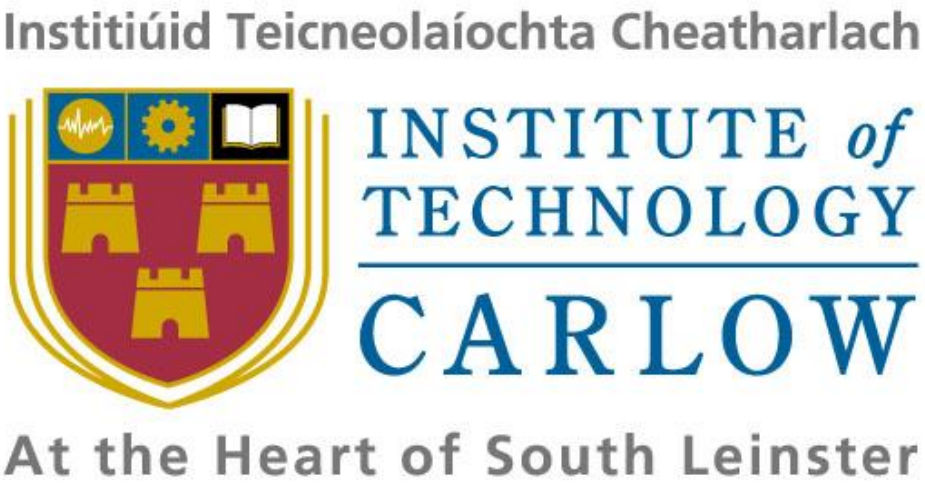

The Effects of Cows Milk, Goats Milk, Whey Protein and an Energy-Matched Carbohydrate Drink on Recovery from Repeated Sprinting and Jumping in Team Sport Athletes

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Submitted for the award of Master of Science from the Higher Education and Training Awards Council

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Submitted to the Institute of Technology, Carlow

TABLE OF CONTENTS

Acknowledgements

I would like to express my thanks and appreciation to the following people for their help, support and guidance throughout my entire college experience and the course of completing my dissertation.

Firstly, my utmost thanks to my supervisors, Paula Rankin and Paula Fitzpatrick for their continued support, guidance, reassurance and time devoted to me has been invaluable and is greatly appreciated.

A special thank you to the Irish Research Council for funding this project under the Employment Based Postgraduate Programme.

Also, on this note, a big thank you to my mentor Paul Smith whose company partnership gave me the opportunity to apply for this project.

A particular mention to all participants in this dissertation for their early starts, discipline and dedication to the study.

My thanks to my fellow postgraduate students in HealthCORE for their continuous motivation and reassurance over copious amounts of coffee throughout my masters.

Finally, a massive thank you to my family, for their continued support and patience throughout my entire education. I could not have completed this masters without my family.

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Table of Abbreviations

AMP	Adenosine Monophosphate
ATP	Adenosine Triphosphate
B	Baseline
BCAAs	Branched Chain Amino Acids
Ca	Calcium
CHO	Carbohydrate
CI	Confidence Intervals
cm	Centimetre
CMJ	Countermovement Jump
CPK	Creatine Phosphokinase
CK	Creatine Kinase
DALDA	Daily Analysis of Life Demands for Athletes
DJ	Drop Jump
DOMS	Delayed-Onset of Muscle Soreness
E-C	Excitation-Contraction
EIMD	Exercise Induced Muscle Damage
g	Gram
GI	Gastrointestinal
h	Hour
H^+	Hydrogen Ion
HR	Heart Rate
HR_{max}	Heart Rate Max
kCal	Kilocalorie
Km	Kilometre
L	Litre
LBM	Lean Body Mass
Mb	Myoglobin
m	Metre
mg	Milligram

min	Minutes
mL	Milllilitres
mmol	Millimol
MPB	Muscle Protein Breakdown
MPS	Muscle Protein Synthesis
MRI	Magnetic Resonance Imaging
ms	Millisecond
mTOR	Mechanistic Target of Rapamycin
MVIC	Maximal Voluntary Isometric Contraction
MVC	Maximal Voluntary Contraction
n	Sample Size
$Nm.s^{-1}$	Newton Metres per Second
º	Degrees
$°.s^{-1}$	Degrees per Second
$m.s^{-1}$	Metres per Second
PCr	Phosphocreatine
PLA	Placebo
PPO	Peak Power Output
RBE	Repeated Bout Effect
RFD	Rate of Force Development
ROM	Range of Motion
RSI	Reactive Strength Index
s	Second
SD	Standard Deviation
SEM	Standard Error of the Mean
Sp	Sprint
Ub-P	Ubiquitin-Proteasome Pathway
VAS	Visual Analogue Scale
VJ	Vertical Jump
WPH	Whey Protein Hydrolysate

List of Tables

List of Figures

Abstract

Introduction

Effective recovery following intense exercise is integral for any athlete to ensure subsequent performance is optimised (Kellmann, 2010). The aim of this investigation was to determine the effects of cows milk, goats milk and whey protein on recovery from repeated sprinting and jumping.

Methods

Thirty-two (*n*=32) team sport athletes (male *n*=16; female *n*=16), participated in an independent group investigation. Mean (± SD) height, body mass, and age for male participants were 181.5 ± 6.9 cm, 79.9 ± 10.7 kg, 22.8 ± 3.5 yr, respectively, and for females were 164.9 ± 5.6 cm, 62.0 ± 8.2 kg, 20.6 ± 1.7 yr, respectively. Participants were equally assigned to a cows milk group (COW), a goats milk group (GOAT), a whey protein group (WHEY), or an energy-matched carbohydrate group (CHO), with 750 mL of the allocated fluid consumed following a sprinting and jumping protocol. Assessment of muscle function (peak torque ($60°.s^{-1}$, $180°.s^{-1}$), 5, 10 and 20 m sprint performance, countermovement jump (CMJ), reactive strength index (RSI), rate of force development (RFD), creatine kinase, symptoms of stress and soreness and tiredness were recorded pre- and 24 h, 48 h, and 72 h post-exercise.

Results

Within-group data demonstrated completion of the exercise protocol resulted in reduced muscle function, increased muscle soreness and tiredness and increased levels of serum CK. Overall analysis of data reported protein drinks ‘likely’, or ‘possibly’, attenuated small/moderate losses in muscle function (CMJ, RSI, peak torque, RFD, sprint performance), to a greater extent than CHO and were more beneficial for limiting increases in soreness, tiredness and symptoms of stress compared to CHO. However, effect sizes were small and the benefits observed did not extend across all variables nor all time points.

Conclusion

When compared to the energy matched carbohydrate group, consumption of 750 mL of GOAT, COW and WHEY minimised losses for some muscle function variables and limited increases in muscle soreness and tiredness. Thus, these protein beverages are potential valuable recovery interventions following exercise involving sprinting and jumping.

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Exercise induced muscle damage (EIMD), was first described by Hough (1902), demonstrating small tears to muscle fibres resulted in delayed onset of muscle soreness (DOMS), and increases in serum protein (Sorichter *et al.*, 2001). Associated with this muscle damage is power and strength loss and impairments of neuromuscular and reflex actions which can adversely affect performance (Twist and Eston, 2005).

Recovery can be defined as the whole set of processes that result in an athlete's renewed ability to meet or exceed a previous performance and further relates to the time necessary for various physiological parameters, which were modified by exercise to return to resting values (Hausswirth and Mujika, 2013). Recovery from exercise and competition is a vital component of the overall exercise training paradigm, and paramount for high-level performance and continued improvement. Recovery is typically challenging for athletes undertaking two or more sessions a week, training for prolonged periods, or competing in a programme that involves multiple training sessions and games/matches. Between each training session, the body needs to adapt to the induced physiological stress. A proactive recovery, from a nutritional perspective, means providing the body with all the nutrients it needs, in a timely and practical manner, to optimise the desired recovery processes following each session (Beelen *et al*., 2010).

The application of effective nutritional recovery strategies is a well-established priority following intense exercise in order to attenuate decrements in subsequent performance (Beelen *et al*., 2010; Pritchett *et al.*, 2011; Desbrow *et al*., 2014), with aspects such as timing and composition of foods pertinent areas of consideration for optimal recovery (Maughan and Shirreffs, 2011). Muscle protein breakdown (MPB) and muscle protein synthesis (MPS) are both stimulated in response to exercise (Maughan and Shirreffs, 2012; McGlory *et al*., 2017), with the eccentric component of exercise promoting protein breakdown and decreasing synthesis which can result in muscle damage (Poortmans *et al*., 2012; Morton *et al.*, 2015).

To address muscle recovery post-exercise, sufficient amino acid intake is required to achieve net protein accretion as well as carbohydrate to stimulate insulin release for efficient uptake of amino acids into the muscle (Kreider *et al*., 2010; Jäger *et al*., 2017). Recent research has shown that early intake after exercise (within the first hour) of essential amino acids from good quality protein sources helps to promote the increase in protein rebuilding (Aragon and Schoenfeld, 2013). There is evidence to show that insulin may reduce protein breakdown by having a positive effect on leucine balance due to its inhibitory effect on leucine transamination (Meek *et al.*, 1998), which in turn leads to inhibition of protein breakdown (Børsheim *et al.*, 2004; Chow, 2006). The measurement of MPS is useful in conjunction with the other markers of recovery which include measures of muscle function, perceptual measures of soreness and other useful serum markers. MPS is a valuable marker for recovery from muscle damaging exercise giving an insight and understanding of the mechanisms that are involved and occurring in the muscle (Pasiakos and Carbone, 2014). Therefore, provision of amino acids post-exercise is necessary to stimulate insulin-signalling and the critical mTOR pathway necessary to achieve net protein synthesis (Karlsson *et al*., 2006; Cermak *et al*., 2012). Specifically, the consumption of 20 – 25 g of animal protein such as milk/whey is advised for optimal protein synthesis with leucine amounts greater than 2.2 g (Layman *et al*., 2015) recognised as a potent signalling amino acid of the mTOR pathway (Farnfield *et al*., 2009; Farnfield *et al.,* 2012).

Carbohydrate requirements before, during and post exercise will depend on a number of aspects such as the duration and intensity of the session, performance and body composition goals, as well as the duration of time to recover between sessions (Beck *et al.*, 2015). To fulfil both the provision of amino acids and glucose for these purposes, the co-ingestion of protein and carbohydrate is suggested within 30 - 60 min post exercise (Pritchett *et al.*, 2011).

Whey protein has received considerable attention in relation to performance nutrition and recovery (Buckley *et al*., 2010; Howatson *et al.*, 2012). It is water soluble and quickly

digested in the body and, therefore, characterised as a ‘fast protein’ (Dangin *et al.*, 2002; Tang *et al*., 2009; Wilborn *et al*., 2013). Whey is considered a high quality protein (Ha and Zemel, 2003) recognised for its valuable source of branched chained amino acids (BCAAs); (Greer *et al.*, 2007; Tang *et al.,* 2009) which are particularly noted for their role in MPS (Salinas-García *et al*., 2014; Wolfe, 2017). Additionally, whey protein is particularly high in the rapidly digested amino acid leucine, which is acknowledged for its anti-catabolic properties, regulation of protein metabolism and promotion of MPS (Devries and Phillips, 2015). Studies have reported that post-exercise whey protein consumption has a positive effect on recovery from eccentric exercise due to its quick rate of digestion and abundance of essential amino acids which enhance stimulation of MPS (Tipton *et al.*, 2006; Hulmi *et al.*, 2009; Burd *et al.,* 2012; Townsend *et al*., 2017)**.** MPS is part of the recovery process, however, recovery is very complex. Dependent on the mode of exercise, many other variables may need to be considered such as inflammation and oxidative stress (Powers and Jackson, 2008).

Cows milk and goats milk fall under the heading 'functional foods' which refers to foods and their components that may provide a health benefit beyond basic nutrition. The use of functional foods in enhancing recovery from exercise is, thus, a valid and topical research area. With growing interest in the relationship between diet and health the demand for information on functional foods is increasing and it is believed the information gained from this research study will be highly beneficial.

The scientific evidence supporting the role of milk as an effective recovery option is increasingly prevalent, with emerging applications including roles in rehydration and muscle recovery (Shirreffs *et al*., 2007; Gilson *et al.*, 2010; Lauricella and Koster, 2016). Milk’s effectiveness is attributed to its natural nutritional composition which assists to satisfy the key components of recovery. In addition to glycogen replacement and protein synthesis, another priority for the athlete is to restore fluid and electrolyte balance (Sawka *et al.*, 2007). Milk contains water, carbohydrate, protein and electrolytes such as sodium and potassium as well as being a source of essential vitamins and minerals such

as calcium, iodine, phosphorus, riboflavin (vitamin B2) and vitamin B12 which play a number of important roles in health (Finglas *et al*., 2015). A recent extensive review showed that as well as assisting in meeting nutrient recommendations, milk and dairy products may play a neutral or protective role against the development of chronic diseases such as obesity, type 2 diabetes, cardiovascular disease and some cancers (Thorning *et al*., 2016). Milk has been highlighted in the literature as an effective recovery option post exercise (Cockburn, 2010). Specifically, 500 mL of semi-skimmed milk has been demonstrated to attenuate EIMD in males and females (Cockburn *et al*., 2008; Cockburn *et al.*, 2013; Rankin *et al.,* 2015), including aspects of team sport performance, such as agility and sprinting among males (Cockburn *et al.*, 2013) and females (Rankin *et al.,* 2015).

To date, there has been no previous research on the use of goats milk in relation to exercise performance. Goats milk is lower in lactose and the softer curd assists digestive comfort, making it a better choice for those with stomach sensitivities (Park, 2007). Goats milk contains a higher leucine content than cows milk and accepting that leucine is a major amino acid in the stimulation of protein synthesis, theoretically it may be beneficial in recovery from exercise, especially exercise that induces muscle damage (Park, 2007).

Therefore, the purpose of this investigation is to examine the effects of cows milk, goats milk, whey protein and an energy-matched carbohydrate drink on recovery from exercise indicative of the physiological demands of team field sports. The proposed research aims to induce muscle damage, fatigue and metabolic stress at a level that is associated with normal training and competition, utilising similar exercise activities. Nutritional interventions utilising this type of protocol provides knowledge that may be valuable for post-exercise recovery and subsequent performance.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

To provide context, this review of literature discusses the structure, action and maintenance of muscle. The mechanisms that cause exercise induced muscle damage (EIMD), the effects of muscle damage and the markers of muscle damage are also examined. The review then focuses on recovery from muscle damage and nutritional interventions.

Sport and exercise elicit a number of biochemical, mechanical and physiological responses in the body and, therefore, it is necessary for sport and exercise participants to optimise recovery to support subsequent performance at the next competition, training session or match (Lanham-New *et al*., 2011). The recovery process is particularly challenging to manage in team field sports and depends on several contextual factors such as the training and game schedule. Physical performance recovery takes up to ≥ 48 hours after regular training (Doeven *et al*., 2018).

Considering the various demands of intense exercise, the necessity of adopting an effective nutrition strategy to address recovery needs is well established (Thomas *et al*., 2016). It is recognised that physical activity, athletic performance and recovery from exercise are all improved with appropriate nutrition (Rodriguez *et al*. 2009). Other than the limits imposed by heredity and training, no single factor plays a greater role in optimising performance than diet (Aragon and Schoenfeld, 2013). To date, no research has investigated goats milk in relation to exercise performance or as a post-exercise recovery drink to maximise recovery. This is the first investigation to determine the effect of goats milk on recovery from repeated sprinting and jumping in team field sports athletes and compared to other protein sources (cows milk and whey protein).

2.2 TEAM SPORTS

Team field sports may be described as dynamic, complex, and highly interdependent activities that require coordination on various levels (Reimer *et al*., 2006). During high intensity intermittent team field sports, numerous accelerations and decelerations take place, with and without changes of direction (Stolen *et al*., 2005; Bloomfield *et al*., 2007). Team field sports require physical and physiological demands that elicit high energy expenditure and challenge movement patterns as seen in various field sports such as hockey (Sell and Ledesma, 2016), soccer (Bangsbo *et al*., 2006) and rugby (Cunningham *et al*., 2016).

There is contribution from both the aerobic and anaerobic energy systems in team field sports performance. Energy system contribution is heavily influenced by the duration of the movements such as sprint duration (Spencer *et al*., 2005). Contrary to traditional perceptions, the aerobic energy system is utilized during shorter bouts of exercise such as sprinting over 12 - 22 s (Spencer and Gastin, 2001). Spencer *et al*. (2005) reported a small aerobic contribution to a single short-duration sprint but an increased aerobic contribution to repeated sprints. There is also significant anaerobic glycolytic activity during this type of exercise. Anaerobic glycolysis is associated with the intracellular accumulation of hydrogen ions, which have been associated with muscular fatigue (Spriet *et al*., 1985). During sprint exercise of 10 – 30 seconds duration, anaerobic glycolysis provided twice as much ATP as PCr degradation (Bogdanis *et al*., 1996). Gaitanos *et al*. (1993) conducted a study investigating muscle metabolism that simulated the activity patterns that are typically seen in field based team sports. Over 10 repeated sprints separated by 30 seconds of recovery, they reported a significant reduction in peak power output (PPO) by the fifth sprint.

During soccer match play, 656 accelerations and 612 decelerations were recorded (Russell *et al*., 2016). The ability to accelerate, decelerate and change direction efficiently is imperative to successful team field sports performance (Delaney *et al*., 2017). During field based team sports, elite athletes may cover 8 – 14 km at an average

intensity of ~85 – 90 % of their maximal heart rate (HR_{max}) or 75 – 80 % of their maximal oxygen uptake (VO_2max), (Gabbett, 2005; Spencer *et al*., 2005; Aughey, 2013). Di Salvo *et al*. (2007) showed that soccer players perform between 3 and 40 sprints per game. In professional soccer the mean distance and duration of a sprint are relatively short with distances rarely exceeding 20 m and typically lasting no longer than 4 s (Andrzejewski *et al*., 2015). Marked differences dependent on a player's position is also a considerable factor in varying demands. For example, in Gaelic football, a corner forward may engage in multiple short and sharp, multidirectional movement cuts whereas a midfielder may demonstrate higher running distances at a lower mean speed and may therefore be exposed to different physiological and metabolic demands (Bloomfield *et al*., 2007). Depending on formation and position on the pitch, a player's physical activities change every 4 - 6 s (Andrzejewski *et al*., 2015).

The demands of team field sports performance, impose physiological stresses and result in muscle damage with the eccentric loading associated with decelerations being the biggest contributor to muscle damage (Howatson and Milak, 2009). Therefore, adequate recovery strategies post-exercise become highly important in ensuring sufficient recovery is achieved. Resynthesised muscle structure, restored muscle function and adaptability are essential in preparing for subsequent competition (Reilly and Ekblom, 2005).

2.3 MUSCLE STRUCTURE and MUSCLE CONTRACTION

Skeletal muscle is a dynamic compound of proteins that responds to both internal and external cues to facilitate muscle adaptation (Meyer and Lieber, 2012) and produces joint movement to exert force (Cockburn *et al*., 2008). The basic structural and functional unit of a muscle cell is the sarcomere, which consists of thin filaments of the protein actin and thicker filaments of the protein myosin. Myofibrils are made up of sarcomeres, the functional units of a muscle. The function of the myofibril is to perform muscle contraction via the sliding filament model. Skeletal muscle is made up of a highly

complex protein structure as seen in Figure 2.1, which is responsible for the control of force generated (Kenney *et al*., 2012).

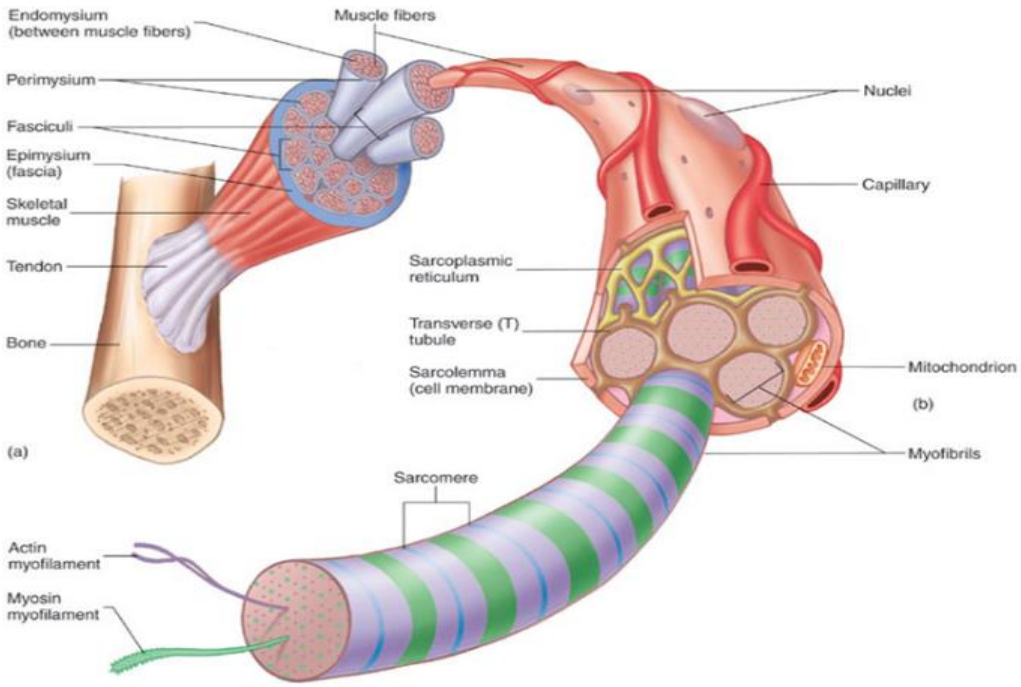

Figure 2.1 Structure of skeletal muscle from the gross to molecular level. Reprinted from Seeley *et al*. (2007).

Skeletal muscle is surrounded by the epimysium and contains muscle fascicles (Figure 2.1). Muscle fascicles are made up of muscle fibres that are comprised of myofibrils which are surrounded by the sarcoplasmic reticulum. Myofibrils are made up of sarcomeres and the main contractile proteins are actin and myosin (Kenney *et al*., 2012). Titin, a structural protein, connects the Z-disc to the myosin filaments and plays a role in locating thick filaments in the centre of the sarcomere (Morgan and Allen, 1999). Titin regulates force by binding to calcium upon activation and then by shortening its spring free length by binding to actin (Armstrong *et al*., 1983; Ebbeling and Clarkson, 1989). Desmin is a major intermediate filament protein, mainly located at the periphery of Z-disc of striated muscles and at the dense bodies of smooth muscle cells, playing an essential role for the structural integrity and function of muscle (Paulin and Li, 2004). When a nerve impulse arrives in the muscle, actin is released and binds to the sarcolemma which leads to calcium ions being released. Calcium binds with troponin which causes tropomyosin to lift off active sites on actin. Myosin cross-bridges bind to

actin and the myosin head tilts pulling actin filaments in a power stroke. Calcium is then pumped back to the sarcoplasmic reticulum and the structure goes back to its original state (Peake *et al*., 2005).

2.4 MUSCLE DAMAGE

Eccentric exercise results in skeletal muscle damage that causes a remarkable number of localised and systemic changes within the muscle (Evans and Cannon, 1991). Muscle damaging exercise is associated with a number of symptoms. There is a decreased ability to produce force (Byrne and Eston, 2002; Harrison and Gaffney, 2004; Twist and Eston, 2005), an increase in intramuscular proteins measured in the plasma (Sorichter *et al*., 2001) and a concurrent decrement in physical performance (Assumpção *et al*., 2013). Unaccustomed eccentric exercise, is the most common cause of muscle damage as the contracting muscle is forcibly lengthened resulting in damage to the muscle fibres, an acute inflammatory response, pain development and a loss of muscle force generating capacity (Byrne *et al*., 2004). Eccentric actions cause muscles to elongate while under tension due to an opposing force, such as weight being greater than the force generated by the muscle (Fridén and Lieber, 1992). During an eccentric action, the actin proteins move away from each other as the myosin cross-bridges attach as a result of the weight being greater than the force of the muscle, lengthening the sarcomere (Hessel *et al*., 2017). Eccentric muscle actions occur frequently in daily activities and sporting performance (Enoka, 1996) and have been discussed previously in several studies (Armstrong *et al*., 1991; Warren *et al*., 1999; Eston *et al*., 2000; Allen, 2001;).

EIMD occurs when the nature or magnitude of eccentric force production significantly changes (Lindstedt *et al*., 2001). It is generally agreed that there are two prominent signs of damage in a muscle immediately after it has been exposed to eccentric exercise (Proske and Morgan, 2001). Firstly, there is disruption to sarcomeres which causes a shift in optimum length and damage to the excitation – contraction coupling (E-C coupling) system, which secondly, leads to a fall in tension that is reversible. Therefore, this fall in tension is a potential mechanism underlying the reductions in force-

generating capacity (Byrne *et al*., 2004). The initial or primary damage events that occur from eccentric exercise may be further subdivided into two possible pathways: mechanical and metabolic (Armstrong *et al*., 1991; Clarkson and Ebbeling, 1988).

2.4.1 Primary damage - Mechanical

Damaged muscle fibres initiate a cascade of reactions that result in a prolonged and complex interaction between protein synthesis and degradation (Sorichter *et al*., 1999). These change and peak between 24 and 72 hours by initiated disturbances in Ca^{2+} homeostasis (MacIntyre *et al*., 2001). EIMD may increase degradation of the protein and membrane structures leading to myofibrillar disruption, and the loss of cell membrane integrity (Armstrong *et al*., 1991; Evans and Cannon, 1991; Gissel, 2005). Stimulation of protein synthesis and minimization of protein breakdown (proteolysis) are the two cellular processes that are essential for muscle recovery after damage (Rennie and Tipton, 2000).

Mechanical stress refers to muscle damage caused by direct mechanical loading placed on the muscle fibre (Tee *et al*., 2007). Eccentric actions can generate more force than isometric and concentric contractions and require less energy expenditure per unit of torque (Newham *et al*., 1983; Hessel *et al*., 2017). This is because during a concentric muscle action, one molecule of ATP is used to detach each actin-myosin cross-bridge. However, during an eccentric action some cross-bridges are forcibly detached due to the stretching of the muscle fibre, thus using less ATP (McHugh *et al*., 1999). Eccentric actions place a stretch upon the sarcomere to the point at which the myofilaments may experience sarcomere strain, or damage (Proske and Allen, 2005). A main contributor is the E-C coupling mechanism of the myosin cross-bridges attaching to actin proteins (Proske and Allen, 2005). The release of Ca^{2+} from the sarcoplasmic reticulum, which initiates the sliding of actin over myosin proteins, results in part of the sarcomere being stretched with eccentric actions. This elongation disruption, followed by substantial Ca^{2+} release, results in disruption of the sarcomeres (Lamb, 2009). Sarcomeres are unstable on the descending limb of the force - length relationship following active stretching and it has been concluded that this is the region where sarcomere in-homogeneities develop

(Morgan, 1990; Morgan, 1994; Allinger *et al*., 1996; Zahalak, 1997). Isometric contractions on the descending limb of the force-length relationship are associated with sarcomeres of essentially uniform length (Morgan, 1990; Morgan, 1994). Sarcomere length non-uniformities increase when a muscle is actively stretched compared to the corresponding isolated isometric contractions (Allinger *et al*., 1996). Repeated overextension of sarcomeres leads to their disruption. Muscle fibres with disrupted sarcomeres show a shift in optimum length for tension in the direction of longer muscle lengths (Proske and Morgan, 2001). When the region of disruption is large enough it leads to membrane damage. This could be envisaged as a two-stage process, beginning with tearing of transverse tubules, followed by damage to the sarcoplasmic reticulum and uncontrolled Ca^{2+} release from its stores.

With the overextension of the sarcomeres during an eccentric contraction, there is a release of tension from within the sarcomere, often described as "popping" (Morgan, 1990). This is caused by little or no overlap between some of the myosin and actin filaments, and thus there is elongated tension being placed on the connective tissues and other proteins in the sarcomere which is beyond their capacity (Armstrong *et al*., 1991; Proske and Allen, 2005). Eccentric muscle actions can elicit damage without the presence of maximal effort. Despite this, more damage is observed when exercise is maximal and carried out at longer muscle lengths (Peake *et al*., 2005). Other research has suggested that the initial event is due to E-C coupling failure (Warren *et al*., 2001). Warren *et al*. (2001) reported that the primary damage arises in the E-C coupling system and only a small component arises at the sarcomeres. This theory has been supported from the observation of decreased tension in mouse muscle post exercise, which can be recovered with caffeine (Warren *et al*., 1993; Balnave and Allen, 1995). Tension was recovered with 50 mmol caffeine, which releases Ca^{2+} from the sarcoplasmic reticulum and develops a contracture in the muscle. In a second study, Allen (2001) used 10 mmol caffeine to create tension in single fibres in response to direct electrical stimulation. It was concluded that in mouse fibres, a main contributor to the fall in tension observed after eccentric contractions is from changes in the E-C coupling system (Allen, 2001). However, it is still unclear which comes first, E-C coupling failure or sarcomere

disruption. The sarcomere non-uniformity hypothesis predicts that damage will only occur if sarcomeres are actively stretched to beyond optimum length (Proske and Morgan, 2001). Observations by Takekura *et al*. (2001) reported four obvious ultrastructural changes in the arrangement of the transverse tubules and the disposition of triads after downhill running. The main difficulty is trying to account the reason why transverse tubules should be the primary site for damage and why this only occurs at lengths beyond the optimum. Proske and Morgan (2001) speculated that disruption to the sarcomere and membrane leads to damage of the E-C coupling system and thus force loss.

2.4.2 Primary Damage - Metabolic

Metabolic damage refers to muscle damage caused by metabolic deficiencies in the muscle (Tee *et al*., 2007). Metabolic muscle damage can result from ischaemia or hypoxia during exercise of a prolonged duration (Armstrong *et al*., 1983; Ebbeling and Clarkson, 1989). Ischaemia is thought to cause changes in ion concentration, metabolic waste accumulation and ATP deficiency, which ultimately results in muscle damage (Clarkson *et al*., 1986). Comparisons of uphill and downhill running, highlighted a higher metabolic cost in plasma creatine phosphokinase (CPK) and no evidence of damage in uphill running in comparison to downhill running which displayed a high incidence of damage at a lower metabolic cost (Schwane *et al*., 1983). Beltman *et al*. (2004) showed a reduced metabolic cost during electrically stimulated lengthening contractions when compared with concentric and isometric contraction in rats. In light of this, metabolic factors tend not to be a basis for EIMD occurring from eccentric exercise and may be limited to exercise of a long duration exceeding 45 minutes (Proske and Morgan, 2001).

2.4.3 Secondary Damage

The secondary events that follow the primary phase, result in increased damage to the muscle following the exercise bout, with increased protein degeneration and change in myofibrillar protein metabolism rate (Howatson and Van Someren, 2008). Impairment to the sarcolemma or sarcoplasmic reticulum occurs which may lead to increases in

intracellular Ca^{2+} concentration and consequently initiate a number of degradative pathways (Cockburn *et al*., 2010). The influx of Ca^{2+} results in further damage to the sarcoplasmic reticulum and myofilaments (Warren *et al*., 2001; Gissel and Clausen, 2001) causing the activation of proteolytic and lipolytic pathways that lead to degradation of the cell membrane (Armstrong *et al*., 1991). Overgaard *et al*. (2004) demonstrated an increase in cellular Ca^{2+} accumulation following long distance running and noticed a significant increase in cellular Ca^{2+} at 20 km (Overgaard *et al*., 2004). Thus the duration of exercise may have an impacting factor even without significant eccentric loading. The loss of integrity from the membrane allows for leakage of intramuscular proteins which are evident in the blood days after (Proske and Morgan, 2001). Increased levels of Ca^{2+} activate calcium dependent proteases such as calpain which disrupt the integrity of Z-discs damaging the membrane and sarcoplasmic reticulum allowing further influx of Ca^{2+} (Allen, 2001; Gissel, 2005). Goll *et al*. (2003) previously reported that calpain plays a significant role in myofibrillar protein degradation, especially in the disassembly of the myofibril during early stages of turnover.

Raastad *et al*. (2010) observed increased calpain activity in the exercised leg post 30 minute isokinetic eccentric exercise. These levels of total calpain remained increased in the exercised leg for 7 days (Raastad *et al*., 2010). A result of calpain involvement with Z-disc disruption, there is separation of desmin. Desmin links adjacent Z-discs together and when it is separated there is an increased chance of damage (Yu *et al*., 2004). Titin is a known substrate of calpain (Goll *et al*., 2008). Titin is an elastic filament that anchors thick filaments to Z-discs (Allen, 2001), therefore, its loss would lead to sarcomere disruption (Proske and Morgan, 2001). Calpain may lead to early disruption of the muscle fibre and is responsible for the initial breakdown of proteins but could also lead to further degradation of the muscle via other processes (Cockburn *et al*., 2010). Eccentric actions have been shown to stimulate increases in intracellular Ca^{2+} concentration which in turn stimulates a number of other degradative pathways, either directly or indirectly. The ubiquitin-proteasome pathway (Ub-P) completes the breakdown of these proteins. This pathway involves activation of ubiquitin by cytokines and interleukins from activated macrophages, thus playing an important role in the

accelerated breakdown of myofibrillar proteins (Lecker *et al*., 1999). The pathway for stimulating the Ub-P system is activated during EIMD (Cockburn, 2010). An inflammatory reaction also occurs with a rise in white blood cell count after exercise. There are increased cytokines, macrophages and histamines which all stimulate free nerve endings in the muscle (Peake *et al*., 2005). Disruption of calcium homeostasis results in cell necrosis, thus decreasing glycogen storage capabilities which may impact subsequent exercise performance (Tee *et al*., 2007).

2.5 MARKERS OF MUSCLE DAMAGE

2.5.1 Direct markers of muscle damage

Direct assessment of muscle damage is difficult because it is only possible through analysis of muscle biopsies or through magnetic resonance imaging (MRI) (Clarkson and Hubal, 2002). The problems inherent in muscle biopsy analysis are obvious in that such a small and very invasive sample is used to estimate damage in an entire muscle which leads to overestimating or underestimating the extent of the damage (Clarkson and Hubal, 2002). Imaging techniques have been used to assess damage in whole muscle. Although this is a non-invasive technique, the significance of the changes in the images is still unclear.

Eccentric exercise usually results in cellular and subcellular disturbances, particularly Z-disc streaming (Clarkson and Hubal, 2002). Direct markers of muscle damage include damage to the sarcomere observed from muscle biopsy samples (Newham *et al*., 1983). There is ultrastructural evidence of disrupted sarcomeres with other sarcomeres remaining intact (Fridén *et al.*, 1981; Newham *et al*., 1983), distributed throughout the muscle (Talbot and Morgan, 1996) and significant Z-disc streaming (Fridén *et al*., 1983; Lieber and Fridén, 1999). The excessive tension placed upon passive structures such as desmin and titin as a result of repeated eccentric actions may lead to failure of the structure and reduction in the muscles ability to generate force (Proske and Morgan, 2001; Clarkson and Hubal, 2002; Tipton, 2011). Fridén *et al*. (1983) proposed that the Z-discs are the ‘weak link’ in the myofibrillar chain.

