, Japan) was then used to sample the blood. Multiple measurements of blood lactate were taken in a single session. So, the participant was instructed to maintain a light pressure, using the tissue, between the sampling instances to contain the blood flow. At the completion of the testing, the incision site was cleaned and a Band-Aid was applied.

After the initial BL sample was taken, the participant was helped into the trampoline and instructed to bounce at the low intensity. Participants were given a 3 second countdown, then instructed to begin. For three minutes; HR, $\dot{V}O_2$ and EE were recorded using the gas analyzer. Total jump height and the number of jumps performed were recorded during the bout using an accelerometer built into the trampoline (TGOMA, Springfree, Christchurch, New Zealand). At the end of the bout, the participant was stopped and asked to sit. BL was then collected. The participant was asked to remain seated until their $\dot{V}O_2$ and HR had returned to resting levels. This protocol was then repeated for the medium and maximum effort intensities.

5.3.2 Treadmill Testing

Prior to testing each participant was fitted with the same heart rate monitor and gas analyser that were used during the trampolining test. RHR and BL were then recorded. Participants were then instructed to begin moving on the treadmill (EXC Run 900, Technogym, Bracknell, U.K.). The treadmill speed was adjusted, by 0.5km/hr every 15 seconds, until HR reached a value within five beats per minute (bpm) of the value recorded during the last ten seconds of the low trampoline intensity. The treadmill speed was adjusted throughout the bout to maintain a HR within 5 bpm of the target HR. HR, $\dot{V}O_2$ and EE were recorded for the entire bout. At the end of the bout, the participant was stopped and asked to sit. BL, the final treadmill speed and total distance run were then recorded. The participant was asked to remain seated until their $\dot{V}O_2$ and HR had returned to resting levels. This procedure was then repeated for the medium and maximum effort intensities.

5.3.3 Participants

The participants consisted of 23 healthy adults (9 male, 14 female). Participants age ranged from 18-40 years, with a mean age of 25 ±4 years. Mean values for the anthropometric measures for males and females can be seen in Table 5.1. All participants had prior, recreational, trampolining experience. None had experience trampolining in a competitive or sporting context. The study was completed across two separate sessions, one week apart, between June and August, 2017. Exclusion criteria were health risks that contraindicate exercise testing (American College of Sport Medicine, 2013), diseases that are associated with loss of balance, as well as the presence of infections, injuries or an existing drug treatment that could potentially limit physical performance. Participants who passed the screening were given detailed information about the study's aim and protocol and gave written consent before participation. This study was approved by the ethics committee of the University of Canterbury (HEC 2017/27).

Table 5.1 *Anthropometric measurements for participants. Mean ±SD*

	Male	**Female**
Age (years)	26 ±5	24 ±4
Height (cm)	178 ±6cm	165 ±4cm
Mass (kg)	78 ±11kg	69 ±11kg
BMI (kg/m^2)	25 ±4	25 ±4

5.3.4 Statistical Analysis

Statistical analysis was performed using SPSS Statistics for Windows (Version 24, IBM Corp, Armonk, NY, USA). For each of the variables, the data was averaged across the final 30 seconds of each bout. Datasets were first assessed for normality using a Shapiro-Wilks test. All variables, except the blood lactate results, were found to follow a normal distribution. A two-way, repeated measures, MANOVA was used to assess whether differences existed between the means for $\dot{V}O_2$, EE and BL. Equipment type (trampoline, treadmill) and intensity (low, medium and maximum) were used as the independent variables. After finding a difference between the groups ($p < 0.05$), a series of two-way repeated measures ANOVAs were used to identify where the differences existed between the individual variables. A difference was found between the intensities for each of the variables. Paired samples t-tests were then used to determine the degree of the difference between the running and bouncing at each of the different intensities for $\dot{V}O_2$, EE and BL. Effect size (Cohen's d) was then used to interpret the differences.

5.4 Results

Means and standard deviations for the collected variables can be seen in Table 5.2.

Table 5.2 *Means (±SD) for the recorded variables, at each intensity, for both the trampoline and treadmill efforts.*

Low Effort	**Trampoline**	**Treadmill**
Heart Rate (bpm)	118 ±16	118 ±19
Oxygen Consumption (mL/min/kg)	22 ±5	23 ±6
Energy Expenditure (kj/min/kg)	0.3 ±0.1	0.3 ±0.1
Blood Lactate (mmol/L)	1.8 ±0.6	1.5 ±0.6
Average Bounce Height (m)	0.2 ±0.1	
Final Treadmill Speed (km/hr)		6.3 ±0.6
Medium Effort		
Heart Rate (bpm)	145 ±18	147 ±17
Oxygen Consumption (mL/min/kg)	30 ±6	33 ±6
Energy Expenditure (kj/min/kg)	0.3 ±0.1	0.4 ±0.1
Blood Lactate (mmol/L)	2.9 ±1.2	2.4 ±1.2
Average Bounce Height (m)	0.4 ±0.1	
Final Treadmill Speed (km/hr)		8.0 ±1.3
Maximum Effort		
Heart Rate (bpm)	179 ±10	175 ±10
Oxygen Consumption (mL/min/kg)	43 ±8	44 ±8
Energy Expenditure (kj/min/kg)	0.5 ±0.1	0.5 ±0.1
Blood Lactate (mmol/L)	8.2 ±2.5	4.9 ±1.8
Average Bounce Height (m/bounce)	0.8 ±0.2	
Final Treadmill Speed (km/hr)		12.1 ±2.0

A two-way, repeated measures MANOVA was used to assess whether differences existed between the means for $\dot{V}O_2$, EE and BL ($F_{6,86}$ = 9.3, p < 0.0005, η_p^2 = 0.39). Two, one way repeated measures ANOVAs were then used to identify differences between the individual variables. Differences were found between the intensities for $\dot{V}O_2$ ($F_{2,44}$ =

159, $p < 0.0005$, $\eta_p^2 = 0.88$), EE ($F_{2,44} = 136$, $p < 0.0005$, $\eta_p^2 = 0.86$) and BL ($F_{2,44} = 171$, $p < 0.0005$, $\eta_p^2 = 0.89$).

Post-hoc tests were then used to evaluate the differences between the trampoline and treadmill for each of the three intensities. Paired samples t-tests and Cohen's d were used to interpret the differences. For the low effort, a difference existed between the trampoline and treadmill for BL (p = 0.04, d = 0.4). For the medium effort, a difference was found between the trampoline and treadmill for $\dot{V}O_2$ (p = 0.01, d = 0.6), EE (p = 0.003, d = 0.7) and BL (p = 0.03, d = 0.5). For the maximum effort, a difference was found between the trampoline and treadmill for EE (p = 0.02, d = 0.5) and BL (p = 0.001 d = 1.4).

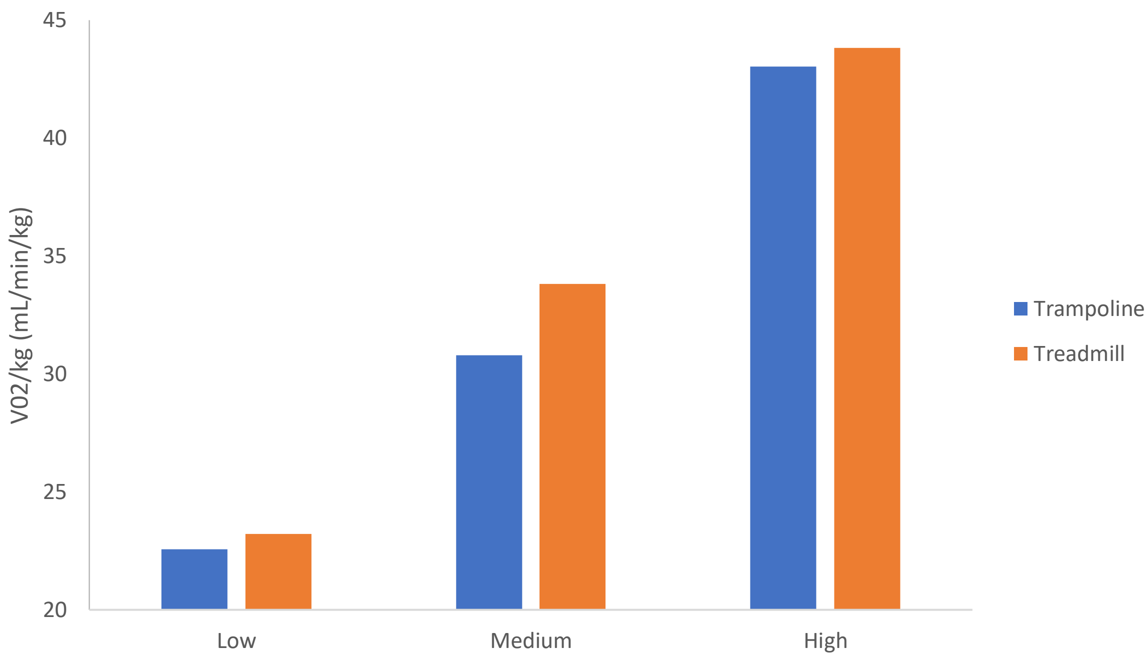

Figure 5.1 *Comparing the $\dot{V}O_2$/kg at each intensity for running and trampolining.*

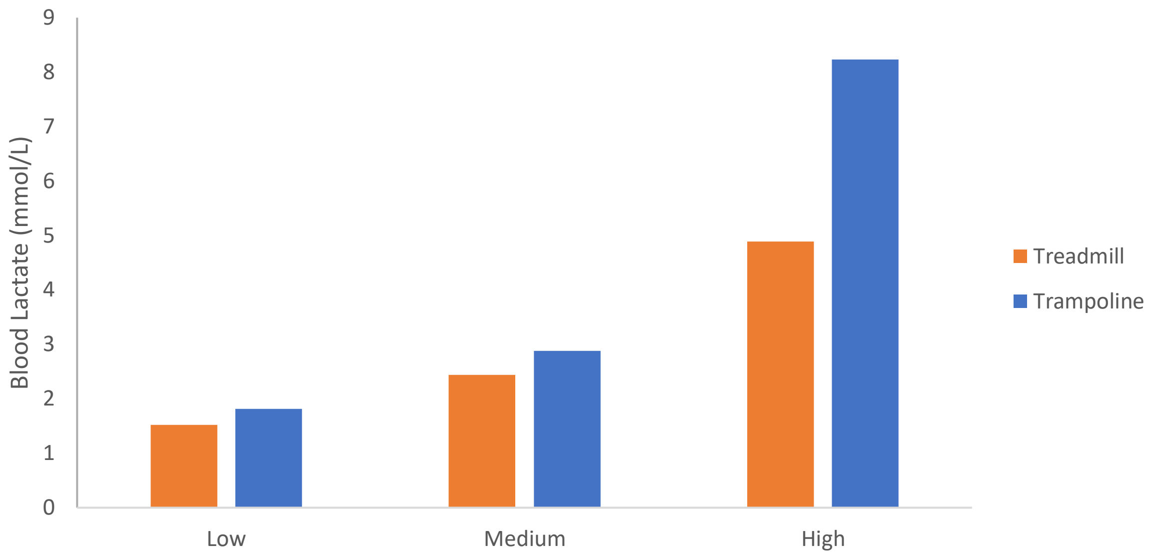

Figure 5.2 *Comparing the blood lactate at each intensity for running and trampolining.*

5.5 Discussion

The aim of this study was to investigate the EE while trampolining, using a larger sample size and more physiological measures than has been reported in previous research. A two way, repeated measures MANOVA indicated differences existed, between the means of the variables, when comparing the trampoline and treadmill efforts. Further analysis indicated that a difference existed between each of the intensities. At the low intensity, $\dot{V}O_2$ and EE were similar between bouncing and running, whereas, BL differed. At the medium intensity, $\dot{V}O_2$, EE and BL were different between the modalities. At the high intensity, $\dot{V}O_2$ values were similar, whereas, EE and BL differed. These differences indicate that the mode of exercise is affecting the demands on the participant's energy systems.

Though the oxygen consumption was similar between the exercise modalities, differences do exist between the demands for trampolining and running, as can be seen from Table 5.2. It is well established, for running, that the outcomes of training may be affected by altering the intensity at which the training is performed (Bacon et al., 2013). Therefore, it is likely that the training outcomes from the use of either a trampoline or treadmill are similar. This means the trampolining is likely to provide the myriad of benefits associated with regular running such as increased cardiorespiratory fitness, muscle mass, bone density and improved mental wellbeing.

Trampolining and running differed, most noticeably, for the production of BL during the high intensity effort. BL is commonly used as a measure of anaerobic energy production. The BL threshold is a marker for the point at which blood lactate has exceeded the concentration that can be managed for a long time period (Beneke et al., 2011). This threshold is approximately 4 mmol/L. Once this threshold is exceeded, lactate production will continue to increase until exercise, at this intensity, must be halted. Both the trampoline and treadmill efforts, at maximum intensity, have exceeded 4 mmol/L. The BL measure for the trampoline was almost double the treadmill BL, at the maximum intensity. This indicates that the participant's BL threshold was surpassed earlier during the trampoline bout than the treadmill bout. This indicates that trampolining causes the BL threshold of a participant to be exceeded at a lower heart rate than treadmill running. Therefore, trampolining must require greater anaerobic energy production to maintain a given intensity, when that intensity is measured by heart rate. This suggests that heart rate is not a complete measure of intensity when utilised for trampolining.