Fridén *et al*. (1981) provided some of the first evidence of muscle fibre damage in humans after exercise. Participants performed repeated stair descents, and biopsies of the soleus muscle were collected two and 7 days later. The biopsy analysis showed myofibrillar disturbances and Z-disc streaming. In a follow-up study, Fridén *et al*. (1983) examined muscle samples taken one hour, three days, and 6 days after a backwards cycling exercise and reported that 32 %, 52 %, and 12 %, respectively, of the observed fibres showed evidence of local disturbance. Findings of Newham *et al*. (1983) concurred with those of Fridén *et al*. (1983) in that biopsy samples collected 24 – 48 h after exercise showed greater damage than those taken immediately after exercise, suggestive of the secondary phase of damage.

Newham *et al*. (1983) compared muscle biopsy samples of the quadriceps following concentric and eccentric actions during bench stepping. They observed no abnormalities in samples from the concentrically exercised leg but observed many disrupted sarcomeres as well as disorganised myofilaments and Z-disc streaming immediately after eccentric exercise. The force loss associated with eccentric exercise is said to be an outcome of the amount of structural damage caused within the muscle as a result of the exercise performed (Proske and Morgan, 2001). Nevertheless, biopsies are specific only to a small area of investigation and, therefore, may not represent the universal extent of damage to the muscle groups exercised. Indeed, the biopsy procedure may itself cause damage to muscle fibres (McHugh 2003).

MRI has been a powerful tool to gain understanding of what is occurring in the entire muscle (Clarkson and Hubal, 2002). Mair *et al*. (1992) examined the relationship between changes in MRI and changes in other indices of muscle damage (i.e. myoglobin concentrations) after eccentric contractions of the knee extensors. The T2 relaxation by which the transverse components of magnetization (Mxy) decay or diphase revealed peak increases at 6 days post-exercise which occurred later than peak soreness development. These data showed that strength was being restored and soreness was

dissipating while the signal intensity was increasing. Nurenberg *et al*. (1992) revealed that ultrastructural damage assessed from MRI-guided biopsies correlated significantly with increased MRI signal intensity 48 h after downhill running. MRI has been useful in assessing which exact muscles have been damaged after the exercise (Clarkson and Hubal, 2002). Changes in MRI signal intensity have been discovered after eccentric exercise and are taken to indicate muscle edema, yet these changes, which can last up to one month, are not fully understood.

2.5.2 Indirect markers of muscle damage

As a result of the invasive nature and inherent errors in using the biopsy technique and the lack of knowledge of exact mechanisms MRI assessments display and inform, several investigators have used indirect measures to assess damage. Indirect indices of muscle damage such as assessment of delayed onset muscle soreness (DOMS), muscle force production, swelling, perception of pain, range of movement (ROM), and serum markers of muscle damage have been utilised in many studies (Lavender and Nosaka, 2008; Saka *et al*., 2009), as have blood chemical markers of inflammation and stress such as creatine kinase (CK); (Chen and Hsieh, 2001). These additional measures can assist in quantifying and substantiating muscle disturbance parameters.

2.5.2.1 Serum marker – Creatine Kinase

CK is an intramuscular protein found in the mitochondria of tissue that demands a high amount of energy. There are 2 specific types of CK (Mt- CK) – ubiquitous (brain, smooth muscle and sperm) and sarcomeric (cardiac and skeletal muscle). Myofibrillar CK-MM is bound to the M-line of the sarcoplasmic reticulum of myofibrils and is also found in the space of the I-band sarcomeres providing support for muscle energy requirements (Heled *et al*., 2007). CK serum levels change in accordance with different exercise protocols and intensity (Klapcińska *et al*., 2001). Weight bearing exercises which include eccentric actions such as downhill running elicit the greatest increases in muscle CK levels (Malm *et al*., 2004). Raised serum CK levels may be a consequence of both metabolic and mechanical stresses or local tissue damage with sarcomeric degeneration

from Z-disc fragmentation (Brancaccio *et al*., 2007). When exercise intensities reach a high level, there is an increase in muscle membrane permeability as a result of damage to the membrane and enzymes released (Brancaccio *et al*., 2007).

CK is one of the most common blood serum proteins examined to identify muscle damage (Brancaccio *et al*., 2007). However, analysis of muscle proteins in the blood provides only a qualitative indicator of damage, and the changes observed demonstrate a large inter subject variability (Clarkson and Hubal, 2002). The level of any protein in the blood is a function of both what is being released from the damaged tissues and what is being cleared from the blood (Baird *et al*., 2012). The time of CK release into and cleared from plasma depends on the level of training, type, intensity and duration of exercise (Brancaccio *et al*., 2007). CK may be higher in individuals with greater muscle mass (Mastaloudis *et al*., 2006) or during times of high force, pure eccentric exercise (Rodenburg *et al*., 1993). Of relevance, Clarkson and Ebbeling (1988) discovered no correlations between the increase in CK and loss of muscle force, which is a more practical measure of the ability of the muscle to perform.

Hyatt and Clarkson (1998) discovered the release of CK following eccentric exercise peaked 96 h post-exercise and a subsequent additional bout of exercise produced only small increases. Similar findings were recorded by Clarkson and Hubal (2002) post muscle damaging exercise, thus, 96 h may not be sufficient time for adequate recovery to be achieved. Daily training may result in persistent elevated CK levels among athletes and thus higher resting CK levels compared to those that are untrained (Kratz *et al*., 2002). Individuals who regularly participate in high-volume, intense exercise, tend to have significantly raised base levels of CK compared to sedentary and moderately exercising individuals (Chevion *et al*., 2003). Fielding *et al*. (2000) reported that serum CK levels were affected by hydration status prior to eccentric exercise and varied within subject groups of comparable male volunteers, whilst muscle biopsies revealed similar ultrastructure damage to Z-disc muscle fibres. Furthermore, muscle soreness did not differ between groups regardless of CK levels.

Protocols using electrical stimulation may induce higher CK responses (Brown *et al*., 1997) with peaks occurring between 24 and 72 h post exercise. However, previous research has observed plasma CK activity may not be a reliable index of microscopic injuries that occur to muscle fibres that are not conditioned for eccentric activity (Fielding *et al*., 1993). MacIntyre *et al*. (2001) revealed downhill running to result in low concentrations of CK (<1000 IU). Similarly, following eccentric actions of knee extensors (Eston *et al*., 1996) CK levels remained low (125 – 131 IU). Nevertheless, there are studies that demonstrated very high concentrations of CK (>10,000) post eccentric exercise (Newham *et al*., 1983; Nosaka and Clarkson, 1996). There is high variability among these studies and one factor responsible for this may be whether individuals are high or low responders, taking into account training level, muscle size and/or genetics (Brancaccio *et al*., 2007).

The mechanisms by which CK is cleared from the blood has not been fully elucidated and it is likely that observed serum CK levels reflect complex interactions associated with energy status and scale of muscle disturbance (Baird *et al*., 2012). Thus, measured serum CK will reflect relative amounts of CK released, degree of enzyme activity of released CK, and the rate of clearance of CK from the serum (Clarkson *et al*., 2006). While CK is typically used as a marker of muscle damage, it has limited use as a marker of overall recovery as it does not correlate well with muscle function (Nosaka *et al*., 2002). Individuals can have high CK concentrations while their muscle function is maintained or returning towards pre-exercise concentrations (Chevion *et al*., 2003).

Daily training may result in persistent elevated CK concentrations among athletes and thus higher resting CK concentrations compared to those that are untrained (Kratz *et al*., 2002). Young adult males have high CK concentrations which decline slightly with age (Borges and Essén-Gustavsson, 1989). Lower concentrations have been reported in females as a result of oestrogen potentially playing a protective role in maintenance of membrane stability, limiting CK leakage from damaged muscle post exercise (Tiidus,

2000). With this in mind, caution is needed when using CK as a marker to assess muscle damage.

2.5.2.2 Peak Torque

Warren *et al*. (1999) suggested that the best measure for measuring muscle damage is post exercise muscle function. The ability for an athlete to perform at their highest functional capacity following eccentric exercise proves difficult with the muscle damage inflicted from this type of exercise. An athlete's force producing capability is affected by their ROM, velocity, activation, muscle length and bout duration, and eccentric exercise will impact on each of these. Peak torque is a reliable and effective indirect measure of muscle damage after eccentric exercise (Margaritelis *et al*., 2015). In addition to the impact of structural damage on the ability to generate force, peak torque is affected by an individual's fatigue and pain status. Thus, the ability to reach peak torque can prove difficult with tiredness and DOMS following physically demanding eccentric exercise (Eston *et al*., 1996). Peak torque has been shown to reduce significantly 30 min to 48 h following eccentric exercise, with the largest decrements occurring between 24 and 48 h post exercise (Eston *et al*., 1996; Twist *et al*., 2008; Cockburn, 2010).

Maximal voluntary isometric contraction (MVIC) is a commonly used marker for muscle damage (Tseng *et al*., 2016). In general, isometric strength is lower immediately post eccentric exercise (within one hour) and recovery is gradual and prolonged (Byrne *et al*., 2004). Previous studies have reported decreases in MVIC following eccentric exercise (Harrison and Gaffney, 2004; Prasartwuth *et al*., 2005; Marginson, 2005; Howatson and Milak, 2009). Hesselink *et al*. (1996) also reported a decline in maximal isometric torque after both isometric and eccentric exercise. However, the decline after eccentric exercise was more pronounced. Isokinetic tests have been used to investigate whether strength loss after eccentric EIMD is dependent on the muscle action being performed (Twist and Eston, 2005). Previous research has reported isokinetic peak torque is decreased following eccentric exercise (Eston *et al*., 1996; Jakeman and Eston, 2013).

2.5.2.3 Rate of force development

Rate of force development (RFD) is the ability to rapidly develop muscular force and can be measured as the slope of the torque–time curve obtained during isometric conditions in the early phase of muscle contraction (0 – 200 ms); (Andersen and Aagaard, 2006). Increased RFD has been reported in explosive type exercise as a result of neural adaptations (Van Cutsem *et al*., 1998). However, following eccentric exercise, significant reductions in RFD lasting at least 48 h have been reported (Molina and Denadai, 2012). Studies that have examined the effects of EIMD on the torque–velocity relationship are open to more than one interpretation (Twist and Eston, 2005). Eston *et al*. (1996) support the notion that type II fibres may be selectively damaged during eccentric exercise. EIMD has an effect on the body's capability to generate power. The potential loss of concentric and eccentric strength at high angular velocities has implications for athletic performance. There may be a decrease in the rate of force development following sub-maximal stretch-shortening exercise (Twist and Eston, 2005).

2.5.2.4 Vertical Jump

Vertical jump height is commonly used when assessing performance in team based field sports (Gabbett, 2006). Vertical jumps including squat, countermovement and drop jumps are commonly used measures as markers of muscle damage (Byrne and Eston 2002). The use of these different vertical jumps allows researchers to examine the effect of EIMD on the stretch-shortening cycle (Cockburn *et al*., 2008). Mike *et al*. (2017) reported longer eccentric contractions negatively impacted explosive movements such as the vertical jump whereas shorter eccentric contractions initiated greater amounts of soreness. Byrne and Eston (2002) observed decrements in all forms of vertical jump performances from 1 h to 72 h post eccentric exercise. These findings are consistent with Harrison and Gaffney (2004) and Marginson (2005). Previous research investigating all three vertical jumps have found that squat jumps are affected to a greater extent than either countermovement and/or drop jumps (Harrison and Gaffney, 2004). It has been proposed that the slow stretch phase used during countermovement and drop

jumps may provide potentiating mechanisms that attenuate the detrimental effects of EIMD (Byrne and Eston, 2002), thus, reducing decrements in performance.

2.5.2.5 Reactive Strength Index

Reactive strength index (RSI) is a measure of an athlete's ability to utilise the stretch shortening cycle and provides a measure of dynamic muscle actions that can be related to sports involving multi-directional movements such as running and jumping (Young *et al*., 1995). RSI is derived by calculating jump height divided by ground contact time during the drop jump (DJ). The DJ has previously been used as it is the only plyometric exercise with an identifiable ground contact time (Ebben and Petushek, 2010). The RSI was developed to assess an athlete's performance during plyometric activities by measuring the muscle-tendon stress and their reactive jump capacity (Flanagan *et al*., 2008). RSI demonstrates an athlete's ability to rapidly change from an eccentric motion into a concentric muscular contraction and is an expression of their dynamic explosive vertical jump capacity (Young *et al*., 1995; Flanagan *et al*., 2008). The incremental DJ-RSI can also be used to provide recommendations for an athlete's optimal drop height for plyometric exercises (Flanagan and Comyns, 2008). RSI appears to be linked with acceleration, agility and change of direction speed. Jump height and flight time can both be used to measure RSI. The ground contact time of the RSI test is an important parameter for test selection and when interpreting results. Technical proficiency may significantly affect the reliability of the test data (Flanagan *et al*., 2008). A number of investigations have reported decreases in RSI following eccentric exercise (Harrison and Gaffney, 2004; Comyns *et al*., 2011; Cockburn *et al*., 2013; Rankin *et al*., 2015). Furthermore, RSI remained below baseline levels 48 – 72 h post exercise (Cockburn *et al*., 2013; Rankin *et al*., 2015).

2.5.2.6 Sprint Time

Field sports require bouts of high-intensity, intermittent, repeated sprint activity over short distances incorporating accelerations and decelerations (Sirotic and Coutts, 2007).

Mean sprint duration in field sports is generally 2 - 3 s over a distance of no more than 20 m (Spencer *et al*., 2005). It has been reported that intermittent sprint performance results in muscle damage (Thompson *et al*., 1999). Twist and Eston (2005) assessed the effects of EIMD on maximal intermittent sprint performance. Ten healthy male participants performed a plyometric, muscle damaging protocol including sprints and vertical jumps. All variables were measured immediately before and at 30 min, 24, 48 and 72 h post exercise. Peak power was lower than baseline at all times. Sprint times were higher at 30 min, 24 h and 48 h compared to baseline. Values returned to normal at 72 h. Overall, data revealed that, following a plyometric, muscle-damaging exercise protocol, the ability of the muscle to generate power is reduced for at least 3 days. Subsequent investigation by Twist and Eston (2005) reported the ability to generate PPO during a Wingate test and the ability to sprint over 10 m from a standing start were reduced at all-time intervals following the plyometric exercise protocol. Highton *et al*. (2009) examined the effects of EIMD on agility and sprint performance over 5 and 10 m at baseline and then 24, 48 and 168 h following muscle-damaging exercise. They reported reduced sprint performance following EIMD with peak decrements occurring at 48 h. These studies provide evidence that performance of activities requiring rapid generation of force such as sprinting is impaired following muscle-damaging exercise.

2.5.2.7 Muscle Soreness/Tiredness

Following exercise involving eccentric muscle actions, muscle soreness is evident (Cockburn, 2010). The mechanisms, treatment strategies, and impact on athletic performance remain uncertain, despite the high incidence of DOMS (Cheung *et al*., 2003). Increases in soreness have been reported following isolated eccentric exercise (Armstrong, 1990; Nosaka and Clarkson, 1995), downhill running (Eston *et al*., 1995; Byrnes *et al*., 1985), jumping (Nosaka and Kuramata, 1991; Byrne and Eston, 2002; Marginson *et al*., 2005) and sprinting (Thompson *et al*., 1999; Howatson and Milak, 2009). These studies measured soreness using a 200 mm visual analogue scale (VAS) with ‘no soreness’/ ‘0’ and/or ‘unbearably sore’/ ‘10’ anchored at each end of the scale. Previous studies using sprinting and jumping protocols to induce muscle damage reported elevations of soreness at 24 h and 72 h post eccentric exercise with a peak at

48 h (Howatson and Milak, 2009; Rankin *et al*., 2015) and responses remaining elevated at 72 h (Howatson and Milak, 2009; Marginson, 2005). Muscle soreness mechanisms have been investigated in many studies, which have previously been reviewed (Cheung *et al*., 2003). Tissue edema and inflammation are two mechanisms which have been associated with DOMS (MacIntyre *et al*., 1995). Tissue edema may lead to stiffness and increased sensitivity to muscle receptors causing pain (Cockburn, 2010). Milias *et al*. (2005) reported strong correlations between markers of inflammation and soreness at 2 h and 24 h following eccentric exercise. However, muscle soreness generally does not correlate well with other indicators of eccentric EIMD and inflammation (Warren *et al*., 1999; Malm *et al*., 2000), thus, caution is needed when measuring soreness as a marker of muscle damage (Nosaka *et al*., 2002). Nevertheless, an athlete's perception of soreness may give an indication of their overall wellbeing and psychological state to perform exercise and thus is an important factor to consider.

There has been no systematic study of all of these markers together, so there is uncertainty about their relationship to one another in time course or extent of appearance in the blood. This is further complicated by the fact that the two types of exercise predominantly used to study muscle damage, downhill running and high force eccentric muscular contractions, show very different and varied results (Nosaka and Clarkson, 1996).

2.5.3 Perception of Recovery

The Daily Analysis of Life Demands for Athletes questionnaire (DALDA), developed by Rushall (1990) was designed to monitor the signs and symptoms of stress. The effects of training stress can have a big effect on physiological and subjective markers of an athlete (Freitas *et al*., 2014). The results of a DALDA questionnaire give a perception of recovery among athletes with individual responses indicating how well they perceive they are recovering from the exercise trial regarding physical recovery, energy levels, stress levels, enthusiasm and motivation (Robson-Ansley *et al*., 2007; Gomes *et al*,. 2013). Witard *et al*. (2011) reported the increase in dietary protein consumed by cyclists during

and after a period of intensified training had a positive effect on markers of stress as measured by DALDA. The DALDA may also be a useful tool for developing an athlete's self-awareness to exercise and performance (Robson-Ansley *et al*., 2009). The subjective reporting of DALDA has been shown to be a reliable indicator of adaptation to training load and may prove to be more practical and reliable than physiological and biochemical tests (Rushall, 1990).

2.6 NUTRITIONAL INTERVENTIONS

Consumption of macronutrients post exercise particularly carbohydrate and protein are important in the early recovery phase after exercise. The combined ingestion of carbohydrate and protein during recovery from exercise forms an effective strategy to stimulate MPS, inhibit protein degradation creating a positive net muscle protein balance (Koopman *et al*., 2007).

2.6.1 Protein

Unlike other macronutrients, provision of fuel is not the primary function of protein. The body can store substantial amounts of carbohydrates and fats but once protein is consumed it must be used (Tipton *et al*., 1999). Protein is responsible for many processes in the body including enzyme function and neural adaptations (Molfino *et al*., 2017). When apportioning body composition, skeletal muscle including fat mass and lean body mass and bone, protein is the constituent that makes up all of those structures (Phillips and Van Loon, 2011). Protein is made up of amino acids which are the building blocks of muscles and body (Macnaughton *et al*., 2016). Without protein, it would be impossible to build, repair and even maintain muscle (Macnaughton *et al*., 2016). Muscle proteins are constantly being turned over, broken down, degraded and resynthesized (Tipton *et al*., 2018). The balance between the rates of synthesis and degradation, known as net muscle protein balance (Tipton *et al*., 2006), determines the amount of protein that is in the muscle (Tipton *et al*., 2018). Changes in the breakdown and synthesis of muscle are also crucial for repair and remodelling of muscle proteins following exercise (Witard *et al*., 2016). The breakdown of muscle in response to

exercise is an extremely important part of the adaptive process for remodelling and reconditioning of muscle proteins (Macnaughton *et al*., 2016; Witard *et al*., 2016). While breakdown of muscle is important for adaptation, the negative effects on muscle function may negatively impact performance. Immediate intake of protein post exercise has shown an increase in net protein synthesis rate (Levenhagen *et al*., 2001).

2.6.1.1 Protein synthesis, metabolism and breakdown

Exercise has a profound effect on muscle growth and anabolism, which can only occur if muscle protein synthesis is greater than muscle breakdown (Tipton *et al*., 1999). Stimulating protein synthesis and minimising protein catabolism are two cellular processes that are essential for recovery after muscle damage (Rennie and Tipton, 2000). Delivering a constant supply of protein to the body throughout the day is essential for optimum growth. Since many elite athletes perform multiple daily training sessions, sufficient recovery for the maintenance of quality training output is essential (Gee *et al*., 2012). Strategies promoting a positive net protein balance during the day to increase the rate of protein synthesis and muscle regeneration post exercise should be integrated into an athlete's schedule (Cooke *et al*., 2010). The provision of adequate nutrition is required to confer a positive protein balance reflective of both the synthesis and the breakdown of muscle following the exercise stimulus to increase myofibrillar protein synthesis rates (Tang *et al*., 2009; Tipton *et al*., 2018). Therefore, the consumption of sufficient amount of high quality protein following exercise is essential for muscle repair, synthesis and remodelling.

Proteins are constantly being turned over in the body (Witard *et al*., 2016). Protein synthesis and breakdown are influenced by many factors including age, fitness, sex, hormones, health and diet (Rennie and Tipton, 2000). The gains and losses in lean body mass are due to acute and chronic imbalances in protein turnover (Molfino *et al*., 2017). The protein turnover rate and the size of the protein pool vary substantially among athletes (Poortmans *et al*., 2012). Essential Amino Acids (EAAs) stimulate increased rates of MPS (Yang *et al*., 2012). Acute feeding and fasting time periods influence protein

synthesis and breakdown of proteins (Morton *et al*., 2015). Amino acid provision from direct protein feeding alone stimulates MPS above basal rates (Morton *et al*., 2015; Macnaughton *et al*., 2016). It is well established that in the absence of protein feeding post exercise, net protein synthesis is low and muscle may actually be in negative protein balance (Tipton *et al*., 1999; Elliot *et al*., 2006). It has been proposed that MPS is maximised in young adults with an intake of ~20 – 25 g of a high-quality protein; anything above this amount is believed to be oxidized (Morton *et al*., 2015). Moore *et al*. (2009) investigated the effect of 0, 5, 10, 20 or 40 g of egg protein consumption post-exercise in 6 healthy, active males with previous experience of recreational weight-lifting after performing an intense bout of bilateral, leg-based resistance exercise. Moore *et al*. (2009) demonstrated that 20 g of protein was sufficient to maximally stimulate MPS. These results were replicated by Witard *et al*. (2014) after 48 healthy, active male participants who also had previous experience of recreational weight-lighting performed an intense, unilateral leg-resistance exercise bout and then ingested a 500 mL solution that contained 0, 10, 20, or 40 g of whey protein isolate and demonstrated 20 g to be the most substantial for MPS stimulation. This amount of protein includes 3 g of leucine and 8 – 10 g of EAAs which is thought to be the optimal amount (Wilson and Wilson 2006). Greater amounts of leucine result in a plateau in MPS and there is a marked stimulation of whole body leucine oxidation and no further increase in protein synthesis (Tang *et al*., 2009; Wolfe, 2017). However, Macnaughton *et al*. (2016) demonstrated 40 g of protein resulted in greater protein synthesis than 20 g of protein following whole body resistance exercise in 30 resistance-trained males. This may be due to the fact that when larger muscle groups are trained, a higher protein intake may be required especially in young adults possessing greater amounts of muscle mass. However, with the current doses of ~20 - 25 g daily consumption of protein, the total amount of lean body mass (LBM) did not seem to influence the response of MPS (Macnaughton *et al*., 2016). Methodological variances and the amount of muscle activated between studies may offer some explanation for differences found.

The timing, type and total amount of protein are key factors in relation to protein consumption and the effect on MPS (Macnaughton *et al*., 2016). The timing of protein

for optimal recovery is highly important and in particular when consuming post-eccentric exercise resulting in muscle damage (Cockburn, 2010). Protein ingestion elicits an increase in aminoacidemia that stimulates rates of MPS (West *et al*., 2011). West *et al*. (2011) examined the effect of rapid aminoacidemia on protein synthesis post exercise. Greater enhances in MPS and anabolic signalling were observed after an intake of a large single bolus of whey protein in comparison to small pulse amounts fed repeatedly over a certain time period. Willoughby *et al*. (2003) reported an upregulation of the Ub – P pathway at 48 h following an eccentric exercise bout. Therefore, consuming protein as soon as possible after EIMD may support myofibrillar protein synthesis and facilitate recovery (Eddens *et al*., 2017).

There is a dose-dependent relationship between amino acid (Bohé *et al*., 2003; Cuthbertson, 2004) and protein provision and MPS (Moore *et al*., 2009). Some studies have looked at protein branching and amino acids (Bianchi *et al*., 2005; Greer *et al*., 2007; Howatson *et al*., 2012). Exercise and amino acids seem to have complementary effects on MPS (Tipton *et al*., 2001). The normal post-exercise increase in muscle protein breakdown was attenuated when amino acids were infused after an eccentric exercise bout. Tipton *et al*. (2001) reported that oral provision of amino acids was just as effective as infusion for developing net muscle protein synthesis after resistance exercise. A distribution of 3.5:1, CHO:PRO ratio was noted as particularly effective to stimulate MPS, which is required for optimal muscle recovery (Lunn *et al*., 2012). Ferguson-Stegal *et al*. (2011) suggested the insulin response from CHO ingestion as well as amino acid provision for effective MPS stimulation improved performance by facilitating muscle adaptation to exercise. The provision of essential amino acids, particularly leucine and branched chained amino acids (BCAAs) are recognised for effective MPS (Wolfe, 2017). BCAAs are a group of EAAs that are a key substrate for protein synthesis and recovery (Churchward-Venne *et al*., 2014). In conditions of protein mass loss and catabolism, BCAAs are thought to preserve muscle mass (Bianchi *et al*., 2005) and are extremely important for protein synthesis in the hours immediately after ingestion. Continued provision of EAAs has been demonstrated to reduce muscle soreness and damage and may contribute to long-term recovery from eccentric exercise (Nosaka *et al*., 2006).

High quality protein such as whey contains a large concentration of BCAAs. BCAAs appear to elicit similar mTOR signalling as occurs in response to intact whey and casein hydrolysate when provided during resistance exercise (Hulmi *et al*., 2010). However, research has shown only leucine is required to induce protein synthesis and mTOR signalling (Atherton and Smith, 2012). The quality of protein is also an important consideration with a particular emphasis on leucine threshold. The amino acid leucine is a building block and also a trigger for protein synthesis by activating the m-TOR pathway (Churchward-Venne *et al*., 2012). It is believed that the trigger stimulus of leucine elevates MPS as it delivers protein into the muscle in a relatively quick fashion (Atherton *et al*., 2010). Research has found whey protein to have the highest leucine count increasing the rate of protein turnover and ultimately protein synthesis (Phillips, 2016). MPS is also reliant on sufficient calorie intake and thus, if there is calorie deficiency, specific protein content may not necessarily matter (Atherton and Smith, 2012).

2.6.1.2 Whey Protein

Both casein and whey are milk proteins but whey remains soluble in the stomach and empties more rapidly in the small intestine than casein (Weinert, 2009). Consequently, whey, is considered a 'fast' protein and casein, a 'slow' protein as it coagulates in the stomach and is emptied at a slower rate, allowing for a more prolonged rise in levels of plasma amino acids (Tipton *et al*., 2004). Whey protein has been found to elevate plasma and intracellular leucine levels greater than casein (Tipton *et al*., 2004; Tang *et al*., 2009). Greater circulating concentrations of leucine after ingestion of whey protein, compared with casein protein are associated with elevated rates of MPS (Pennings *et al*., 2011). Studies have identified a strong relationship between peak leucine concentrations and MPS (Burd *et al*., 2012; Pennings *et al*., 2011; Phillips, 2014). Whey protein is readily digested, rapidly increasing amino acid availability, thereby making it ideal to consume post exercise (Pasiakos *et al*., 2014). Whey protein and casein protein possess different patterns of amino acid release which lead to differential levels of protein synthesis and protein breakdown (Kerksick *et al*., 2006). Whey protein provides a post exercise insulin response such that net protein balance can be slightly smaller and

glycogen resynthesis occurs more rapidly, thus, the recovery from exercise may be enhanced (Hulmi *et al*., 2010).

Protein recommendations must consider factors known to regulate amino acid utilisation for muscle remodelling; timing, pattern, co-ingestion, source, dose (MacNaughton *et al*., 2016). High quality protein such as whey, effectively stimulates the synthesis of myofibrillar and sarcoplasmic protein tractions in muscle under resting conditions and in response to resistance exercise (Moore *et al*., 2009). Whey protein, in hydrolysate form (pre-digested), compared to placebo and whey protein has been shown to accelerate recovery of muscle force generating capacity following eccentric exercise (Buckley *et al*., 2010). Fast absorbing hydrolysed whey protein, which has free amino acids, needs to be ingested both immediately following the exercise bout, and in the days during recovery in order to maximise protein synthesis (Cooke *et al*., 2010). Nutritional mixtures containing whey protein hydrolysate (WPH) greatly augment plasma amino acids concentrations and insulin response compared to milk-based or casein protein mixtures when ingested at rest (Pennings *et al*., 2011). These effects would theoretically lead to an increase in protein synthesis and potentially a more rapid and complete restoration of muscle function following stressful training (West *et al*. 2017).

Tang *et al.* (2009) examined the regulation of protein metabolism in exercise and recovery and concluded that WPH consumption stimulated MPS in young men at a greater rate than that of soy protein (despite also being classified as a fast protein), or casein protein both at rest and after resistance exercise. These findings may be related to the rate at which these proteins are digested or the small differences in leucine content of each protein.

Following resistance exercise, ingestion of whey protein results in increased net protein balance (Tipton *et al*., 2004)**.** Whey protein supplementation is reported as being beneficial in facilitating post resistance exercise recovery by increasing protein synthesis and reducing muscle damage (Buckley *et al*., 2010; Cooke *et al*., 2010; Berryman *et al*., 2017). In addition, whey protein supplementation enhanced recovery before and after resistance exercise (Hoffman *et al*., 2010) and increased gains in lean body mass compared to soy (Volek, 2013) and in conjunction with resistance training (Hulmi *et al*., 2009). Protein intake provides the required amino acids necessary for improving protein balance which is essential for repairing damaged muscle (Tipton *et al*., 2006). More recently, WPH has been reported to reduce symptoms of EIMD following a repeated sprinting protocol and improve recovery of muscle function in female athletes (Brown *et al*., 2017). Measures of muscle soreness, limb girth, flexibility, muscle function and CK were measured pre, immediately post, and 24, 48 and 72 h post eccentric exercise. Flexibility improved beyond baseline measures, reductions in muscle soreness and CK activity were greater with whey supplementation and resulted in greater attenuation of function loss. Other studies have observed contrasting results (Eddens *et al*., 2017). The reason for these differences in the results may be due to a number of reasons including the participants used, the amount of whey consumed, the timing of whey intake or the nature of the muscle damaging exercise. Eddens *et al*. (2017) induced muscle damage with a concurrent exercise protocol in well trained male cyclists who consumed 20 g of protein hydrolysate over two daily serves from the onset of muscle damaging exercise. Contrastingly, Brown *et al*. (2017) utilised a sprint protocol, following which female participants consumed two doses of 70 mL of WPH.

Table 2.1: Amino acid composition of the proteins. Amounts are shown in g per 20 g protein. AA, amino acids; EAA, Essential AA; NEAA, Non-EAA

	Whey	**Casein**
Alanine (g)	1.0	0.6
Arginine (g)	0.5	0.7
Aspartic acid (g)	2.3	1.3
Cysteine (g)	0.7	0.1
Glutamic acid (g)	3.2	4.1
Glycine (g)	0.4	0.3
Histidine (g)	0.4	0.5
Isoleucine (g)	1.2	1.1
Leucine (g)	2.5	1.7
Lysine (g)	2.1	1.4
Methionine (g)	0.4	0.5
Phenylalanine (g)	0.7	0.9
Proline (g)	0.7	2.1
Serine (g)	0.7	1.3
Threonine (g)	0.9	0.8
Tryptophan (g)	0.5	0.2
Tyrosine (g)	0.8	1.1
Valine (g)	1.0	1.3
Total AA (g)	**20.0**	**20.0**
Total NEAA (g)	**10.7**	**12.1**
Total EAA (g)	**9.3**	**7.9**

2.6.2 Cows milk

The use of cows milk as a recovery and rehydration beverage has become a growing practice among sporting athletes. Based on the current evidence for its use, milk has shown to be an effective post exercise recovery option following resistance exercise (Wilkinson *et al*., 2007) and eccentric exercise (Cockburn, 2010), as well as being as an efficient rehydration option (Shirreffs *et al*., 2007). Milk is a natural source of protein, calcium, potassium, phosphorus, iodine, vitamin B2, B5 and B12 which are vital nutrients that play a key role in generating energy in our bodies, reducing feelings of fatigue and ensuring an overall healthy immune system (National Dairy Council, NDC, 2015). The use of cows milk as an effective post-exercise recovery beverage has been promoted with the '3 R's of exercise recovery' concept (National Dairy Council, NDC, 2015), – (i) refuelling glycogen stores with the provision of carbohydrate lactose, (ii) repairing muscles with whey and casein protein sources and (iii) rehydrating sufficiently with

adequate fluid and electrolytes. Milk is considered a natural, convenient, accessible, inexpensive and generally well tolerated recovery beverage for athletes (National Dairy Council, NDC, 2015).

Consuming carbohydrate as soon as possible following high-intensity and endurance type exercise is necessary for effective replenishment of muscle glycogen stores (Pritchett *et al*., 2011). Studies indicate a greater restoration of exercise capacity with the ingestion of milk post exercise compared to other commercially available sports drinks (Karp *et al*., 2006; Thomas *et al*., 2009). For most athletes, the ability to maximise the storage of glycogen as well as resynthesising post-exercise muscle glycogen stores are important aspects of performance (Burke *et al*., 2017). The carbohydrate content of milk can contribute to glycogen restoration which would be particularly useful for athletes whose participation in exercise results in a depletion of glycogen stores. Unless glycogen stores are sufficiently restored prior to subsequent training, performance will be compromised (Williams *et al*., 2003). To achieve optimum glycogen resynthesis post training and games, a common strategy for team sport players is to consume a mix of carbohydrate and protein. Milk also plays an important role in post-exercise appetite regulation as it has shown to be more satiating compared to carbohydrate drinks due to its protein content (Rumbold *et al*., 2015). This may help enhance recovery from exercise whilst also helping to promote a negative energy balance that would encourage individuals that are interested in weight loss. Milk is comprised of two categories of protein – whey and casein. About 20 % of the protein in commercial cows milk comes from whey (Ha and Zemel, 2003) and 80 % casein by mass (Hartman *et al*., 2007). Milk contains casein and whey in a ratio of 4:1 which allows for slower digestion and absorption of these proteins resulting in sustained elevations of blood amino acid concentrations (Bos *et al*., 2003). Proteins that are ‘complete’ or ‘incomplete’ refer to the essential amino acid availability and the source from which they come from, whether it is animal or plant based. Milk, being an animal based source is a ‘complete’ protein, containing all of the essential amino acids that the body requires. Milk appears to have acute effects on protein metabolism and MPS. Milk consumption increases MPS, leading

to an improved net muscle protein balance (Phillips *et al*., 1997). The metabolic response to protein differs by the type consumed (Rumbold *et al*., 2015). Evidence suggests that dairy protein and especially the whey component, may stimulate the greatest rise in MPS, result in greater muscle cross-sectional area when combined with chronic resistance training and enhance exercise recovery compared to casein and plant based sources (Tang *et al*., 2009; Pennings *et al*., 2011).

Milk's provision of essential amino acids, as well as insulin-stimulating carbohydrate to promote MPS is attributed to its effectiveness (Devries and Phillips, 2015). Casein in milk may be the effective component for rehydration (James *et al*., 2011; James *et al*., 2012). This may be related to the effect of digestion of different proteins on the rehydration process, primarily gastric emptying. The casein content of protein has been reported to clot and coagulate in the stomach (Billeaud *et al*., 1990) and this results in reduced gastric emptying (Burn-Murdoch *et al*., 1978), thus an increase in fluid retention. Contrastingly, whey protein empties faster from the stomach thereby enhancing fluid movement and diuresis (Hall *et al*., 2003). Thus, the ingestion of casein or milk protein might influence the retention of a rehydration solution by reducing the rate at which the drink enters the circulation (Evans *et al*., 2011). The consumption of milk results in increased urine output being reduced leading to net positive fluid balance (Shirreffs *et al*., 2007).

2.6.2.1 Cows milk and resistance exercise

Milk based beverages are more effective in modulating the activation of key intracellular signaling proteins such as AMP involved in protein synthesis during recovery from resistance exercise (Ferguson-Stegall *et al*., 2011). In recovery from sport performance, the amino acid composition of post exercise refueling strategies is very important. The consumption of amino acids following resistance training stimulates protein synthesis resulting in increased net protein synthesis (Tipton *et al*., 2004). There is evidence to suggest that consuming milk after resistance exercise can lead to increased

enhancements in protein metabolism (Hartman *et al*., 2007). In relation to resistance training, the effectiveness of milk post exercise is as a result of the whey content in milk particularly which has been noted for the promotion of muscle mass accretion and hypertrophy (Hartman *et al*., 2007; Wilkinson *et al*., 2007) and body fat loss (Miller *et al*., 2014), in males and females (Josse *et al*., 2010). There are both acute and chronic long-term evidence to support the use of cows milk as a post resistance exercise recovery beverage. The acute benefits of milk were recognised by Wilkinson *et al*. (2007) when eight healthy resistance trained males consumed 500 mL of skimmed milk or a soy beverage following a unilateral leg resistance exercise protocol. Data revealed both groups experienced positive net protein balance, and further analysis displayed an overall greater net balance and greater fractional synthetic rate after skimmed milk ingestion compared to the soy beverage. Elevation in blood amino acids was slower and remained elevated for a more prolonged period in the skimmed milk group, providing a more sustained delivery of amino acids for MPS (Wilkinson *et al*., 2007). More chronic studies in milk and recovery have been conducted (Hartman *et al*., 2007; Josse *et al*., 2010). Hartman *et al*. (2007) reported greater hypertrophy and greater fat free mass after consuming 500 mL of skimmed milk immediately and 1 h post resistance exercise in novice weight-lighters who trained for 5 days over a 12 - week period in comparison to soy milk or a CHO control. Josse *et al*. (2010) undertook the same protocol with recreationally active women (milk versus CHO) and reported greater muscle mass accretion, strength gains and fat mass loss in the milk group.

Consuming amino acids and carbohydrate together has been shown to result in an increased rate of MPS (Miller *et al*., 2003), though recent studies have not reported this (Staple *et al*., 2011) especially if protein intake is sufficient to stimulate MPS maximally (Staples *et al*., 2011). Whole milk ingestion results in greater utilisation of ingested amino acids during exercise recovery versus skimmed milk. This may be due to the slightly higher carbohydrate content (Elliot *et al*., 2006). Skimmed milk had a 0.8 g higher protein count than whole milk (8.8 g vs 8.0 g) and half the energy balance (377 kj vs. 627 kj) but slightly higher carbohydrate content (12.3 g vs 11.4 g). The provision of amino

acids early in the post exercise period may enhance protein synthesis rates, which reach peak values within 2 – 3 h after exercise (Van Loon, 2014).

2.6.2.2 Cows milk and eccentric exercise

Muscle protein breakdown (MPB) and MPS are both stimulated in response to exercise and diet (Maughan and Shirreffs, 2012; Tipton *et al*., 2018). Eccentric exercise protocols result in muscle damage (Eston *et al*., 1995; Howatson and Milak, 2009; Margaritelis *et al*., 2015). Furthermore, the eccentrically demanding nature of team sports increases MPB which results in muscle damage (Cooke *et al*., 2010; Cockburn *et al*., 2013). Therefore, provision of amino acids post-exercise is necessary to stimulate insulin-signalling and the critical mTOR pathway required to achieve net protein synthesis (Ferguson-Stegall *et al*., 2011; Lunn *et al*., 2012). Changes in MPS and MPB may also be crucial for repair and remodelling of muscle proteins following resistance exercise (Witard *et al*., 2016).

Milk's provision of essential amino acids and carbohydrate to promote MPS and demote MPB has a positive effect on performance following eccentric exercise (Hulmi *et al*., 2010). Cockburn *et al*. (2010) demonstrated that 500 mL of semi-skimmed milk post eccentric exercise attenuated EIMD in male athletes and Rankin *et al*. (2015) reported similar benefits with the provision of milk in females post eccentric exercise. Cockburn *et al*. (2008) demonstrated milk-based beverages attenuated increases in CK and Mb at 48 h post-exercise in milk based trials compared to CHO only. Further research by Cockburn *et al*. (2010) demonstrated milk-based carbohydrate-protein immediately or 24 h post muscle-damaging exercise may hasten recovery at 72 h. Five hundred mL of milk was reported to have similar effects on EIMD attenuation as 1,000 mL of milk (Cockburn *et al*., 2012) and 500 mL of milk is effective at attenuating EIMD, demonstrating reduced loss of performance in the team sport demands of agility and sprinting performance (Cockburn *et al*., 2013). This may suggest that there is an upper limit of effect with the added effect of exercise and protein intake. It has been shown

500 mL milk post muscle damaging exercise can limit performance decrements in females and limit serum markers of muscle damage in males and females (Rankin *et al*., 2015). However, in these studies muscle damage was induced with heavily loaded eccentric exercise on an isokinetic machine, a load that far surpasses the usual stress imposed by team sport exercise, and thus investigations utilising more sport-relevant protocols are warranted. The natural nutritional composition of milk provides satisfying protein and carbohydrate contents to stimulate MPS but as suggested by Cockburn *et al*. (2013) and Rankin *et al*. (2015), further investigation into the actual extent of attenuation on EIMD is recommended.

2.6.3 Goats milk

To date, no research has investigated goats milk in relation to exercise performance or as a post exercise recovery drink to maximise recovery.

2.6.3.1 Nutritional content

Goats milk contains slightly more leucine than cows milk (mg.100g^{-1} milk – goat; 341.01 vs. cow; 266.23); (Ceballos *et al*., 2009) and accepting that leucine is a major amino acid in the stimulation of protein synthesis (Churchward-Venne *et al*., 2012), theoretically it may be beneficial in enhancing recovery from exercise, especially exercise that induces muscle damage. Goats milk differs from cows milk in that it results in enhanced digestibility, alkalinity and buffering capacity (Park, 1994). It also has fewer allergenic proteins and causes less inflammation (Park, 1994). The higher protein (goat – 3.5 g.100mL^{-1} *vs.* cow – 3.4 g.100mL^{-1}), non-protein N and phosphate in goats milk results in a greater buffering capacity compared to cows milk (Park, 1991; Park, 1992). Recent studies confirm that nutrients such as iron, calcium, magnesium and phosphorous were more easily digested and used by the body when consumed in goats milk than cows milk (Ceballos *et al*., 2009). Goats milk also had a greater iron bioavailability in anaemic rats than that of cows milk (Park *et al*., 1986). Goats milk is naturally lower in cholesterol and it contains higher amounts of calcium, magnesium and potassium than cows milk but less vitamin D, vitamin B12 and folate (Jandal, 1996; Park, 2007).

Goats milk may be a useful alternative recovery drink for athletes who are lactose intolerant. The sugar in milk is called lactose and the enzyme lactase is responsible for digesting lactose in our bodies. There are certain individuals who have low levels of lactase and have difficulty processing lactose and thus are 'lactose intolerant' (Lomer *et al*., 2008). Symptoms relevant to athletes include abdominal pain, bloating, flatulence, nausea and overall gastrointestinal distress. The symptoms of lactose intolerance include mild to extreme intestinal discomfort, so lactose-intolerant individuals and athletes often choose to eliminate anything containing lactose from their diet. Most people with lactose intolerance can digest about 12 g of lactose which is equal to a large glass of cows milk (250 mL) spread over the day. Goats milk contains 9 g of lactose per 250 mL (Haenlein, 2004). Many athletes who are affected by lactose intolerance or believe that they are, tend to avoid dairy products and as a result ingest inadequate amounts of calcium and vitamin D. This may cause them to be more susceptible to having decreased bone mineral density, osteopenia, osteoporosis, and other adverse health outcomes ultimately hindering sporting performance (Yang *et al*., 2013). Bone health plays a vital part in protein nutrition also. Calcium helps keep bones strong and healthy.

Goats milk contains more beta caseins and less lactose than cows milk, which may make it a more suitable option for those with mild lactose sensitivities. Research has revealed that the alpha-casein proteins found in cows milk are responsible for cows milk allergy (Wal *et al*., 1995; Hochwallner *et al*., 2014). Casein acts as a potent allergen in cows milk allergy where each different fraction (S1-, S2, β- and κ-casein) can induce specific IgE responses (Rangel *et al*., 2016). The four caseins αS1-, αS2- β- and κ-casein bind essential minerals, such as calcium phosphate, that would otherwise precipitate and would not be easily ingested (Marchesseau *et al*., 2002). B-lactoglobulin and alpha-S1 casein are the most common cows milk allergens, although other cows milk proteins may play important roles in some cases (Tsabouri *et al*., 2014; Mills *et al*., 2004).

Despite the fact that goats milk contains some lactose, the softer curd from smaller fat globules assists digestive comfort, making it a better choice for those with stomach sensitivities (Park, 2007). This has never been investigated in an athletic population in relation to exercise performance. There is a prevalence of 2.5 % in children affected by a cows milk allergy during the first three years of their life (Anagnostou *et al*., 2015). Goats milk as a substitute has positively impacted and resolved many of these cases and in particular, one study observed that 49 out of 55 children with cows milk allergy benefited from substitution with goats milk (Haenlein, 2004). Barrionuevo *et al*. (2002) conducted studies with rats, which had 50 % of their distal small intestine removed by resection, simulating the pathological condition of malabsorption syndrome. The feeding of goats milk compared to cows milk as part of the diet resulted in significantly higher digestibility and absorption of iron and copper, thus preventing anaemia. The observed results were attributed to the higher contents of cysteine (derived from cystine) in goats milk (83 $mg.100g^{-1}$) than in cows milk (28 $mg.100g^{-1}$). Fat and weight gain also improved with goats milk in these studies compared to cow milk (Barrionuevo *et al*. 2002). Similar findings were obtained in studies with rats which also revealed oligosaccharides (which act as pre-biotics) in goats milk eased inflammation in rats with colitis and other bowel difficulties (Park *et al*., 1986). There are thought to be four to five times more oligosaccharides in goats milk compared to cows milk (Park *et al*., 2007). Zeng (1996) compared goats milk standards with cows milk standards for analyses of somatic cell count, fat and protein and reported the levels of fat and protein in goats milk samples were 0.04 % and 0.27 % higher, respectively, than with cows milk component standards.

Many people, although not medically diagnosed as being lactose intolerant may experience gastrointestinal discomfort with the digestion of cows milk. These individuals may be referred to as lactose sensitive as opposed to allergic to lactose (Rangel *et al*., 2016). Hence for this population, goats milk may be a viable alternative. Most people do not have clinical lactose intolerance to cows milk but are mal – absorbers and are sensitive to one of the proteins found in it and lack the ability to digest the A1 allele of beta-casein. The issue causing lactose intolerance is likely to be with bovine beta-

cosmorphin-7 (BCM-7) derived from A1-beta casein in regular milk which affects receptors in the GI tract causing motility disorders, inflammation, abdominal pain and loose stools (Pal *et al*., 2015; Yang *et al*., 2013). Goats milk does not contain A1-beta casein, therefore, individuals who cannot tolerate cows milk can often tolerate goats milk. A1 casein can contribute to gastrointestinal issues such as irritable bowel syndrome, Crohn's disease, leaky gut and colitis (Pal *et al*., 2015; Ho *et al*., 2014). Goats milk contains only A2- beta casein, which is not associated with any inflammation responses. Goats milk has a softer curd due to the presence of smaller fat globules which assists digestive enzymes in breaking down more rapidly (Tomotake *et al*., 2006). In addition, goats milk does not contain agglutinin, a substance that causes the fat globules to form clusters. Therefore, this enhances the process of digestion and supports digestive comfort which may enhance its suitability for those with gastrointestinal sensitivities. Goats milk also contains higher levels of short and medium chain fatty acids, enhancing the digestive process (Park, 1991; Park *et al*., 2007). Townsend *et al*. (2017) reported immediate ingestion of carbohydrate and protein after exhaustive exercise may be beneficial, as it decreases bone resorption marker concentrations and increases bone formation marker concentrations, creating a more positive bone turnover balance. Therefore, goats milk, as with cows milk, may be an effective post-exercise recovery beverage for sustaining bone health as it is both a source of carbohydrate and protein and is also higher in calcium.

2.6.3.2 Cows milk vs goats milk

Cows milk and goats milk protein are both comprised of around 80 % casein protein and 20 % whey protein (Hartman *et al*., 2007). Despite having similar nutritional composition and benefits on health, growth and development, cows milk and goats milk may vary in their whey protein concentration levels.

The average size of goats milk fat globules is smaller than that of cow and other species milks enhancing the process of digestion (Par *et al*., 2007). Goats milk also resulted in a greater iron bioavailability in anaemic rats compared to cows milk (Park *et al*., 1986).

Higher levels of nitrogen and phosphate in goats milk correlated with an increase in buffering capacity (Park, 1991). Goats milk proteins may be digested more readily and their amino acids absorbed more efficiently than those of cows milk due to goats milk containing less αS1- casein (Haenlein, 2004; Jenness, 1980). Athletes training and competing in intensive sports need increased protein intake than the more sedentary individual and with goats milk being easier to digest with a slightly more concentrated whey content (Park, 1994) it may make it a more viable choice for certain athletes to meet their daily protein needs.

The average composition of goats milk does not differ remarkably from that of cows milk as detailed in Table 2.2.

Table 2.2 Amino acid composition (mg.100g^{-1} milk) of goats milk and cows milk (Ceballos *et al*., 2009)

Essential amino acids	Goats milk	Cows milk	Difference % for goats milk
Threonine	138.6	115.8	+16.5
Isoleucine	160.5	128.0	+20.2
Leucine	341.0	266.2	+21.9
Lysine	342.8	252.5	+26.3
Methionine	77.9	71.1	+8.7
Cysteine	30.6	23.2	+24.2
Phenylalanine	175.4	133.5	+23.9
Tyrosine	162.5	159.9	+2.5
Valine	210.2	147.8	+29.7
Total	1639.8	1298.3	+20.8

Goats milk has some particular properties that produce advantages in comparison to cows milk, such as a smaller size of fat globules, which provides a smoother texture in derived products, lower amounts of as1-casein, resulting in softer gel products, a higher water holding capacity and a lower viscosity (Haenlein 2004). However, the flavour of goats milk is more intense in comparison to cows milk, which can restrict the acceptance of its derivatives by consumers (Gomes *et al*., 2013).

2.7 CONCLUSION

It is widely known in terms of research that without adequate nutrition after strenuous exercise an athlete will be in a state of negative protein balance (Pasiakos *et al*., 2014). There is evidence that milk leads to positive protein balance (Elliot *et al*., 2006; Lunn *et al*., 2012) . Additionally, the observed benefits of consuming whey protein as a single beverage post exercise provide evidence of enhanced amino acid availability leading to a positive net protein balance making it a convenient post-exercise recovery option (Pasiakos *et al*. 2014). With strenuous exercise there is protein breakdown occurring, therefore consuming cows milk, goats milk or whey protein which contains the key protein components will limit that breakdown and enhance the repair.

Furthermore, milk provides many nutrients such as essential amino acids, BCAAs and both whey and casein protein that when consumed, amino acids in the blood are raised for longer impacting the rate of protein synthesis. Milk also contains carbohydrate in the form of lactose and there is some evidence that carbohydrate raises insulin and that can inhibit protein breakdown (Dimitriadis *et al*., 2011; Figueiredo and Cameron-Smith, 2013). Previous research reports cows milk is a beneficial recovery intervention from strenuous exercise with an eccentric component in both males and females (Cockburn *et al*., 2008; Cockburn *et al*., 2010; Rankin *et al*., 2015). Goats milk contains a slightly higher leucine content than cows milk and accepting that leucine is a major amino acid in the stimulation of protein synthesis, theoretically it may be beneficial in recovery from exercise, especially exercise that induces muscle damage (Park, 2007). The concept that leucine ingestion and plasma leucine concentrations are key regulators of MPS has been supported recently by Gorrisen and Witard (2018), reporting plant-based proteins with leucine co-ingestion can further augment the postprandial muscle protein synthetic response. Van Vliet *et al*. (2015) have agreed that despite the proposed lower anabolic properties of plant versus animal proteins, various strategies may be applied to augment the anabolic properties of plant proteins such as the fortification of plant-based protein sources with leucine. Dairy proteins stimulate MPS to a greater extent than plant-based proteins (Wilkinson *et al*., 2007), and whey protein stimulates MPS to a greater extent than casein protein (Tang *et al*., 2009), thus, the choice of protein often depends on the

application. To date, no research has investigated goats milk in relation to exercise performance or as a post-exercise recovery drink to maximise recovery.

To restate, the purpose of this study is to investigate the effects of cows milk, goats milk, whey protein and an energy matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes. The hypotheses are as follows: (i) Protein containing drinks are more effective in attenuating the effects of EIMD compared to an energy matched carbohydrate drink (ii) Goats milk is as effective as cows milk and whey protein in attenuating the effects of EIMD.

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

3.1 Participants

Thirty – two collegiate team sport players (male n=16; female n=16) took part in this study. Mean (± SD) height, body mass, and age for male participants were 181.5 ± 6.9 cm, 79.9 ± 10.7 kg, 22.8 ± 3.5 yr, respectively, and for females were 164.9 ± 5.6 cm, 62.0 ± 8.2 kg, 20.6 ± 1.7 yr, respectively. Anthropometric measures can be found in Table 3.1. Prior to participation, volunteers completed a medical health screening questionnaire (Appendix C) and were excluded from the study if they met any of the following criteria: current or recent use of nutritional supplements, intolerance to dairy or lactose products, lower limb or back injury in previous three months, surgery in previous 6 months, known coronary disease, uncontrolled metabolic disorder or respiratory disease, pregnancy, post-partum. Following verbal and written briefings (Appendix A), written informed consent (Appendix B) was provided by all participants. Ethics approval (Ethical Application Number 159) was given from the Ethics Committee in IT Carlow.

There were several procedures put in place to protect the confidentiality of participants. Each participant was allocated an individual participant code used to identify any data they provided and to ensure anonymity. Participant names or other personal details were not associated with data, for example, the consent form each participant signed was kept separate from their data. All paper records were stored in a locked filing cabinet, accessible only to the research team, and all electronic data was stored on a password protected computer.

Table 3.1 Group mean anthropometric information

GROUPS	COW	GOAT	WHEY	CHO
Male Participants	*n*=4	*n*=4	*n*=4	*n*=4
Female Participants	*n*=4	*n*=4	*n*=4	*n*=4
Height (cm)	172.1	176.3	169.8	174.5
Body Mass (kg)	70.1	77.1	66.9	69.7
Age (yr)	22.9	20.4	21.5	22.4
Training Sessions	3 – 5 weekly	3 – 5 weekly	3 – 5 weekly	3 – 5 weekly
Sport Played	Field based	Field based	Field based	Field based

3.2 Study Design

The study utilised an independent group design that required participants to visit the laboratory on six separate occasions, participants were equally divided into four groups: cows milk (COW), goats milk (GOAT), whey protein (WHEY), or the control group - an energy matched carbohydrate drink (CHO). Groups were matched according to peak torque of the dominant leg knee extensors at 60°.s^{-1} on a Biodex System3 Isokinetic dynamometer (Biodex Medical System, NY, USA). Visits two, three, 4 and 5 were conducted on consecutive days no more than 7 days after familiarisation, with all visits taking place at the same time of day following an overnight fast and 24 h abstinence from alcohol, caffeine and exercise which was self-reported. Familiarisation involved participants completing the procedures for each of the dependent variables. Following baseline measures participants completed a muscle damage-inducing exercise protocol comprising repeat sprinting and jumping as outlined below. Participants returned to the laboratory at 2 h (blood sample only), 24, 48 and 72 h post-muscle damaging exercise to repeat baseline measures. Participants were requested to refrain from strenuous activity for the duration of the study, and from treating the symptoms of muscle damage and soreness with interventions such as nutritional supplements, massage, cryotherapy and nonsteroidal anti-inflammatory drugs. Assessment of muscle damage (CK), soreness and tiredness (VAS), perceived recovery (DALDA), Palatability (Likert Scale), and muscle function (PkTq), (RFD), (Sp), (CMJ), (RSI), took place pre- and 24h, 48h, and 72 h post-exercise.

Table 3.2 Participant involvement

Visit	Duration	What I will do
Visit 1: Familiarisation	I hour	Health screening questionnaire; consent form; S/T, BS, PkTq, RFD, CMJ, RSI, Sp
Visit 2: Baseline easures	40 min	S/T, BS, PkTq, RFD, CMJ, RSI, Sp
Visit 3: Exercise Protocol	3 hours in total (1 h for exercise protocol & return 2 h later for blood sample)	10min warm up 20 x 20 m maximal sprints 8 sets of 10 plyometric jumps 10min cool down Consumption of fluid Palatability (Likert Scale) 2 h fast Provision of blood sample
Visits 4-6	30 min	PR, S/T, BS, PkTq, RFD, CMJ, RSI, Sp

BS: blood sample; S/T: soreness/tiredness; PR: perception of recovery, Sp: sprint

3.3 Muscle Damage Inducing Exercise Protocol

The aim of the exercise protocol was to incorporate exercise activities indicative of team field sport performance. All participants completed a 10 min warm up consisting of self-paced jogging, sprint drills and sprints at 60 %, 80 % and 100 % of perceived maximum speed (Howatson and Milak, 2009). Participants then lined up at a marker 30 cm from the start line and completed 20 x 20 m sprints. Participants were instructed to sprint maximally and stop within the 10 m deceleration zone which was marked out immediately after the 20 m sprint. Standardised verbal encouragement was provided to all participants for each sprint and they had 30 s rest between each completed sprint. Following a second rest period, participants completed 8 sets of 10 plyometric jumps, a protocol which has been shown to induce muscle damage (Marginson, 2005). With feet shoulder width apart and hands on the hips, participants were asked to flex their knees to approximately 90 degrees, and to jump as high as possible on each jump. Each set of 10 continuous maximal jumps were separated by a one minute rest period during which participants walked around (Marginson, 2005). Upon completion of the jumping protocol, participants completed a standard cool-down.

3.4 Dietary control

Immediately following the sprinting/jumping exercise protocol on visit three, participants were provided with either 750 mL of cows milk (*n*=8), 750 mL of goats milk (*n*=8), 750 mL of whey protein (*n*=8), or 750 mL of an energy-matched carbohydrate solution (*n*=8), which consisted of glucose mixed with water and a commercially available orange flavoured fruit cordial. Each drink was consumed within 30 minutes post exercise. This amount of fluid provided between 25 - 26 g of protein (for each of the protein drinks but not CHO) as seen in Table 3.3, which has been shown in previous research as an adequate amount to stimulate maximal protein synthesis (Tang *et al*., 2009; Burd *et al*., 2012). 750 mL provided the required amount of protein and was unlikely to cause stomach upset.

Table 3.3 Nutritional information regarding the macronutrient composition of drinks

	COWS MILK (Per 750mL**)**	**GOATS MILK (Per 750**mL**)**	**WHEY PROTEIN (Per 750**mL**)**	**CHO (Per 750**mL**)**
Energy (kCal)	479.25	508.5	480.1	480.0
Protein (g)	25.5	26.25	25.4	0.0
Carbohydrate (g)	35.25	36.75	89.0	120.0
Fat (g)	26.25	28.5	2.5	0.0

All four drinks were volume matched (750 mL). Cows milk, goats milk and whey protein had similar protein contents (25 g, 26 g, 25 g, respectively), and all four drinks had similar energy content. The energy content of both cows milk and goats milk is stated as 64kcal.100mL^{-1} by the manufacturers (480kcal.750mL^{-1}), though the macronutrient calculation of the goats milk suggests that the manufacturer has subtracted 1.25kCal.g^{-1} protein to correct for incomplete digestibility. During familiarisation, each participant was provided with a weighing scale and a measuring jug to record their daily food and fluid intake. Having been instructed to maintain their habitual diet in order to monitor and track food intake that may have had an impacting factor, participants completed a food diary for 4 days following baseline measurements which were analysed using Nutritics Professional Diet Analysis, Nutritics Ltd. Dublin, Ireland.

3.5 Outcome Measures

3.5.1 Blood sampling

On each day, prior to any other measures and two hours post completion of the exercise protocol a blood sample was collected by venepuncture from a forearm vein in 8.5 mL serum separator (SST) tubes. Tubes were centrifuged at 3,000 rev.min^{-1} for 15 min before the serum was removed and immediately stored in aliquots at −70 °C for later analysis. Creatine kinase (CK) was measured as a marker of muscle membrane disruption (Baird *et al*., 2012). Total serum CK was analysed using Randox RX Daytona clinical chemical analyser (Randox Laboratories Ltd., 55 Diamond Road, Crumlin, Co. Antrim, United Kingdom, BT29 4QY). Coefficients of variation for this system are reported as below 2 % by Randox.

3.5.2 Peak Torque

Following a standardised 5 minute warm up on a Wattbike, (Wattbike Ltd, Nottingham, UK) participants completed three bilateral maximal efforts of knee flexion and extension at 60 and 180°.s^{-1}, with 60 s recovery between speeds and approximately 3 min between legs on a Biodex System3 Isokinetic dynamometer (Biodex Medical System, NY, USA). Immediate post-exercise measures of peak torque were not recorded as measurement at this time is more likely to be reflective of metabolic fatigue rather than injury to the muscle (Warrant *et al*., 1999). All participants were instructed to give maximal effort and to complete full range of motion at the knee for each repetition. Interclass correlations co-efficients for this protocol are 0.83-0.94 which is deemed to be a good to excellent level reliability (Lehance *et al*., 2005).

3.5.3 Rate of Force Development

Rate of force development (RFD) was determined over the first 200 ms of an isometric contraction as reported in previous studies (Aagaard *et al*., 2002; Holtermann *et al*., 2007). Two maximal 5 s bilateral isometric contractions of the quadriceps were performed on the same isokinetic dynamometer used for isokinetic peak torque measurements, with the knee fixed at an angle of 70° (0° = full extension). Participants were instructed to contract and push away as fast and forcefully as possible. RFD ($Nm.s^{-1}$) was determined from the repetition with the highest torque measurement i.e. over the time interval of 0-200 ms (Δtorque/Δtime) relative to the onset of contraction, which was defined as the time point when the torque generated exceeded the baseline by >7.5 Nm (Aagaard *et al*., 2002; Holtermann *et al*., 2007).

3.5.4 Countermovement Jump Height

Countermovement jump height (cm) was measured in cm using an Optojump optical measurement system (Microgate, Bolzano, Italy). Standing with feet shoulder width apart and hands placed on hips, participants were required to flex their knees to approximately 90° and then, in one continuous movement, jump vertically for maximum height. Jump height was calculated from flight time and each participant completed

three jumps; the highest recorded jump was used for analysis. Interclass correlations co-efficients, from reliability trials for this protocol are 0.97–0.98 (Glatthorn *et al*. 2011).

3.5.5 Reactive Strength Index

Reactive Strength Index (RSI) was determined from dividing jump height (cm) by ground contact time (ms) following the execution of three maximal effort drop jumps from a height of 45 cm as in previous research (Flanagan *et al*., 2008). The RSI measurement is sensitive to prior experience of testing (Healy *et al*., 2006), and all participants had previous experience of this measure. Participants were instructed to spend as little time as possible in contact with the ground when landing from the drop height, and to jump as high as possible. Hands were maintained on the hips for the duration of the jump to eliminate any contribution of arm swing and participants stepped of the box with the same leading leg each time. Ground contact time and flight time were measured using the Optojump optical measurement system (Microgate, Bolzano, Italy).

3.5.6 Sprint Performance

For the determination of sprint performance, 20 m sprint time with split 5 m and 10 m times, from a standing start 20 cm behind the start line was measured using timing gates (Microgate Racetime 2, Bolzano, Italy). Each participant was instructed to sprint through the timing gates as fast as possible, completing three sprints in total, with a rest time of 60 seconds between trials. The fastest sprint time was used for analysis. ICC from reliability trials for this protocol are 0.89–0.98 (Healy *et al*., 2016).

3.5.7 Muscle Soreness and Tiredness

Active muscle soreness immediately after squatting to approximately 90° knee flexion was measured on a VAS; (Bijur *et al*., 2001; Twist and Eston, 2005) with participants rating their level of soreness on a scale of 0 (no soreness) to 10 (as bad as it could be). A similar VAS was used to measure muscle tiredness, with 0 indicating no tiredness, and 10 indicating as tired as could be. Using similar scales, previous research has reported

increased levels of muscle soreness following EIMD (Nosaka *et al*., 2002; Lewis *et al*., 2012).

3.5.8 Perception of Recovery

Perception of recovery was monitored using a validated questionnaire – Daily Analysis of Life Demands for Athletes (DALDA) (Appendix G). The questionnaire is made up of part A and part B with a list of stressors to describe the athlete's response to training over the consecutive testing days (Saw *et al*., 2016; Crowther *et al*., 2017). Participants had the option of ticking 'normal', 'worse than normal', 'better than normal' for each stressor. Data from part B (symptoms of stress) were utilised for analysis. Participants completed the questionnaire daily prior to provision of venous blood sample.

3.5.9 Palatability

Palatability was measured using a validated 5 - point Likert scale (Flint *et al*., 2000; Veling *et al*., 2013) in which participants answered questions regarding the smell, taste, aftertaste and palatability of each drink outlined in section 3.5 (1 – good/none, 5 – bad/much) and rated their stomach comfort after consumption of assigned drink (1 – very comfortable, 5 – very uncomfortable) (Appendix H). Experiences and comparisons can be measured indirectly with a standardised assumption scale among groups such as that of the Likert Scale (Bartoshuk *et al*. 2003).

3.6 Statistical Analysis

Data were analysed by making probabilistic magnitude based inferences (MBI) about the true value of outcomes as described by Batterham and Hopkins (2006). This approach to data analysis has become more common in sport and exercise research, including nutritional interventions (Saunders *et al*., 2013; Highton *et al*., 2013; Braakhuis *et al*., 2014; D'Lugos *et al*., 2016), and those with smaller sample sizes as seen in this study. There is increased suspicion that null hypothesis testing is flawed given that a *P* value cannot measure the probability that the hypothesis is true and cannot measure

the size of an effect or the importance of a result (Bernards *et al*. 2017). The term 'significant' has been used to equate to 'important' (Cumming 2014) when, in fact, a significant statistic (P<0.05), could represent an effect that is not clinically or practically relevant (Batterham and Hopkins, 2006). By defining the smallest practical or biological effect, the probability of a worthwhile effect with inferential descriptions is possible. Additionally, it has been shown that MBI outperforms null hypothesis testing in terms of Type-1 and Type-11 error rates (Hopkins and Batterham 2016). Thus, MBI is an alternative to traditional null-hypothesis testing (Wilkinson, 2014;Bernards *et al.,* 2017). An effect is classified in terms of its size as beneficial, harmful or trivial. The limiting case is 25 % chance of benefit and 0.5 % risk of harm (Batterham and Hopkins, 2006). Therefore, an outcome showing harmful effect, does not necessarily quantify the other condition as beneficial. Qualitative inference was the likelihood that the true value would have the observed magnitude at 90 % confidence intervals to encompass the actual 'true' population value (Barde and Barde 2012). The effect of cows milk, versus goats milk, versus whey protein versus an energy-matched carbohydrate drink was analysed using a published spreadsheet for analysis of a controlled trial (Hopkins, 2006). Comparisons were made between baseline and all other time points (baseline - 24 h, baseline - 48 h, baseline - 72 h). Data for peak torque, countermovement jump, sprint performance, RSI and RFD were log-transformed to diminish the effects of non-uniformity and overcome heteroscedastic error (Nevill *et al*., 1995; Nevill *et al*., 2008). Means of log-transformed data were then back transformed to provide mean percentage change and percentage standard deviation (SD). In order to know the variability within the sample and not proximity of mean to the population mean, data was summarised with SD and not with SEM (Lang 2004; Jaykaran *et al*. 2010). CK is reported as factor because of large percentage changes (Batterham *et al*., 2005). The smallest worthwhile effect was the smallest Cohen change in the mean: 0.2 times the between-subject SD for the baseline values of all participants (Batterham and Hopkins, 2006). Effect Size (ES) magnitudes were calculated as the mean difference between two groups and then dividing the result by the pooled standard deviation for all four groups. They were graded according to Cohen's *d* and were classified as follows: trivial, 0.00 – 0.2, small, 0.2 – 0.6, moderate, 0.6 - 1.2, large, 1.2 - 2.0, very large, 2.0 - 4.0, extremely large 4.0. ES thresholds for measures of soreness and tiredness were set at 10 %, 30 %,

50 %, 70 %, 90 % of the VAS and Likert Scale range for small, moderate, large, very large and extremely large respectively.

CHAPTER 4

RESULTS

4.0 RESULTS

Analysis of results presented some clear and unclear outcomes, with limited consistent trends observed. Additionally, comparisons between beverages were not conclusive but typically the protein sources tended to result in more beneficial performance results than the control.

4.1 Within group results

Completion of the exercise protocol resulted in EIMD for all participants. Analysis of within-group effects revealed small/moderate post-exercise decreases in peak torque, CMJ, RSI, sprint performance and RFD, increases in serum CK, DALDA, muscle soreness and tiredness. Please refer to Appendix J for within groups analysis results.

4.2 Countermovement jump (CMJ)

Baseline CMJ heights prior to the muscle damaging exercise for GOAT, COW, WHEY and CHO were 26.0 ± 6.0 cm, 28.4 ± 7.4 cm, 28.6 ± 6.9 cm and 28.4 ± 7.2 cm, respectively. Changes in CMJ performance can be seen in Figure 4.1.