The mechanism which caused these differences in anaerobic energy production for a given heart rate, is unknown. The authors propose that it could have been caused by any, or all, of three different mechanisms. The first mechanism is a lack of exercise economy with trampolining compared to running. Exercise economy, or the efficiency of movement during exercise, heavily contributes to the energy demands on the body (Daniels & Daniels, 1992). Running is an exercise mode where the participant is likely to exhibit a higher economy of movement, compared to bouncing on a trampoline, due to prior practise (Kyröläinen et al., 2001). Therefore, it may be that the participants were less efficient at trampolining, compared to running, which was reflected in the increased anaerobic energy production while trampolining. Future research could include a training block, prior to beginning the study intervention, where the participants are bouncing on a trampoline regularly. This would improve the participant's familiarisation with the trampoline and may mitigate exercise economy as a confounding variable.

The second potential mechanism is the difference in energy production between concentric focused exercises and eccentric focused exercises. An exercise being more or less eccentric focused, affects both energy (Perrey et al., 2001) and metabolite production (Goto et al., 2009). To the best of the author's knowledge, no research has been published investigating whether the motions of trampolining and running differ significantly enough for one to be considered concentric focused and the other eccentric focused. If this classification could be made then this difference in muscle action may explain the difference in anaerobic energy production.

The third mechanism is the unique properties of trampolining as an exercise modality. Most exercise modalities involve continuous muscle action throughout the exercise bout. Trampolining has a distinct break between the muscle actions, as the participant travels through the air. This air time provides a short rest interval between the muscle actions. Further investigation is necessary to determine whether this rest time provides significant benefit or detriment in terms of the desired training outcome.

5.6 Conclusion

The aim of this study was to validate the only previous study investigating EE while trampolining, using a larger sample size and more physiological measures. Analysis of the dataset, confirmed the statement made by the previous study (Bhattacharya et al., 1980) that “trampolining had a similar oxygen demand to treadmill running, at the same intensity”. Though the oxygen demand was similar between the exercise modes, a difference was found between the trampoline and treadmill for $\dot{V}O_2$, EE and BL. These differences indicate that trampolining and treadmill running exert different physiological demands on the body, most notably for anaerobic energy production. This difference in energy production led the authors to believe that heart rate is not a complete predictor of exercise intensity, while on a trampoline. The source of this difference in anaerobic energy production has been discussed, but is ultimately unknown and further research is necessary to determine its source.

6 Study 3: The Effect of the Bouncing Action on the Energy Expenditure of Trampolining

6.1 Project Background

While completing the first study (Chapter 4), it was found that the energy expenditure (EE) for trampolining was much higher than had been reported in previous literature. It was also noted that data collected had only investigated vertical bouncing. Intuitively, it made sense that if you added further actions to the bouncing such as: lateral movement, spinning, flipping and/or movement of the arms or legs while airborne, the energy demand would increase. Therefore, it was decided to investigate to what degree EE was affected by altering the bounce type. This could affect both the metabolic equivalent of task (MET) value for trampolining and update the EE calculation model developed in Chapter 4.

6.2 Introduction

Regular physical activity is a crucial component of a healthy lifestyle, which provides a myriad of health benefits including: decreased body fat percentage (Verheggen et al., 2016), increased cardiovascular function (Gist et al., 2014), improved muscle mass (Peterson et al., 2011) and cognitive benefits (Smith et al., 2010). Despite this, a lack of physical activity is still very common, with lack of regular exercise being the fourth greatest risk factor for non-communicable diseases, which are estimated to cause 3.2-5 million deaths per year (World Health Organisation, 2016).

A major problem with increasing activity rates among the general populace is a lack of adherence, with approximately 50% of people who begin an exercise regimen dropping out within 6 months (Dishman, 2001). Improving adherence to exercise is a difficult task due to the complexity of the issue (Prasad & Cerny, 2002). However, it has been suggested that enjoyment may be a strong determinant of exercise adherence

(Ekkekakis et al., 2011; White et al., 2005). Enjoyment of exercise is not only influenced by psycho-sociological factors but also by mode, intensity and duration of the exercise (Raedeke, 2007). Utilizing different modes of movement has been found to increase enjoyment of an aerobic exercise regimen (Miller et al., 2005).

The first trampoline was created by George Nissen and Larry Griswold in 1936 (Hayward, 2010). Since that time, trampolining has become a popular sporting and recreational activity. Some trampolining manufacturers have promoted trampolines as a way to improve exercise adherence through providing an alternative exercise modality. While trampolining may offer an enjoyable exercise alternative, it is currently difficult to quantify the intensity of exercise on a trampoline in a manner similar to other popular exercise modes.

Tracking the intensity of an exercise program is important, as it provides information about the resultant training adaptions. The intensity at which exercise is performed alters the stimulus experienced by the body and, therefore, the adaptions incurred (MacInnis & Gibala, 2017). Subjective measures of intensity are unreliable, as they are influenced by the participant's biases (Scherr et al., 2013). Objective measures are better suited for comparing intensities, as the participant's perspective cannot alter the measure. There are many objective measures which are commonly used to quantify intensity during exercise such as: percentage of maximum heart rate, rate of energy expenditure (EE)(kJ/min), rate of perceived exertion (RPE) or percentage of maximum $\dot{V}O_2$. A metabolic equivalent of task (MET)(kcal/kg/hr) is a method of expressing EE which allows comparison between different exercise modes. One MET represents a resting EE (Ainsworth et al., 1993). Currently, the literature surrounding trampolining and the physiological responses related to exercise on a trampoline are limited. This makes quantifying EE during trampolining difficult, as no consensus exists amongst the literature for the exact rate of EE for trampolining. Trampolining has been shown to have a similar oxygen consumption rate, to running, for a similar intensity (Bhattacharya et al., 1980; Draper et al., 2020). The Compendium of Physical Activities

(Ainsworth B. E. et al., 2011) lists the MET value of recreational trampolining at 3.5 METs and competitive trampolining at 4.5 METs, but both of these values are acknowledged to be estimates only. A 2009 study (Arvidsson et al., 2009) found a METs value of 6.9 METs while trampolining, almost double the estimated value from the Compendium of Physical Activities. EE while using a mini-trampoline (rebounder) has been more thoroughly explored. Comparison between the outcomes for a training regime on a rebounder, verses a trampoline, are difficult due to the differences in the jumping action. On a rebounder, the bounce is often focused on a downward push into the mat, rather than an upward movement. This difference in the bouncing action may affect the outcomes of training, using that modality (McGlone et al., 2002).

Direct investigation into the EE of trampolining can be seen in Chapter 4 and 5. Draper et al, compared the physiological effects of trampolining to those of running and found the rate of EE to be similar when intensity is matched (Draper et al., 2020). Alexander et al produced a model by which EE could be calculated while bouncing on a trampoline (Alexander et al., 2020). A limitation of both these studies was that they only investigated a vertical bounce pattern. Trampolining is a complex sport, which requires the body to move in a variety of planes of motion. The rate of EE previously recorded in the literature did not account for the fact that bouncing on a trampoline can involve more than just one plane of motion. To the best of the author's knowledge, no other studies have explored how altering the bouncing action on a trampoline, to increase the number of planes of motion used, affects the energy expenditure and other physiological markers. Therefore, the aim of this study was to investigate how altering the bouncing type affected the energy expenditure of trampolining.

6.2.1 Hypothesis

- Altering the bouncing action of a trampoline to include more planes of motion (spinning, flipping, movement of the arms or legs while airborne) will increase the energy demand.

6.2.2 Strengths of the Study

- This study is building on a previous study, by further developing the model for predicting EE on a trampoline.

6.2.3 Delimitations

- Energy expenditure is the average of the recorded values across the final 30 seconds of the bout.

6.2.4 Assumptions

- All participants reached a steady state of energy expenditure by the conclusion of each bout.
- Energy lost to the trampoline will be similar for similar masses.

6.2.5 Limitations

- Participants were mostly young adults (18-24), therefore findings may not be applicable to children and the elderly
- Participants were recruited, solely, from the University of Canterbury population. Therefore findings may be less applicable to other populations.

6.3 Methods

6.3.1 Anthropometric Measures

First, the participant's height and mass were obtained to allow accurate analysis of oxygen consumption. Weight was obtained using a bio-impedance scale (Inbody 230, Inbody, Seoul, Korea).

6.3.2 Trampoline Intervention

Following the anthropometric measures, each of the different bouncing actions (conventional, lateral jumps, star jumps, 180° rotational jumps and tuck jumps) were summarized for the participant. The participant was then asked to remove their shoes and socks and helped into the trampoline. The participant was asked to bounce on the trampoline (Model O77, Springfree, Christchurch, New Zealand), at a comfortable height. The height of the bounce was then manipulated so the participant exhibited a small amount of knee flexion during each jump. As opposed to a jumping action generated primarily through plantarflexion of the foot, which some participants exhibited at low bouncing heights. Participants were then instructed to try to maintain this height. An adjustable target was placed outside the trampolining area. This target was lined up with the eye level of the participant at the top of the bounce. The participant was then instructed to bounce so their eyes lined up with the target at the top of each bounce. This target was then secured at this height and the participant was instructed to try their best to bounce maintain this target height for each bounce.

For the lateral jumps, a 0.5m distance was marked on the surface of the trampoline. The participant was asked to perform a bilateral bounce with their medial foot (relative to the centre of the trampoline) landing outside the lines for each bounce.

For the star jumps, the participant was asked to touch their hands to their thighs each time they contacted the trampoline mat and to touch their hands above their head at the top of each bounce.

For the 180° rotational jumps, the participants were asked to complete a 180° rotation around the frontal plane with every jump. To prevent excessive inducement of vertigo, the participant was asked to complete two jumps while spinning clockwise, then complete the next two jumps while spinning counter-clockwise. This pattern was repeated throughout the bout.

Finally, during the tuck jump, the participants were instructed to pull their knees as high as possible at the top of each bounce without exceeding the desired bounce height. The participants were given practice attempts for each bouncing action, until they felt reasonably confident that they could complete the entire three minutes for each variation while maintaining the desired height. Each of the practice attempts for the different bouncing variations was continued until the participant felt confident they could complete the task. This took approximately 20 bounces per variate. All bouncing actions used were performed bilaterally (both legs contacting the mat simultaneously for each bounce).

At the completion of the familiarization session a 5 minute rest period was utilised while a heart rate monitor (H7, Polar, Kemplele, Finland) and a portable breath by breath gas analyser (K5, COSMED, Rome, Italy) were placed on the participant. The participant was asked to sit and their resting heart rate was recorded. The participant was then helped into the trampoline and instructed to bounce, to the desired height, using the conventional bouncing action for three minutes. During the bout, the participant's jump height was monitored using tri-axial accelerometers, that were built into the trampoline (TGOMA, Springfree, Christchurch, New Zealand), which recorded the participant's jump height and number of jumps. At the end of the three minutes, the participant was asked to exit the trampoline and rest until their heart rate returned to resting levels. The protocol was then repeated for the lateral jumps, star jumps, 180° rotational jumps and tuck jumps.

6.3.3 Participants

The participants consisted of 28 adults (12 male, 16 female). Participants ranged from 19-29 years of age, with a mean age of 24 ±2 years. Means and standard deviations of the anthropometric measures for males and females can be seen in Table 6.1.

Table 6.1 *Anthropometric measurements for participants. Mean ± SD*

	Male	**Female**
Age (years)	25 ±1	24 ±3
Height (cm)	181 ±5cm	164 ±6cm
Mass (kg)	84 ±13kg	70 ±14kg
BMI (kg/m^2)	26 ±4	26 ±5

All participants had prior trampolining experience (defined as having used a trampoline, at some stage of their life, prior to the study), but none had experience trampolining in a competitive or sporting context. Each participant completed all testing in a single session between November 2018 and February 2019. The testing was completed in the University of Canterbury Exercise Physiology Laboratory. Exclusion criteria were health risks that contraindicate exercise testing (American College of Sport Medicine, 2013), diseases that are associated with loss of balance, as well as the presence of infections, injuries or an existing drug treatment that could potentially affect physical performance. Participants who passed the screening were given detailed information about the study's aim and protocol and gave written consent before participation. This study was approved by the ethics committee of the University of Canterbury (HEC 2018/15).

6.3.4 Statistical Analysis

For each bouncing action, EE was averaged across the final 30 seconds of the bout. The average jump height affects EE as can be seen in Equation 6.1. So, if the jump height differed between the efforts, it would affect EE. To account for this error, the jump height of each of the variates were corrected to match the height of the conventional bounce. This was achieved by working out the percentage difference between the two jump heights then multiplying the EE by this value. The formula used to calculate this can be seen in Equation 6.1.

$$EE_2 = EE_1(h_2 + S)/(h_1 + S)$$

Equation 6.1 *Calculating energy expenditure during different bounce types*

Where:

EE_2 = *The corrected EE value*

EE_1 = *The recorded EE value*

h_2 = *The average recorded jump height above the undeflected mat surface*

h_1 = *The height of the comparison bounce (normal)*

S = *Static mat deflection with the jumper stationary on the mat (m)*

The values were corrected for each participant's dataset. These corrected values were then compiled in an excel spreadsheet and exported into SPSS Statistics for Windows (Version 24, IBM Corp, Armonk, NY, USA). The dataset for EE was first assessed for normality using a Shapiro-Wilks test. The dataset was found to follow a normal distribution. The dataset failed Mauchly's Test of Sphericity ($p < 0.05$), therefore a one way repeated measures ANOVA, with a Greenhouse-Geisser correction, was used to identify whether a difference had occurred between the jump variates ($p=0.05$). Post-hoc tests using the Bonferroni correction were then used to assess the difference between the conventional bounce and each of the bounce variates. Effect size was estimated using partial eta squared.