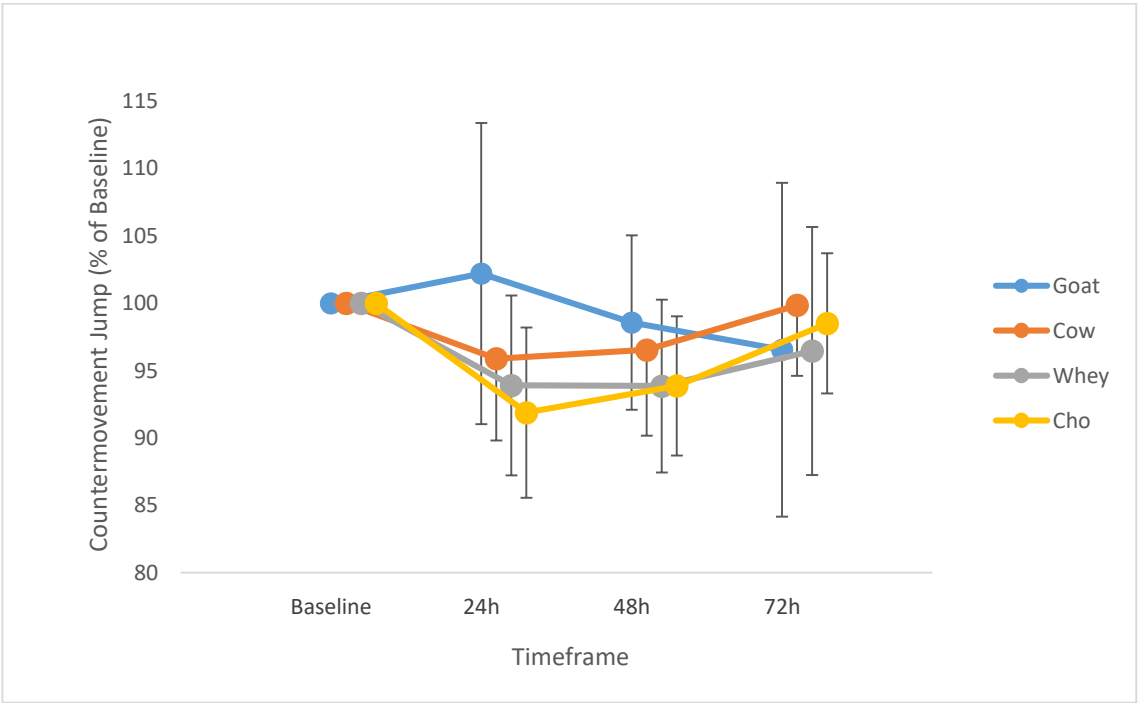

Figure 4.1 Percentage change in countermovement jump in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between GOAT and CHO from baseline to 24h showed a likely small beneficial effect for those consuming GOAT (2.2±11.2% *vs.* -8.1±6.8%, GOAT *vs.* CHO, respectively) and a possible trivial beneficial effect from baseline to 48h (-1.4±6.5% *vs.* -6.1±5.2%, GOAT *vs.* CHO, respectively). Peculiarly, GOAT demonstrated a possible trivial harmful effect from baseline to 72h (-3.4±12.4% *vs.* -1.5±5.2%, respectively). From baseline to 24h, comparisons between COW and CHO showed a possible trivial beneficial effect for those consuming COW (-4.1±6.1% *vs.* -8.1±6.3%, COW *vs.* CHO, respectively). Comparisons between COW and WHEY from baseline to 24h showed a possible trivial harmful effect for WHEY (-4.1±6.1% *vs.* -6.1±6.8%, COW *vs.* WHEY, respectively) and from baseline to 48h (-3.5±6.4% *vs.* -6.1±6.4%, respectively). From baseline to 24h GOAT had a possible small beneficial effect compared to COW (2.2±11.2% *vs.* -4.1±6.1%, GOAT *vs.* COW, respectively) but had a possible trivial harmful effect from baseline to 72 h (-3.4±12.4% *vs.* 0.1±5.3%, respectively). GOAT compared to WHEY had a possible trivial beneficial effect from baseline to 48h (-1.4±6.5%, *vs.* -6.1±6.4%, GOAT *vs.* WHEY, respectively). When compared to CHO, WHEY had a possible trivial harmful effect from baseline to 72h (-3.5±9.2% *vs.* -1.5±5.2%, WHEY *vs.* CHO, respectively). All other comparisons were unclear.

A summary of the statistical analysis for CMJ can be seen in Table 4.1.

Table 4.1 Effect on CMJ following muscle damaging exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
CMJ				
Cow *vs.* Cho	B - 24	-4.2, ± 4.8	COW Possibly Beneficial	Trivial (0.16)
	B - 48	-2.7, ± 4.6	Likely Trivial	Trivial (0.11)
	B - 72	-1.3, ± 4.4	Likely Trivial	Trivial (0.05)
Cow *vs.* Whey	B - 24	4.4, ± 13.3	WHEY Possibly Harmful	Trivial (0.08)
	B - 48	-2.8, ± 5.8	Possibly Trivial	Trivial (0.14)
	B - 72	-3.7, ± 7.5	Unclear	Trivial (0.16)
Goat *vs.* Cho	B - 24	-10.6, ± 7.7	GOAT Likely Beneficial	Small (0.41)
	B - 48	-5.4, ± 5.3	GOAT Possibly Beneficial	Trivial (0.18)
	B - 72	2.7, ± 9.5	GOAT Possibly Harmful	Trivial (0.12)
Goat *vs.* Whey	B - 24	-4.8, ± 9.7	Unclear	Small (0.24)
	B - 48	-4.8, ± 6.4	GOAT Possibly Beneficial	Trivial (0.19)
	B - 72	1.1, ± 10.9	Possibly Trivial	Trivial (0.03)
Goat *vs.* Cow	B - 24	-6.9, ± 7.8	GOAT Possibly Beneficial	Small (0.24)
	B - 48	-3.0, ± 5.6	Possibly Trivial	Trivial (0.07)
	B - 72	4.0, ± 9.6	GOAT Possibly Harmful	Trivial (0.17)
Whey *vs.* Cho	B - 24	-4.9, ± 7.8	Unclear	Trivial (0.12)
	B - 48	0.1, ± 5.8	Likely Trivial	Trivial (0.05)
	B - 72	2.4, ± 0.8	WHEY Possibly Harmful	Trivial (0.11)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.3 Peak torque 60°.s^{-1} dominant leg extension

Immediately prior to the muscle damaging exercise peak torque values for dominant leg extension at 60°.s^{-1} for GOAT, COW, WHEY and CHO were 178.6 ± 80.5, 174.0 ± 51.0, 155.3 ± 42.9 and 171.8 ± 59.9 Nm, respectively. Changes in peak torque at 60°.s^{-1} for dominant leg extension can be seen in Figure 4.2.

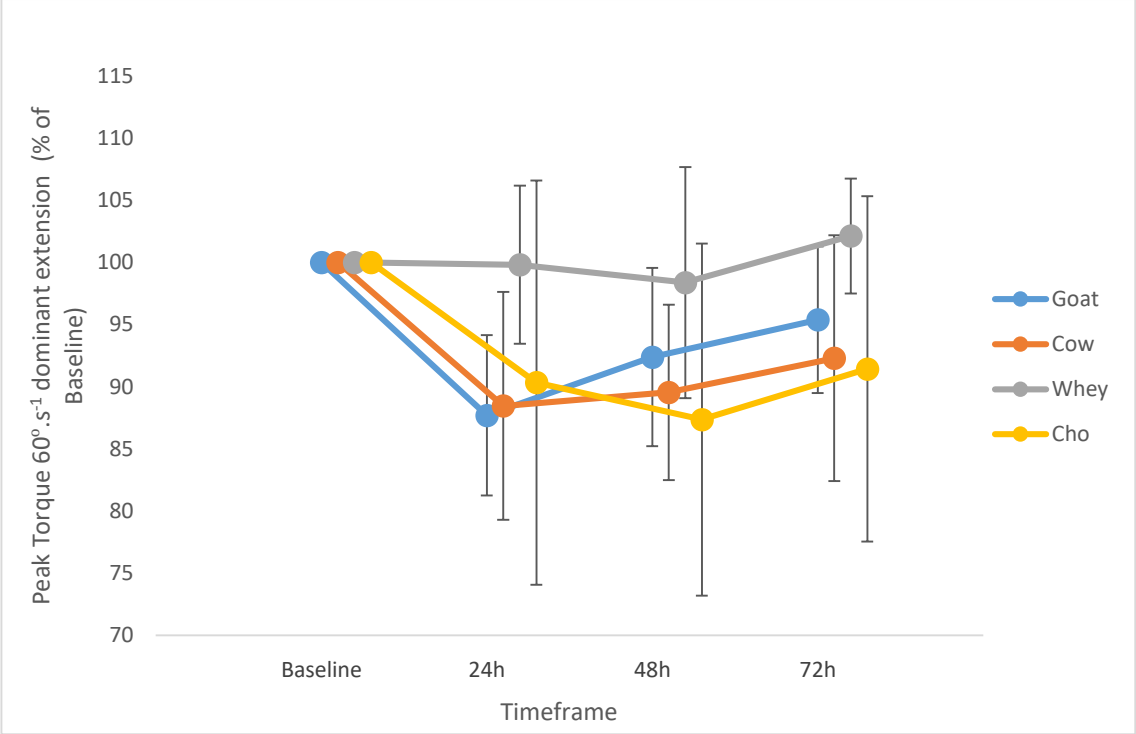

Figure 4.2: Percentage change in peak torque at 60°.s^{-1} for dominant leg extension in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW compared to WHEY, had a likely small harmful effect from baseline to 24h (-11.5±9.2% *vs.* -0.2±6.4%, COW *vs.* WHEY, respectively), a possible small harmful effect was observed from baseline to 48h (-10.5±7.1% *vs.* 1.6±9.3%, respectively) and a likely small harmful effect from baseline to 72h (-7.7±9.9% *vs.* 2.1±4.6%, respectively). At 48h post muscle damaging exercise comparisons between GOAT and CHO showed a possible trivial beneficial effect for GOAT and another possible trivial beneficial effect from baseline to 72h (-4.6±5.9% *vs.* -8.6±13.9%, respectively). WHEY in comparison to GOAT had a likely small beneficial effect from baseline to 24h, (-0.2±6.4% *vs.* -12.3±6.4%, WHEY *vs.* GOAT, respectively). WHEY had a possible trivial beneficial effect from baseline to 48h (-1.6±9.3% *vs.* -7.6±7.2%, respectively) and a possible small beneficial effect from baseline to 72h (2.1±4.6% *vs.* -4.6±5.9%, respectively). WHEY had a possible small beneficial effect from baseline to 24h when compared to CHO (-0.2±6.4% *vs.* -9.7±16.3%, WHEY *vs.* CHO, respectively), and subsequently had a likely small beneficial effect from baseline to 48h (-1.6±9.3% *vs.* -12.6±14.1%, respectively) and a likely small beneficial

effect from baseline to 72h (2.1±4.6% *vs.* -8.6±13.9%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the dominant leg at 60°.s^{-1} extension can be seen in Table 4.2.

Table 4.2 Effect on peak torque 60°.s^{-1} dominant leg extension following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 60°/s Dominant Extension				
Cow *vs.* Cho	B - 24	1.1, ± 14.7	Possibly Trivial	Trivial (0.06)
	B - 48	-3.4, ± 12.6	Unclear	Trivial (0.03)
	B - 72	-1.5, ± 13.1	Possibly Trivial	Trivial (0.05)
Cow *vs.* Whey	B - 24	13.8, ± 10.3	COW Likely Harmful	Small (0.37)
	B - 48	9.7, ± 9.2	COW Possibly Harmful	Small (0.32)
	B - 72	13.2, ± 11.1	COW Likely Harmful	Small (0.42)
Goat *vs.* Cho	B - 24	1.8, ± 13.7	Possibly Trivial	Trivial (0.03)
	B - 48	6.5, ± 14.0	GOAT Possibly Beneficial	Trivial (0.11)
	B - 72	5.5, ± 12.9	GOAT Possibly Beneficial	Trivial (0.12)
Goat *vs.* Whey	B - 24	-13.3, ± 6.3	WHEY Likely Beneficial	Small (0.27)
	B - 48	-6.8, ± 7.9	WHEY Possibly Beneficial	Trivial (0.16)
	B - 72	-8.4, ± 6.6	WHEY Possibly Beneficial	Small (0.23)
Goat *vs.* Cow	B - 24	0.5, ± 8.7	Likely Trivial	Trivial (0.02)
	B - 48	-3.1, ± 7.2	Likely Trivial	Trivial (0.10)
	B - 72	-3.6, ± 8.7	Likely Trivial	Trivial (0.08)
Whey *vs.* Cho	B - 24	-11.5, ± 12.5	WHEY Possibly Beneficial	Small (0.29)
	B - 48	-12.6, ± 11.9	WHEY Likely Beneficial	Small (0.34)
	B - 72	-12.8, ± 10.9	WHEY Likely Beneficial	Small (0.43)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.4 Peak torque 60°.s^{-1} non-dominant leg extension

At baseline the peak torque values for non-dominant leg extension at 60°.s^{-1} for GOAT, COW, WHEY and CHO were 169.2 ± 67.5, 159.6 ± 42.1, 143.9 ± 36.7, 167.4 ± 50.8 Nm, respectively. Changes in peak torque at 60°.s^{-1} for non-dominant leg extension can be seen in Figure 4.3.

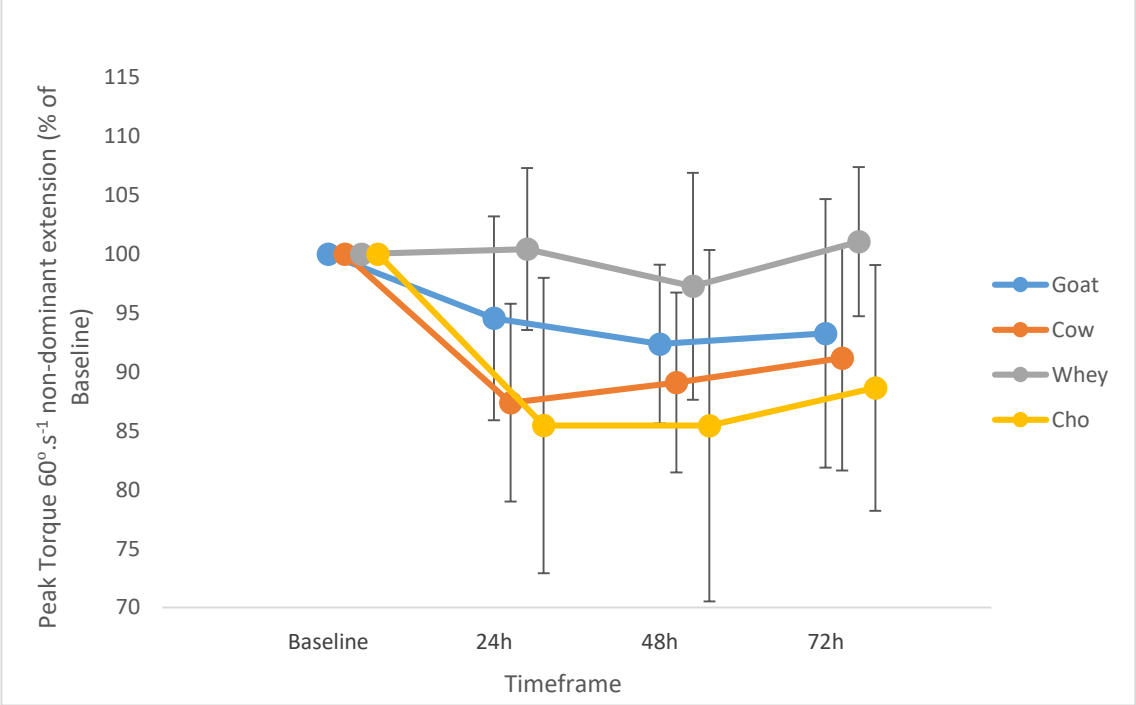

Figure 4.3 Percentage change in peak torque at 60°.s^{-1} for non-dominant leg extension in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Compared to WHEY, COW had a very likely small harmful effect from baseline to 24h (-12.6±8.4% *vs.* 0.4±6.9%, COW *vs.* WHEY, respectively), a possible small harmful effect from baseline to 48h (-10.9±7.6% *vs.* 2.7±9.6%, respectively) and a likely small harmful effect from baseline to 72h (-8.8±9.5% *vs.* 1.1±6.3%, respectively). At 24h post muscle damaging exercise, GOAT compared to CHO had a possible small beneficial effect (-5.4±8.6% *vs.* -14.5±12.5%, GOAT *vs.* CHO, respectively). GOAT had a possible trivial beneficial effect from baseline to 48h (-7.6±6.7% *vs.* -14.6±14.9%, respectively) and from baseline to 72h (-6.7±11.4% *vs.* -11.4±10.4%, respectively). Comparisons between WHEY and GOAT demonstrated a possible small beneficial effect for WHEY from baseline to 24h (0.4±6.9% *vs.* -5.4±8.6%, WHEY *vs.* GOAT, respectively) and from baseline to 72h (1.1±6.3% *vs.* -6.7±11.4%, respectively). In comparison to COW, GOAT had a possible small beneficial effect from baseline to 24h (-5.4±8.6% *vs.* -12.6±8.4%, GOAT *vs.* COW, respectively). WHEY had a very likely small beneficial effect compared to CHO from baseline to 24h (0.4±6.9% *vs.* -14.5±12.5%, WHEY *vs.* CHO, respectively), a likely small beneficial effect was observed from baseline to 48h (-2.7±9.6% *vs.* -14.6±14.9%,

respectively) and another likely small beneficial effect from baseline to 72h (1.1±6.3% *vs.* -11.4±10.4%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the non-dominant leg at 60°.s^{-1} extension can be seen in Table 4.3.

Table 4.3 Effect on peak torque 60°.s^{-1} non-dominant leg extension following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 60°/s Non Dominant Extension				
Cow *vs.* Cho	B - 24	-3.0, ± 10.9	Unclear	Trivial (0.01)
	B - 48	-5.5, ± 13.0	Unclear	Trivial (0.10)
	B - 72	-3.1, ± 10.8	Unclear	Trivial (0.09)
Cow *vs.* Whey	B - 24	17.4, ± 11.0	COW Very Likely Harmful	Small (0.56)
	B - 48	9.5, ± 9.8	COW Possibly Harmful	Small (0.30)
	B - 72	13.8, ± 11.3	COW Likely Harmful	Small (0.40)
Goat *vs.* Cho	B - 24	11.1, ± 12.1	GOAT Possibly Beneficial	Small (0.22)
	B - 48	9.3, ± 14.6	GOAT Possibly Beneficial	Trivial (0.12)
	B - 72	5.2, ± 12.4	GOAT Possibly Beneficial	Trivial (0.11)
Goat *vs.* Whey	B - 24	-8.8, ± 8.4	WHEY Possibly Beneficial	Small (0.22)
	B - 48	-4.7, ± 7.9	Unclear	Trivial (0.15)
	B - 72	-9.7, ± 9.8	WHEY Possibly Beneficial	Small (0.23)
Goat *vs.* Cow	B - 24	-7.7, ± 8.1	GOAT Possibly Beneficial	Small (0.23)
	B - 48	-3.8, ± 7.2	Unclear	Trivial (0.06)
	B - 72	-2.0, ± 10.7	Possibly Trivial	Trivial (0.05)
Whey *vs.* Cho	B - 24	-18.8, ± 9.4	WHEY Very Likely Beneficial	Small (0.57)
	B - 48	-14.2, ± 12.2	WHEY Likely Beneficial	Small (0.39)
	B - 72	-14.5, ± 9.5	WHEY Likely Beneficial	Small (0.44)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.5 Peak torque 180°.s^{-1} dominant leg extension

Immediately prior to the muscle damaging exercise peak torque values for dominant leg extension at 180°.s^{-1} for GOAT, COW, WHEY and CHO were 129.0 ± 56.6, 119.1 ± 36.8, 112.4 ± 42.6 and 129.9 ± 46.0 Nm, respectively. Changes in peak torque at 180°.s^{-1} for dominant leg extension can be seen in Figure 4.4.

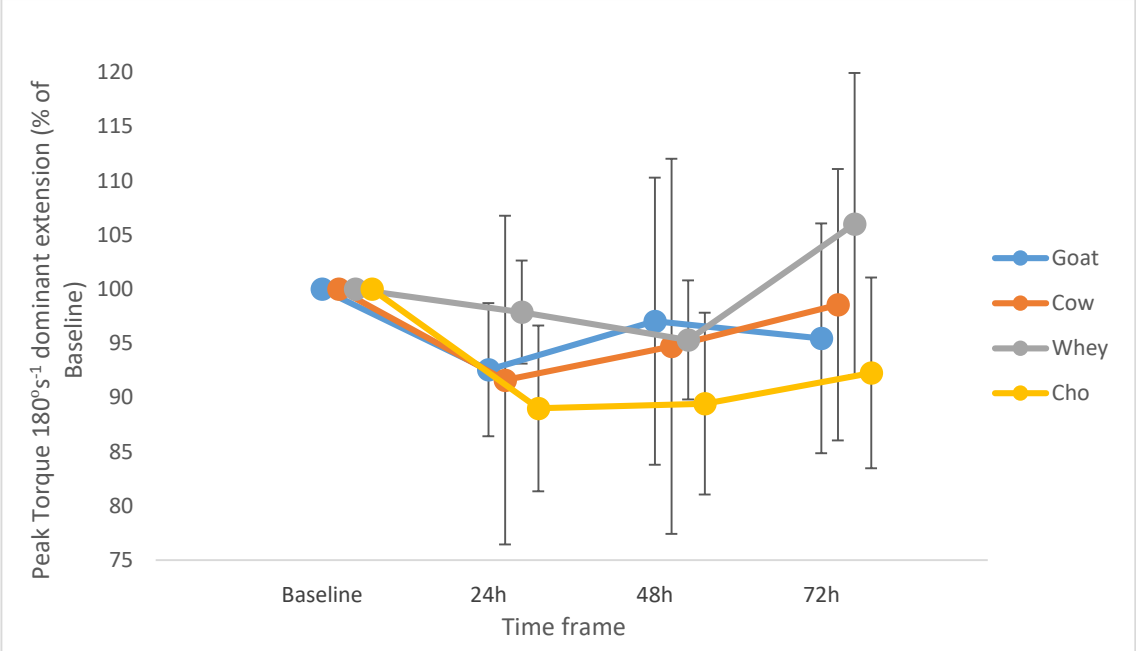

Figure 4.4 Percentage change in peak torque at 180°.s^{-1} for dominant leg extension in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and WHEY demonstrated a possible trivial harmful effect for COW from baseline to 24h (-8.4±15.2% *vs.* -2.1±4.7%, COW *vs.* WHEY, respectively), baseline to 48h (-5.3±17.3% *vs.* -4.7±5.5%, respectively) and baseline to 72h (-1.4±12.5% *vs.* 6.0±13.9%, respectively). Comparisons between GOAT and CHO demonstrated GOAT had a possible small beneficial effect from baseline to 48h (-3.0±13.2% *vs.* -10.6±8.4%, GOAT *vs.* CHO, respectively). WHEY had a possible trivial beneficial effect from baseline to 72h compared to GOAT (6.0±13.9% *vs.* -4.5±10.6%, WHEY *vs.* GOAT, respectively). Comparisons between WHEY and CHO demonstrated a possible trivial beneficial effect for WHEY from baseline to 24h (-2.1±4.7% *vs.* -11.0±7.6%, WHEY *vs.* CHO, respectively), baseline to 48h (-4.7±5.5% *vs.* -10.6±8.4%, respectively) and baseline to 72h (6.0±13.9% *vs.* -7.7±8.8%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the dominant leg at 180°.s^{-1} extension can be seen in Table 4.4.

Table 4.4 Effect on peak torque 180°.s^{-1} dominant leg extension following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 180°/s Dominant Extension				
Cow *vs.* Cho	B - 24	-1.2, ± 13.2	Possibly Trivial	Trivial (0.02)
	B - 48	-4.0, ± 15.9	Unclear	Trivial (0.11)
	B - 72	-5.1, ± 10.1	Unclear	Trivial (0.14)
Cow *vs.* Whey	B - 24	7.4, ± 13.7	COW Possibly Harmful	Trivial (0.17)
	B - 48	2.3, ± 16.4	COW Possibly Harmful	Trivial (0.02)
	B - 72	6.6, ± 12.4	COW Possibly Harmful	Trivial (0.16)
Goat *vs.* Cho	B - 24	4.2, ± 7.9	Likely Trivial	Trivial (0.08)
	B - 48	8.1, ± 12.6	GOAT Possibly Beneficial	Small (0.20)
	B - 72	3.3, ± 10.7	Likely Trivial	Trivial (0.10)
Goat *vs.* Whey	B - 24	-5.1, ± 5.3	Unclear	Trivial (0.09)
	B - 48	0.5, ± 10.6	Likely Trivial	Trivial (0.07)
	B - 72	-8.9, ± 10.6	WHEY Possibly Beneficial	Trivial (0.16)
Goat *vs.* Cow	B - 24	-2.8, ± 12.7	Possibly Trivial	Trivial (0.06)
	B - 48	-3.4, ± 16.7	Unclear	Trivial (0.11)
	B - 72	2.5, ± 12.0	Possibly Trivial	Trivial (0.04)
Whey *vs.* Cho	B - 24	-8.9, ± 6.5	WHEY Possibly Beneficial	Trivial (0.19)
	B - 48	-9.6, ± 9.8	WHEY Possibly Beneficial	Trivial (0.12)
	B - 72	-11.2, ± 9.4	WHEY Possibly Beneficial	Small (0.27)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.6 Peak torque 180°.s^{-1} non-dominant leg extension

At baseline the peak torque values at 180°.s^{-1} for the non-dominant leg of athletes consuming GOAT, COW, WHEY or CHO were 129.9 ± 43.2, 115.2 ± 34.1, 115.6 ± 40.9 and 124.2 ± 42.2 Nm, respectively. Changes in peak torque at 180°.s^{-1} for non-dominant leg extension can be seen in Figure 4.5.

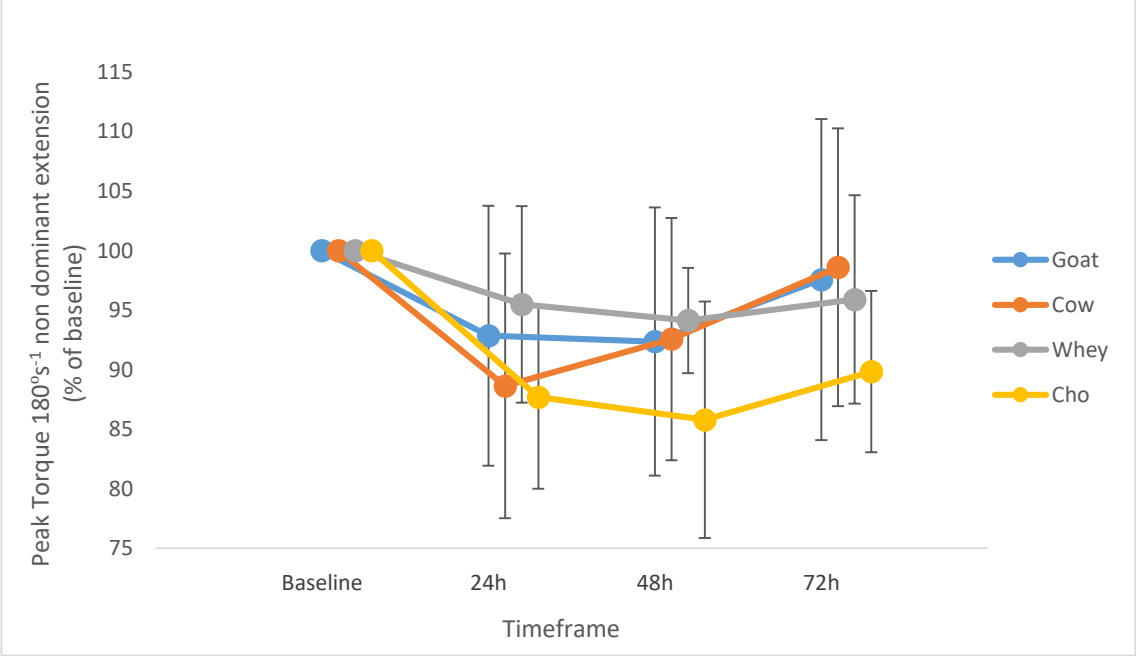

Figure 4.5 Percentage change in peak torque at 180°.s^{-1} for non-dominant leg extension in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and CHO observed COW had a possible trivial beneficial effect from baseline to 48h (-7.4±10.2% *vs.* -14.2±9.9%, COW *vs.* CHO, respectively), and a possible small beneficial effect from baseline to 72h (-1.4±11.7% *vs.* -10.2±6.8%, respectively). When compared to WHEY, COW had a possible small harmful effect from baseline to 24h (-11.4±11.1% *vs.* -4.5±8.3%, COW *vs.* WHEY, respectively). GOAT and CHO comparisons displayed a possible trivial beneficial effect for GOAT from baseline to 24h (-7.1±10.9% *vs.* -12.3±7.7%, GOAT *vs.* CHO, respectively), baseline to 48h (-7.6±11.3% *vs.* -14.2±9.9%, respectively) and baseline to 72h (-2.4±13.5% *vs.* -10.2±6.8%, respectively). GOAT and COW comparisons showed GOAT had a possible trivial harmful effect from baseline to 72h (-2.4±13.5% *vs.* -1.4±11.7%, respectively). WHEY compared to CHO had a possible trivial beneficial effect from baseline to 24h (-4.5±8.3% *vs.* -12.3±7.7%, WHEY *vs.* CHO, respectively). WHEY displayed a possible small beneficial effect from baseline to 48h (-5.9±4.4% *vs.* -14.2±9.9%, respectively) and WHEY had a possible trivial beneficial effect from baseline to 72h (-4.1±8.7% *vs.* -10.2±6.8%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the non-dominant leg at 180°.s^{-1} extension can be seen in Table 4.5.

Table 4.5 Effect on peak torque 180°.s^{-1} non-dominant leg extension following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 180°/s Non Dominant Extension				
Cow *vs.* Cho	B - 24	-0.9, ± 10.8	Possibly Trivial	Trivial (0.01)
	B - 48	-7.7, ± 10.2	COW Possibly Beneficial	Trivial (0.18)
	B - 72	-8.6, ± 9.6	COW Possibly Beneficial	Small (0.26)
Cow *vs.* Whey	B - 24	8.1, ± 11.4	COW Possibly Harmful	Small (0.22)
	B - 48	2.1, ± 8.6	Likely Trivial	Trivial (0.06)
	B - 72	-2.5, ± 9.9	Possibly Trivial	Trivial (0.09)
Goat *vs.* Cho	B - 24	5.1, ± 10.0	GOAT Possibly Beneficial	Trivial (0.15)
	B - 48	6.8, ± 11.0	GOAT Possibly Beneficial	Trivial (0.13)
	B - 72	7.3, ± 10.0	GOAT Possibly Beneficial	Trivial (0.17)
Goat *vs.* Whey	B - 24	-3.9, ± 9.0	Unclear	Trivial (0.05)
	B - 48	-4.0, ± 7.1	Possibly Trivial	Trivial (0.11)
	B - 72	0.1, ± 10.0	Likely Trivial	Trivial (0.02)
Goat *vs.* Cow	B - 24	-3.4, ± 11.0	Unclear	Small (0.29)
	B - 48	1.8, ± 10.2	Possibly Trivial	Trivial (0.03)
	B - 72	2.7, ± 11.5	GOAT Possibly Harmful	Trivial (0.06)
Whey *vs.* Cho	B - 24	-8.1, ± 7.9	WHEY Possibly Beneficial	Trivial (0.16)
	B - 48	-9.8, ± 8.2	WHEY Possibly Beneficial	Small (0.22)
	B - 72	-6.1, ± 7.9	WHEY Possibly Beneficial	Trivial (0.16)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.7 Peak torque 60°.s^{-1} dominant leg flexion

Immediately prior to the muscle damaging exercise peak torque values for dominant leg flexion at 60°.s^{-1} for GOAT, COW, WHEY and CHO were 99.2 ± 36.9, 92.1 ± 28.9, 86.0 ± 28.8 and 95.2 ± 24.8 Nm, respectively. Changes in peak torque at 60°.s^{-1} for dominant leg flexion can be seen in Figure 4.6.

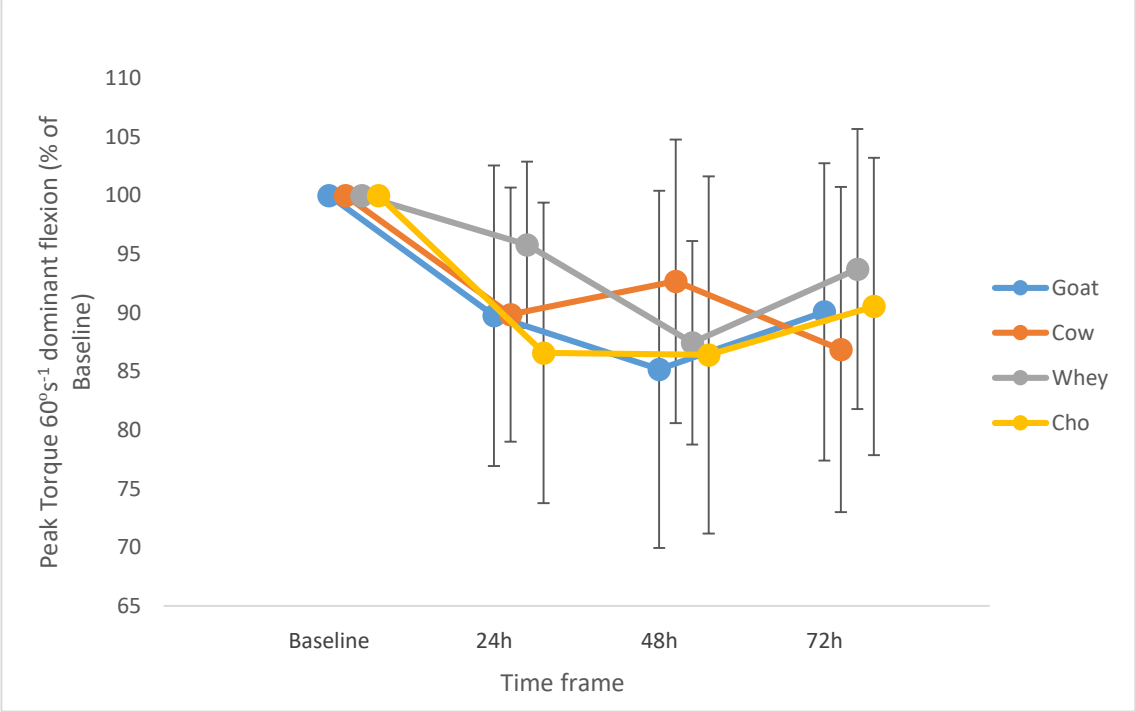

Figure 4.6 Percentage change in peak torque at 60°.s^{-1} for dominant leg flexion in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

At 72h post muscle damaging exercise, COW had a possible trivial harmful effect compared to CHO (-13.1±13.9% *vs.* -9.5±16.4%, COW *vs.* CHO, respectively). Comparisons between COW and WHEY displayed a possible trivial harmful effect for COW from baseline to 72h (-13.1±13.9% *vs.* -6.3±11.9%, respectively). Compared to CHO, GOAT had a possible trivial beneficial effect from baseline to 24h (-10.3±12.8% *vs.* -13.4±16.8%, GOAT *vs.* CHO, respectively). GOAT and COW comparisons revealed GOAT had a possible trivial harmful effect from baseline to 48h (-14.8±15.2% *vs.* -7.3±12.1%, GOAT *vs.* COW, respectively). WHEY compared to CHO had a possible trivial beneficial effect from baseline to 24h (-4.2±7.1% *vs.* -13.4±16.8%, WHEY *vs.* CHO, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the dominant leg at 60°.s^{-1} flexion can be seen in Table 4.6.

Table 4.6 Effect on peak torque 60°.s^{-1} dominant leg flexion following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 60°/s Dominant Flexion				
Cow *vs.* Cho	B - 24	-5.3, ± 12.7	Unclear	Trivial (0.02)
	B - 48	-8.9, ± 13.3	Unclear	Trivial (0.12)
	B - 72	-3.0, ± 14.4	COW Possibly Harmful	Trivial (0.19)
Cow *vs.* Whey	B - 24	3.1, ± 11.2	Possibly Trivial	Trivial (0.05)
	B - 48	-7.6, ± 11.8	Unclear	Trivial (0.19)
	B - 72	8.2, ± 15.6	COW Possibly Harmful	Trivial (0.19)
Goat *vs.* Cho	B - 24	3.8, ± 14.6	GOAT Possibly Beneficial	Trivial (0.04)
	B - 48	-2.3, ± 15.3	Unclear	Trivial (0.09)
	B - 72	-0.8, ± 13.2	Possibly Trivial	Trivial (0.13)
Goat *vs.* Whey	B - 24	-8.3, ± 11.2	Possibly Trivial	Trivial (0.04)
	B - 48	-8.9, ± 12.8	Unclear	Trivial (0.01)
	B - 72	-3.3, ± 13.5	Unclear	Trivial (0.08)
Goat *vs.* Cow	B - 24	-0.2, ± 12.7	Possibly Trivial	Trivial (0.01)
	B - 48	10.6, ± 16.0	GOAT Possibly Harmful	Trivial (0.17)
	B - 72	-3.8, ± 14.3	Unclear	Trivial (0.06)
Whey *vs.* Cho	B - 24	-14.9, ± 11.0	WHEY Possibly Beneficial	Trivial (0.10)
	B - 48	-8.8, ± 12.9	Unclear	Trivial (0.04)
	B - 72	-5.9, ± 12.2	Unclear	Trivial (0.03)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.8 Peak torque 60°.s^{-1} non-dominant leg flexion

At baseline the peak torque values at 60°.s^{-1} for the non-dominant leg flexion of athletes consuming GOAT, COW, WHEY and CHO were 90.4 ± 31.0, 85.9 ± 26.7, 83.7 ± 27.8 and 83.3 ± 19.5 Nm, respectively. Changes in peak torque at 60°.s^{-1} for non-dominant leg flexion can be seen in Figure 4.2.

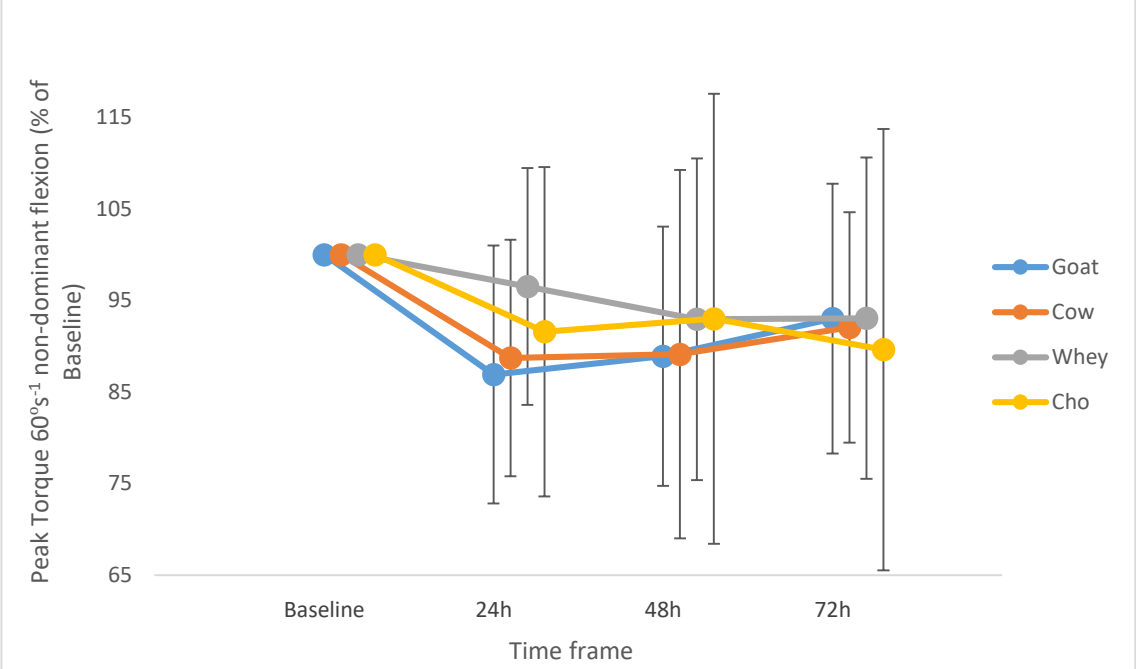

Figure 4.7 Percentage change in peak torque at 60°.s^{-1} for non-dominant leg flexion in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW compared to CHO had a possible small harmful effect from baseline to 24h (-11.3±12.9% *vs.* -8.4±18.0%, COW vs CHO, respectively) and baseline to 48h (-10.9±20.1% *vs.* -7.0±24.6%, respectively). COW and WHEY comparisons showed a possible small harmful effect for COW from baseline to 24h (-11.3±12.9% *vs.* -3.5±12.9%, COW *vs.* WHEY, respectively) and a possible trivial harmful effect from baseline to 48h (-10.9±20.1% *vs.* -7.0±17.6%, respectively). GOAT compared to CHO had a possible trivial beneficial effect from baseline to 72h (-7.0±14.7% *vs.* -10.4±24.1%, GOAT *vs.* CHO, respectively). Evaluations between GOAT and COW showed GOAT had a possible trivial harmful effect from baseline to 24h (-13.1±14.1% *vs.* -11.3±12.9%, GOAT *vs.* COW, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the non-dominant leg at 60°.s^{-1} flexion can be seen in Table 4.7.

Table 4.7 Effect on peak torque 60°.s^{-1} non-dominant leg flexion following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 60°/s Non Dominant Flexion				
Cow *vs.* Cho	B - 24	3.2, ± 14.2	COW Possibly Harmful	Small (0.24)
	B - 48	4.8, ± 25.7	COW Possibly Harmful	Small (0.24)
	B - 72	-3.8, ± 16.4	Unclear	Trivial (0.07)
Cow *vs.* Whey	B - 24	8.4, ± 15.3	COW Possibly Harmful	Small (0.22)
	B - 48	5.5, ± 23.2	COW Possibly Harmful	Trivial (0.09)
	B - 72	0.0, ± 16.7	Possibly Trivial	Trivial (0.02)
Goat *vs.* Cho	B - 24	-6.8, ± 14.1	Unclear	Small (0.30)
	B - 48	-5.1, ± 19.6	Unclear	Small (0.26)
	B - 72	2.5, ± 18.5	GOAT Possibly Beneficial	Trivial (0.10)
Goat *vs.* Whey	B - 24	-9.4, ± 3.8	Unclear	Small (0.23)
	B - 48	-3.8, ± 16.2	Unclear	Trivial (0.08)
	B - 72	1.7, ± 17.9	Trivial	Trivial (0.05)
Goat *vs.* Cow	B - 24	1.5, ± 15.2	GOAT Possibly Harmful	Trivial (0.01)
	B - 48	-1.1, ± 21.2	Unclear	Trivial (0.00)
	B - 72	-0.9, ± 14.7	Possibly Trivial	Trivial (0.01)
Whey *vs.* Cho	B - 24	-5.8, ± 13.2	Unclear	Trivial (0.04)
	B - 48	-1.8, ± 20.4	Unclear	Trivial (0.10)
	B - 72	-5.3, ± 18.2	Unclear	Trivial (0.00)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.9 Peak torque 180°.s^{-1} dominant leg flexion

Immediately prior to the muscle damaging exercise peak torque values for dominant leg flexion at 180°.s^{-1} for GOAT, COW, WHEY and CHO were 74.7 ± 32.1, 69.7 ± 29.7, 64.9 ± 23.2 and 71.9 ± 29.0 Nm, respectively. Changes in peak torque at 180°.s^{-1} for dominant leg flexion can be seen in Figure 4.8.

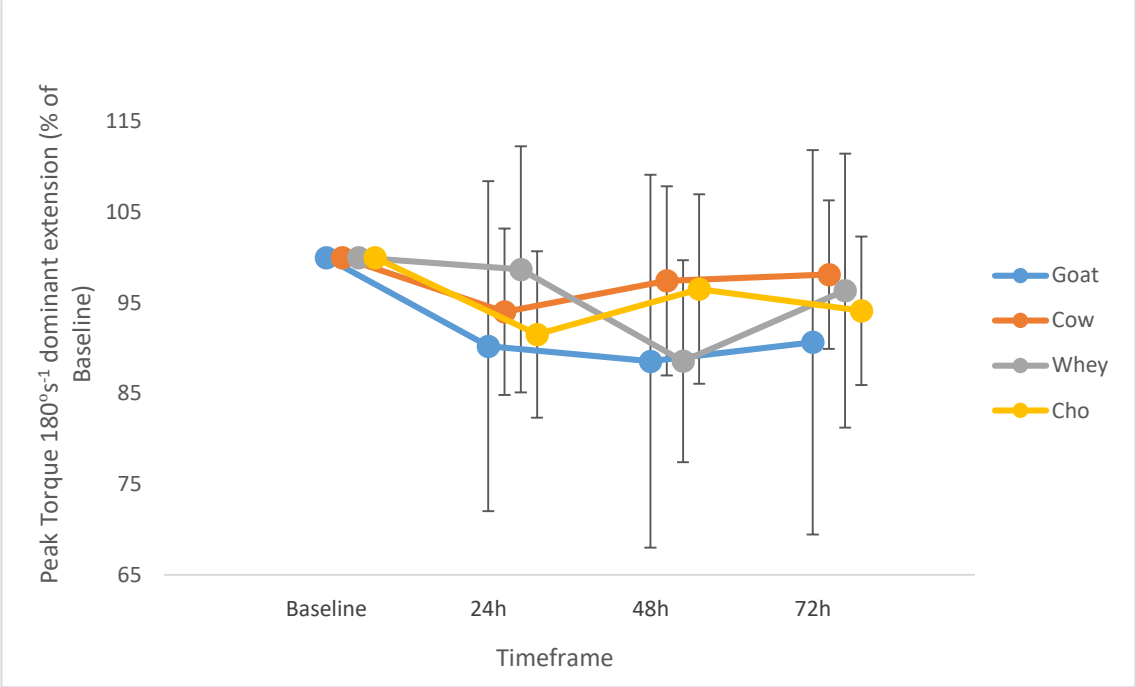

Figure 4.8 Percentage change in peak torque at 180°.s^{-1} for dominant leg flexion in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and CHO reported a possible small harmful effect for CHO from baseline to 24h (-6.0±18.1% *vs.* -8.5±9.2%, COW *vs.* CHO, respectively), baseline to 48h (-2.6±16.4% *vs.* -3.5±10.4%, respectively) and baseline to 72h (-1.9±17.0% *vs.* -5.9±8.2%, respectively). When compared to WHEY, COW had a possible trivial harmful effect from baseline to 24h (-6.0±18.1% *vs.* -1.3±13.6%, COW *vs.* WHEY, respectively). However, COW had a possible trivial beneficial effect from baseline to 48h (-2.6±16.4% *vs.* -11.4±11.1%, respectively). CHO compared to GOAT had a likely small beneficial effect from baseline to 48h (-11.4±20.6% *vs.* -3.5±10.4%, GOAT *vs.* CHO, respectively). When compared to COW, GOAT showed a possible trivial harmful effect from baseline to 48h (-11.4±20.6% *vs.* -2.6±16.4%, respectively) and from baseline to 72h (-9.3±21.2% *vs.* -1.9±17.0%, respectively). CHO compared to WHEY had a possible trivial harmful effect from baseline to 24h (-1.3±13.6% *vs.* -8.5±9.2%, WHEY *vs.* CHO, respectively) and had a possible small harmful effect from baseline to 72h (-3.6±15.1% *vs.* -5.9±8.2%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the dominant leg at 180°.s^{-1} flexion can be seen in Table 4.8.

Table 4.8 Effect on peak torque 180°.s^{-1} dominant leg flexion following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 180°/s Dominant Flexion				
Cow *vs.* Cho	B - 24	4.0, ± 14.9	CHO Possibly Harmful	Small (0.27)
	B - 48	5.1, ± 16.0	CHO Possibly Harmful	Small (0.26)
	B - 72	3.2, ± 14.8	CHO Possibly Harmful	Small (0.22)
Cow *vs.* Whey	B - 24	4.6, ± 14.2	COW Possibly Harmful	Trivial (0.19)
	B - 48	-8.9, ± 11.7	COW Possibly Beneficial	Trivial (0.12)
	B - 72	-3.2, ± 12.9	Possibly Trivial	Trivial (0.02)
Goat *vs.* Cho	B - 24	-6.6, ± 16.8	Unclear	Small (0.23)
	B - 48	-13.9, ± 17.0	CHO Likely Beneficial	Small (0.34)
	B - 72	-10.5, ± 18.5	Unclear	Small (0.26)
Goat *vs.* Whey	B - 24	-8.6, ± 16.2	Unclear	Small (0.20)
	B - 48	-2.7, ± 18.0	Unclear	Trivial (0.03)
	B - 72	-5.6, ± 19.1	Unclear	Trivial (0.06)
Goat *vs.* Cow	B - 24	2.4, ± 17.9	Possibly Trivial	Trivial (0.04)
	B - 48	10.7, ± 20.9	GOAT Possibly Harmful	Trivial (0.10)
	B - 72	8.2, ± 21.1	GOAT Possibly Harmful	Trivial (0.05)
Whey *vs.* Cho	B - 24	7.4, ± 26.5	CHO Possibly Harmful	Trivial (0.08)
	B - 48	25.1, ± 30.8	Unclear	Small (0.40)
	B - 72	14.5, ± 28.0	CHO Possibly Harmful	Trivial (0.26)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.10 Peak torque 180°.s^{-1} non-dominant leg flexion

At baseline the peak torque values at 180°.s^{-1} for the non-dominant leg flexion of athletes consuming GOAT, COW, WHEY and CHO were 64.1 ± 24.7, 64.0 ± 22.0, 65.7 ± 22.2 and 65.0 ± 21.9 Nm, respectively. Changes in peak torque at 180°.s^{-1} for non-dominant leg extension can be seen in Figure 4.9.

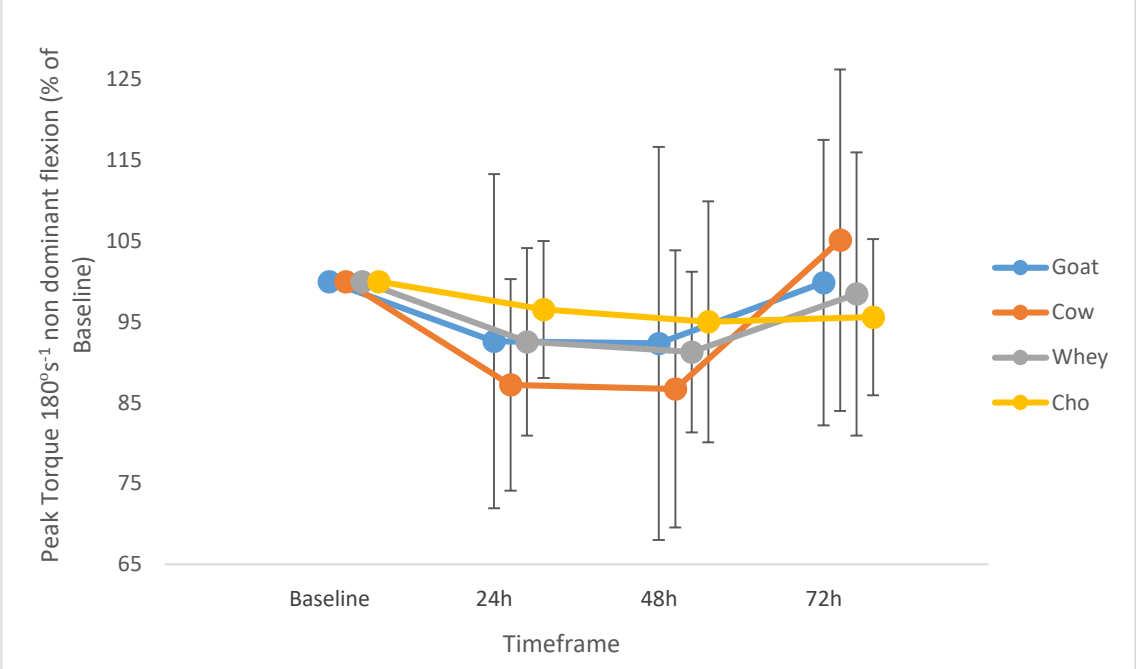

Figure 4.9 Percentage change in peak torque at 180°.s^{-1} for non-dominant leg flexion in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and CHO demonstrated COW had a possible trivial harmful effect from baseline to 24h (-12.8±13.1% *vs.* -3.5±8.5%, COW *vs.* CHO, respectively). CHO compared to GOAT had a possible trivial harmful effect from baseline to 72h (-0.1±17.7% *vs.* -4.4±9.7%, GOAT *vs.* CHO, respectively). Similarly, WHEY compared to GOAT had a possible trivial harmful effect from baseline to 72h (-1.5±17.5% *vs.* -0.1±17.7%, WHEY *vs.* GOAT, respectively). When compared to GOAT, COW had a possible trivial harmful effect from baseline to 24h (-7.4±20.7% *vs.* -12.8±13.1%, GOAT *vs.* COW, respectively) and baseline to 48h (-7.6±24.3% *vs.* -13.3±17.1%, respectively). However, GOAT had a possible trivial harmful effect from baseline to 72h (-0.1±17.7% *vs.* 5.1±21.1%, respectively). From baseline to 24h, WHEY had a possible trivial harmful effect compared to CHO (-7.5±11.6% *vs.* -3.5±8.5%, WHEY *vs.* CHO, respectively) and alike from baseline to 48h (-8.7±10.0 *vs.* -5.0±14.9, respectively). All other comparisons were unclear.

A summary of the statistical analysis for peak torque of the non-dominant leg at 180°.s^{-1} flexion can be seen in Table 4.9.

Table 4.9 Effect on peak torque 180°.s^{-1} non-dominant leg flexion following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
Peak Torque 180°/s Non Dominant Flexion				
Cow *vs.* Cho	B - 24	0.8, ± 20.6	COW Possibly Harmful	Trivial (0.09)
	B - 48	-0.7, ± 27.8	Unclear	Trivial (0.01)
	B - 72	-8.0, ± 13.4	Unclear	Trivial (0.17)
Cow *vs.* Whey	B - 24	6.0, ± 19.1	Unclear	Trivial (0.06)
	B - 48	3.8, ± 25.2	Unclear	Trivial (0.13)
	B - 72	-5.9, ± 17.3	Unclear	Trivial (0.10)
Goat *vs.* Cho	B - 24	-5.8, ± 17.4	Unclear	Trivial (0.01)
	B - 48	-4.6, ± 20.2	Unclear	Trivial (0.10)
	B - 72	3.8, ± 14.9	CHO Possibly Harmful	Trivial (0.01)
Goat *vs.* Whey	B - 24	-5.8, ± 19.5	Unclear	Trivial (0.05)
	B - 48	-5.6, ± 20.6	Unclear	Trivial (0.12)
	B - 72	1.6, ± 18.6	WHEY Possibly Harmful	Trivial (0.04)
Goat *vs.* Cow	B - 24	5.7, ± 26.2	COW Possibly Harmful	Trivial (0.02)
	B - 48	6.0, ± 32.9	COW Possibly Harmful	Trivial (0.01)
	B - 72	4.9, ± 18.4	GOAT Possibly Harmful	Trivial (0.06)
Whey *vs.* Cho	B - 24	3.0, ± 15.3	WHEY Possibly Harmful	Trivial (0.17)
	B - 48	-1.0, ± 15.8	WHEY Possibly Harmful	Trivial (0.14)
	B - 72	-1.4, ± 16.8	Unclear	Trivial (0.06)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.11 5m sprint performance

Initial 5m sprint times, prior to muscle damaging exercise for GOAT, COW, WHEY and CHO were 1.24 ± 0.11, 1.20 ± 0.08, 1.28 ± 0.12 and 1.27 ± 0.13 s, respectively. Percentage change in 5m sprint time performance compared to baseline is presented in Figure 4.10.

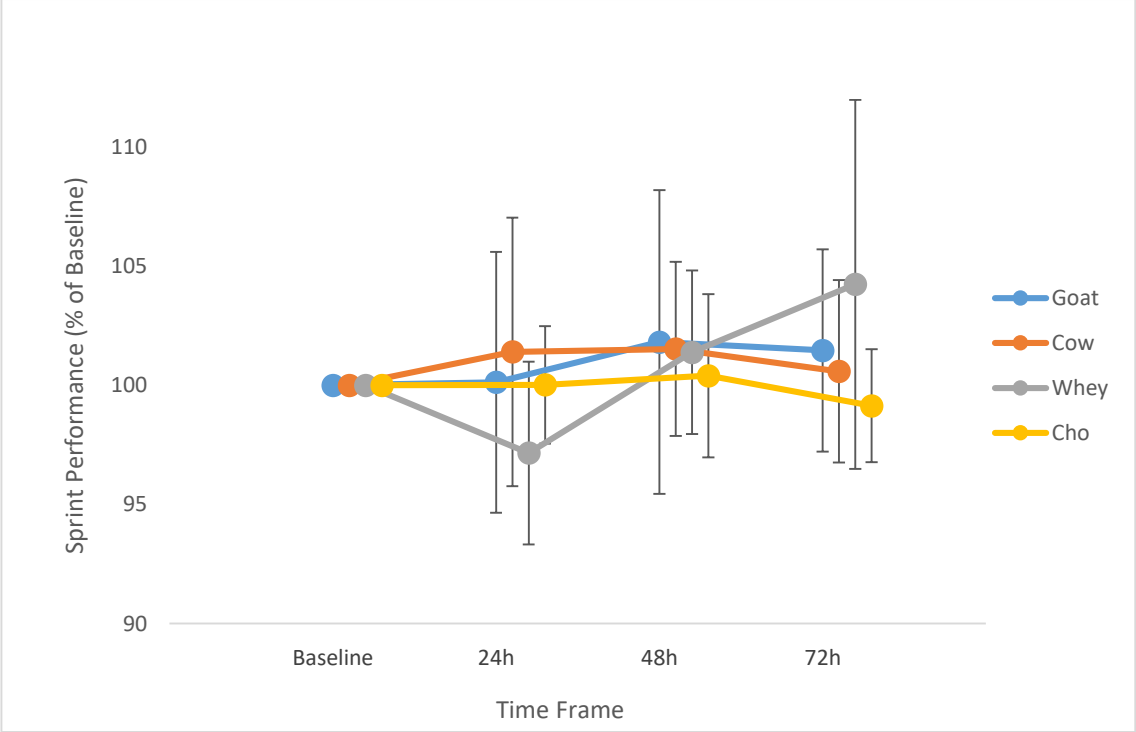

Figure 4.10 Percentage change in 5m sprint performance response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and CHO showed CHO had a possible trivial beneficial effect from baseline to 24h (1.4±5.6% *vs.* 1.1±4.0%, COW *vs.* CHO, respectively) and a possible small beneficial effect from baseline to 48h (1.5±3.7% *vs.* -0.3±4.2%, respectively) and baseline to 72h (0.6±3.8% *vs.* -0.7±2.4%, respectively). COW compared to WHEY had a likely small harmful effect from baseline to 24h (1.4±5.6% *vs.* -1.1±6.2%, COW *vs.* WHEY, respectively) and baseline to 48h (1.5±3.7% *vs.* 1.1±6.2%, respectively). However, WHEY, had a possible small harmful effect from baseline to 72h (0.6±3.8% *vs.* 4.2±7.7%, respectively). WHEY compared to CHO had a possible small beneficial effect from baseline to 24h (-2.8±3.8% *vs.* -0.0±2.5%, WHEY *vs.* CHO, respectively). However, WHEY had a possible small harmful effect from baseline to 72h (4.2±7.7% *vs.* -0.9±2.4%, WHEY *vs.* CHO, respectively). All other comparisons presented unclear outcomes.

A summary of the statistical analysis for 5m sprint performance can be seen in Table 4.10.

Table 4.10 Effect on 5m sprint performance following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
5m SPRINT				
Cow *vs.* Cho	B - 24	1.6, ± 4.7	CHO Possibly Beneficial	Trivial (0.13)
	B - 48	2.9, ± 5.5	CHO Possibly Beneficial	Small (0.27)
	B - 72	2.8, ± 6.1	CHO Possibly Beneficial	Small (0.26)
Cow *vs.* Whey	B - 24	4.0, ± 6.6	COW Likely Harmful	Small (0.44)
	B - 48	4.7, ± 7.1	COW Likely Harmful	Small (0.45)
	B - 72	2.4, ± 8.4	WHEY Possibly Harmful	Small (0.22)
Goat *vs.* Cho	B - 24	0.4, ± 4.0	Unclear	Trivial (0.11)
	B - 48	-0.8, ± 4.9	Unclear	Trivial (0.07)
	B - 72	-2.1, ± 6.0	Unclear	Small (0.29)
Goat *vs.* Whey	B - 24	-1.7, ± 5.7	Unclear	Trivial (0.17)
	B - 48	-2.0, ± 6.2	Unclear	Trivial (0.19)
	B - 72	-0.5, ± 8.2	Unclear	Trivial (0.04)
Goat *vs.* Cow	B - 24	-1.9, ± 4.9	Unclear	Small (0.22)
	B - 48	-2.0, ± 5.4	Unclear	Small (0.23)
	B - 72	-1.2, ± 6.8	Unclear	Trivial (0.14)
Whey *vs.* Cho	B - 24	-3.4, ± 4.5	WHEY Possibly Beneficial	Small (0.32)
	B - 48	-0.8, ± 5.9	Unclear	Trivial (0.07)
	B - 72	2.8, ± 7.3	WHEY Possibly Harmful	Small (0.33)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.12 10m sprint performance

Baseline 10m sprint times for those who consumed GOAT, COW, WHEY and CHO were 2.08 ± 0.17, 2.02 ± 0.13, 2.10 ± 0.16 and 2.09 ± 0.20 s, respectively. Percentage change in 10m sprint time performance compared to baseline is presented in Figure 4.11.

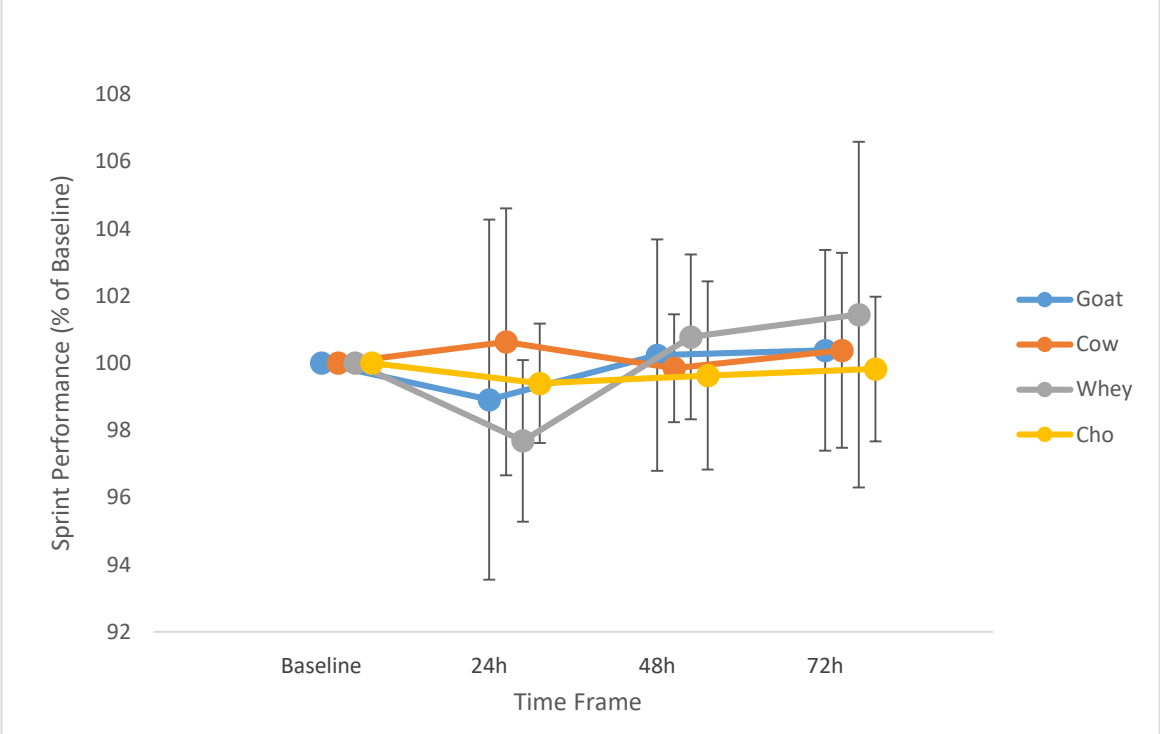

Figure 4.11 Percentage change in 10m sprint performance response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

CHO compared to COW had a possible trivial beneficial effect from baseline to 24h (0.6±4.0% *vs.* 0.4±2.6%, COW *vs.* CHO, respectively) and baseline to 48h (-0.3±1.6% *vs.* -0.4±2.8%, respectively). When compared to COW, WHEY had a possible small beneficial effect from baseline to 24h (0.6±4.0% *vs.* -1.5±3.3%, COW *vs.* WHEY, respectively). However, WHEY had a possible trivial harmful effect from baseline to 72h (1.2±2.4% *vs.* 1.4±5.1%, respectively). From baseline to 24h, CHO presented a possible small harmful effect compared to GOAT (-1.1±5.4% *vs.* -0.6±1.8%, GOAT *vs.* CHO, respectively). Comparisons between WHEY and GOAT found a possible trivial harmful effect for WHEY from baseline to 72h (1.4±5.1% *vs.* 0.1±2.9%, WHEY *vs.* GOAT, respectively). When compared to CHO, WHEY had a possible small beneficial effect from baseline to 24h (-1.5±3.3% *vs.* 0.4±2.6%, WHEY *vs.* CHO, respectively). However, WHEY had a possible trivial harmful effect from baseline to 72h (1.4±5.1% *vs.* -0.3±2.2%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for 10m sprint performance can be seen in Table 4.11.

Table 4.11 Effect on 10m sprint performance following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
10m SPRINT				
Cow *vs.* Cho	B - 24	0.5, ± 3.2	CHO Possibly Beneficial	Trivial (0.03)
	B - 48	1.1, ± 4.0	CHO Possibly Beneficial	Trivial (0.12)
	B - 72	1.2, ± 4.7	Unclear	Trivial (0.11)
Cow *vs.* Whey	B - 24	2.1, ± 3.8	WHEY Possibly Beneficial	Small (0.26)
	B - 48	0.5, ± 5.4	Unclear	Trivial (0.07)
	B - 72	0.8, ± 5.6	WHEY Possibly Harmful	Trivial (0.08)
Goat *vs.* Cho	B - 24	1.4, ± 3.9	CHO Possibly Harmful	Small (0.32)
	B - 48	-1.5, ± 3.9	Possibly Trivial	Trivial (0.01)
	B - 72	-1.3, ± 4.5	Unclear	Small (0.22)
Goat *vs.* Whey	B - 24	0.6, ± 4.1	Unclear	Trivial (0.07)
	B - 48	0.1, ± 5.1	Unclear	Trivial (0.01)
	B - 72	1.1, ± 4.8	WHEY Possibly Harmful	Trivial (0.12)
Goat *vs.* Cow	B - 24	-2.1, ± 4.3	Unclear	Small (0.24)
	B - 48	0.2, ± 4.6	Unclear	Trivial (0.02)
	B - 72	-0.1, ± 5.8	Unclear	Trivial (0.01)
Whey *vs.* Cho	B - 24	-1.9, ± 1.5	WHEY Possibly Beneficial	Small (0.22)
	B - 48	1.5, ± 3.2	Unclear	Trivial (0.01)
	B - 72	1.5, ± 3.7	WHEY Possibly Harmful	Trivial (0.18)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.13 20m sprint performance

Initial 20m sprint times prior to muscle damaging exercise were 3.52 ± 0.34 s, 3.47 ± 0.24 s, 3.56 ± 0.25 s and 3.52 ± 0.33 s for those who consumed GOAT, COW, WHEY and CHO, respectively. Percentage change in 20m sprint time performance compared to baseline is presented in Figure 4.12.

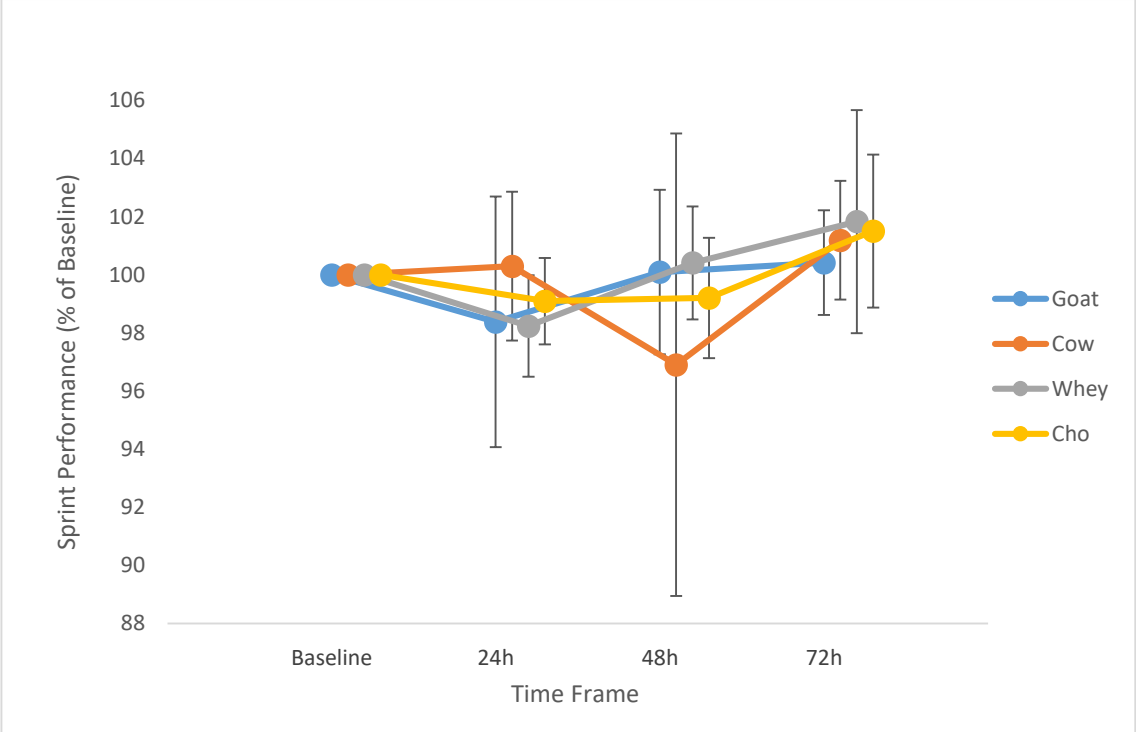

Figure 4.12 Percentage change in 20m sprint performance response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW compared to CHO had a possible trivial harmful effect from baseline to 24h (0.3±2.6% *vs.* -0.9±1.5%, COW *vs.* CHO, respectively). However, CHO had a possible trivial harmful effect from baseline to 48h (-3.1±8.0% *vs.* -0.8±2.1%, respectively). Compared to WHEY, COW had a possible small harmful effect from baseline to 24h (0.5±2.6% *vs.* -1.8±1.7%, COW *vs.* WHEY, respectively). CHO had a possible trivial harmful effect from baseline to 24h compared to GOAT (-1.6±4.3% *vs.* -0.9±1.5%, GOAT *vs.* CHO, respectively). WHEY compared to GOAT had a possible trivial harmful effect from baseline to 48h (1.5±3.8% *vs.* 0.1±2.8%, WHEY *vs.* GOAT, respectively) and a possible small harmful effect from baseline to 72h (1.8±3.8% *vs.* 0.3±1.8%, respectively). GOAT had a possible small beneficial effect compared to COW from baseline to 24h, (-1.6±4.3% *vs.* 0.3±2.6%, GOAT *vs.* COW, respectively) and baseline to 72h (0.4±1.8% *vs.* 1.2±2.0%, respectively). WHEY compared to CHO had a possible trivial harmful effect from baseline to 48h (1.5±3.8% *vs.* -0.8±2.1%, WHEY *vs.* CHO, respectively) and baseline to 72h (1.8±3.8% *vs.* 1.5±2.6%, respectively).