6.4 Results

Means, standard deviations and the percent difference for the EE for each of the bouncing actions can be seen in Table 6.2.

Table 6.2 *Descriptive statistics for each bounce variate. Note: Total jump height is the combined bounce height across the 3-minute bout. "*" Indicates a significant change from the EE of the conventional bounce.*

Type of Bounce	Total Jump Height (m)	Recorded Value for EE (kJ/min)	Corrected Value for EE (kJ/min)	MET (kCal/kg/hr)	EE Difference from Conventional Bounce (kJ/min)
Conventional	65.9 ±12.5	47.6 ±10.7	47.6 ±10.7	9.0 ±2.0	0%
Lateral	67.3 ±14.3	55.5 ±11.6	54.8 ±11.4*	10.3 ±2.1	+15%
Star	66.3 ±13.7	58.4 ±13.2	57.6 ±12.3*	10.8 ±2.3	+21%
180 Rotational	65.3 ±13.7	58.4 ±12.2	59.8 ±12.0*	11.3 ±2.3	+26%
Tuck	70.3 ±13.3	63.1 ±13.3	60.3 ±12.7*	11.4 ±2.4	+27%

A one-way repeated measures ANOVA was used to identify whether a difference had occurred between the bounce action's EE. A difference was found ($F_{2.989,27}$= 44.979, p = 0.0005, η_p^2 = 0.6). Post-hoc tests found that a difference existed between the conventional bounce and each of the bouncing actions (p = 0.0005).

To further interpret these differences, the difference between the EE for the conventional bounce and the other bouncing actions was converted into a percentage value. The equation for this can be seen in Equation 6.2. These values are reported in Table 6.2.

$$V = \frac{EE_2}{EE_1} * 100$$

Equation 6.2 *Percent different between bounce types.*

Where:

V = The percentage difference between EE of conventional bounce and EE of bounce variate

EE_2 = *EE of bounce variate*

EE_1 = EE of conventional bounce

6.5 Discussion

The aim of this study was to investigate how altering the bouncing type affected the energy expenditure of trampolining. Omnibus tests indicated that differences did exist between the EE's of the bouncing actions. Post hoc tests found that the EE for each of the bouncing actions was higher than the EE for the conventional bounce.

These findings support the hypothesis that altering the bouncing action does significantly affect the EE of trampolining. This means an alteration is required to the equation to predict EE while bouncing on a trampoline as developed by Alexander et al (Alexander et al., 2020). The findings of this study indicate that to accurately predict EE during a trampolining bout, that involves additional planes of movement, a multiplier should be used to adjust the value for EE. The updated equation can be seen in Equation 6.3.

$$EE = (1-C)W\ g\ (h+S)N\ V/1000/e$$

Equation 6.3 *Updated model for EE on a trampoline (including conversion for different bounce types.*

Where:

EE = energy expenditure of a jumper continuously jumping on a trampoline (kJ/min)

C = coefficient of restitution for the weight of the jumper on the given trampoline

W = weight of the jumper (kg)

g = gravity (9.81m/s^2)

h = average jump height above the undeflected mat surface, over the measurement duration (m)

S = static mat deflection with the jumper stationary on the mat (m)

N = number of jumps per minute (1/min)

V = The variate coefficient (EE_2/EE_1)

e = efficiency of human energy conversion from stored to mechanical energy while jumping

The results of this study also indicate that the MET value for trampolining is higher than has been reported in previous literature. The highest previously reported values being 6.9 METs (Arvidsson et al., 2009) and 9.4 METs (Alexander et al., 2020). Whereas, this study found MET values, for exercise on a trampoline, of up to 11.3 METs. A point to note is that none of the bounce variates were performed at maximum intensity, so an even higher MET value is theoretically possible.

The lateral bounce was found to have the smallest increase to EE (+15%) when compared to the conventional bounce. For the testing, the lateral distance was set at 0.5m. It is likely that if this distance was increased, EE would rise accordingly. Vertical height becomes difficult to maintain when large lateral distances are used, so there may exist a highest possible EE, for lateral bouncing, which uses an ideal ratio between lateral and vertical height.

Star jumps had the next greatest increase to EE when compared to the conventional bounce (+21%). Interestingly, during testing, many participants found this to be the "hardest" bounce action. The participants commented that their arms became very fatigued during the bout.

The 180° rotational bouncing and tuck bouncing were found to have a similar EE, having a +26% and +27% increase respectively. During testing, many participants found the 180° rotational bouncing to be the most difficult in terms of the required coordination to accurately complete the task. This was likely due to the difficulty of maintaining a consistent bounce height while spinning. Few participants found 180° rotational bouncing to be as physically demanding as the other bouncing actions, but many did find it to be very mentally taxing due to the coordination involved.

Tuck jumps were ranked equally with star jumps in terms of what bounce action the participants found to be the 'hardest'. An interesting aspect of tuck jumps was that pulling the knees as high as possible tended to cause the participant to exceed their target bounce height. This meant nearly all participants had to reduce the height to which they pulled their knees, thereby never entering a full 'tuck' position. It would be interesting to investigate whether increasing the bounce height would actually lower the difficulty of this variate. An increased bounce height would give a greater air-time, reducing the rate at which the participant is required to flex at the hip to enter the tuck position.

Another bounce action of interest would be completing 180° rotations around the transverse plane or sagittal plane (flipping). The 180° rotational bounce, around the frontal plane, produced a large increase to the EE (+26%), while having a relatively small turning radius. Flipping would require a greater turning radius, which may lead to an even greater increase to EE. Flipping has some significant practical difficulties which complicate its investigation. Compared to the bouncing actions used in this study, flipping involves a much greater degree of risk, due to the danger of inverted landing if performed incorrectly. To mitigate this danger, a high level of skill is required to perform flipping continuously. This level of skill is uncommon amongst the general populace. This would make participant recruitment, to investigate this phenomenon, difficult due to a decreased density of the relevant population. Another difficulty is due to the nature of EE testing. Standard practise for EE testing is to have the participant perform the movement for a minimum of 3 minutes, continuously, in order to allow the participant to reach a steady-state of EE. Flipping for three minutes continuously would be incredibly difficult due, not only, to the taxing nature of the movement, but also due to the extreme vertigo that would be induced. These practical difficulties are likely to cause the EE of flipping to remain unknown until they can be addressed.

6.6 Conclusion

Despite trampolining being a popular recreational activity, the literature surrounding the exact energy expenditure required while trampolining is lacking. This study has found that increasing the planes of motion used, while bouncing on a trampoline, does increase the energy expenditure. This study then updated the model for predicting energy expenditure while trampolining and allows the intensity of a trampolining session to be more accurately characterized.

7 Study 4: The Effect of High Intensity, Short Duration Trampolining, on markers related to health, across an 8-week Intervention.

7.1 Project Background

With the first three studies complete, further meetings were had to determine the direction for the final two studies of the thesis. Three main directions for the research were proposed: investigating how trampolining affected lymphatic drain, investigating how 100 bounces per day would affect health outcomes and whether trampolining had utility for the treatment of stress urinary incontinence amongst women who had given birth. Literature reviews for each of the topics gave further direction for the investigation. From the investigation into trampolining's effect on the lymphatic system, it was concluded that investigating lymphatic drain (requiring the injection of a tracing fluid into the participants) would make gaining ethical approval and participant recruitment too difficult. Therefore, it was shelved as a topic. The literature review for trampolining as an exercise modality or as a novel treatment for stress urinary incontinence found more positive results. Therefore, these two topics were further explored. This chapter discusses trampolining's application as a novel exercise modality. Specifically, using a 100 bounces per day exercise format.

7.2 Introduction

Engaging in regular exercise provides many health benefits including: increased muscle mass (Rogers & Evans, 1993), increased bone density (Marques et al., 2012), improved cardiovascular function (Berthouze et al., 1995), mental health benefits (Lawlor & Hopker, 2001) and a decreased mortality risk (Ekelund et al., 2016). Despite this, lack of regular exercise is the fourth greatest risk factor for non-communicable diseases, which is estimated to cause 3.2-5 million deaths per year (McIntyre, 2015). One of the most common barriers to engaging in regular exercise is a lack of time (Schutzer & Graves, 2004). The current guidelines for physical activity recommend either 2.5 hours of moderate or 1.25 hours of vigorous exercise per week (McIntyre, 2015). For a person with limited free time this may be an unrealistic goal.

Low availability of free time is commonly listed as a major contributing factor to lack of participation in exercise (Greaney et al., 2009). Therefore, if the duration of exercise can be reduced, this may make participating in regular exercise more attractive. In recent years the popularity of high intensity interval training (HIIT) has increased dramatically. The premise behind HIIT training is to perform either very high or maximal effort, repeated bouts. Meta-analyses investigating HIIT vs steady state exercise saw either superior or matched improvements to cardiovascular function (Ramos et al., 2015) and body composition (Wewege et al., 2017), despite steady state exercise being performed for significantly longer periods of time. This difference in required time makes HIIT an attractive exercise modality to those with limited time availability.

Jumping as an exercise regime (also known as plyometrics) has been investigated extensively, finding benefit to leg muscular power output (de Villarreal et al., 2009; Stojanović et al., 2017) and bone density (Zhao et al., 2014). Comparisons between the training results of jumping on a compliant surface (such as a trampoline) and a non-compliant surface (such as the ground) may not be appropriate. This is because the jumping action differs between a compliant and non-compliant surface (Crowther et al., 2007). Therefore, conclusions from studies conducted on non-compliant surfaces may not be applicable to trampolining.

Mini-trampolines (also known as rebounders) are the most popular compliant surface modality used in a research setting. Exercise using rebounders has been shown to improve: balance (Arabatzi, 2018), vertical jump (Şahin et al., 2016), anthropometric measures (Cugusi et al., 2016), cardiovascular function (Şahin et al., 2016) and insulin resistance (Nuhu & Maharaj, 2017). At the surface level, the bouncing action of rebounders and trampolines may appear similar, but there are some fundamental differences. On a rebounder, the bouncing action is often focused on a downward push into the mat, which limits the upwards propulsion (McGlone et al., 2002). Whereas, the bouncing action on a trampoline is solely focussed on upwards propulsion. The bouncing action on a rebounder can then be further characterised as either a "bounce" or a "jog". With the different characterisations producing different physiological responses (Gerberich et al., 1990). How these differences, between the bouncing action on a trampoline and rebounder, affect the results of a training regime haven't been investigated at this time. Therefore, the conclusions from studies conducted on rebounders may not be applicable to trampolining.

Studies directly investigating exercise on trampolines have found benefit to: anthropometric measures, jump height, balance and leg power (Aalizadeh et al., 2016). So far, no studies have directly investigated the efficacy of using a trampoline to improve cardiovascular fitness. Due to the appeal of a low time commitment, a single, max effort bout protocol was devised. For a protocol to be considered HIIT, multiple intervals must be used. Therefore, the format used in this experiment is not an example of HIIT. The protocol used in this experiment has been coined a high intensity, short duration (HISD) protocol. Therefore, the aim of this study was to investigate whether a high intensity, short duration exercise protocol, on a trampoline, would improve markers related to health, across an 8-week intervention.

7.2.1 Hypothesis

- A HISD protocol on a trampoline will improve cardiovascular function, body composition, blood markers and vertical jump height by the end of the 8 weeks.

7.2.2 Strengths of the Study

- This is the first study to investigate the efficacy of trampolining as an exercise regime on adults.

- The study utilised TGOMA software for the collection of bounce height during the trampolining bout, which meant that the data for every bouncing session could be reasonably collected.

7.2.3 Assumptions

- Energy lost to the trampoline will be similar for similar masses.

7.2.4 Limitations

- The age range of the participants was large (19-60).
- Participants were recruited, solely, from the University of Canterbury population.
- Participants were instructed to bounce “as high as possible”. Other than this cue, the intensity of the intervention was self-directed.
- The assessment method for cardiovascular output was also self-directed with the participant being instructed to stop when they felt like they could no longer safely continue.
- Diet was not controlled in this study.
- Sitting time wasn’t controlled in this study.
- Drug use was not controlled in this study.

7.3 Methods

7.3.1 Anthropometric Measures

Participants were invited to visit the University of Canterbury Physiology Laboratory at Week 0, Week 4 and Week 8 of the intervention. The full testing session took approximately an hour each visit. All testing sessions were completed in the morning and participants were instructed to fast prior to the session (no water or food since the previous evening). Body mass was obtained using a bio-impedance scale (Inbody 230, Inbody, Seoul, Korea). Body-fat and muscle mass were obtained using the same machine by method of bioelectrical impedance analysis (Lukaski et al., 1985).

7.3.2 Blood Assessments

Next, blood pressure was assessed using an automated blood pressure cuff (5200-103Z, Welch Allyn, New York, USA), which measured the participants resting HR, blood oxygenation and systolic/diastolic blood pressure.

Blood pressure is a measure of the force of the circulating blood on the arteries within the body (CardioMed, 2018). Blood pressure is measured using two measurements; systolic (measured when the heart beats, when blood pressure is at its highest) and diastolic (measured between heart beats, when blood pressure is at its lowest). A "normal" measure for blood pressure is considered 140mm of mercury (Hg) systolic and 85mm diastolic. For each increase by 10mm systolic or 5mm diastolic, the chance of death within 25 years increases by 1.1-1.2% (Van Den Hoogen et al., 2000). Therefore, the monitoring and management of normal blood pressure is critical to long-term health.