A summary of the statistical analysis for 20m sprint performance can be seen in Table 4.12.

Table 4.12 Effect on 20m sprint performance following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
20m SPRINT				
Cow *vs.* Cho	B - 24	1.4, ± 2.0	COW Possibly Harmful	Trivial (0.14)
	B - 48	1.2, ± 2.8	CHO Possibly Harmful	Trivial (0.13)
	B - 72	1.0, ± 2.7	Unclear	Trivial (0.10)
Cow *vs.* Whey	B - 24	3.9, ± 7.0	COW Possibly Harmful	Small (0.45)
	B - 48	-0.4, ± 3.6	Unclear	Trivial (0.05)
	B - 72	-0.5, ± 4.0	Unclear	Trivial (0.07)
Goat *vs.* Cho	B - 24	0.8, ± 2.7	CHO Possibly Harmful	Trivial (0.06)
	B - 48	0.1, ± 2.9	Possibly Trivial	Trivial (0.02)
	B - 72	1.9, ± 4.1	Possibly Trivial	Trivial (0.17)
Goat *vs.* Whey	B - 24	-0.3, ± 2.7	Possibly Trivial	Trivial (0.06)
	B - 48	1.3, ± 3.7	WHEY Possibly Harmful	Trivial (0.12)
	B - 72	3.3, ± 5.0	WHEY Possibly Harmful	Small (0.34)
Goat *vs.* Cow	B - 24	-2.3, ± 2.8	GOAT Possibly Beneficial	Small (0.23)
	B - 48	-1.4, ± 3.3	Unclear	Trivial (0.13)
	B - 72	-3.1, ± 4.2	GOAT Possibly Beneficial	Small (0.32)
Whey *vs.* Cho	B - 24	0.9, ± 1.5	Likely Trivial	Trivial (0.11)
	B - 48	1.5, ± 3.2	WHEY Possibly Harmful	Trivial (0.16)
	B - 72	1.5, ± 3.7	WHEY Possibly Harmful	Trivial (0.17)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.14 Reactive strength index (RSI)

Baseline reactive strength index (RSI) values for GOAT, COW, WHEY and CHO were 0.81 ± 0.19, 0.96 ± 0.26, 0.91 ± 0.25 and 0.96 ± 0.23 $Nm.s^{-1}$, respectively. Changes in RSI can be seen in Figure 4.13.

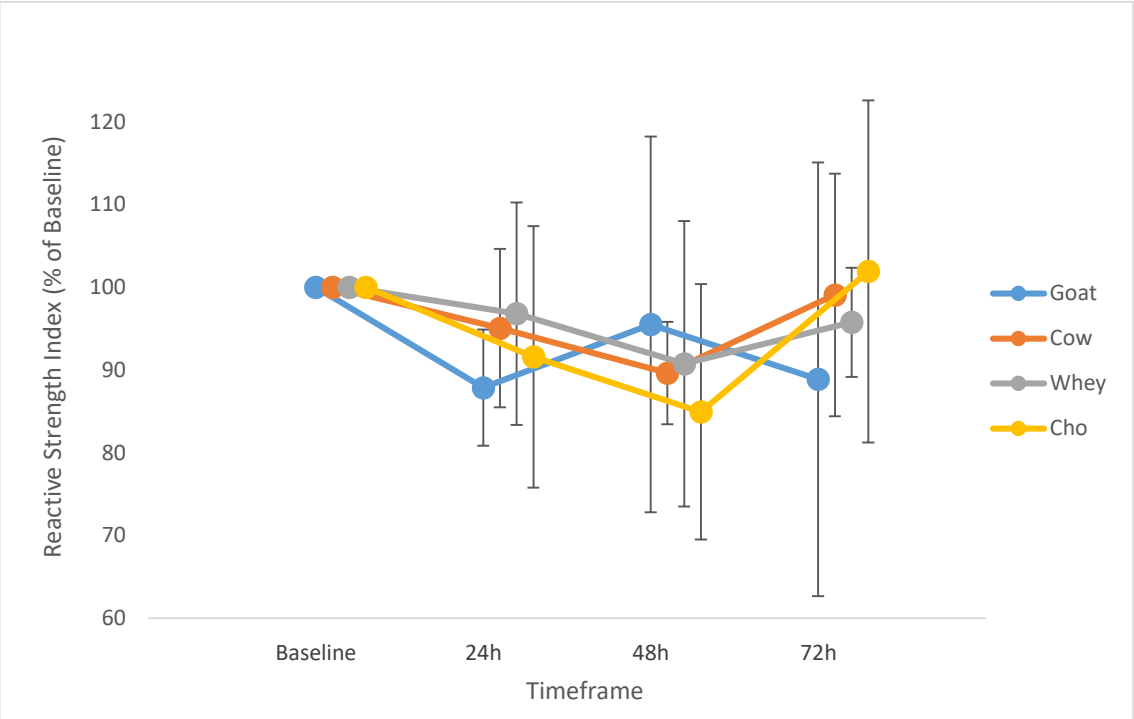

Figure 4.13 Percentage change in reactive strength index in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW compared to CHO had a possible small beneficial effect from baseline to 48h (-10.4±6.2% *vs.* -15.1±15.4%, COW *vs.* CHO, respectively). Despite this, COW had a possible trivial harmful effect from baseline to 72h (-0.9±14.7% *vs.* 1.9±20.7%, respectively). GOAT compared to CHO, had a possible small beneficial effect from baseline to 48h (-4.5±22.7% *vs.* -15.1±14.4%, GOAT *vs.* CHO, respectively). However, GOAT had a likely small harmful effect from baseline to 72h (-11.1±26.2% *vs.* 1.9±22.6%, respectively). From baseline to 48h, GOAT had a possible small beneficial effect compared to WHEY (-4.5±22.7 *vs.* -9.2±17.2%, GOAT *vs.* WHEY, respectively). GOAT and COW comparisons revealed a possible trivial harmful effect for GOAT from baseline to 24h (-6.2±18.2% *vs.* -4.9±9.6%, GOAT *vs.* COW, respectively) and a likely small harmful effect from baseline to 72h (-11.1 ± 26.2% *vs.* -0.9±14.7%, respectively). WHEY had a

possible small harmful effect from baseline to 72h compared to CHO (-4.2±6.6% *vs.* 1.9±20.7%, WHEY *vs.* CHO, respectively). All other comparisons were unclear.

A summary of the statistical analysis for RSI can be seen in Table 4.13.

Table 4.13 Effect on RSI following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
RSI				
Cow *vs.* Cho	B - 24	-4.5, ± 14.9	Unclear	Trivial (0.12)
	B - 48	-11.8, ± 15.3	COW Possibly Beneficial	Small (0.38)
	B - 72	8.7, ± 18.8	COW Possibly Harmful	Trivial (0.05)
Cow *vs.* Whey	B - 24	0.6, ± 11.3	Possibly Trivial	Trivial (0.01)
	B - 48	-6.1, ± 14.4	Unclear	Small (0.20)
	B - 72	-3.3, ± 10.9	Unclear	Trivial (0.13)
Goat *vs.* Cho	B - 24	0.5, ± 18.9	Unclear	Trivial (0.02)
	B - 48	11.6, ± 24.6	GOAT Possibly Beneficial	Small (0.45)
	B - 72	-24.3, ± 19.8	GOAT Likely Harmful	Small (0.59)
Goat *vs.* Whey	B - 24	-5.7, ± 14.3	Unclear	Trivial (0.16)
	B - 48	2.9, ± 21.7	GOAT Possibly Beneficial	Small (0.21)
	B - 72	-11.4, ± 20.1	Unclear	Small (0.30)
Goat *vs.* Cow	B - 24	4.4, ± 15.8	GOAT Possibly Harmful	Trivial (0.10)
	B - 48	-1.3, ± 19.7	Unclear	Trivial (0.13)
	B - 72	16.6, ± 29.0	GOAT Likely Harmful	Small (0.42)
Whey *vs.* Cho	B - 24	-5.2, ± 15.4	Unclear	Trivial (0.14)
	B - 48	-4.2, ± 17.7	Unclear	Trivia (0.11)
	B - 72	14.1, ± 18.5	WHEY Possibly Harmful	Small (0.22)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.15 Rate of force development (RFD) – dominant leg

Baseline rate of force development (RFD) values for GOAT, COW, WHEY and CHO were 0.73 ± 0.34, 0.72 ± 0.17, 0.64 ± 0.30 and 0.55 ± 0.19 $Nm.s^{-1}$, respectively. Changes in RFD for dominant leg can be seen in Figure 4.14.

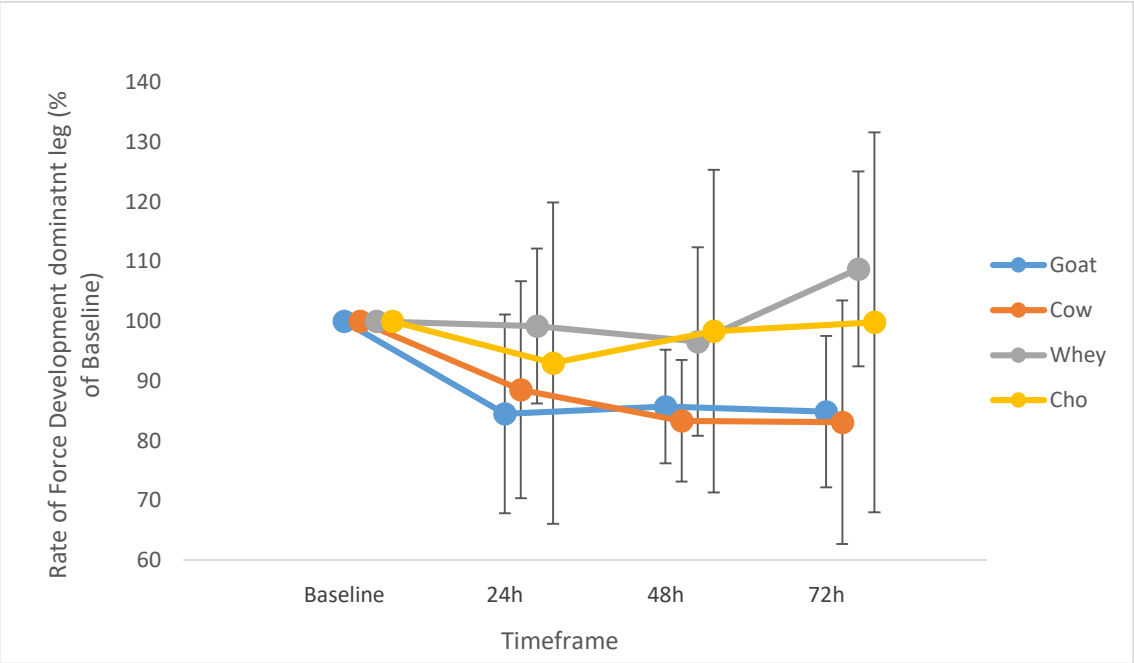

Figure 4.14 Percentage change in rate of force development of dominant leg in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Comparisons between COW and CHO presented a possible small harmful effect for COW from baseline to 48h (-16.7±10.2% *vs.* -1.7±27.0%, COW *vs.* CHO, respectively) and baseline to 72h (-16.9±20.4% *vs.* -0.2±31.8%, respectively). Compared to WHEY, COW had a possible small harmful effect from baseline to 24h (-11.5±19.6% *vs.* -0.8±13.0%, COW *vs.* WHEY, respectively), baseline to 48h (-17.1±10.9% *vs.* -3.4±15.8%, respectively) and a likely small harmful effect from baseline to 72h (-15.3±21.5% *vs.* 8.8±16.4%, respectively). From baseline to 24h, GOAT had a likely small harmful effect compared to WHEY (-15.5±16.7% *vs.* 0.8±13.0%, GOAT *vs.* WHEY, respectively), a possible trivial harmful effect from baseline to 48h (-14.3±9.5% *vs.* -3.4±15.8%, respectively) and a likely small harmful effect from baseline to 72h (-15.2±12.7% *vs.* 8.8±16.4%, respectively). Compared to GOAT, COW had a possible trivial harmful effect from baseline to 48h (-

14.3±9.5% *vs.* -16.7±10.2%, GOAT *vs.* COW, respectively). All other comparisons were unclear.

A summary of the statistical analysis for dominant leg RFD can be seen in Table 4.14.

Table 4.14 Effect on RFD in dominant leg following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
RFD Dominant Leg				
Cow *vs.* Cho	B - 24	-2.0, ± 27.0	Unclear	Small (0.21)
	B - 48	15.8, ± 29.1	COW Possibly Harmful	Small (0.54)
	B - 72	18.7, ± 37.2	COW Possibly Harmful	Small (0.53)
Cow *vs.* Whey	B - 24	13.0, ± 24.5	COW Possibly Harmful	Small (0.21)
	B - 48	15.9, ± 19.5	COW Possibly Harmful	Small (0.30)
	B - 72	29.7, ± 32.3	COW Likely Harmful	Small (0.53)
Goat *vs.* Cho	B - 24	-12.3, ± 22.4	Unclear	Small (0.42)
	B - 48	-11.3, ± 22.9	Unclear	Small (0.35)
	B - 72	-12.0, ± 25.9	Unclear	Small (0.33)
Goat *vs.* Whey	B - 24	-15.1, ± 14.5	GOAT Likely Harmful	Small (0.24)
	B - 48	-10.1, ± 13.1	GOAT Possibly Harmful	Trivial (0.19)
	B - 72	-21.2, ± 12.2	GOAT Likely Harmful	Small (0.40)
Goat *vs.* Cow	B - 24	4.4, ± 23.7	Possibly Trivial	Trivial (0.17)
	B - 48	-3.6, ± 13.2	COW Possibly Harmful	Trivial (0.06)
	B - 72	-2.0, ± 23.0	Unclear	Trivial (0.02)
Whey *vs.* Cho	B - 24	-7.6, ± 19.6	Unclear	Small (0.40)
	B - 48	-0.6, ± 24.8	Unclear	Small (0.28)
	B - 72	-12.1, ± 24.2	Unclear	Small (0.37)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.16 Rate of force development (RFD) – non-dominant leg

Immediately prior to the damage inducing exercise baseline rate of force development (RFD) values in the non-dominant leg of those who consumed GOAT, COW, WHEY and CHO were 0.63 ± 0.29, 0.66 ± 0.16, 0.64 ± 0.39 and 0.58 ± 0.20 $Nm.s^{-1}$, respectively. Changes in RFD for dominant leg can be seen in Figure 4.15.

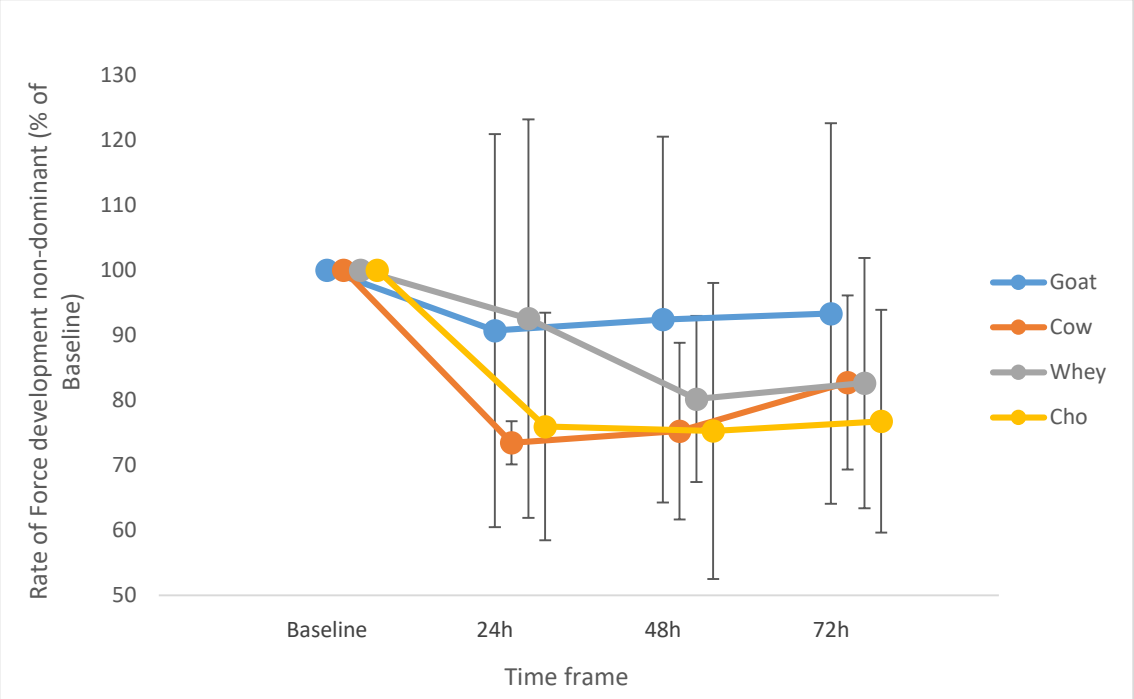

Figure 4.15 Percentage change in rate of force development of non-dominant leg in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW compared to CHO had a possible small beneficial effect from baseline to 72h (-17.3±13.4% *vs.* -23.3±17.1%, COW *vs.* CHO, respectively). WHEY and COW comparisons demonstrated COW had a likely small harmful effect from baseline to 24h (-26.6±3.3% *vs.* -7.5±20.1%, COW *vs.* WHEY, respectively), and a likely trivial harmful effect from baseline to 48h (-24.8±13.6% *vs.* -18.7±12.8%, respectively) and baseline to 72h (-17.3±13.4% *vs.* -13.4±19.3%, respectively). GOAT compared to CHO had a possible small beneficial effect from baseline to 24h (-9.3±30.2% *vs.* -24.1±17.5%, GOAT *vs.* CHO, respectively), and a likely small beneficial effect from baseline to 48h (-7.6±28.1% *vs.* -24.7±22.8%, respectively), and baseline to 72h (-6.7±29.3% *vs.* -23.3±17.1%, respectively). GOAT compared to COW had a likely small beneficial effect from baseline

to 48h (-7.6±28.1% *vs.* -24.8±13.6%, GOAT *vs.* COW, respectively). Comparisons between WHEY and CHO presented a very likely small beneficial effect for WHEY from baseline to 24h (-7.5±20.1% *vs.* -24.1±17.5%, WHEY *vs.* CHO, respectively) and a likely small beneficial effect from baseline to 48h (-18.7±12.8% *vs.* -24.7±22.8%, respectively) and baseline to 72h (-13.4±19.3% *vs.* –23.3±17.1%, respectively). All other comparisons were unclear.

A summary of the statistical analysis for non-dominant leg RFD can be seen in Table 4.15.

Table 4.15 Effect on RFD in non-dominant leg following muscle damage exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
RFD Non Dominant Leg				
Cow *vs.* Cho	B - 24	-7.7, ± 15.0	Unclear	Small (0.21)
	B - 48	-3.5, ± 20.0	Unclear	Small (0.20)
	B - 72	-12.2, ± 12.5	COW Possibly Beneficial	Small (0.44)
Cow *vs.* Whey	B - 24	24.6, ± 23.7	COW Likely Harmful	Small (0.29)
	B - 48	19.5, ± 25.3	COW Likely Harmful	Trivial (0.13)
	B - 72	14.1, ± 25.8	COW Possibly Harmful	Trivial (0.08)
Goat *vs.* Cho	B - 24	18.1, ± 31.5	GOAT Possibly Beneficial	Small (0.38)
	B - 48	25.9, ± 33.4	GOAT Likely Beneficial	Small (0.45)
	B - 72	23.2, ± 32.1	GOAT Likely Beneficial	Small (0.46)
Goat *vs.* Whey	B - 24	-11.0, ± 25.1	Unclear	Trivial (0.06)
	B - 48	-0.5, ± 26.8	Unclear	Trivial (0.09)
	B - 72	-5.6, ± 28.6	Unclear	Trivial (0.02)
Goat *vs.* Cow	B - 24	-7.8, ± 24.0	Unclear	Small (0.24)
	B - 48	-16.7, ± 20.4	GOAT Likely Beneficial	Small (0.31)
	B - 72	-7.7, ± 25.2	Unclear	Trivial (0.15)
Whey *vs.* Cho	B - 24	-17.5, ± 25.4	WHEY Very Likely Beneficial	Small (0.40)
	B - 48	-9.4, ± 28.4	WHEY Likely Beneficial	Small (0.28)
	B - 72	-12.0, ± 22.3	WHEY Likely Beneficial	Small (0.37)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.17 Serum Creatine Kinase

Serum creatine kinase baseline values prior to muscle damaging exercise for GOAT, COW, WHEY and CHO were 284.6 ± 278.4, 152.6 ± 113.0, 186.5 ± 76.4 and 172.3 ± 113.1 $U.L^{-1}$, respectively. Changes in CK levels can be seen in Figure 4.16.

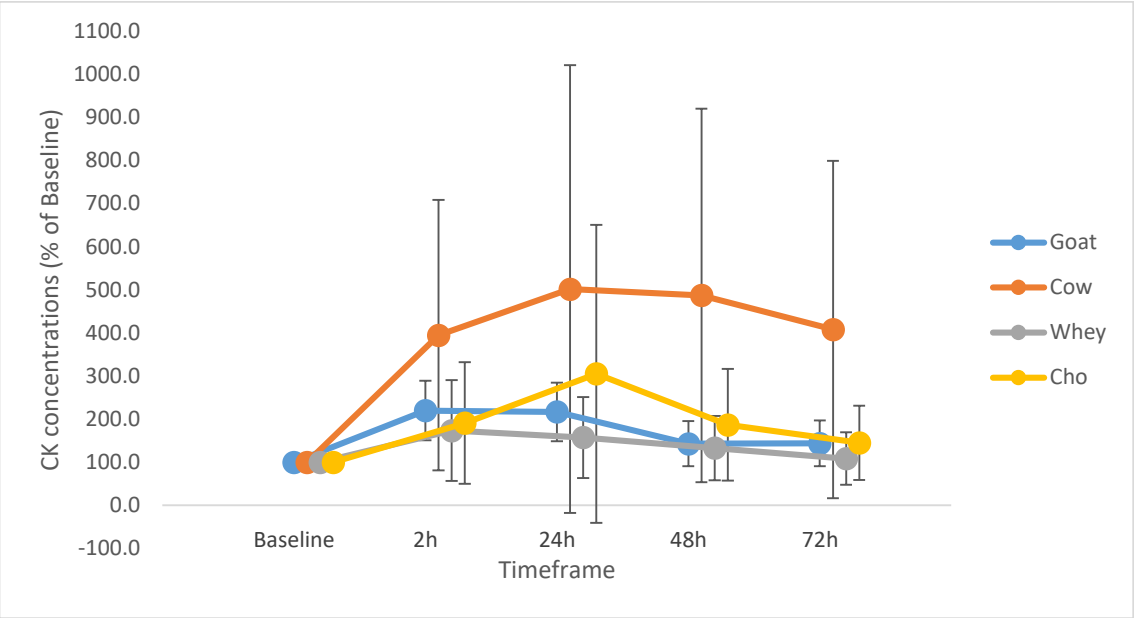

Figure 4.16 Percentage change of serum CK values in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

Increases in CK for those consuming COW compared to CHO showed a likely large harmful effect from baseline to 2h, a likely very large harmful effect from baseline to 24h, baseline to 48h and baseline to 72h. Comparisons between COW and WHEY showed increases in COW had a likely large harmful effect from baseline to 2h, a very likely extremely large harmful effect from baseline to 24h and a very likely very large harmful effect from baseline to 48h and baseline to 72h. Increases in CK for those consuming GOAT compared to CHO had a likely moderate harmful effect from baseline to 2h. Comparisons between GOAT and WHEY had a likely moderate harmful effect for GOAT from baseline to 2h and baseline to 24h with a likely small harmful effect from baseline to 48h and baseline to 72h. Less severe CK increases in GOAT compared to COW had a likely large beneficial effect from baseline to 24h and a likely moderate beneficial effect from baseline to 48h and baseline to 72h. CK levels in CHO compared to WHEY

had a likely moderate harmful effect from baseline to 24h, a possibly moderate harmful effect from baseline to 48h and a possibly small harmful effect from baseline to 72h.

A summary of the statistical analysis for CK serum levels can be seen in Table 4.16.

Table 4.16 Effects on increases in CK following muscle damaging exercise

VARIABLE	TIMEFRAME	MEAN EFFECT, x/÷90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
CK				
Cow *vs.* Cho	B - 2h	1.815 x/÷ 1.906	COW Likely Harmful	Large (1.77)
	B - 24	1.878 x/÷ 2.503	COW Likely Harmful	Very Large (3.43)
	B - 48	1.987 x/÷ 2.222	COW Likely Harmful	Very Large (2.07)
	B - 72	2.188 x/÷ 2.042	COW Likely Harmful	Very Large (2.23)
Cow *vs.* Whey	B - 2h	2.037 x/÷ 1.947	COW Likely Harmful	Large (1.55)
	B - 24	2.929 x/÷ 2.358	COW Very Likely Harmful	Extremely Large (4.95)
	B - 48	2.630 x/÷ 2.175	COW Very Likely Harmful	Very Large (3.00)
	B - 72	2.814 x/÷ 1.984	COW Very Likely Harmful	Very Large (3.15)
Goat *vs.* Cho	B - 2h	1.302 x/÷ 1.542	GOAT Likely Harmful	Moderate (1.03)
	B - 24	0.971 x/÷ 1.810	Unclear	Small (0.42)
	B - 48	0.860 x/÷ 1.605	Unclear	Trivial (0.04)
	B - 72	1.078 x/÷ 1.583	Unclear	Trivial (0.10)
Goat *vs.* Whey	B - 2h	1.461 x/÷ 1.608	GOAT Likely Harmful	Moderate (0.85)
	B - 24	1.514 x/÷ 1.541	GOAT Likely Harmful	Moderate (0.91)
	B - 48	1.138 x/÷ 1.499	GOAT Likely Harmful	Small (0.33)
	B - 72	1.386 x/÷ 1.496	GOAT Likely Harmful	Small (0.38)
Goat *vs.* Cow	B - 2h	0.717 x/÷ 1.809	Unclear	Trivial (0.10)
	B - 24	0.517 x/÷ 2.287	GOAT Likely Beneficial	Large (1.36)
	B - 48	0.433 x/÷ 2.155	GOAT Likely Beneficial	Moderate (1.03)
	B - 72	0.492 x/÷ 1.976	GOAT Likely Beneficial	Moderate (1.05)
Whey *vs.* Cho	B - 2h	1.222 x/÷ 1.726	Unclear	Small (0.50)
	B - 24	1.560 x/÷ 1.883	CHO Likely Harmful	Moderate (1.00)
	B - 48	1.323 x/÷ 1.643	CHO Possibly Harmful	Moderate (0.61)
	B - 72	1.286 x/÷ 1.604	CHO Possibly Harmful	Small (0.58)

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. x/÷ 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.18 Muscle Soreness

At 24h post muscle damaging exercise all groups indicated an increase in muscle soreness of both the dominant and non-dominant legs. Soreness peaked at 24h for GOAT, COW, CHO and for WHEY at 48h. By 72h soreness had started to return towards baseline values. Changes in muscle soreness can be seen in Figure 4.17.

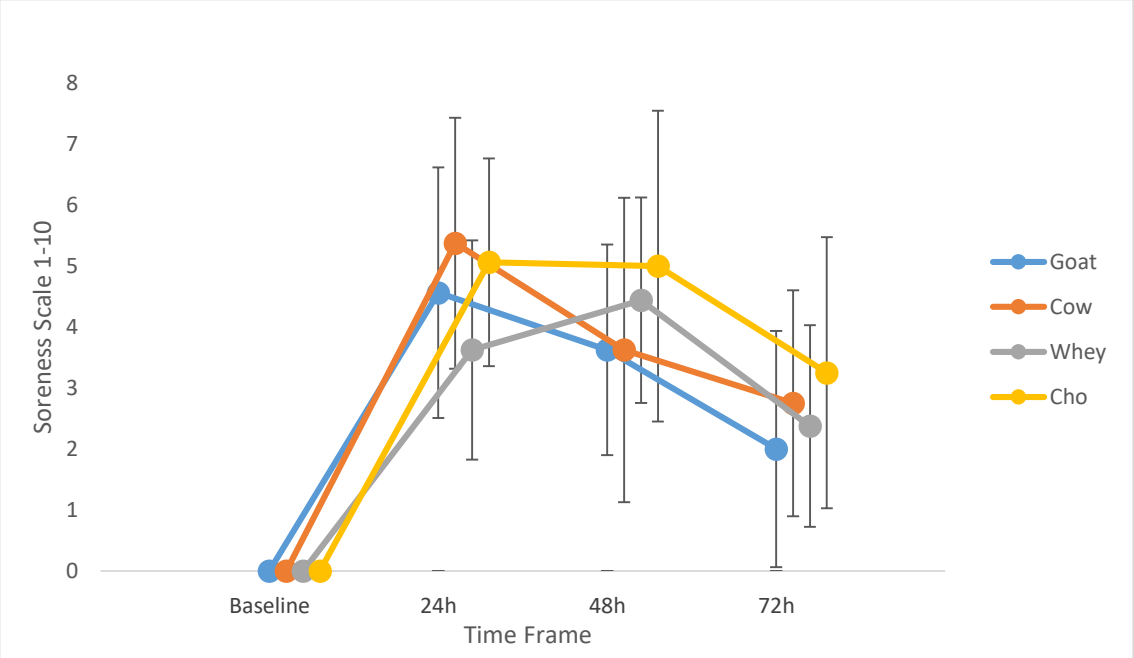

Figure 4.17 Muscle soreness in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW had a possible small beneficial effect compared to CHO from baseline to 48h and a possible trivial beneficial effect from baseline to 72h. WHEY had a likely small beneficial effect from baseline to 24h when compared to COW but had a possible trivial harmful effect from baseline to 48h. GOAT had a possible trivial beneficial effect from baseline to 24h, baseline to 72h and had a possible small beneficial effect from baseline to 48h when compared to CHO. GOAT had a possible trivial beneficial effect from baseline to 48h and baseline to 72h in comparison to WHEY. GOAT had a possible trivial beneficial effect from baseline to 24h and baseline to 72h compared to COW. WHEY had a likely small beneficial effect from baseline to 24h compared to CHO and a possible trivial beneficial effect from baseline to 48h and baseline to 72h.

A summary of the statistical analysis for muscle soreness can be seen in Table 4.17.

Table 4.17 Effects on soreness following muscle damaging exercise

GROUPS	TIMEFRAME	MEAN EFFECT	QUALITATIVE INFERENCE	EFFECT SIZE
Cow *vs.* Cho	B - 24	-0.3, ± 1.8	Unclear	Trivial
	B - 48	1.4, ± 2.4	COW Possibly Beneficial	Small
	B - 72	0.5, ± 1.9	COW Possibly Beneficial	Trivial
Cow *vs.* Whey	B - 24	-1.8, ± 1.8	WHEY Likely Beneficial	Small
	B - 48	0.8, ± 2.0	WHEY Possibly Harmful	Trivial
	B - 72	-0.4, ± 1.7	Unclear	Trivial
Goat *vs.* Cho	B - 24	0.5, ± 1.8	GOAT Possibly Beneficial	Trivial
	B - 48	1.4, ± 2.1	GOAT Likely Beneficial	Small
	B - 72	1.3, ± 2.0	GOAT Possibly Beneficial	Small
Goat *vs.* Whey	B - 24	-0.9, ± 1.8	Unclear	Trivial
	B - 48	0.8, ± 1.6	GOAT Possibly Beneficial	Trivial
	B - 72	0.4, ± 1.7	GOAT Possibly Beneficial	Trivial
Goat *vs.* Cow	B - 24	0.8, ± 1.9	GOAT Possibly Beneficial	Trivial
	B - 48	0.0, ± 2.0	Unclear	Trivial
	B - 72	0.8, ± 1.8	GOAT Possibly Beneficial	Trivial
Whey *vs.* Cho	B - 24	1.4, ± 1.7	WHEY Likely Beneficial	Small
	B - 48	0.6, ± 2.1	WHEY Possibly Beneficial	Trivial
	B - 72	0.9, ± 1.9	WHEY Likely Beneficial	Trivial

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.19 Muscle Tiredness

At 24h post muscle damaging exercise all groups indicated an increase in muscle tiredness of both the dominant and non-dominant legs. By 72h tiredness had started to return towards baseline values. Changes in muscle tiredness can be seen in Figure 4.18.

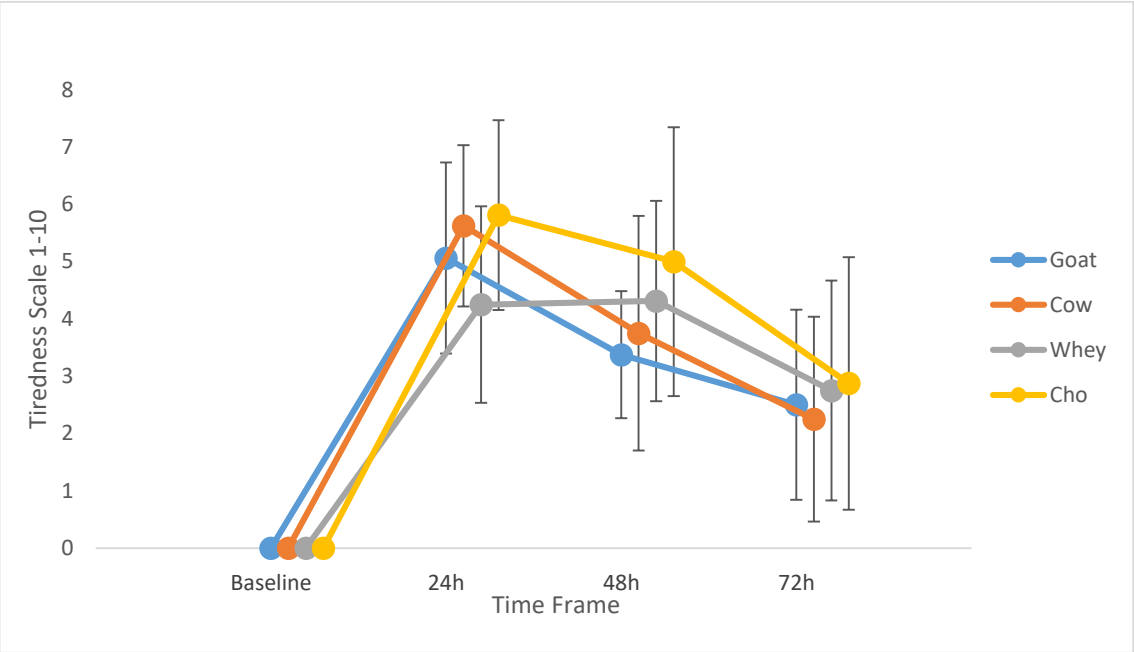

Figure 4.18 Muscle tiredness in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW had a possible trivial beneficial effect from baseline to 24h, baseline to 72h and a possible small beneficial effect from baseline to 48h in comparison to CHO. WHEY had a likely small beneficial effect from baseline to 24h, however, had a possible trivial harmful effect from baseline to 48h and baseline to 72h when compared to COW. GOAT had a possible trivial beneficial effect from baseline to 24h and baseline to 72h when compared to CHO and a likely small beneficial effect from baseline to 48h. GOAT when compared to WHEY had a possible beneficial effect from baseline to 48h and baseline to 72h. GOAT had a possible trivial beneficial effect in comparison to COW from baseline to 24h and baseline to 48h. WHEY had a likely small beneficial effect compared to CHO from baseline to 24h and a possible trivial beneficial effect from baseline to 48h.