The participant was asked to sit on a provided chair, with feet uncrossed, left arm propped up on a navel height table. Once in position, the participant was asked to relax as much as possible. The blood pressure cuff was aligned with the brachial artery as indicated by the markings on the cuff and wrapped firmly. The sphygmomanometer was then activated. Resting heart rate was recorded to the nearest beat per minute. Systolic and diastolic blood pressure were recorded to the nearest 1mm of Hg.

Total blood cholesterol (fasted) was then assessed using lancet blood sampling (BK6-10M, Benecheck, New Taipei City, Taiwan). High blood cholesterol is a risk factor for heart disease (Beveridge et al., 1956; Hooper et al., 2001; Kannel et al., 1971) and engaging in regular exercise can positively affect blood cholesterol concentration

(Kodama et al., 2007; Tambalis et al., 2009). A total blood cholesterol concentration less than 5.2mmol/L is considered desirable. Anything greater than 6.2 mmol/L is considered high risk (American Heart Association, 2019).

Analysis of blood glucose is used as a means of assessing the body's ability to maintain metabolic homeostasis (Wasserman, 2009). In healthy, fasted adults, blood glucose should range from approximately 3.5mmol/L to 5.5 mmol/L (Güemes et al., 2016). Values consistently higher than 5.5 mmol/L (known as hyperglycaemia) leads to blood toxicity, which contributes to cell dysfunction (Martin et al., 1992). Values consistently lower than 3.5 mmol/L (hypoglycaemia) can lead to a variety of symptoms including clumsiness, trouble talking, confusion, loss of consciousness, seizures or death (Cryer, 1999).

Prior to sampling, gloves, safety goggles and a lab coat were donned by the technician. The participant was asked whether they were left or right handed and how much typing they would be completing throughout the rest of their day. Their non-dominant hand was always selected for the sample point. If the participant indicated that they would be completing a significant amount of typing throughout their day, their pinky finger was selected, if not their index finger was used. These questions and the selection of the sampling point were utilised to minimize impact on the participant's regular daily activities.

After selecting the sampling point, the site was cleaned with an alcohol wipe. A spring-loaded blood lancet (Haemolance, HTL Strefa, Marietta, USA) was then used to apply an incision, by which the blood could be sampled. The incision was applied to the most distal pad of the finger, approximately 10mm, laterally, from the centre of the finger. The participant was then given a tissue to hold, to help contain the bleeding. Blood glucose was assessed using a portable blood analyser (BK6-G, Benecheck, Taipei City, Taiwan). Next, total blood cholesterol was assessed using a portable blood analyser (BK-

C2, Benecheck, Taipei City, Taiwan). At the completion of the testing, the incision site was cleaned and a Band-Aid was applied.

7.3.3 Testing Procedure

At this point, the participants were encouraged to eat and drink if they desired. Next, each participant underwent a $\dot{V}O_{2\max}$ test using a modified Bruce protocol, which was measured using a breath by breath analyser (K5, COSMED, Rome, Italy). Following the $\dot{V}O_{2\max}$ test, the participant was instructed to rest until they felt fully recovered (a 5-minute minimum was utilised). Finally, anaerobic power was assessed using vertical jump height (Yardstick, Swift Performance Equipment, NSW, Australia). Vertical jump height is an expression of lower body power output. High power output of the lower body musculature has a strong correlation with vertical jump (Changela & Bhatt, 2012) and horizontal sprinting speed (Tharp et al., 1985). Lower body power output can be assessed using a variety of methods, with the most common direct measures being a 10 second Wingate Test and a mass acceleration test, measured using a suitable device such as a Tendo™ unit. Both Wingate and mass acceleration tests require expensive equipment and a large time commitment. Vertical jump height has been validated as a proxy measure for the assessment of lower body power output and is commonly used due to its ease of measurement and time-efficiency (Gajewski et al., 2018).

Finally, vertical jump height was assessed to measure change to the lower body power output of the participant. Jump height was assessed using a yardstick (Yardstick, Swift Performance Equipment, NSW, Australia). The yardstick was first assembled. The participant was then asked to stand underneath the device with their dominant hand fully extended (vertically). The device was then adjusted so the bottom "flag" touched the tip of their outstretched hand. The participant was then asked to push away the highest "flag" they could reach, without their heels lifting off the ground. The height of this flag was then recorded. The participant was then instructed to jump as high as they could and swipe the highest flag that they could reach. No running start was allowed.

The participants were allowed as many attempts as they desired, until they felt they had hit the highest flag they were capable of. This height was then recorded and their standing height (the highest flag they could reach while standing) was subtracted from the total jump height to give the relative jump height.

Finally, the average amount of hours the participant spent exercising, weekly, outside of the intervention, was recorded. Participants were instructed to maintain their current level of exercise outside of the intervention and were excluded if the amount changed by more than an hour per week.

7.3.4 Intervention

For the duration of the 8 weeks, the intervention group were required to come into the laboratory 4 times per week to bounce on the designated trampoline (O77, Springfree, Christchurch, New Zealand). Participants were excluded if they completed less than an average of 4 sessions per week. Each session consisted of the participant first completing a 10 bounce warm-up at a self-directed, moderate intensity. The participant then completed a further 100 bounces at the maximum intensity (height) they were capable of. For each session; time to completion, total bounce height (the cumulative height of the 100 bounces) and caloric expenditure (during the 100 bounces) were recorded using the TGOMA software on the trampoline (TGOMA, Springfree, Christchurch, New Zealand). The control group completed no bouncing sessions during the 8 weeks and were instructed to maintain their current level of exercise.

7.3.5 Participants

The study was completed in three separate blocks from September 2018-November 2018, February 2019-June 2019 and June 2020-August 2020. Twenty five participants were recruited for the intervention group (8 were removed due to non-adherence, two were removed due to injury or sickness not related to the study, one was removed due to injury related to the study). Ten participants were recruited for the control group (one was removed due to non-adherence).

The analysis group consisted of 23 adults (8 Male, 15 Female) (14 intervention group, 9 control group). Participants ranged from 19-60 years of age, with a mean age of 29 ±12 years. Means of the anthropomorphic measures for males and females were respectively; height (180 ±3cm) (164 ±5cm), mass (93 ±18kg) (71 ±15kg) and BMI (29 ±7) (27 ±6). The participants had a range of prior trampolining. Some having no experience at all on a trampoline, to the most experienced participant having competed for four years in gymnastic trampolining. None of the participants had regularly bounced on a trampoline in the prior five years to beginning the study. Exclusion criteria were health risks that contraindicate exercise testing (American College of Sport Medicine, 2013), diseases that are associated with loss of balance, as well as the presence of infections, injuries or an existing drug treatment that could potentially limit physical performance. Participants who passed the screening were given detailed information about the study's aim and protocol and gave written consent before participation. This study was approved by the ethics committee of the University of Canterbury (HEC 2018/22) and was registered with the Australia, New Zealand Clinical Trials Registry (26/11/2019), registration number: ACTRN12619001646134. All procedures were performed in accordance with the relevant guidelines and regulations.

7.3.6 Statistical Analysis

Statistical analysis was performed using SPSS Statistics for Windows (Version 24, IBM Corp, Armonk, NY, USA). Datasets were first assessed for normality using a Shapiro-Wilks test. All variables were found to follow a normal distribution, therefore multivariate normality was assumed. Two, separate, one way, repeated measures MANOVAs were then used to assess whether differences existed between the means, for each of the variables, for both the intervention and control group ($p \leq 0.05$). Differences were found between the variables for the intervention group, but not the control group. Due to finding no differences, analysis wasn't continued for the control group.

For the intervention group, a series of repeated measures ANOVAs were used to identify whether differences existed between the time points for each of the variables. The data set for vertical jump failed Mauchly's Test of Sphericity, therefore a repeated measures ANOVA with a Greenhouse-Geisser correction was used for this dataset. Partial eta squared was used to interpret the effect size for all variables. Post hoc tests using the Bonferroni correction were then used to identify where these changes occurred, for each of the variables.

Finally, independent samples t-tests were used to compare means, between the intervention and control group, for vertical jump and relative $\dot{V}O_{2\max}$, for each of the time points. To investigate whether either group began with a higher base fitness.

7.4 Results

Two, one way repeated measures MANOVAs were used to assess whether differences existed between the means for mass, muscle mass, fat mass, blood pressure, blood cholesterol, relative $\dot{V}O_{2\max}$ and vertical jump for both the intervention and control group. A difference was found between the time points for the intervention group ($F_{12,18}$ =2.767, p =0.038), but not for the control group ($F_{14,16}$=0.654, p =0.794).

Descriptive statistics for the control and intervention can be seen in Table 7.1.

Table 7.1 *Means ± SD of the variables for the control and intervention groups. "*" indicate significant change occurred within the intervention group.*

	Control Pre	**Control Post**	**Intervention Pre**	**Intervention Post**
Mass (Kg)	79 ±18.2	79.4 ±19.3	78.6 ±20.0	78.6 ±20.1
Muscle Mass (Kg)	31 ±7.6	31.6 ±7.7	30.5 ±8.0	30.5 ±8.0
Fat Mass (Kg)	24 ±13.8	23.5 ±12.7	24.1 ±12.8	24.3 ±12.7
Systolic Blood Pressure (Mmhg)	123 ±13	119 ±10	119 ±14	114 ±14
Diastolic Blood Pressure (Mmhg)	76 ±9	74 ±6	74 ±7	73 ±8
Blood Cholesterol (Mmol/L)	4.5 ±0.5	5.5 ±1.5	5.0 ±1.3	5.7 ±1.7
Relative $\dot{\mathbf{V}}\mathbf{O_2}$ (ML/Min/Kg)	44 ±8.5	40.8 ±7.2	40.2 ±8.4	42.6 ±9.9
Vertical Jump (Cm)	41 ±9	43 ±10	32 ±9	36 ±9*
Average physical activity/week (hours)	5.1 ±2.6	5.1 ±2.6	3.4 ±2.6	3.4 ±2.6

A series of one-way repeated measures ANOVAs were then used to identify which of the measured variables had changed for the intervention group. A difference was found for blood cholesterol ($F_{2,26}$ = 7.358, p = 0.003, η_p^2 = 0.4), relative $\dot{V}O_{2\max}$ ($F_{2,26}$ = 4.185, p = 0.027, η_p^2 = 0.2), vertical jump ($F_{2,26}$ = 10.547, p = 0.003, η_p^2 = 0.4), total bounce height ($F_{2,26}$ = 4.956, p = 0.015, η_p^2 = 0.3), time to completion ($F_{2,26}$ = 20.779, p < 0.0005, η_p^2 = 0.6) and caloric expenditure ($F_{2,26}$ = 4.956, p = 0.015, η_p^2 = 0.3).

Post hoc tests found that blood cholesterol increased Week 0-4 (p = 0.001). No change occurred Week 4-8 (p = 0.403). Overall, no change occurred Week 0-8 (p = 0.255).

Relative $\dot{V}O_{2\max}$increased Week 0-4 (p = 0.04). No change occurred Week 4-8 (p = 0.481). Overall, no change occurred Week 0-8 (p = 0.502).

For vertical jump, no change occurred Week 0-4 ($p = 0.213$). An increase occurred Week 4-8 ($p = 0.002$). Overall, an increase occurred Week 0-8 ($p = 0.005$).

Total bounce height increased Week 0-4 ($p = 0.04$). No change occurred Week 4-8 ($p = 0.114$). Overall, an increase occurred Week 0-8 ($p = 0.04$).

For time to completion no change occurred Week 0-4 ($p = 0.035$). An increase occurred Week 4-8 ($p = 0.001$). Overall, an increase occurred Week 0-8 ($p = 0.035$).

Caloric expenditure increased Week 0-4 ($p = 0.04$). No change occurred Week 4-8 ($p = 0.114$). Overall, an increase occurred Week 0-8 ($p = 0.04$).

Descriptive statistics for the variables of the intervention group can be seen in Table 7.2.

Table 7.2 Means ±SD of the variables for the intervention group. "*" indicates a change occurred within the intervention group.

	WEEK 0	WEEK 4	WEEK 8
Mass (Kg)	78.6 ±20.0	78.7 ±20.9	78.6 ±20.1
Muscle Mass (Kg)	30.5 ±8.0	30.2 ±8.8	30.5 ±8.0
Fat Mass (Kg)	24.1 ±12.8	25.1 ±14.1	24.3 ±12.7
Systolic Blood Pressure (Mmhg)	119 ±14	119±15	114 ±14
Diastolic Blood Pressure (Mmhg)	74 ±7	75 ±9	73 ±8
Blood Cholesterol (Mmol/L)	5.0 ±1.3	6.2 ±1.4*	5.7 ±1.7
Relative $\dot{\mathbf{V}}\mathbf{O}_2$ (Ml/Min/Kg)	40.2 ±8.4	44.1 ±7.4*	42.6 ±9.9
Vertical Jump (Cm)	32 ±9	34 ±9	36 ±9*
Total Jump Height (M)	46 ±20.7	61.6 ±24.7*	69 ±25.7
Time To Completion (S)	110 ±9	116 ±10*	119 ±11*
Caloric Expenditure (Kcal)	34 ±27	45 ±43*	50 ±48

Finally, independent samples t-tests were used to compare the means for vertical jump and relative $\dot{V}O_{2\max}$ between the intervention and control group for each of the time points. This used was to confirm that both the intervention and control group began with a similar baseline fitness. No differences were found for either variable for any of the time points ($p > 0.05$).

7.5 Discussion

The aim of this study was to investigate whether a high intensity, short duration exercise protocol, on a trampoline, would improve markers related to health, across an 8-week intervention. Omnibus tests indicated change had occurred for the intervention group, but not for the control group (see Table 7.1). Further analysis for the intervention group found that the change had occurred for blood cholesterol, relative $\dot{V}O_{2\max}$, vertical jump, total bounce height, time to completion and caloric expenditure.

No change occurred for mass, muscle mass, fat mass or blood pressure for either group (see Table 7.1). This suggests that this intervention had little to no effect on these attributes, for the considered time frame, and therefore is likely not a viable modality for affecting change related to these markers.

The intervention group did see an increase to the total blood cholesterol Week 0-4. Exercise may affect blood cholesterol by increasing the concentration of high-density lipoprotein (HDL) (Tambalis et al., 2009). Increasing the concentration of HDL relative to low-density lipoprotein (LDL) is considered to be a positive change (Hooper et al., 2001). It is also well known that high total blood cholesterol is a risk factor for heart disease (Kannel et al., 1971). The measuring equipment used in this study was unable to discern between HDL and LDL concentration. Therefore, it cannot be concluded whether this change in total blood cholesterol was positive or negative. Future research, using more sensitive testing equipment, is necessary to ascertain the nature of this change.

This research found that relative $\dot{V}O_{2\max}$ increased Week 0-4, then no change occurred Week 4-8 for the intervention group. With overall, (Week 0-8) no change occurring. The authors' hypothesis for this phenomenon is that the participants tried significantly harder during the $\dot{V}O_{2\max}$ in the Week 0 and Week 4 testing days. This theory is supported by two different results. First, the control group saw a negative change in their $\dot{V}O_{2\max}$. The control group's Week 0 $\dot{V}O_{2\max}$was 44 ±8.5 which then decreased to 40.9 ±9.4 in Week 4 and decreased again to 40.8 ±7.2 in Week 8. Whereas, the intervention group improved from their Week 0 result. Second, manual inspection of the graphs from the output of the $\dot{V}O_{2\max}$ tests, showed no plateauing of the gradient of the graph, for five of the participants (3 intervention, 2 control). This indicates that these participants did not reach their $\dot{V}O_{2\max}$ during the final testing day (Week 8). The protocol used in this study was athlete-led. With the participant instructed to cease the test at the point where they felt like they could no longer continue. Max effort cardiovascular tests are inherently difficult. Requiring pushing to a level of fatigue that most participants find unpleasant. It is likely that participants were unwilling to exert themselves as strongly in the latter testing days, therefore lowering their results. Pushing to extreme fatigue is likely to injure the participant. Further research should consider this phenomenon and be prepared to control for it.

These results indicate that cardiovascular fitness may be improved above the baseline level with a low exercise dosage on a trampoline. The current guidelines for physical activity recommend either 2.5 hours of moderate or 1.25 hours of vigorous exercise per week to maintain good health (McIntyre, 2015). The protocol used in this study equated to approximately 6-8 minutes of vigorous exercise per week. This means that just 10% of the recommended dosage caused an improvement to the participant's fitness. This indicates that a HISD protocol on a trampoline could be a relevant exercise modality for those with limited time availability for exercise. Further research with a larger sample size is necessary to validate this finding.

A draw-back of traditional HIIT is it requires an intensive warm-up protocol to allow maximum effort exertion, as high exertion from a resting state dramatically increases the chance of injury (Shellock & Prentice, 1985). Warm ups associated with HIIT are often similar in length to the exercise protocol (10 minutes warming up vs 16 minutes of HIIT) (Foster et al., 2015). Traditional warm up times for vigorous exercise can be anywhere from 5-30 minutes long (McGowan et al., 2015). For this study the protocol utilised a warm-up consisting of 10 bounces on the trampoline, at a moderate intensity, selected by the participant. This took approximately 10 seconds to complete and, therefore, did not add a significant amount of time to the protocol. This suggests that a HISD exercise protocol on a trampoline may be an even more time efficient exercise modality than traditional forms of HIIT. Of note is that one participant dropped out this study, due to an injury sustained during the study, so further investigation is necessary to validate the use of such a short duration warm up.

Two studies were found investigating trampolining's effect on vertical jump. Both reported trampolining improved vertical jump (Atilgan, 2013; Ross & Hudson, 1997). The authors of these studies hypothesised that the increased vertical jump was due to an improvement to the participant's jumping technique, specifically to their co-ordination (the timing of the contraction of the participant's muscles during their jump). This study also found an improvement to the participant's vertical jump height. This suggests that trampolining is a viable modality for improving the technique of a vertical jump. This may also lead to an improvement to the user's vertical jump height.

Of note is that the participant's trampolining ability increased dramatically during the intervention. Improvement to trampolining ability can be measured by an increase to the participant's total bounce height. Improving total bounce height will also increase time spent in the air and caloric expenditure. The average Week 0 total bounce height was 46 meters which, by Week 8, had increased to 69 meters. This meant that the amount of work done, during each session, increased across the intervention. Exercise has a dose-response relationship (Iwasaki et al., 2003). This means that as work increases, the response to exercise increases proportionately. Across the intervention, the average total bounce height of the participants increased by 50%. Therefore, their work output became greater towards the end of the intervention. This indicates that the participants experienced a significant learning effect across the intervention. Such a dramatic improvement in ability is unlikely to occur during a study using more traditional exercise modalities (such as running or biking). This is because the participant is likely to have a higher previous experience level with the more common exercise modalities. By increasing the length of the intervention, the learning effect of a novel exercise will be minimized. Further research should consider using longer intervention lengths to mitigate how the learning effect affects outcomes on a trampoline.

7.6 Conclusion

Low time availability is commonly listed as the primary barrier to exercise. Creating a time efficient exercise routine may benefit those who struggle to find enough time to participate in regular physical activity. This study found that completing a HISD routine on a trampoline, for just 10 minutes total per week, increased cardiovascular function and vertical jump. This suggests that trampolining may be a viable exercise modality to promote physical activity amongst members of the general populace with limited time availability.

8 Study 5: The Effect of Trampolining on Body Composition, Cardiovascular Fitness, Bone Density and Stress Urinary Incontinence.

8.1 Project Background

The final project for this thesis was ambitious. It was suggested, during the meetings for the direction of the final project, that trampolining may also have health benefits for women who have given birth. This was based on anecdotal evidence from one of the sponsors of the study, whose wife had found trampolining beneficial. A literature review was conducted to assess the validity of the hypothesis. A mechanism was found that supported that trampolining could have benefit to women suffering from stress urinary incontinence. A local gynaecologist was consulted to assess the safety of the protocol. Following his input and approval, the project was initiated. Prior to this project, the research team had consisted of just Tāne Clement, Nick Draper and Keith Alexander. This project required the collaborated effort of the research team, two research assistants and two women's health physiotherapists. The following is the summary of almost three years of collaborated effort.

8.2 Introduction

Urinary Incontinence is defined by the International Incontinence Society as any involuntary loss of bladder control (Haylen et al., 2010). A complication of childbirth is a weakening of the perineum and pelvic floor, which may lead to urinary and faecal incontinence, pelvic organ prolapse, sensory and emptying abnormalities of the lower urinary tract, defecation dysfunction, sexual dysfunction and chronic pain syndromes (Bump & Norton, 1998). Approximately 50% of women lose some pelvic floor function following childbirth (Swift, 2000). With urinary incontinence (UI) being the most common symptom of pelvic floor dysfunction (Milsom & Gyhagen, 2019).

Urinary Incontinence is often classed into one of four categories depending on the mechanism by which it occurs; stress incontinence, urge incontinence, mixed incontinence and continuous incontinence (Haylen et al., 2010). This review focuses on the management of stress incontinence.

Stress urinary incontinence (SUI) is the involuntary loss of urine on effort or physical exertion, including from sneezing or coughing (Haylen et al., 2010). SUI is a serious medical condition that can cause urinary tract infections, pressure ulcers and perineal dermatoses (Resnick et al., 1989). SUI may also cause withdrawal from exercise and is a barrier to participation in regular physical activities (Bø, 2004). Finally, SUI presents an undeniable social problem that creates embarrassment and negative self-perception (Hunskaar & Vinsnes, 1991; Johnson et al., 1998). Prevalence rates for SUI, amongst women, range from 25-45% (Milsom & Gyhagen, 2019). Two broad pathophysiological mechanisms are proposed; urethral hypermobility (weakness in the supporting mechanism of the urethra) and intrinsic sphincter deficiency (defective urethral sphincter mechanism) (Downey & Inman, 2019). Conservative treatment for SUI may include weight reduction, pelvic floor muscle training and biofeedback (Dumoulin & Hay-Smith, 2008; Wing et al., 2010).

Pelvic floor muscle training (PFMT) has been verified as the gold standard conservative treatment for SUI (Dumoulin & Hay-Smith, 2008; Hay-Smith et al., 2011; Mørkved & Bø, 2014). While it maintains its status as the gold standard treatment, two main critiques exist for PFMT. Firstly that, for best results, it requires regular clinician supervision (Dumoulin & Hay-Smith, 2008; Hay-Smith et al., 2011). Secondly, that long term adherence to a PMFT programme is low, with dropout rates having been reported between 30-90% (Bø & Hilde, 2013; Bø et al., 2005). Therefore, a demand exists for a treatment that could address these two concerns.

It has been shown that general exercise has a positive effect on SUI, due to contraction of the abdomen causing co-contraction of the pelvic floor musculature (Bø, 2004;

Kikuchi et al., 2007). Thereby, improving pelvic floor muscle strength and reducing rates of incontinence. It is also known that exceeding the point where the participant can remain continent will worsen the symptoms of SUI (Bø, 2004; Eliasson et al., 2002; Orr et al., 2001).

Theoretically then, any form of exercise that causes contraction of the abdomen could have a beneficial effect toward the treatment of SUI. This concept has been explored with the Paula Method (Liebergall-Wischnitzer et al., 2005) and Pilates (Savage, 2005). Cross-sectional studies investigating the effect of activity rate on UI, have also found that physically active women have lower rates of UI (Hannestad et al., 2003; Kikuchi et al., 2007).

Previous research involving trampolining and UI has shown that competitive trampolining increases the risk of UI, due to the large forces that the high bouncing exerts on the pelvic floor musculature (Eliasson et al., 2008; Eliasson et al., 2002). This is in line with other literature that suggests that, exercise that exceeds the intensity where the participant can remain continent, will worsen the symptoms of UI. To date, no literature has investigated how low intensity trampolining affects UI. All of these findings suggest that an optimal exercise intensity exists for general pelvic floor training. The authors propose that this intensity, for trampolining, is the maximum height a participant can maintain while remaining continent.

Osteoporosis is a common disease amongst the aging populace, which increases risk of serious injury, due to its association with low energy trauma and fragility fractures (Marques et al., 2012). It has been estimated that over 200 million people worldwide suffer from osteoporosis (Cooper, 1999). With 85,000 cases of osteoporosis related fracture being reported in New Zealand in 2011 (Brown et al., 2011). Postmenopausal women are at particular risk due to perimenopause being associated with elevated bone reabsorption rates and lowered bone mineral density (BMD) (Ebeling et al., 1996). This results in women older than 50 having a osteoporotic fracture chance greater than 40%

(Bessette et al., 2008). With osteoporotic related injuries estimated to cost $330 million per year in New Zealand alone (Brown et al., 2011).

The probability of fracture can be estimated by risk factor assessment (Bonaiuti et al., 2002). Low bone mass is one of the most important risk factors, usually assessed by measuring BMD (Bonaiuti et al., 2002). BMD, measured by dual X-ray absorptiometry (DXA), is reported to account for 60% to 70% of the variation in bone strength (Ammann & Rizzoli, 2003). With life time risk of osteoporotic fracture increasing 150-300% with each standard deviation decrease in BMD (Cummings et al., 1993). Therefore, interventions which improve BMD are critical for the prevention of osteoporotic fractures (Marques et al., 2012).

Weight bearing activity is defined as force generating exercises that place higher mechanical stress on the human skeleton than daily living (Behringer et al., 2014). Weight bearing activity has been shown to improve BMD amongst a variety of age ranges (Behringer et al., 2014; Bolam et al., 2013; Marques et al., 2012). Trampolining is an example of a weight bearing exercise, with the forces experienced during trampolining being reported as high as 13x body weight (Farquharson, 2012). Retroactive comparison of the BMD of competitive trampolinists has been investigated and they were found to have significantly greater BMD than a control group (Burt et al., 2016). Other studies have compared bouncing on rebounders to similar exercise on a non-compliant surface and found similar improvement to bone density between the two modalities (Bunyaratavej, 2015). Studies conducted on adolescent children have found that a low dose jumping protocol (on a non-compliant surface) can significantly improve BMD amongst adolescent children (Fuchs et al., 2001; Johannsen et al., 2003). Suggesting that, even very short exercise protocols can be of benefit for the improvement of BMD. Currently, to the best of the author's knowledge, no studies exist directly investigating the efficacy of a trampolining intervention on BMD.

A summary of the research, that currently exists, surrounding UI and BMD suggests that a demand exists for the treatment of UI and low BMD using an exercise modality that is both efficacious and enjoyable. It also suggests that trampolining could be a viable option. The authors propose that a hypothetical mechanism exists by which trampolining could positively benefit the treatment of UI and BMD. Therefore, the efficacy of this treatment should be explored.

The summary of all this is that a mechanism exists that suggests that trampolining could be a viable exercise modality for the treatment of SUI and osteoporosis amongst parous women. Therefore, the aim of this study was to investigate whether trampolining could be an efficacious treatment for the improvement of body composition, cardiovascular fitness, bone density and SUI amongst parous woman.