A summary of the statistical analysis for muscle tiredness can be seen in Table 4.18.

Table 4.18 Effect on tiredness following muscle damaging exercise

GROUPS	TIMEFRAME	MEAN EFFECT	QUALITATIVE INFERENCE	EFFECT SIZE
Cow *vs.* Cho	B - 24	0.2, ± 1.5	COW Possibly Beneficial	Trivial
	B - 48	1.3, ± 2.1	COW Possibly Beneficial	Small
	B - 72	0.6, ± 1.9	COW Possibly Beneficial	Trivial
Cow *vs.* Whey	B - 24	-1.4, ± 1.5	WHEY Likely Beneficial	Small
	B - 48	0.6, ± 1.8	WHEY Possibly Harmful	Trivial
	B - 72	0.5, ± 1.8	WHEY Possibly Harmful	Trivial
Goat *vs.* Cho	B - 24	0.8, ± 1.6	GOAT Possibly Beneficial	Trivial
	B - 48	1.6, ± 1.8	GOAT Likely Beneficial	Small
	B - 72	0.4, ± 1.8	GOAT Possibly Beneficial	Trivial
Goat *vs.* Whey	B - 24	-0.8, ± 1.6	Unclear	Trivial
	B - 48	0.9, ± 1.4	GOAT Possibly Beneficial	Trivial
	B - 72	0.3, ± 1.7	GOAT Possibly Beneficial	Trivial
Goat *vs.* Cow	B - 24	0.6, ± 1.5	GOAT Possibly Beneficial	Trivial
	B - 48	0.4, ± 1.6	GOAT Possibly Beneficial	Trivial
	B - 72	-0.3, ± 1.6	Unclear	Trivial
Whey *vs.* Cho	B - 24	1.6, ± 1.6	WHEY Likely Beneficial	Small
	B - 48	0.7, ± 2.0	WHEY Possibly Beneficial	Trivial
	B - 72	0.1, ± 2.0	Unclear	Trivial

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.20 DALDA

The validated Daily Analyses of Life Demands of Athletes (DALDA) questionnaire gave a perceived measure of the athlete's response to recovery as illustrated in Figure 4.19.

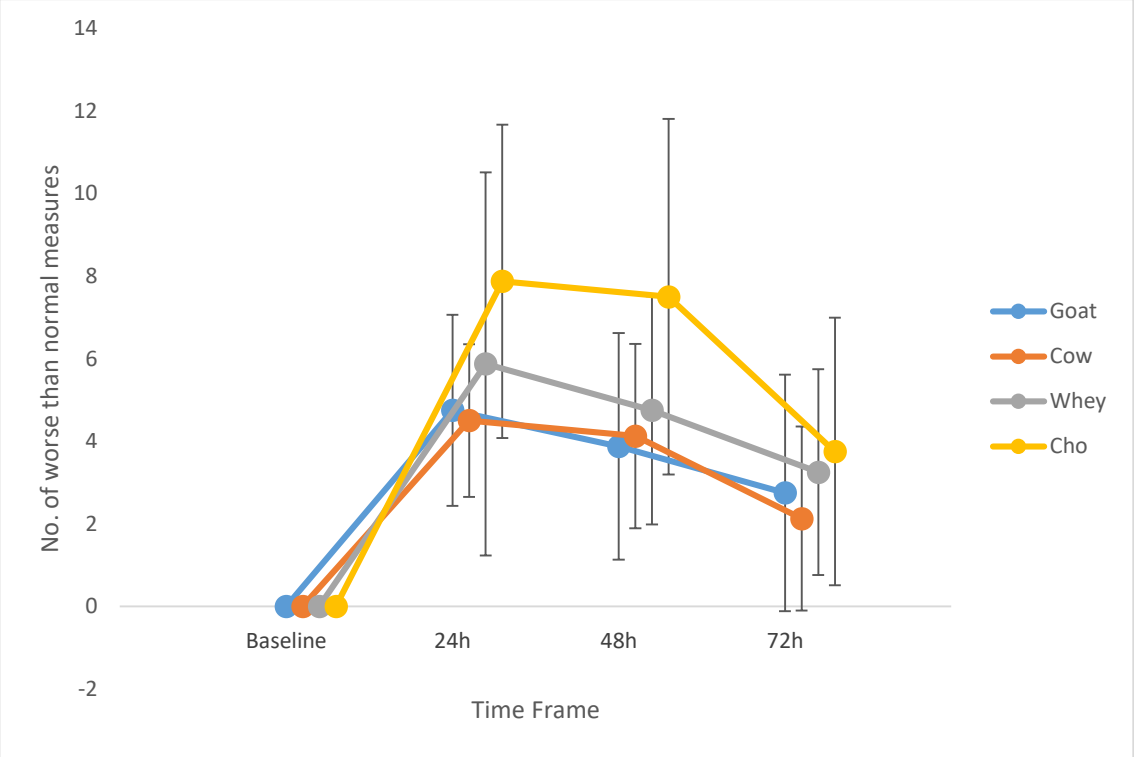

Figure 4.19 Perceived recovery in response to muscle damaging exercise for GOAT, COW, WHEY and CHO. Values are presented as means ± SD, *n*=8 per group

COW had a likely small beneficial effect from baseline to 24h, baseline to 48h and a likely trivial beneficial effect from baseline to 72h compared to CHO. GOAT had a likely small beneficial effect from baseline to 24h and baseline to 48h compared to CHO. WHEY had a likely trivial beneficial effect from baseline to 24h and a likely small beneficial effect from baseline to 48h compared to CHO. All other comparisons were unclear.

A summary of the statistical analysis for DALDA can be seen in Table 4.19.

Table 4.19 Perceived reception of recovery from DALDA questionnaire following muscle damaging exercise

GROUPS	TIMEFRAME	MEAN EFFECT	QUALITATIVE INFERENCE	EFFECT SIZE
Cow *vs.* Cho	B - 24	3.4, ± 2.7	COW Likely Beneficial	Small
	B - 48	3.4, ± 3.1	COW Likely Beneficial	Small
	B - 72	1.6, ± 2.5	COW Likely Beneficial	Trivial
Cow *vs.* Whey	B - 24	1.4, ± 3.2	Unclear	Trivial
	B - 48	0.6, ± 2.2	Unclear	Trivial
	B - 72	1.1, ± 2.1	Unclear	Trivial
Goat *vs.* Cho	B - 24	3.1, ± 2.8	GOAT Likely Beneficial	Small
	B - 48	3.6, ± 3.2	GOAT Likely Beneficial	Small
	B - 72	1.0, ± 2.7	Unclear	Trivial
Goat *vs.* Whey	B - 24	1.1, ± 3.3	Unclear	Trivial
	B - 48	0.9, ± 2.4	Unclear	Trivial
	B - 72	0.5, ± 2.4	Unclear	Trivial
Goat *vs.* Cow	B - 24	0.3, ± 1.9	Unclear	Trivial
	B - 48	0.3, ± 2.2	Unclear	Trivial
	B - 72	0.6, ± 2.3	Unclear	Trivial
Whey *vs.* Cho	B - 24	2.0, ± 3.8	WHEY Likely Beneficial	Trivial
	B - 48	2.8, ± 3.3	WHEY Likely Beneficial	Small
	B - 72	0.5, ± 2.6	Unclear	Trivial

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.

4.21 Palatability

The Likert Scale represented participant's opinion to drinks that were agreeable to the palate as illustrated in illustrated in Figure 4.20.

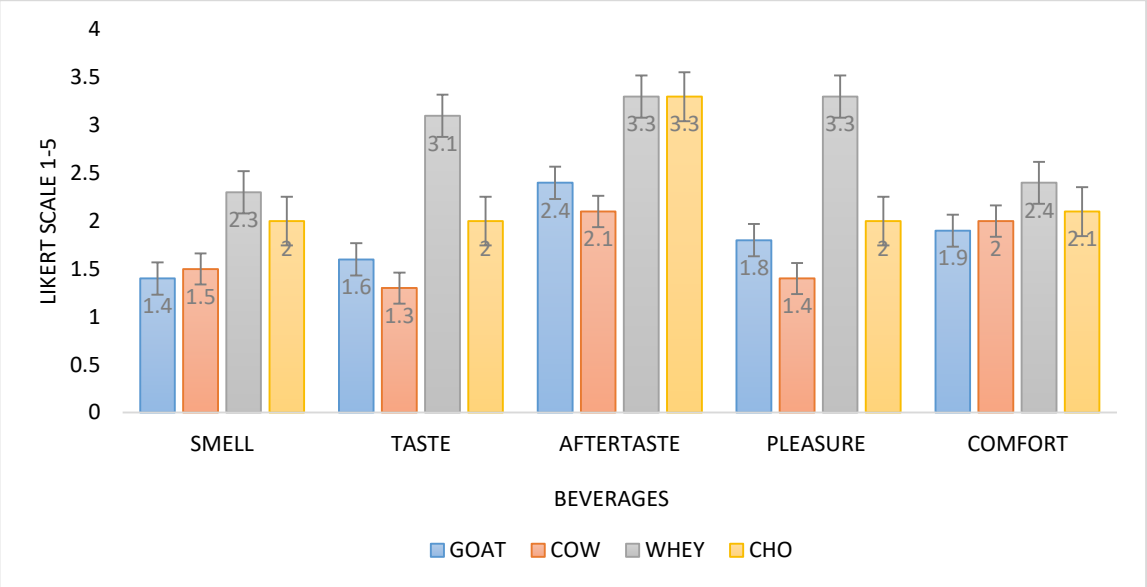

Figure 4.20 Palatability scores for consumption of GOAT, COW, WHEY and CHO. 1=good/none/comfortable, 5=bad/much/very uncomfortable. Values are presented as means ± SD, *n*=8 per group

Consumption of COW post-exercise displayed a possible small better effect for smell, taste and pleasure on the palate with a likely small better effect for aftertaste and a possible trivial effect on stomach comfort compared to CHO consumption. Consumption of COW compared to WHEY showed a possible small better effect for smell and stomach comfort, a very likely moderate better effect for taste and pleasure on the palate and a likely small better effect for aftertaste. GOAT consumption had a possible small better effect for smell and taste, a likely small better effect for aftertaste, a possible trivial better effect on pleasure on the palate and a possible trivial better effect on stomach comfort compared to CHO. GOAT consumption versus WHEY consumption showed a likely small better effect for GOAT for smell, taste, aftertaste and pleasure on the palate and a possible small better effect on stomach comfort. Consumption of GOAT compared to COW had trivial effects for smell, aftertaste and stomach comfort and unclear effects for taste and pleasure on the palate. Consumption of CHO post-exercise had a likely small better effect on taste and pleasure on the palate compared to WHEY. All other comparisons were unclear.

A summary of the statistical analysis for palatability can be seen in Table 4.20.

Table 4.20 Comparison of palatability scores among groups

GROUPS	MEASURE	QUALITATIVE INFERENCE	EFFECT SIZE
Cow *vs.* Cho	Smell	COW Possibly Better	Small
	Taste	COW Possibly Better	Small
	Aftertaste	COW Likely Better	Small
	Pleasure	COW Possibly Better	Small
	Comfort	Possibly Trivial	Trivial
Cow *vs.* Whey	Smell	COW Possibly Better	Small
	Taste	COW Very likely Better	Moderate
	Aftertaste	COW Likely Better	Small
	Pleasure	COW Very likely Better	Moderate
	Comfort	COW Possibly Better	Small
Goat *vs.* Cho	Smell	GOAT Possibly Better	Small
	Taste	GOAT Possibly Better	Small
	Aftertaste	GOAT Likely Better	Small
	Pleasure	GOAT Possibly Better	Trivial
	Comfort	Possibly Trivial	Trivial
Goat *vs.* Whey	Smell	GOAT Likely Better	Small
	Taste	GOAT Likely Better	Moderate
	Aftertaste	GOAT Likely Better	Small
	Pleasure	GOAT Likely Better	Moderate
	Comfort	GOAT Possibly Better	Small
Goat *vs.* Cow	Smell	Likely Trivial	Trivial
	Taste	Unclear	Small
	Aftertaste	Possibly Trivial	Trivial
	Pleasure	Unclear	Small
	Comfort	Possibly Trivial	Trivial
Whey *vs.* Cho	Smell	Unclear	Trivial
	Taste	CHO Likely Better	Small
	Aftertaste	Possibly Trivial	Trivial
	Pleasure	CHO Likely Better	Moderate
	Comfort	Unclear	Small

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Effect size is a quantitative measure of the magnitude.

4.22 Food Diary Analysis

Analysis of food diaries across the 4-day assessment period demonstrated some variance among food groups for GOAT, COW, WHEY and CHO as illustrated in Table 4.21.

Table 4.21 Energy and macronutrient comparisons between groups across 4-day assessment

GROUPS	FOOD TYPE	QUALITATIVE INFERENCE	EFFECT SIZE
Cow *vs.* Cho	kCal	Unclear	Small (0.26)
	CHO	Unclear	Trivial (0.02)
	PRO	Unclear	Trivial (0.19)
	FAT	CHO Likely Higher	Small (0.44)
Cow *vs.* Whey	kCal	COW Likely Lower	Large (1.25)
	CHO	COW Likely Lower	Large (1.09)
	PRO	COW Possibly Lower	Small (0.34)
	FAT	COW Likely Lower	Large (1.86)
Goat *vs.* Cho	kCal	CHO Likely Lower	Moderate (0.66)
	CHO	CHO Likely Lower	Large (1.02)
	PRO	CHO Likely Lower	Large (0.81)
	FAT	CHO Possibly Lower	Small (0.21)
Goat *vs.* Whey	kCal	Unclear	Trivial (0.13)
	CHO	Unclear	Small (0.26)
	PRO	Unclear	Small (0.31)
	FAT	Unclear	Trivial (0.10)
Goat *vs.* Cow	kCal	GOAT Likely Higher	Moderate (0.68)
	CHO	GOAT Very Likely Higher	Moderate (0.78)
	PRO	GOAT Likely Higher	Small (0.47)
	FAT	GOAT Likely Higher	Moderate (0.68)
Whey *vs.* Cho	kCal	CHO Likely Lower	Small (0.48)
	CHO	CHO Likely Lower	Moderate (0.68)
	PRO	Unclear	Trivial (0.15)
	FAT	CHO Likely Lower	Small (0.31)

Data is presented as mean values for 4-day assessment period. Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Effect size is a quantitative measure of the magnitude.

CHAPTER 5

DISCUSSION

5.0 DISCUSSION

The results of this study indicate that the consumption of 750 mL of goats milk, cows milk and whey protein post muscle damaging exercise attenuated losses for some muscle function variables and attenuated increases in muscle soreness and tiredness compared to an energy-matched carbohydrate drink. Although some of the outcomes were unclear or in fact harmful as detailed in the results section, overall benefits were possible or likely. Considerable variation was observed across beverages and time points. Thus, while these beverages may provide valuable recovery interventions for team field sport athletes, additional investigation is necessary to further elucidate responses.

Within-group results (Appendix J) demonstrated that completion of the exercise protocol resulted in reduced muscle function (small–moderate decreases), increased muscle soreness and tiredness (moderate-large increases) and increased levels of serum CK concentrations (moderate-large increases). Furthermore, athletes were not fully recovered by 72 h post exercise. These findings are in agreement with other studies in which necessary time for variables to return to normal, in particular CK and muscle soreness, exceeded the 72 h timeframe previously reported (Clarkson and Hubal, 2002; Rankin *et al*., 2015).

Overall analysis of data reported protein drinks attenuated losses in muscle function to a greater extent than CHO and were more beneficial for limiting increases in soreness, tiredness and daily stresses compared to CHO. However, the benefits observed did not extend to all variables nor all time points. The benefit of post exercise protein intake compared to CHO may be as result of the effect on post exercise protein balance. Following consumption of protein drinks, rapid aminoacidemia occurs, leading to a positive net protein balance, thus creating an environment for increased MPS (Miller *et al*., 2003; Tipton *et al*., 2004; Børsheim *et al*., 2004). Consuming protein and carbohydrate together has been shown to result in an increased rate of protein

synthesis, as it is known that the muscle has an enhanced response to protein if it is in a CHO fed state (Witard *et al*., 2016) and thus, this leads to a positive protein balance. However, in this study, a lot of the comparisons were unclear, and WHEY, which did not contain carbohydrate, was more beneficial compared to COW and GOAT for some variables such as peak torque extension and flexion. The consumption of milk post resistance exercise has been shown to result in increased amino acid availability (Wilkinson *et al*., 2007). Additionally, given that the body releases a large amount of insulin in response to consumption of milk (West *et al*., 2011), which contains protein, it has been identified as a suitable drink for stimulating net protein synthesis and preventing protein breakdown. Thus, speculatively, the consumption of COW, GOAT and WHEY in the current study may have resulted in a positive net protein balance reflective of the synthesis and the breakdown of muscle, which had a positive effect on the variables measured over the recovery period. However, there is a large inter-subject variability, thus, further investigation is warranted to elucidate responses. It is probable that the insulin response from carbohydrate (for COW and GOAT) as well as the amino acid provision from protein during the post-exercise period inhibited protein breakdown (Dimitriadis *et al*., 2011) and enhanced MPS stimulation, thus, positively impacting recovery (Ferguson-Stegall *et al*., 2011; Jäger *et al*., 2017).

For some measures of muscle function (CMJ, peak torque 60°.s^{-1} and sprint performance), GOAT resulted in greater attenuation of function loss compared to COW, particularly over the first 24 h of recovery. GOAT also resulted in a smaller increase in CK concentrations over the 72 h recovery period and reduced levels of soreness over 48 h (see Table 4.16). In comparison to GOAT, WHEY resulted in a beneficial effect in reducing the losses in peak torque at 60°.s^{-1}. However, in contrast, GOAT was more beneficial than WHEY for CMJ, RSI and muscle soreness and tiredness particularly over 48 h of recovery. Most comparisons between COW and WHEY were unclear, though COW was beneficial in attenuating losses in a single peak torque measure, and contrastingly, WHEY was beneficial for 10 m sprint performance at 24 h (see Table 4.11). WHEY also resulted in smaller increases in soreness and tiredness over the full recovery period. These findings are discussed in further detail below.

The exercise protocol utilised in this study incorporated movement patterns associated with field sports such as sprinting with a deceleration and jumping. Both of these exercise activities result in considerable eccentric loading of the quadriceps, likely resulting in greater muscle damage in this muscle group compared to the hamstrings. As well as resulting in muscle damage, repeated sprinting also results in neuromuscular fatigue (Mendez-Villanueva *et al*., 2008). In order to maintain the desired power output during supramaximal sprints the nervous system would need to recruit all motor unit pools at their highest firing rate thus, impacting post exercise torque production. (Krustrup *et al*., 2004). Despite this, sprinting and jumping were least affected by the intervention (see Figure 4.1; 4.12). The majority of comparisons between beverages for sprint performance resulted in unclear outcomes, though unexpectedly, CHO was more beneficial than COW across all time points. It is possible that the large day to day variability in 5 m sprint performance observed for all groups (see Table 4.10) may have masked the impact of any intervention as has been previously reported (Clifford *et al*., 2016). Previous research reported that, more than 72 hours is needed for sprint performance to return to baseline values (Ispirlidis *et al*., 2008). Despite this, other studies have demonstrated performance test markers such as CMJ and sprint performance return to baseline after 48 h (Twist and Sykes, 2011; Rampinini *et al*., 2011; Silva *et al*., 2014). In this study, both CMJ and sprint performance remained reduced 72 h post-exercise. Future studies should examine more time points to provide a clear indication of adequate time frames that are necessary for sufficient recovery to be achieved., both with and without recovery interventions.

Previous research has reported that the post exercise consumption of WHEY had a positive effect on the attenuation of losses in peak torque following muscle damaging exercise (Buckley *et al*., 2010; Cooke *et al*., 2010). In this study, WHEY in particular had the greatest beneficial effects on peak torque measures at both $60°.s^{-1}$ and $180°.s^{-1}$ extension and flexion in dominant and non-dominant legs. While peak torque is described as a valid and reliable measure of recovery (Warren *et al*., 1999), its relevance in a practical context may be less than other measures. Peak torque is an isolated measure of an isolated muscle group, and the speeds utilized in this study ($60°.s^{-1}$ and

180°.s^{-1}) are much less than the muscle contraction speeds in sprinting (>900°.s^{-1}); (Young *et al*., 1995). Despite this, it is a beneficial method as it is relevant in the context of exploring muscle force production capability following fatiguing and muscle damaging exercise.

Previous studies have reported elite athletes with high lower body strength and speed execution ability have better tolerance to higher workloads and are less inclined to develop severe EIMD (Malone *et al*., 2018). For both CMJ height and sprint time, athletes physical fitness differences may have an impact on variability among results (Impellizzeri *et al*., 2005). Twist and Sykes (2011) examined symptoms of EIMD following a simulated rugby game in non-elite players and reported a strong decrease in both CMJ height and sprint performance. In the current study, all participants were competing in their chosen sport, but this may have been at different levels, thus impacting the magnitude of loss of muscle function and possibly the impact of the intervention. Results of jump measures in this study reported beneficial effects for GOAT compared to other groups for CMJ, however, harmful for RSI. Nevertheless, these performance markers are assessing two quite different measures although they both involve the stretch shortening cycle (Healy *et al*., 2016). The CMJ is quite a slow stretch shortening cycle action while RSI is a faster and more difficult action (Flanagan and Comyns, 2008). While the RSI describes the performance of the athlete during the jumping phase of a depth jump (DJ), the nature of the landing from such a jump can also have an impact and be quantified (Flanagan *et al*., 2008). It has been reported that the variability in the measurement of RSI is extremely high and that despite familiarisation with the protocol, participants find it very difficult to grasp the concept of minimal ground contact time and that does affect the reliability (Ball *et al*., 2010). Other studies examining nutritional interventions post-eccentric exercise have not reported a clear effect of their intervention on RSI, despite benefits on measures of peak torque (Cockburn, 2010, 2012; Rankin, 2018). Despite this, they have reported benefits on other measures of muscle function including peak torque, sprint performance and CMJ. Thus, the variability in RSI observed in this study may have affected the potential impact of the intervention.

In this study, GOAT, WHEY and CHO limited increases in CK activity particularly GOAT and WHEY over 24 h. The protein beverages may have reduced myofibrillar protein disruption via the Ub-P system. However, CK represents sarcolemma damage and not myofibrillar damage, therefore, an impact on CK may not have the same impact on muscle function as different mechanisms are involved. The positive protein balance may have limited sarcolemma damage or may have enhanced sarcolemma repair post-exercise (Proske and Morgan, 2001). There is a wide variation in post-exercise CK concentrations. Previous studies have reported peak concentrations ranging from 100 to 500 $U.L^{-1}$ post-eccentric exercise (Howatson and Milak, 2009; Keane *et al*., 2015; Rankin *et al*., 2015; Brown *et al*., 2017), corresponding with concentrations reported in this study. Peak concentrations for WHEY reached 191 $U.L^{-1}$ while peak concentrations reached for COW were 501 $U.L^{-1}$. Some studies have reported peak concentrations at 24 h post eccentric exercise (Silva *et al*., 2014; Russell *et al*., 2016), as observed for COW and CHO in this study, while WHEY and GOAT peaked 2 h after the exercise protocol as previously stated by Clarkson *et al*. (1987). Ispirlidis *et al*. (2008) reported peak CK concentrations 48 h post-soccer match. Furthermore, Doeven *et al*. (2018) found CK recovery time courses ≥ 72 h post intermittent team ball sports. Increases in CK concentrations for COW in this study were comparable to Russell *et al*. (2016) who examined CK activity post-soccer match play and reported that values did not return to baseline by 72 h. In order to get a realistic view of recovery and underlying mechanisms, investigations of physical performance and biochemical markers after team sport performance is necessary (Russell *et al*., 2016). Johnston *et al*. (2016) investigated performance and biochemical responses after a single bout of eccentric training. Although immediately post-training a decrease in performance together with an increase in CK concentrations was reported. Performance returned to pre-training level after 2 h while CK concentrations continued to increase. This suggests that while performance may return to normal, underlying systems are still recovering (Doeven *et al*., 2018). Familarisation with the activity may also have had an impact on the magnitude of CK concentrations (Koch *et al*., 2014) and the other variables. A single exposure to a bout of resistance exercise diminishes the rise in CK concentrations to a subsequent bout of the same exercise (Chen, 2006). This phenomenon is known as the

repeated bout effect (RBE); (McHugh, 2003). Thus, regular training by athletes may limit CK activity from reaching high concentrations.

Post strenuous exercise, optimal performance is affected and an increase in muscle soreness and tiredness accompanies this (MacIntyre *et al*., 1995), as was observed in the current study. The VAS scale used in this study was subjective in nature with athletes rating their perception of muscle soreness. Peak soreness was reported at 24 h for COW, GOAT and CHO and for WHEY at 48 h which corresponds to peak concentrations in CK response. Similar findings were demonstrated by Cockburn *et al*. (2012) who reported that peak soreness aligned with peak CK concentrations. However, in the current study, CK concentrations remained elevated after 24 h for COW despite low levels of soreness reported. On the contrary, the CK serum concentrations for CHO decreased after 24 h despite participants reporting high soreness at 48 and 72 h post-exercise. Similar findings were reported by Clarkson and Ebbeling (1988). These data suggest a disconnect between these measures for CHO, which could suggest differing underlying mechanisms such as exhausted muscle fibres or local tissue damage (Brancaccio *et al*., 2007). Between 24 and 72 h post the exercise bout, muscle soreness levels were still above baseline, potentially impacting the athlete's ability to perform optimally (Cheung *et al*., 2003). There is always the possibility, that as a result of participants not being blinded, they were aware that both cows milk and goats milk may offer recovery benefits. This may have had an influence on their perception of soreness including the psychological impact of the placebo effect (Beedie and Foad, 2009). Research has demonstrated that there is not a link between muscle soreness and muscle function (Rodenburg *et al*., 1993) and the findings in this study support that. The mechanisms underpinning both are different. There is evidence to suggest that a link between muscle pain and psychological distress coexist (Crofford, 2015). The psychological effect of muscle pain caused from intense exercise may have an impact on an athlete's recovery by triggering feelings of anger, depression, anxiety, tension, fear, and decreased self-esteem (Reese *et al*., 2012). Tissue edema and inflammation are associated with soreness (MacIntyre *et al*., 1995). Therefore, it is important to note, that despite consumption of COW and GOAT resulting in reduced muscle soreness and tiredness, it did not necessarily impact on muscle function. Thus, that disconnect between the

variables of muscle force production and soreness demonstrates that muscle soreness does not correlate well with muscle function, an important distinction for athletes and coaches.

Studies have noted disturbed balance between both, physiological and psychological, stress and recovery that can lead to detrimental effects on performance as a direct result of poor mental state (Kenttä and Hassmén, 1998; Beedie *et al*., 2000). Self-reported measures of recovery such as the DALDA used in this study have been demonstrated to be highly accurate to monitor training response among athletes (Saw *et al*., 2016). Results from DALDA in this study reported protein intake, regardless of source, had a positive effect on markers of increased stress following the exercise protocol. Witard *et al*. (2011) stated the DALDA questionnaire revealed that the number of psychological symptoms of stress reported by cyclists during and after a period of intensified training was attenuated when dietary protein intake was augmented. The results of this study show similar findings following a single intake of milk protein post exercise. Again, there is the possibility that due to the lack of blinding in this study and the placebo effect, participants may have perceived the milk protein beverage to be beneficial, thus influencing their perception of the symptoms measured by DALDA. In order to overcome this bias, a carbohydrate drink was used as the comparative beverage, as most participants would be aware of the potential benefits of post exercise consumption of carbohydrate. Regardless, wellbeing is important for all athletes in order to maximise performance in sport. Reduced symptoms of stress increases a sense of wellbeing which is likely to be beneficial for the athlete.

Results reported COW and GOAT were more beneficial than CHO and WHEY for all measures of palatability. CHO performed better than WHEY for taste and pleasure on the palate. These are important practical findings as beverage palatability is known to influence fluid consumption and may positively influence hydration status and help prevent fatigue, heat illness, and decreased performance (Burdon *et al*. 2012). Similarly, beverage palatability may impact net protein balance, thus, impacting recovery. The relationship between palatability of beverages and its effect on fluid intake have been

previously investigated (Minehan *et al*., 2002). Voluntary fluid uptake is predominately affected by flavour and temperature (Passe *et al*. 2004). Minehan *et al*. (2002) reported flavour as a positive characteristic in determining voluntary fluid intake among basketball players. Similarly, Passe *et al*. (2004) reported flavoured beverages were voluntarily consumed in greater quantities than water among triathletes. These findings are of relevance to the practical implications of the current investigation, as palatability may impact intake and thus, the effect on recovery.

Results gathered from food diaries reported GOAT and WHEY had greater calorie, carbohydrate and fat intake than COW and CHO over the full recovery period. In contrast, CHO had greater fat intake than COW. The use of food diaries by athletes to record all food and beverages consumed for the desired period with details provided on specific brands, cooking methods and weight etc. have been reasonably valid depending on physical and psychological profiles of the athlete (Trabulsi and Schoeller, 2001). The disadvantages associated with provision of food diaries include athlete honesty and compliance. It is common that by the end of the desired period the athlete tends to try simplify the process by changing intakes as they grow tired of the requested task and there is the issue of social desirability bias as a result of reporting inaccurately (Trabulsi and Schoeller, 2001). Results are also dependent on the athlete's cooperation, attention to detail and ability/desire to record all foods and beverages at the time of consumption. Under- or over-recording affects general adjustments of intake and leads to increased magnitude of error (Larson-Meyer *et al*., 2018). Ideally, having complete control of diet in this study would have ensured sufficient and equal amounts of the recommended macronutrients (carbohydrate, protein and fat), were met by all participants and thus the effect of the intervention could be isolated. Dietary control is advantageous to nutrition investigation interventions and their findings. By ensuring the daily diet and supplements were isocaloric and athletes received sufficient intake of macronutrients, the reported attenuated reductions in muscle function reported by Brown *et al*. (2017) can be attributed to the additional whey protein hydrolysate provided. Therefore, the lack of dietary regulation in this study, potentially impacts the true effects of the protein drinks. WHEY and GOAT were more beneficial for muscle function, soreness and

tiredness compared to COW but both these groups had greater calorie, carbohydrate and fat intake compared to COW. Similarly, GOAT had greater calorie, carbohydrate and protein intake than CHO, and WHEY had greater carbohydrate intake than CHO. The results of this investigation may have been influenced by these variances in macronutrient intake. Future investigations should attempt to ensure greater control over nutrient control during the recovery period.

For those who suffer from lactose-intolerance or cows milk protein allergy, eliminating dairy consumption completely is not always necessary with the provision of goats milk as a substitute. This study supports the use of goats milk as an effective post-exercise recovery drink and an alternative for athletes who suffer from mild lactose intolerance or GI distress. More evidence-based dietary approaches and supplementation strategies with and without dairy foods are needed to ensure lactose-intolerant athletes or those who suffer from cows milk protein allergy are consuming an appropriate intake of calcium and other nutrients to meet the recommended daily amounts. Educational programs and behavioural approaches should be developed and validated to improve the nutrition and symptoms of athletes with lactose intolerance, cows milk protein allergy and dairy avoidance (Yang *et al*., 2013). In terms of future research, given the variability in the response to a single intake of protein in the post-exercise recovery period, further research may investigate a prescribed intake over the recovery period exceeding 72 h. Future directions could investigate A2 milk for those with a more serious lactose intolerance or cows milk protein allergy, and perhaps explore more with goats milk. This could include examining other goats milk products such as yoghurt, or perhaps examining the effects of goats milk volume and timing including a pre-bedtime intake on recovery. With respect to recovery from athletic participation, milk also provides CHO to a level that is quite similar to commercialised sports drinks and therefore, would benefit glycogen resynthesis following activities that result in a reduction in glycogen levels in the muscle. The markers chosen to measure recovery in this study are not dependent on muscle glycogen resynthesis. However, milk can facilitate in this regard.

5.1 Limitations

There is large variability in the results obtained and lack of obvious changes between groups due to a number of limitations. One particular limitation of this study was that the menstrual cycle phase or use of the contraceptive pill was not noted or controlled for in the female participants. The reason for this was due to the availability of the participants as the testing had to be carried out over a week long period involving no outside activity from the participants. It has been speculated that females experience less muscle damage due to the role of oestrogen and fluctuating oestrogen levels during the menstrual cycle may have an impact on recovery. Females have a higher prevalence of fibromyalgia and myofascial pain than males, but sex differences in muscle pain are inconsistently detected (Dannecker *et al*., 2008). Females report moderately lower and less frequent muscle pain than males following eccentric exercise (Stupka and Tiidus, 2001; Dannecker *et al*., 2012). Despite this, the majority of studies have reported no gender differences in levels of pain following eccentric exercise (Rinard *et al*., 2000; Dannecker *et al*., 2005; Dannecker *et al*., 2008). Similarly, some research has reported an effect of oestrogen on muscle strength or determinants of muscle strength (Rechichi and Dawson, 2009; Bell *et al*., 2011), while others have not (Nichols *et al*., 2008; Tsampoukos *et al*., 2010). Determining gender differences and examining different phases of the menstrual cycle for females in response to nutritional interventions such as those in the current study, would allow for the development of gender-specific strategies to enhance recovery following exercise.

Despite beverages being volume matched, protein volumes were only similar and therefore not isonitrogenous. While no evident effects were observed between groups, the level of variance observed may have been influenced by the protein content. Interestingly, there appears to be inconsistency in manufacturers labelling practice in relation to the presentation of calorie and macronutrient content. It is speculated that the manufacturer of the goats milk has accounted for 1.25kCal.g^{-1} protein to correct for incomplete digestibility leading to a discrepancy in the presentation of calorie content and the caloric determination of macronutrients.

The dependent measures chosen for the monitoring of recovery are considered valid and reliable. However, the variability in the measurement of RSI is extremely high and despite familiarisation with the protocol, the participants did find it very difficult to grasp the concept of minimal ground contact time and this does affect the reliability and thus, another limitation of the study.

It is acknowledged that there are potential problems with the use of MBI for analysis of data. A recent publication by Sainani (2018), has questioned the level of error rate with the use of MBI. The inflation of the type 1 error rate is a concern given the large number of between and within-group comparisons in this study that are typically controlled for in traditional null hypothesis statistical testing (Sainani, 2018). However, these concerns have been addressed by Hopkins *et al*. (2018) and suggest there is justification for the use of MBI, while remaining cognisant of the ongoing debate and developments of using this method of analysis. Furthermore, the level of variability in the participants resulted in large standard deviations which lead to subsequently small effect sizes. Other influencing factors such as the lack of homogeneity of participants, and the possibility of responders and non-responders are also limitations in this study as previously mentioned.