8.2.1 Hypothesis

- A 12 week intervention on a trampoline will improve the cardiovascular fitness, bone density, pelvic floor strength and decrease the severity of stress urinary incontinence amongst the participants.

8.2.2 Strengths of the Study

- This is the first study investigating whether trampolining is a viable method for the improvement of stress urinary incontinence and bone density.
- The study utilised TGOMA software for the collection of bounce height during the trampolining bouts, which meant that the data for every bouncing session could be reasonably collected.

8.2.3 Assumptions

- Energy lost to the trampoline will be similar for similar masses.

8.2.4 Limitations

- Participants were instructed to bounce "as high as possible, while remaining continent". Other than this cue, the intensity of the intervention was self-directed.
- The assessment method for cardiovascular output was also self-directed.
- Diet was not controlled in this study.
- Sitting time wasn't controlled in this study.
- Drug use was not controlled in this study.

8.3 Methods

8.3.1 Testing Procedure

After agreeing to participate in the trial, the participants were invited to St George's Hospital (Christchurch, New Zealand). All procedures were performed on site at the hospital. For all groups, on the initial testing day, the participants were given multiple questionnaires to complete these included; a pre-screening medical questionnaire, a questionnaire for assessing the activity level of the participant (The International Physical Activity questionnaire (Craig et al., 2003)) and two questionnaires for assessing the severity of the participant's urinary incontinence (The Questionnaire for female Urinary Incontinence Diagnosis, (QUID) (Gunthorpe et al., 2000) and The International Consultation on Incontinence Questionnaire, (ICIQ) (Shumaker et al., 1994)). ICIQ is used to assess the severity of UI. All instructions are provided on the handout. The questionnaire is composed of four questions, which provide a score between 0-21. Zero would be considered having no symptoms of UI, 21 would be considered having extremely severe symptoms. QUID is used as a proxy measure for the diagnosis of UI. All instructions are provided on the handout. It is composed of six questions, which provide a 0-30 score. Zero is considered as having no symptoms of UI, 30 would be considered as having extremely severe symptoms.

After the questionnaires were complete, the participant then began the Rockport Walk Test (Fenstermaker et al., 1992) to assess their maximal aerobic capacity. The Rockport Walk Test is a submaximal test, used for the estimation of $\dot{V}O_{2max}$ based on the time it takes the participant to walk a mile (1.6km) and their heart rate upon completion. All tests were conducted in a loop around St George's Hospital (Christchurch, New Zealand). Prior to the session, the participant was briefed on the protocol. This included the procedure for the test, directions for the loop and strongly emphasised that the participant could stop at any stage, for any reason. After a warm-up, the participant was instructed to rest until they felt prepared to begin the test. The participant was then instructed to begin. Upon completion of the loop the participant's time and heart rate were recorded. These values were then input into a Rockport Walk Test calculator to find an estimate of the participant's $\dot{V}O_{2max}$. At the completion of the aerobic assessment, a fifteen minute cooldown period was utilised.

The participant then completed a pelvic floor examination. All the pelvic floor examinations were completed by a registered women's health physiotherapist. This examination was comprehensive and assessed overall health of the pelvic floor as well as assessing pelvic floor strength with digital palpitation and an intravaginal pressure device (Femfit, JUNOFEM, New Zealand). Digital palpitation involves the physiotherapist inserting a digit into the participant's vagina. Then asking the participant to contract their pelvic floor as hard as possible and to maintain that contraction. The physiotherapist then assesses the strength of the contraction in four quadrants (anterior, left, right, posterior) and rates the contraction on a scale of 0-5. With zero being no contraction at all and five being an exceptionally strong contraction. The scores for each quadrant are then averaged to provide a total score.

The perineometric assessment was conducted using a FemFit (Femfit, Junofem, Auckland, NZ). A FemFit is a rod-like device which has eight pressure sensors spaced along its length. These sensors assess the pressure change during the contraction for that section of the vagina. The Femfit is inserted into the participants vagina. The participant is then shown the associated FemFit application. This application gives cueing for when the participant should contract their pelvic floor. The procedure used for this study is known as a squeeze and hold. The participant is instructed to contract their pelvic floor maximally and hold the contraction for five seconds, then relax. This is repeated five times. The peak contraction during the testing instance was reported.

Finally, the participant completed a DXA scan (Lunar Prodigy, GE Healthcare, Chicago, US) to assess bone mineral density and body composition. All DXA scans were completed at St George's Hospital. The participant was instructed to change into a provided gown and remove any metal objects on their person. The DEXA technologist then talked the participant through the process. The participant was instructed to lay on the machine table and to remain as still as possible. The scan took approximately 15 minutes.

This completed the testing session. The intervention group completed the first testing session. Then, completed the study protocol for 12 weeks. They were then reassessed with another testing session at 12 weeks. The control-intervention group completed their first testing session at 0 weeks, then were instructed to go about their normal life for 12 weeks. They were reassessed at 12 weeks with another testing session. The control-intervention group then completed the intervention for 12 weeks. Finally they completed a third testing session at 24 weeks.

8.3.2 Intervention

Prior to the participant beginning the intervention, a Springfree trampoline (O77, Springfree, Christchurch, New Zealand) was delivered to and assembled at the participant's home. After delivery, the research assistant in charge of data collection met with the participant at the participant's home. The protocol was explained a final time to the participant. The participant was then instructed to begin their first bouncing session, while supervised by the research assistant. The participant was instructed to complete 100 bounces at the highest intensity, which allowed the participant to remain continent. Number of jumps, total bounce height and time to completion were recorded using TGOMA software (Freebounce, Springfree, Christchurch, New Zealand). The participant was instructed to repeat this protocol five times per week for the duration of the 12 week intervention and record their results (number of jumps, total bounce height and time to completion). This data was then sent to the research team.

8.3.3 Participants

This study utilised both an intervention and control group. The intervention group completed two testing days and a randomised crossover design. Twenty-two women who had given birth at least once and who had some symptoms of SUI were recruited for the study (three were excluded for non-adherence). Participants were randomly assigned to either the intervention or control group. The analysis group consisted of 19 adults (10 intervention, 9 control). Participants ranged from 31-44 years of age, with a mean age of 37 ±3 years. Means of the anthropomorphic measures were; height (166 ±7cm) and mass (69 ±10kg).

Data collection for the study was completed from December 2020 to December 2021. Exclusion criteria for the study were health risks that contraindicate exercise testing (American College of Sport Medicine, 2013), diseases that are associated with a loss of balance, the presence of infections, injuries or an existing drug treatment that could potentially limit physical performance, obesity (BMI 40+), having given birth via caesarean section, symptoms of prolapse or being less than 3-months post birth.

Participants who passed the screening were given detailed information about the study's aim and protocol and gave written consent before participation. This study was approved by the New Zealand Health and Disability Ethics Committee (19/NTA/187). This trial was registered with the Australia, New Zealand Clinical Trials Registry (13/12/2019), registration number: ACTRN12619001770156. All procedures were performed in accordance with the relevant guidelines and regulations.

8.3.4 Statistical Analysis

Statistical analysis was performed using SPSS Statistics for Windows (Version 24, IBM Corp, Armonk, NY, USA). Datasets were first assessed for normality using a Shapiro-Wilks test. All variables were found to follow a normal distribution, therefore multivariate normality was assumed. A one way repeated measures MANOVA was used to assess whether differences existed between the means for; $\dot{V}O_{2\max}$, bone density, QUID, ICIQ, palpation and average bounce height. No difference was found (p = 0.079). So, a second one way repeated measures MANOVA was used to assess whether differences existed between the means for just QUID, ICIQ, palpation and average bounce height. A difference was found between the variables for the intervention group (p = 0.036), but not the control group (p = 0.168). Due to finding no differences analysis wasn't continued for the control group.

For the intervention group, a series of paired samples t-tests were used to identify where the differences had occurred for $\dot{V}O_{2\max}$, bone density, QUID, ICIQ, palpation and average bounce height. Cohen's D was used to interpret the effect size for all variables.

8.4 Results

Descriptive statistics for the control and intervention can be seen in Table 8.1.

Table 8.1 *Means ±SD of the variables for the control and intervention groups. "*" indicates a change occurred within the intervention group.*

	Control Pre	Control Post	Intervention Pre	Intervention Post
Mass (kg)	68.9 ±9.5	69.6 ±10.8	66.2 ±9.7	66.2 ±10.6
Body Fat (kg)	33.6 ±10.2	33.5 ±10.2	34.9 ± 8.6	34.5 ±8.6
Muscle Mass (kg)	43.2 ±4	43.6 ±4.5	40.8 ±5.0	41 ±5.2
BMD (g/cm3)	1.22 ±0.08	1.22 ±0.08	1.17 ±0.1	1.17 ±0.1
$\dot{V}O_{2\max}$ (mL/min)	37.6 ±5.5	38.1 ±5.8	36.6 ±5.4	37.6 ±5.6

QUID (0-30)	10.6 ±5.4	9.4 ±4.9	9.5 ±4.9	8 ±4.9*
ICIQ (0-21)	8.8 ±4.1	6.6 ±4.3	8.3 ±3.5	6.2 ±2.8*
Palp (0-20)	2.1 ±0.9	2.3 ±0.9	2.1 ±0.8	2.4 ±0.9*
Bounce Height (m)			20.2 ±9.6	26 ±10.6*
Weekly Activity (METS/week)	2379 ±2814	1991 ±2740	2015 +3145	2572 ±4222

A one way repeated measures MANOVA was used to assess whether differences existed between the means, for QUID, ICIQ, palpation and average bounce height. A difference was found between the time points for the intervention group (p= 0.036), but not for the control group (p = 0.168).

A series of paired samples t-tests were then used to identify the differences and effect sizes for QUID, ICIQ, palpation and average bounce height for the intervention group. Results were as follows; QUID ($p = 0.023$, $\eta_p^2 = 0.2$), ICIQ ($p = 0.019$, $\eta_p^2 = 0.2$), palpation ($p = 0.001$, $\eta_p^2 = 0.4$) and average bounce height ($p = 0.012$, $\eta_p^2 = 0.4$).

8.5 Discussion

The aim of this study was to investigate whether trampolining could be an efficacious treatment for the improvement of body composition, cardiovascular fitness, bone density and SUI amongst parous woman. Omnibus tests indicated that change had occurred for the intervention group, but not for the control group (see Table 8.1). Post hoc analysis for the intervention group found that the change had occurred for the measures of severity of urinary incontinence (QUID and ICIQ), the measure of pelvic floor strength (palpation) and the average bounce height.

No change occurred for mass, muscle mass, fat mass, $\dot{V}O_{2\max}$ or bone density for either group. This suggests that this intervention had little to no effect on these attributes and is likely not a viable modality for affecting change related to these markers, for the considered time frame. A previous paper by the authors investigated whether a 100 bounce protocol on a trampoline would improve $\dot{V}O_{2\max}$ and found an improvement after 4 weeks (Clement et al, (2022) In press)). The similarity of the protocols led the authors to believe that $\dot{V}O_{2\max}$ would improve across this intervention. The participants of this study were instructed to bounce only as high as they could remain continent. This intensity, for a women with symptoms of SUI, is less than the maximal intensity that was used in the previous study. This can be seen in the differences in the average bounce heights. As the women with SUI improve and their symptoms decrease, they would be capable of greater bounce heights, which will likely lead to the same improvements seen in the previous research.

A goal of this research was to investigate whether trampolining could be an efficacious treatment for SUI amongst parous woman. For the treatment to be considered viable, it must improve the participant's quality of life. Prior research into stress urinary incontinence has indicated that improving the participant's pelvic floor strength has a strong correlation with improved quality of life outcomes related to SUI (Price et al., 2010). This study found an improvement to the pelvic floor strength of the participants as measured by digital palpation ($p = 0.001$, $\eta_p^2 = 0.4$). As well as an improvement to the quality of life scores; ICIQ ($p = 0.019$, $\eta_p^2 = 0.2$) and QUID ($p = 0.023$, $\eta_p^2 = 0.2$). This indicates that trampolining could be a viable treatment for SUI.

The current gold standard, conservative treatment for SUI is pelvic floor muscle training (PFMT). Using PFMT as the treatment of choice has two major drawbacks. The first is that, for optimal results, PFMT requires guidance by a medical professional (Dumoulin & Hay-Smith, 2008; Hay-Smith et al., 2011). Many women who show symptoms of SUI struggle to isolate the contraction of their pelvic floor. Therefore, they require instruction on how to isolate the contraction. This means, due to requiring medical supervision, PFMT has an initial cost which may make it unattractive. The second major drawback is a low adherence to PMFT programs in the long term (+6 months) (Bø & Hilde, 2013; Bø et al., 2005). Despite positive results, any exercise program that the participant cannot adhere to will, ultimately, provide no benefit. Therefore, there is a requirement for a pelvic floor strengthening program which the users find simple and easy to adhere to.

The above drawbacks were the inspiration for this investigation. The protocol used in this study was purposefully designed for time efficiency. With each individual session taking approximately ninety seconds from start to finish. This totalled less than ten minutes, per week, of total exercise time. This was to make adherence to the protocol as likely as possible, as the most common barrier to exercise is lack of time (Greaney et al., 2009).

The implementation of the intervention was also made as simple as possible. The purpose of the simplicity of the protocol, was to reduce the need for supervision by a medical professional. The participant was instructed to bounce on the trampoline for 100 bounces at the highest height possible, while remaining continent. This is a very important caveat. Prior research has indicated that trampolining negatively affects SUI. This study was conducted amongst competitive trampoline gymnasts who would regularly push past the point of incontinence, due to the requirements of the sport. Therefore, it was an important aspect of this study's design, that the participants never pushed to the point of incontinence. The authors' hypothesis was that, by remaining beneath the threshold of incontinence, the pelvic floor would be strengthened without exacerbation of the symptoms of SUI. This appears to have been confirmed by the findings of the study.

The average bounce height of the participants also increased across the intervention ($p = 0.012$, $\eta_p^2 = 0.4$). For this intervention, total bounce height is the main measure of intensity during the exercise bout. Exercise has a dose-response relationship (Iwasaki et al., 2003). This means that, as the work done increases, the response to exercise increases proportionately. Due to the design constraints of the study (requiring that the participants remain continent), intensity for the exercise sessions was low. This was expected, but the fact that the bounce height improved across the intervention indicates that the participants may continue to improve with prolonged adherence to the exercise program. The author's previous study (In press) found that $\dot{V}O_{2\mathrm{max}}$ and vertical jump height could be improved with a similar protocol (100 bounces, 4 times per week at maximum intensity). Therefore, it is likely that, as the participant's pelvic floor strength improved and their total bounce height increased, they would also see similar benefits.

This project was a pilot study to assess the validity of trampolining as a viable alternative treatment for SUI. The results so far have been very positive, but due to the small sample size, no strong conclusions can be drawn. Future research should focus on increasing the participant pool to see if the same conclusion is reached.

8.6 Conclusion

This study investigated whether trampolining could be an efficacious treatment for the improvement of body composition, cardiovascular fitness, bone density and SUI amongst parous woman. A change was found for the strength of the participant's pelvic floor, quality of life measures related to SUI and the average total bounce height of the participants. This indicates that the treatment may be viable. This treatment has the potential benefits (compared to the current gold standard treatment) of being low time commitment and easier to adhere too. Therefore, this indicates that, trampolining may be a viable alternative treatment for SUI. Further research, with larger sample sizes, are necessary to validate this finding.

9 General Discussion

9.1 Introduction

The goal of this series of studies was to expand the literature pool concerning trampolining's effect on human physiology. Each of the studies investigated a different aspect of concern, which then informed the goal of the next study. The purpose of this chapter is to gather the findings of each study in one place and to summarise them in a manner that is accessible, even without a deep understanding of the mechanics involved. The major findings of each study will first be summarised and then discussed. Then these findings will be further coalesced into the key findings. Finally directions for future research will be summarised.

9.2 Study 1

The aim of Study 1 (Chapter 4) was to produce a model which could calculate, in real time, the energy expenditure during a trampolining bout. First, a model was developed using drop tests on a Springfree trampoline. Then the human efficiency while jumping (e) was found by using breath by breath analysis of participants while bouncing on a trampoline.

The developed model can be seen below:

$$EE = (1 - C)\, W\, g\, (h + S)\, N/1000/e$$

Equation 9.1 *Formula for the calculation of energy expenditure while bouncing on a trampoline.*

The human efficiency was found to be 28 ±4%. Using this model the energy expenditure while trampolining can now be calculated, in real time, assuming that the trampoline coefficient (C), and the mass of the jumper are known. It was noted in this study that this equation does not account for movement completed while airborne, which became the aim for Study 3.

It was found that efficiency trended downwards as intensity increases. Efficiency decreasing, as intensity increases, is normal and has been shown with a wide variety of other exercise modes.

The development of this model is useful for trampolining gymnastics as it allows easy and accurate calculation of energy expenditure (EE) once flight time while bouncing is known.

9.3 Study 2

The aim of Study 2 (Chapter 5) was to validate the only previous study investigating EE while trampolining, using a larger sample size and more physiological measures. Three different intensities were compared (low, medium and high). It was found that at the low intensity, oxygen consumption and energy expenditure were similar between bouncing and running, whereas, blood lactate differed. At the medium intensity, oxygen consumption, energy expenditure and blood lactate were different between the modalities. At the high intensity, oxygen consumption values were similar, whereas, energy expenditure and blood lactate differed.

The previous study investigating trampolining, reported higher average values for oxygen consumption. This is likely because the previous study used a population of "young fit males". Despite this difference in oxygen consumption, the findings of Study 2 supported the statement "trampolining had a similar oxygen demand to treadmill running, at the same intensity".

A difference between trampolining and running does exist for anaerobic energy production. This is likely because trampolining requires a greater muscular effort to maintain a given intensity, when that intensity is measured by heart rate. This suggests that heart rate is not a complete measure of intensity for trampolining.

9.4 Study 3

The aim of Study 3 (Chapter 6) was to investigate how altering the bouncing type affected the energy expenditure of trampolining. Five different bouncing actions were compared conventional, lateral, star, 180° Rotations, tuck.

It was found that altering the bouncing action did increase the energy expenditure of trampolining. An update to the model developed in Study 1 was then produced to account for this difference.

$$EE = (1 - C)W\ g\ (h + S)N\ V/1000/e$$

Equation 9.2 *Updated formula for calculating energy expenditure while trampolining including conversion for different bounce types, where "V" is the variate coefficient found from this study.*

The rate of energy expenditure for exercise is often expressed in metabolic equivalent of task (MET). The highest MET value previously reported in the literature for trampolining was 6.9 METs. This study found a MET value of 11.3 while completing the tuck variate. This is a significantly higher value and further validates trampolining's efficacy as an exercise modality. It was also noted that none of the variates were completed at a maximum intensity, so higher MET values may be possible.

A bounce variate that wasn't investigated was rotations around the transverse plane and/or sagittal plane (flipping). Flipping requires a high degree of skill and muscle control. Therefore, flipping may also increase the MET value even higher. Due to the difficulty of flipping for long periods, investigation for this topic wasn't continued.

9.5 Study 4

The aim of Study 4 (Chapter 7) was to investigate whether a high intensity, short duration exercise protocol, on a trampoline, would improve markers related to health, across an 8-week intervention.

No change was found for mass, muscle mass, fat mass or blood pressure. Change was found for blood cholesterol, relative oxygen consumption and vertical jump.

Chronic elevated blood cholesterol increases the risk of heart disease. Cholesterol is composed of both high density lipoprotein (HDL) and low density lipoprotein (LDL). It is considered a positive change to increase the relative concentration of HDL to LDL. This study saw an increase to total blood cholesterol, but the testing equipment was unable to discern HDL vs LDL. Therefore, it cannot be concluded whether this change was positive or negative.

This study found that the intervention did increase the participant's fitness (oxygen consumption). It is important to note that this increase to fitness was achieved with less than 10 minutes total of exercise per week. Time availability is the most commonly listed barrier to exercise. Therefore this protocol may offer a viable alternative for those with limited free time.

This study also found that the intervention improved the participant's vertical jump height. Vertical jump height is a proxy measure of lower body power. Lower body power is valuable for sport performance. Previous studies investigating whether trampolining improves vertical jump height found that the improvement to the participant's jump height was due to improvement to the participant's technique. Therefore, it is likely that trampolining has benefit as a modality for improving vertical jump technique.

9.6 Study 5

The aim of Study 5 (Chapter 8) was to investigate whether trampolining could be an efficacious treatment for the improvement of body composition, cardiovascular fitness, bone density and SUI amongst parous woman. This study used a novel protocol of 100 bounces on a trampoline, x5/week, at the maximum intensity at which the participant can remain continent.

No change was found to body composition, cardiovascular fitness or bone density. This indicates that this protocol was not efficacious at improving these markers.

Change was found to pelvic floor strength, quality of life scores and the severeness of stress urinary incontinence. This finding indicates that trampolining is a viable alternative treatment for stress urinary incontinence. For people who suffer from stress urinary incontinence this protocol provides a treatment which they may enjoy more than the traditional conservative treatment of pelvic floor muscle training.

9.7 Key Conclusions

- A model has now been validated which can calculate bounce height on a trampoline with only the input of the participant's weight.
- Trampolining has been found to have a similar aerobic energy demand as running, when heart rate is matched, but differ for anaerobic energy production.
- Adding additional planes of movement to the bouncing action of trampolining will increase energy expenditure.
- A HISD protocol, on a trampoline, can improve the $\dot{V}O_{2\max}$ and vertical jump height of the user with as little as 10 minutes of exercise per week.
- Trampolining has potential as a viable treatment for SUI. It may improve pelvic floor strength and quality of life outcomes.

9.8 Future Directions

- Will reproducing any of these studies, with larger sample sizes, produce the same results?
- How does the difference in bouncing action between rebounders and trampolines affect the measured physiological outcomes?
- Was the change to total blood cholesterol found in Study 4 positive or negative?
- In a direct comparison between pelvic floor muscle training and a trampolining intervention, what will produce better outcomes for measures related to stress urinary incontinence?

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10 Appendix

For Study 4, it is mentioned in the discussion that the author hypothesised that the participants didn't try as hard in the cardiorespiratory assessment for the third testing bout. This hypothesis was based on a lack of plateauing of the gradient of the VO_2 graphs for these participants. The graphs of the 2nd testing bout and 3rd testing bout have been added to show this.

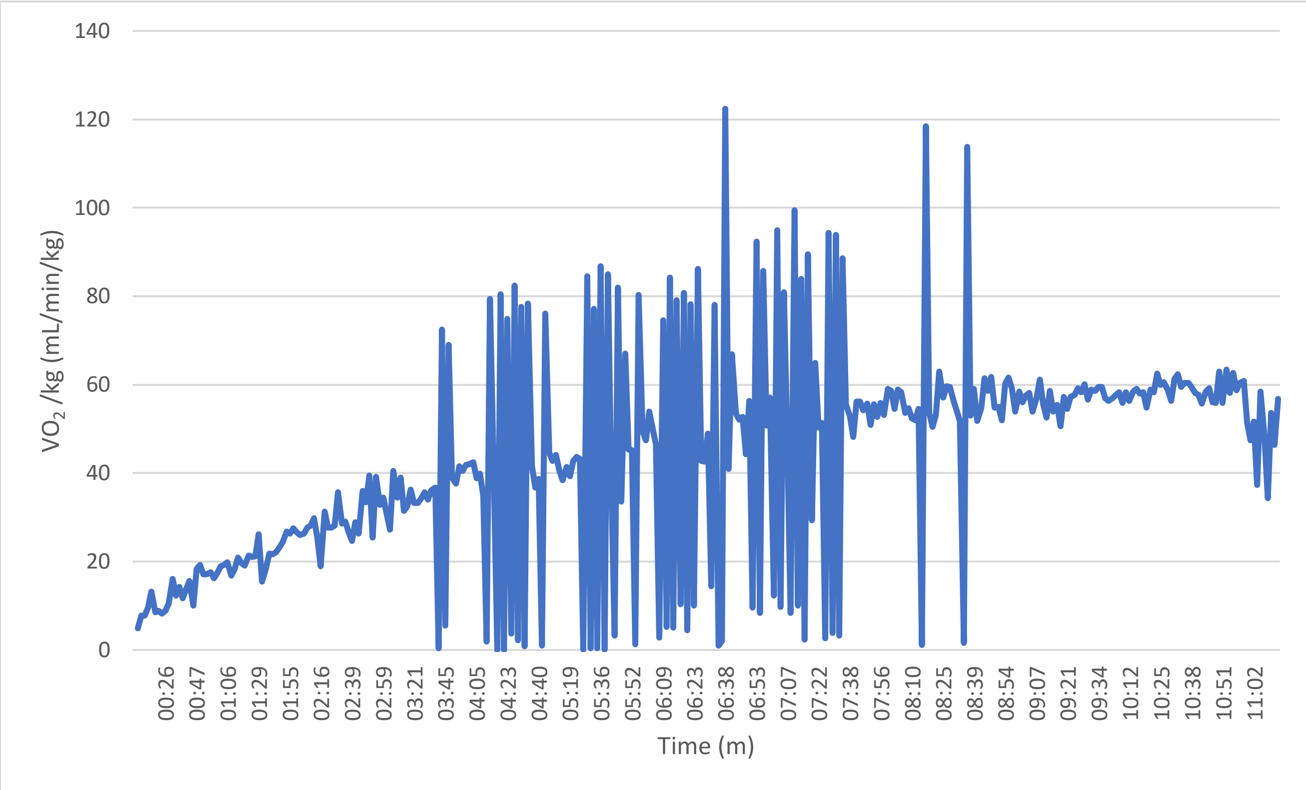

Figure 3: Participant 1, Week 4.

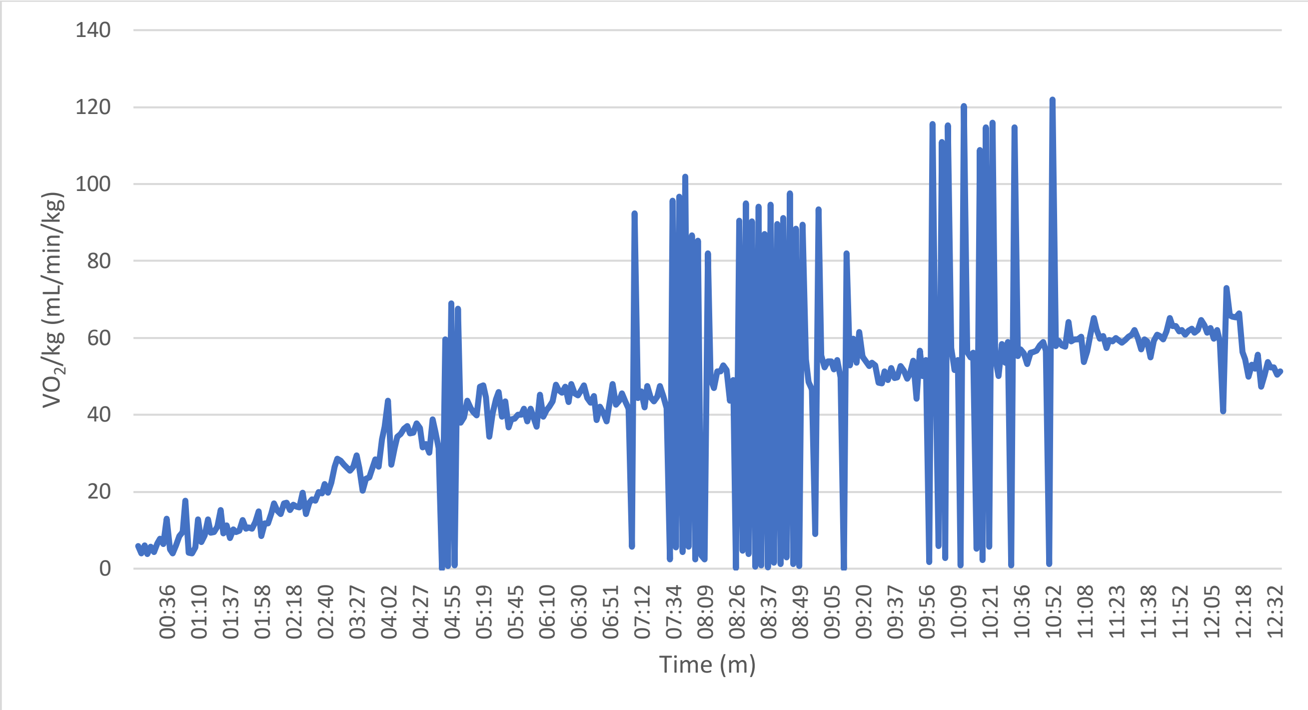

Figure 4: Participant 1, Week 8.

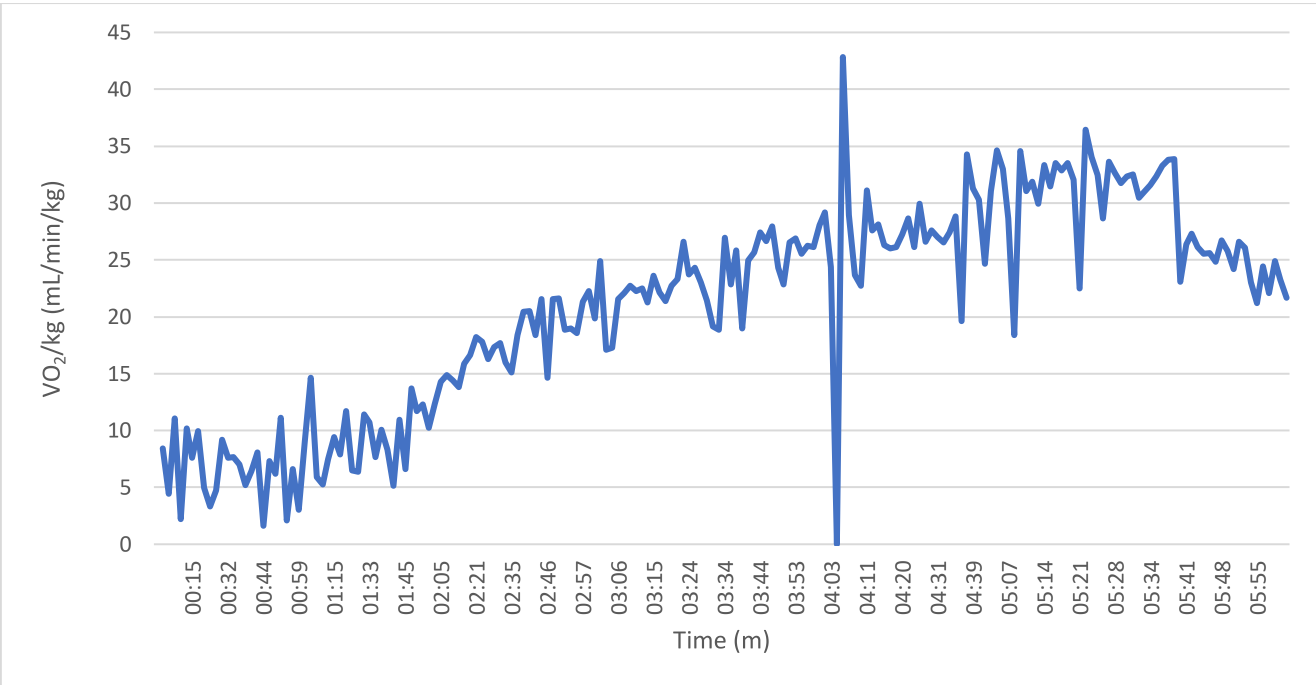

Figure 5: Participant 2, Week 4.

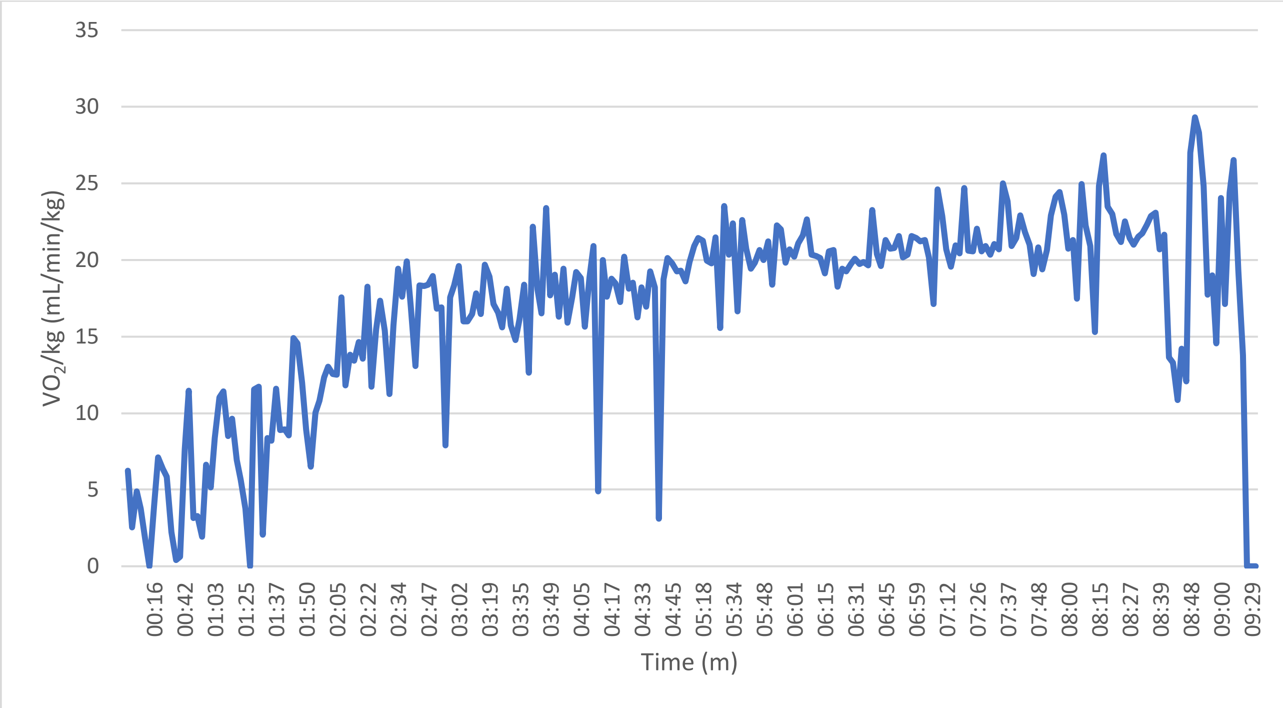

Figure 6: Participant 2, Week 8.

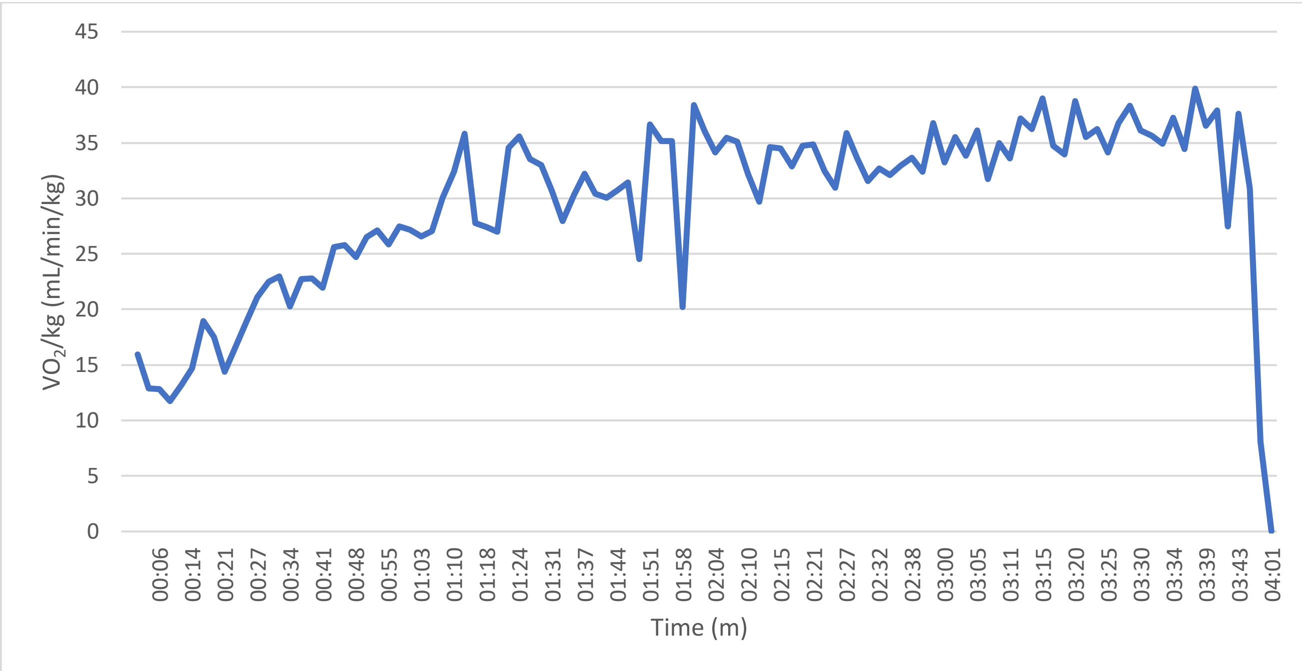

Figure 7: Participant 3, Week 4.

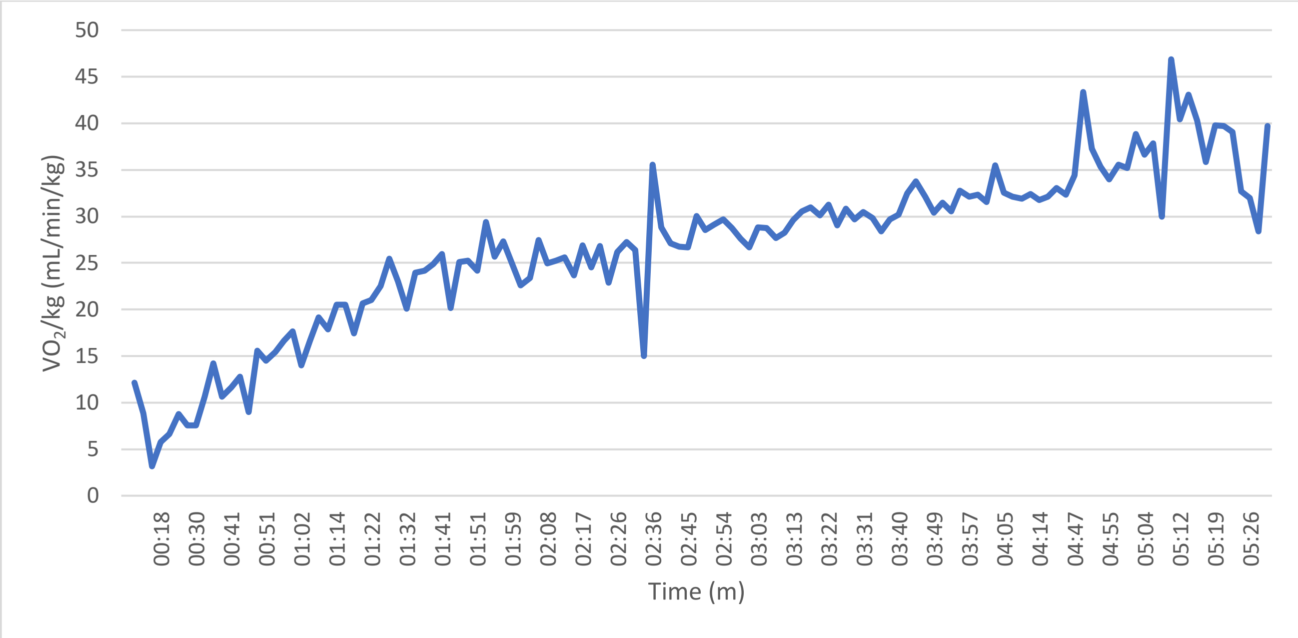

Figure 8: Participant 3, Week 8.