Variability in the fitness levels of the participants may have been an important influencing factor. A vital direction for future research is to assess to what extent greater degrees of variability in physical activity are associated with differential magnitudes of muscle damage.

5.2 Conclusion

The results of this study demonstrate considerable variability and consequently, impact conclusions that can be made. Many outcomes were reported unclear despite large mean differences. A larger sample size in each group could have potentially provided more definitive results. The variability and disconnect between markers of muscle damage in this study may also be due to different uptakes of amino acids in the protein groups. Previous research has reported variability in response to nutrient ingestion following exercise (Miller *et al*., 2003; Tipton *et al*., 2004). There is also the possibility

that previous experience of eccentric exercise may have been an influencing factor on results reported (Nosaka and Clarkson, 1995; Nosaka, 2008; Howatson *et al*., 2007). While all participants were regularly training for their sport, details of training type, intensity and duration were not recorded. It was speculated that the slightly higher leucine content in goats milk would result in increased beneficial effects on outcomes reported. This may be the case for comparisons made to cows milk for certain measures (CMJ, peak torque 60°.s^{-1}, sprint performance, serum CK, soreness and tiredness), however, given the small differences in the leucine content between drinks, further study in this area is required. The ecological validity of the recovery period is a strength of this study. It can be argued that when athletes are left to their own devices, the first recovery meal may not be impactful, though previous research has reported benefits with a single post-exercise intake of milk (Cockburn *et al*., 2010; Rankin *et al*., 2015). Investigation is necessary to further elucidate. In conclusion, the consumption of 750 mL of cows milk, goats milk and whey protein following repeated sprinting and jumping can limit decrements in muscle function, increases in serum proteins and increases in muscle soreness and tiredness and daily stresses, thus, enhancing recovery. From a practical perspective, the consumption of cows milk, goats milk or whey protein following exercise involving sprinting and jumping, including team sports, can be advised. These beverages may augment recovery and thus, have a positive effect on performance during subsequent training and games. However, considerable variation in the results was observed and thus, further investigation is warranted.

CHAPTER 6

REFERENCES

6.0 REFERENCES

Aagaard, P., Simonsen, E.B., Andersen, J.L., Magnusson, P. and Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 93(4), pp.1318–1326.

Achten, J., Halson, S.L., Moseley, L., Rayson, M.P., Casey, A. and Jeukendrup, a E. (2004). Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 96(4), pp.1331–1340.

Allen, D.G. (2001). Eccentric muscle damage: Mechanisms of early reduction of force. In: *Acta Physiologica Scandinavica*. pp.311–319.

Allinger, T.L., Herzog, W. and Epstein, M. (1996). Force-length properties in stable skeletal muscle fibers - theoretical considerations. *Journal of Biomechanics*, 29(9), pp.1235–1240.

Anagnostou, K., Meyer, R. and Shah, N. (2015). The rapidly changing world of food allergy in children. *F1000Prime Reports*, 7(March).

Andersen, L.L. and Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology*, 96(1), pp.46–52.

Andrzejewski, M., Chmura, J., Pluta, B. and Konarski, J.M. (2015). Sprinting Activities and Distance Covered by Top Level Europa League Soccer Players. *International Journal of Sports Science & Coaching*, 10(1), pp.39–50.

Aragon, A.A. and Schoenfeld, B.J. (2013). Nutrient timing revisited: is there a post-exercise anabolic window?. *Journal of the International Society of Sports Nutrition*, 10(1), p.5.

Armstrong, R., Ogilvie, R. and Schwane, J. (1983). Eccentric exercise-induced injury to rat skeletal muscle. *Journal of applied physiology*, 54(1), pp.80–93.

Armstrong, R.B. (1990). Initial events in exercise-induced muscular injury. *Medicine and science in sports and exercise*, 22(4), pp.429–35.

Armstrong, R., Warren, G. and Warren, lA. (1991). Mechanisms of Exercise-Induced Muscle Fibre Injury. *Sports Medicine*, 12(3), pp.184–207.

Assumpção, C.D.O., Lima, L.C.R., Oliveira, F.B.D., Greco, C.C. and Denadai, B.S. (2013). Exercise-induced muscle damage and running economy in humans. *The Scientific World Journal*, 2013.

Atherton, P.J., Smith, K., Etheridge, T., Rankin, D. and Rennie, M.J. (2010). Distinct anabolic signalling responses to amino acids in C2C12 skeletal muscle cells. *Amino Acids*, 38(5), pp.1533–1539.

Atherton, P.J. and Smith, K. (2012). Muscle protein synthesis in response to nutrition and exercise. *The Journal of Physiology*, 590(5), pp.1049–1057.

Aughey, R.J. (2013). Widening margin in activity profile between elite and sub-elite Australian football: A case study. *Journal of Science and Medicine in Sport*, 16(4), pp.382–386.

Baird, M.F., Graham, S.M., Baker, J.S. and Bickerstaff, G.F. (2012). Creatine-kinase- and exercise-related muscle damage implications for muscle performance and recovery. *Journal of Nutrition and Metabolism*, 2012.

Bahr, R., Fossan, B., Loken, S. and Engebretsen, L. (2006). Surgical Treatment Compared with Eccentric Training for Patellar Tendinopathy (Jumper ' s Knee). *The Journal of Bone and Joint Surgery. American volume*, 88–A(8), pp.1689–1698.

Balnave, C.D. and Allen, D.G. (1995). Intracellular calcium and force in single mouse muscle fibres following repeated contractions with stretch. *The Journal of Physiology*, 488(1), pp.25–36.

Bangsbo, J., Mohr, M. and Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. In: *Nutrition and Football: The FIFA/FMARC Consensus on Sports Nutrition*. pp.1–18.

Barrionuevo, M., Alferez, M.J.M., Lopez, A.I., Sanz, S.M.R. and Campos, M.S. (2002). Beneficial effect of goat milk on nutritive utilization of iron and copper in malabsorption syndrome. *Journal of dairy science*, 85(3), pp.657–64.

Barde, P. and Barde, M. (2012). What to use to express the variability of data: Standard deviation or standard error of mean?. *Perspectives in Clinical Research*, 3(3), p.113.

Bartoshuk, L.M., Duffy, V.B., Fast, K., Green, B.G., Prutkin, J. and Snyder, D.J. (2003). Labeled scales (e.g., category, Likert, VAS) and invalid across-group comparisons: What we have learned from genetic variation in taste. *Food Quality and Preference*, 14(2), pp.125–138.

Batterham, A.M. and Hopkins, W.G. (2006a). Making meaningful inferences about magnitudes. *International journal of sports physiology and performance*, 2006.

Batterham, A.M. and Hopkins, W.G. (2006b). Making meaningful inferences about magnitudes. *International journal of sports physiology and performance*, 1(1), pp.50–57.

Batterham, A.M., Hopkins, W.G. and Atkinson, G. (2005). SPORTSCIENCE sportsci.org A Decision Tree for Controlled Trials. *Sportscience*, 9, pp.33–39.

Beck, K., Thomson, J.S., Swift, R.J. and von Hurst, P.R. (2015). Role of nutrition in performance enhancement and postexercise recovery. *Open Access Journal of Sports Medicine*, 2015, p.259.

Beedie, C.J., Terry, P.C. and Lane, A.M. (2000). The profile of mood states and athletic performance: Two meta-analyses. *J Appl Sport Psychol*, 12(1), pp.49–68.

Beedie, C.J. and Foad, A.J. (2009). The placebo effect in sports performance: a brief review. *Sports medicine (Auckland, N.Z.)*, 39(4), pp.313–329.

Beelen, M., Burke, L.M., Gibala, M.J. and van Loon L, J.C. (2010). Nutritional Strategies to promote postexercise recovery.pdf. *International journal of sport nutrition and exercise metabolism*, 20(6), pp.515–532.

Bell, D.R., Blackburn, J.T., Ondrak, K.S., Hackney, A.C., Hudson, J.D., Norcross, M.F. and Padua, D. a. (2011). The effects of oral contraceptive use on muscle stiffness across the

menstrual cycle. Clinical journal of sport medicine: *official journal of the Canadian Academy of Sport Medicine*, 21(6), pp.467-473.

Beltman, J.G.M., Van Der Vliet, M.R., Sargeant, A.J. and De Haan, A. (2004). Metabolic cost of lengthening, isometric and shortening contractions in maximally stimulated rat skeletal muscle. *Acta Physiologica Scandinavica*, 182(2), pp.179–187.

Bernards, J., Sato, K., Haff, G. and Bazyler, C. (2017). Current Research and Statistical Practices in Sport Science and a Need for Change. *Sports*, 5(4), p.87.

Berryman, C.E., Sepowitz, J.J., McClung, H.L., Lieberman, H.R., Farina, E.K., McClung, J.P., Ferrando, A.A. and Pasiakos, S.M. (2017). Supplementing an energy adequate, higher-protein diet with protein does not enhance fat-free mass restoration after short-term severe negative energy balance. *Journal of Applied Physiology*, 2017.

Bianchi, G., Marzocchi, R., Agostini, F. and Marchesini, G. (2005). Update on nutritional supplementation with branched-chain amino acids. *Current opinion in clinical nutrition and metabolic care*, 8(1), pp.83–87.

Bijur, P.E., Silver, W. and Gallagher, E.J. (2001). Reliability of the Visual Analog Scale for Measurement of Acute Pain. *Academic Emergency Medicine*, 8(12), pp.1153–1157.

Billeaud, C., Guillet, J. and Sandler, B. (1990). Gastric emptying in infants with or without gastro-oesophageal reflux according to the type of milk. *European journal of clinical nutrition*, 44(8), pp.577–583.

Bishop, P.A., Jones, E. and Woods, A.K. (2008). Recovery From Training: A Brief Review. *Journal of Strength and Conditioning Research*, 22(3), pp.1015–1024.

Bloomfield, J., Polman, R. and O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine*, 6(1), pp.63–70.

Bogdanis, G.C., Nevill, M.E., Boobis, L.H. and Lakomy, H.K. (1996). Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. *Journal of Applied Physiology*, 80(3), pp.876–884.

Bohé, J., Low, A., Wolfe, R.R. and Rennie, M.J. (2003). Human Muscle Protein Synthesis is Modulated by Extracellular, Not Intramuscular Amino Acid Availability: A Dose-Response Study. *The Journal of Physiology*, 552(1), pp.315–324.

Børsheim, E., Cree, M.G., Tipton, K.D., Elliott, T. a, Aarsland, A. and Wolfe, R.R. (2004). Effect of carbohydrate intake on net muscle protein synthesis during recovery from resistance exercise. *Journal of applied physiology (Bethesda, Md. : 1985)*, 96(2), pp.674–678.

Boyle, P.J., Nagy, R.J., O'Connor, A.M., Kempers, S.F., Yeo, R.A. and Qualls, C. (1994). Adaptation in brain glucose uptake following recurrent hypoglycemia. *Proceedings of the National Academy of Sciences*, 91(20), pp.9352–9356.

Braakhuis, A.J., Hopkins, W.G. and Lowe, T.E. (2014). Effects of dietary antioxidants on training and performance in female runners. *European Journal of Sport Science*, 14(2), pp.160–168.

Brancaccio, P., Maffulli, N. and Limongelli, F.M. (2007). Creatine kinase monitoring in sport medicine. *British Medical Bulletin*, 81–82(1), pp.209–230.

Brown, S.J., Child, R.B., Day, S.H. and Donnelly, A.E. (1997). Indices of skeletal muscle damage and connective tissue breakdown following eccentric muscle contractions. *European Journal of Applied Physiology and Occupational Physiology*, 75(4), pp.369–374.

Brown, M.A., Howatson, G., Keane, K. and Stevenson, E.J. (2016). Exercise-induced muscle damage following dance and sprint-specific exercise in females. *The Journal of sports medicine and physical fitness*, 56(11), pp.1376–1383.

Brown, M.A., Stevenson, E.J. and Howatson, G. (2017). Whey protein hydrolysate supplementation accelerates recovery from exercise-induced muscle damage in females. *Applied Physiology, Nutrition, and Metabolism*, 2017, p.apnm-2017-0412.

Buckley, J.D., Thomson, R.L., Coates, A.M., Howe, P.R.C., DeNichilo, M.O. and Rowney, M.K. (2010). Supplementation with a whey protein hydrolysate enhances recovery of muscle force-generating capacity following eccentric exercise. *Journal of Science and Medicine in Sport*, 13, pp.178-181.

Burd, N.A., Yang, Y., Moore, D.R., Tang, J.E., Tarnopolsky, M.A. and Phillips, S.M. (2012). Greater stimulation of myofibrillar protein synthesis with ingestion of whey protein isolate v. micellar casein at rest and after resistance exercise in elderly men. *British Journal of Nutrition*, 108(6), pp.958–962.

Burd, N.A., Gorissen, S.H., Van Vliet, S., Snijders, T. and Van Loon, L.J.C. (2015). Differences in postprandial protein handling after beef compared with milk ingestion during postexercise recovery: A randomized controlled trial. *American Journal of Clinical Nutrition*, 102(4), pp.828–836.

Burdon, C.A., Johnson, N.A., Chapman, P.G. and O'Connor, H.T. (2012). Influence of beverage temperature on palatability and fluid ingestion during endurance exercise: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism*, 22(3), pp.199–211.

Burn-Murdoch, R.A., Fisher, M.A. and Hunt, J.N. (1978). The slowing of gastric emptying by proteins in test meals. *The Journal of Physiology*, 274(1), pp.477–485.

Burton, D.A., Stokes, K. and Hall, G.M. (2004). Physiological effects of exercise. *Continuing Education in Anaesthesia, Critical Care & Pain*, 4(6), pp.185–188.

Byrne, C. and Eston, R. (2002). The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. *Journal of sports sciences*, 20(5), pp.417–25.

Byrne, C., Twist, C. and Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage: theoretical and applied implications. *Sports medicine (Auckland, N.Z.)*, 34(1), pp.49–69.

Byrnes, W.C., Clarkson, P.M., White, J.S., Hsieh, S.S., Frykman, P.N. and Maughan, R.J. (1985). Delayed onset muscle soreness following repeated bouts of downhill running. *Journal of Applied Physiology*, 59(3), pp.710–715.

Ceballos, L.S., Morales, E.R., de la Torre Adarve, G., Castro, J.D., Martínez, L.P. and Sampelayo, M.R.S. (2009). Composition of goat and cow milk produced under similar conditions and analyzed by identical methodology. *Journal of Food Composition and Analysis*, 22(4), pp.322–329.

Cermak, N.M., Res, P.T., De Groot, L.C.P.G.M., Saris, W.H.M. and Van Loon, L.J.C. (2012). Protein supplementation augments the adaptive response of skeletal muscle to resistance-type exercise training: A meta-analysis. *American Journal of Clinical Nutrition*, 96(6), pp.1454–1464.

Chen, T.C. and Hsieh, S.S. (2001). Effects of a 7-day eccentric training period on muscle damage and inflammation. *Medicine and science in sports and exercise*, 33(10), pp.1732–1738.

Chen, T.C. (2006). Variability in muscle damage after eccentric exercise and the repeated bout effect. *Research Quarterly for Exercise and Sport*, 77(3), pp.362–371.

Cheung, K., Hume, P.A. and Maxwell, L. (2003). Delayed Onset Muscle Soreness. *Sports Medicine*, 33(2), pp.145–164.

Chevion, S., Moran, D.S., Heled, Y., Shani, Y., Regev, G., Abbou, B., Berenshtein, E., Stadtman, E.R. and Epstein, Y. (2003). Plasma antioxidant status and cell injury after severe physical exercise. *Proceedings of the National Academy of Sciences of the United States of America*, 100(9), pp.5119–23.

Chow, L.S. (2006). Mechanism of insulin's anabolic effect on muscle: measurements of muscle protein synthesis and breakdown using aminoacyl-tRNA and other surrogate measures. *AJP: Endocrinology and Metabolism*, 291(4), pp.E729–E736.

Churchward-Venne, T. a, Burd, N. a, Mitchell, C.J., West, D.W.D., Philp, A., Marcotte, G.R., Baker, S.K., Baar, K. and Phillips, S.M. (2012). Supplementation of a suboptimal protein dose with leucine or essential amino acids: effects on myofibrillar protein synthesis at rest and following resistance exercise in men. *The Journal of physiology*, 590(Pt 11), pp.2751–65.

Churchward-Venne, T.A., Breen, L., Di Donato, D.M., Hector, A.J., Mitchell, C.J., Moore, D.R., Stellingwerff, T., Breuille, D., Offord, E.A., Baker, S.K. and Phillips, S.M. (2014). Leucine supplementation of a low-protein mixed macronutrient beverage enhances myofibrillar protein synthesis in young men: A double-blind, randomized trial1-3. *American Journal of Clinical Nutrition*, 99(2), pp.276–286.

Clarkson, P.M., Byrnes, W.C., McCormick, K.M., Turcotte, L.P. and White, J.S. (1986). Muscle soreness and serum creatine kinase activity following isometric, eccentric, and concentric exercise. *International Journal of Sports Medicine*, 7(3), pp.152–155.

Clarkson, P.M., Apple, F.S., Byrnes, W.C., McCormick, K.M. and Triffletti, P. (1987). Creatine kinase isoforms following isometric exercise. *Muscle & Nerve*, 10(1), pp.41–44.

Clarkson, P.M. and Ebbeling, C. (1988). Investigation of serum creatine kinase variability after muscle-damaging exercise. *Clinical science (London, England : 1979)*, 75(3), pp.257–61.

Clarkson, P.M. and Hubal, M.J. (2002). Exercise-induced muscle damage in humans. *American journal of physical medicine & rehabilitation / Association of Academic Physiatrists*, 81(11 Suppl), pp.S52–S69.

Clarkson, P.M., Kearns, A.K., Rouzier, P., Rubin, R. and Thompson, P.D. (2006). Serum creatine kinase levels and renal function measures in exertional muscle damage. *Medicine and Science in Sports and Exercise*, 38(4), pp.623–627.

Clifford, T., Bell, O., West, D.J., Howatson, G. and Stevenson, E.J. (2016). The effects of beetroot juice supplementation on indices of muscle damage following eccentric exercise. *European Journal of Applied Physiology*, 116(2), pp.353–362

Cockburn, E., Hayes, P.R., French, D.N., Stevenson, E. and St Clair Gibson, A. (2008). Acute milk-based protein-CHO supplementation attenuates exercise-induced muscle damage. *Applied physiology, nutrition, and metabolism*, pp.775–783.

Cockburn, E. (2010). The effect of acute milk- based carbohydrate/protein supplementation on the attenuation of exercise- induced muscle damage. Journal of Applied Physiology Nutrition Metabolism, 35, pp.270–277.

Cockburn, E., Stevenson, E., Hayes, P.R., Robson-Ansley, P. and Howatson, G. (2010). Effect of milk-based carbohydrate-protein supplement timing on the attenuation of exercise-induced muscle damage. *Appl Physiol Nutr Metab*, 35(3), pp.270–277.

Cockburn, E., Robson-Ansley, P., Hayes, P.R. and Stevenson, E. (2012). Effect of volume of milk consumed on the attenuation of exercise-induced muscle damage. *European Journal of Applied Physiology*, 112(9), pp.3187–3194.

Cockburn, E., Bell, P.G. and Stevenson, E. (2013). Effect of milk on team sport performance after exercise-induced muscle damage. *Medicine and Science in Sports and Exercise*, 45(8), pp.1585–1592.

Cooke, M.B., Rybalka, E., Stathis, C.G., Cribb, P.J. and Hayes, A. (2010). Whey protein isolate attenuates strength decline after eccentrically-induced muscle damage in healthy individuals. *Journal of the International Society of Sports Nutrition*, 7, p.30.

Coombes, J.S. and McNaughton, L.R. (2000). Effects of branched-chain amino acid supplementation on serum creatine kinase and lactate dehydrogenase after prolonged exercise. *The Journal of sports medicine and physical fitness*, 40, pp.240–246.

Comyns, T.M., Harrison, A.J. and Hennessy, L.K. (2011). An investigation into the recovery process of a maximum stretch-shortening cycle fatigue protocol on drop and rebound jumps. *Journal of Strength and Conditioning Research*, 25(8), pp.2177–2184.

Cress, N.M., Peters, K.S. and Chandler, J.M. (1992). Eccentric and concentric force-velocity relationships of the quadriceps feimoris muscle. *The Journal of orthopaedic and sports physical therapy*, 16(2), pp.82–86.

Crofford, L.J. (2015). Psychological aspects of chronic musculoskeletal pain. *Best Practice & Research Clinical Rheumatology*, 29(1), pp.147-155.

Cunningham, D., Shearer, D.A., Drawer, S., Eager, R., Taylor, N., Cook, C. and Kilduff, L.P. (2016). Movement demands of elite U20 international rugby union players. *PLoS ONE*, 11(4).

Cuthbertson, D. (2004). Anabolic signaling deficits underlie amino acid resistance of wasting, aging muscle. *The FASEB Journal*, 2004.

Dangin, M., Boirie, Y., Guillet, C. and Beaufrère, B. (2002). Influence of the protein digestion rate on protein turnover in young and elderly subjects. *The Journal of nutrition*, 132(10), pp.3228–3233.

Dannecker, E. a, Hausenblas, H. a, Kaminski, T.W. and Robinson, M.E. (2005). Sex differences in delayed onset muscle soreness. *Clinical Journal of Pain*, 21(2), pp.120–126.

Dannecker, E.A., Knoll, V. and Robinson, M.E. (2008). Sex Differences in Muscle Pain: Self-Care Behaviors and Effects on Daily Activities. *Journal of Pain*, 9(3), pp.200–209.

Dannecker, E.A., Liu, Y., Rector, R.S., Thomas, T.R., Fillingim, R.B. and Robinson, M.E. (2012). Sex differences in exercise-induced muscle pain and muscle damage. *The journal of pain : official journal of the American Pain Society*, 13(12), pp.1242–9.

Delaney, J.A., Cummins, C.J., Thornton, H.R. and Duthie, G.M. (2017). Importance, reliability and usefulness of acceleration measures in team sports. *Journal of Strength and Conditioning Research*, 2017, p.1.

Desbrow, B., McCormack, J., Burke, L.M., Cox, G.R., Fallon, K., Hislop, M., Logan, R., Marino, N., Sawyer, S.M., Shaw, G., Star, A., Vidgen, H. and Leveritt, M. (2014). Sports dietitians australia position statement: Sports nutrition for the adolescent athlete. *International Journal of Sport Nutrition and Exercise Metabolism*, 24(5), pp.570–584.

Devries, M.C. and Phillips, S.M. (2015). Supplemental protein in support of muscle mass and health: Advantage whey. *Journal of Food Science*, 80(S1), pp.A8–A15.

Dimitriadis, G., Mitrou, P., Lambadiari, V., Maratou, E. and Raptis, S.A. (2011). Insulin effects in muscle and adipose tissue. *Diabetes Research and Clinical Practice*, 93(1), pp.S52–S59.

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F.J., Bachl, N. and Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine*, 28(3), pp.222–227.

Doeven, S.H., Brink, M.S., Kosse, S.J. and P M Lemmink, K.A. (2018). Postmatch recovery of physical performance and biochemical markers in team ball sports: a systematic review. *BMJ Open Sport Exerc Med*, 4.

Duffield, R., Murphy, A., Snape, A., Minett, G.M. and Skein, M. (2012). Post-match changes in neuromuscular function and the relationship to match demands in amateur rugby league matches. *Journal of Science and Medicine in Sport*, 15(3), pp.238–243.

Ebben, W.P. and Petushek, E.J. (2010). Using the reactive strength index modified to evaluate plyometric performance. *Journal of Strength and Conditioning Research*, 24(8), pp.1983–1987.

Ebbeling, C.B. and Clarkson, P.M. (1989). Exercise-Induced Muscle Damage and Adaptation. *Sports Medicine*, 7(4), pp.207–234.

Eddens, L., Browne, S., Stevenson, E.J., Sanderson, B., van Someren, K. and Howatson, G. (2017). The efficacy of protein supplementation during recovery from muscle-damaging concurrent exercise. *Applied physiology, nutrition, and metabolism. pp. 2016-2026*

Elliot, T.A., Cree, M.G., Sanford, A.P., Wolfe, R.R. and Tipton, K.D. (2006). Milk ingestion stimulates net muscle protein synthesis following resistance exercise. *Medicine and Science in Sports and Exercise*, 38(4), pp.667–674.

Enoka, R.M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 81(6), pp.2339–2346.

Eston, R.G., Finney, S., Baker, S. and Baltzopoulos, V. (1996). Muscle tenderness and peak torque changes after downhill running following a prior bout of isokinetic eccentric exercise. *Journal of sports sciences*, 14(4), pp.291–9.

Eston, R.G., Lemmey, a B., McHugh, P., Byrne, C. and Walsh, S.E. (2000). Effect of stride length on symptoms of exercise-induced muscle damage during a repeated bout of downhill running. *Scandinavian journal of medicine & science in sports*, 10(4), pp.199–204.

Eston, R.G., Mickleborough, J. and Baltzopoulos, V. (1995). Eccentric activation and muscle damage : biomechanical and physiological considerations during downhill running. *British journal of sports medicine*, 29(2), pp.89–94.

Evans, W.J. and Cannon, J.G. (1991). The metabolic effects of exercise-induced muscle damage. *Exercise and sport sciences reviews*, 19, pp.99–125.

Evans, G.H., Shirreffs, S.M. and Maughan, R.J. (2011). The effects of repeated ingestion of high and low glucose-electrolyte solutions on gastric emptying and blood 2H2O concentration after an overnight fast. *British Journal of Nutrition*, 106(11), pp.1732–1739.

Fanelli, C., Pampanelli, S., Epifano, L., Rambotti, A.M., Ciofetta, M., Modarelli, F., Divincenzo, A., Annibale, B., Lepore, M., Lalli, C., Delsindaco, P., Brunetti, P. and Bolli, G.B. (1994). Relative roles of insulin and hypoglycemia on induction of neuroendocrine responses to, symptoms of, and deterioration of cognitive function in hypoglycemia in male and female hunams, *Diabetologia*, 37(8), pp.797–807.

Farnfield, M.M., Carey, K.A., Gran, P., Trenerry, M.K. and Cameron-Smith, D. (2009). Whey protein ingestion activates mTOR-dependent signalling after resistance exercise in young men: A Double-blinded randomized controlled trial. *Nutrients*, 1(2), pp.263–275.

Farnfield, M.M., Breen, L., Carey, K.A., Garnham, A. and Cameron-Smith, D. (2012). Activation of mTOR signalling in young and old human skeletal muscle in response to combined resistance exercise and whey protein ingestion. *Applied Physiology, Nutrition, and Metabolism*, 37(1), pp.21–30.

Faulkner, J.A., Davis, C.S., Mendias, C.L. and Brooks, S. V. (2008). The aging of elite male athletes: age-related changes in performance and skeletal muscle structure and function. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine*, 18(6), pp.501–7.

Ferguson-Stegall, L., McCleave, E.L., Ding, Z., Doerner, P.G., Wang, B., Liao, Y.-H., Kammer, L., Liu, Y., Hwang, J., Dessard, B.M. and Ivy, J.L. (2011). Postexercise carbohydrate-protein supplementation improves subsequent exercise performance and intracellular signaling for protein synthesis. *Journal of strength and conditioning research / National Strength & Conditioning Association*, 25, pp.1210–1224.

Fielding, R.A., Manfredi, T.J., Ding, W., Fiatarone, M.A., Evans, W.J. and Cannon, J.G. (1993). Acute phase response in exercise. III. Neutrophil and IL^{-1} beta accumulation in skeletal muscle. *Am J Physiol*, 265(1 Pt 2), pp.R166-72.

Fielding, R.A., Violan, M.A., Svetkey, L., Abad, L.W., Manfredi, T.J., Cosmas, A. and Bean, J. (2000). Effects of prior exercise on eccentric exercise-induced neutrophilia and enzyme release. *Med Sci Sports Exerc*, 2000, pp.359–364.

Figueiredo, V.C. and Cameron-Smith, D. (2013). Is carbohydrate needed to further stimulate muscle protein synthesis/hypertrophy following resistance exercise?. *Journal of the International Society of Sports Nutrition*, 10.

Finglas, P., Roe, M., Pinchen, H., Berry, R., Church, S., Dodhia, S., Powell, N., Farron-Wilson, M., Mccardle, J. and Swan, G. (2015). McCance and Widdowson's Composition of Foods Integrated Dataset user guide 2 About Public Health England Composition of Foods Integrated Dataset user guide.

Fischer, K., Colombani, P.C., Langhans, W. and Wenk, C. (2002). Carbohydrate to protein ratio in food and cognitive performance in the morning. *Physiology and Behavior*, 75(3), pp.411–423.

Flanagan, E.P. and Comyns, T.M. (2008). The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training. *Strength and Conditioning Journal*, 30(5), pp.32–38.

Flanagan, E.P., Ebben, W.P. and Jensen, R.L. (2008). 63 Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)*, 22(5), pp.1677–1682.

Freitas, V.H., Nakamura, F.Y., Miloski, B., Samulski, D. and Bara-Filho, M.G. (2014). Sensitivity of physiological and psychological markers to training load intensification in volleyball players. *Journal of Sports Science and Medicine*, 13(3), pp.571–579.

Fridén, J., Sjöström, M. and Ekblom, B. (1981). A morphological study of delayed muscle soreness. *Experientia*, 37(5), pp.506–507.

Fridén, J., Sjöström, M. and Ekblom, B. (1983). Myofibrillar damage following intense eccentric exercise in man. *International journal of sports medicine*, 4(3), pp.170–6.

Fridén, J. and Lieber, R.L. (1992). Structural and mechanical basis of exercise-induced muscle injury. *Medicine and science in sports and exercise*, 24(5), pp.521–30.

Gabbett, T.J. (2005). Science of rugby league football: A review. *Journal of Sports Sciences*, 23(9), pp.961–976.

Gabbett, T.J. (2006). Performance changes following a field conditioning program in junior and senior rugby league players. *Journal of Strength and Conditioning Research National Strength & Conditioning Association*, 20(1), pp.215–221.

Gaitanos, G.C., Williams, C., Boobis, L.H. and Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. *Journal of Applied Physiology*, 75(2), pp.712–719.

Gannon, M.C., Nuttall, F.Q., Krezowski, P.A., Billington, C.J. and Parker, S. (1986). The serum insulin and plasma glucose responses to milk and fruit products in Type 2 (non-insulin-dependent) diabetic patients. *Diabetologia*, 29(11), pp.784–791.

Gee, T.I., Olsen, P.D., Fritzdorf, S.W.G., White, D.J., Golby, J. and Thompson, K.G. (2012). Recovery of Rowing Sprint Performance After High Intensity Strength Training. *International Journal of Sports Science & Coaching*, 7(1), pp.109–120.

Gilson, S.F., Saunders, M.J., Moran, C.W., Moore, R.W., Womack, C.J. and Todd, M.K. (2010). Effects of chocolate milk consumption on markers of muscle recovery following soccer training: a randomized cross-over study. *Journal of the International Society of Sports Nutrition*, 7, p.19.

Gissel, H. and Clausen, T. (2001). Excitation-induced Ca^{2+} influx and skeletal muscle cell damage. In: *Acta Physiologica Scandinavica*. pp.327–334.

Gissel, H. (2005). The role of Ca2+ in muscle cell damage. *Annals of the New York Academy of Sciences*, 1066, pp.166–180.

Goll, D.E., Thompson, V.F., Li, H., Wei, W.E.I. and Cong, J. (2003). The calpain system. *Physiological Reviews*, 1990(284), pp.731–801.

Goll, D.E., Neti, G., Mares, S.W. and Thompson, V.F. (2008). Myofibrillar protein turnover: the proteasome and the calpains. *Journal of animal science*, 86(14 Suppl).

Gomes, J.J.L., Duarte, A.M., Batista, A.S.M., de Figueiredo, R.M.F., de Sousa, E.P., de Souza, E.L. and Queiroga, R. de C.R. do E. (2013). Physicochemical and sensory properties of fermented dairy beverages made with goats milk, cows milk and a mixture of the two milks. *LWT - Food Science and Technology*, 54(1), pp.18–24.

Gomes, R. V., Moreira, A., Lodo, L., Nosaka, K., Coutts, A.J. and Aoki, M.S. (2013). Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. *Biology of Sport*, 30(3), pp.173–180.

Gorissen, S.H.M. and Witard, O.C. (2018). Characterising the muscle anabolic potential of dairy, meat and plant-based protein sources in older adults. In: *Proceedings of the Nutrition Society,* 77(1), pp.20-31.

Greer, B.K., Woodard, J.L., White, J.P., Arguello, E.M. and Haymes, E.M. (2007). Branched-chain amino acid supplementation and indicators of muscle damage after endurance exercise. *International Journal of Sport Nutrition and Exercise Metabolism*, 17(6), pp.595–607.

Ha, E. and Zemel, M.B. (2003). Functional properties of whey, whey components, and essential amino acids: Mechanisms underlying health benefits for active people (Review). *Journal of Nutritional Biochemistry*, 14(5), pp.251–258.

Haenlein, G.F.W. (2004). Goat milk in human nutrition. In: *Small Ruminant Research*. pp.155–163.

Hall, W.L., Millward, D.J., Long, S.J. and Morgan, L.M. (2003). Casein and whey exert different effects on plasma amino acid profiles, gastrointestinal hormone secretion and appetite. *British Journal of Nutrition*, 89(2), p.239.

Halson, S.L. (2014). Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine*, 44(SUPPL.1).

Harper, L.D., Hunter, R., Parker, P., Goodall, S., Thomas, K., Howatson, G., West, D.J., Stevenson, E. and Russell, M. (2016). Test-Retest Reliability of Physiological and

Performance Responses to 120 Minutes of Simulated Soccer Match Play. *Journal of Strength and Conditioning Research*, 30(11), pp.3178–3186.

Harris, S.P., Baltzopoulos, B., Herzog, W., Powers, K., Johnston, K. and Duvall, M. (2015). A new paradigm for muscle contraction. *Frontiers in Physiology Front. Physiol*, 6(6).

Harrison, A.J. and Gaffney, S.D. (2004). Effects of muscle damage on stretch-shortening cycle function and muscle stiffness control. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 18(4), pp.771–776.

Hartman, J.W., Tang, J.E., Wilkinson, S.B., Tarnopolsky, M.A., Lawrence, R.L., Fullerton, A. V. and Phillips, S.M. (2007). Consumption of fat-free fluid milk after resistance exercise promotes greater lean mass accretion than does consumption of soy or carbohydrate in young, novice, male weightlifters. *American Journal of Clinical Nutrition*, 86(2), pp.373–381.

Hausswirth, C. and Mujika, I. (2013). Recovery for Performance in Sport. *Human Kinectics,* pp.3-8.

Healy, R., Kenny, I.C. and Harrison, A.J. (2016). Assessing reactive strength measures in jumping and hopping using the optojump™ system. *Journal of Human Kinetics*, 54(1), pp.23–32.

Heled, Y., Bloom, M.S., Wu, T.J., Stephens, Q. and Deuster, P. a. (2007). CK-MM and ACE genotypes and physiological prediction of the creatine kinase response to exercise. *Journal of applied physiology (Bethesda, Md. : 1985)*, 103(2), pp.504–510.

Hessel, A.L., Lindstedt, S.L. and Nishikawa, K.C. (2017). Physiological mechanisms of eccentric contraction and its applications: A role for the giant titin protein. *Frontiers in Physiology*, p. 8

Hesselink, M.K., Kuipers, H., Geurten, P. and Van Straaten, H. (1996). Structural muscle damage and muscle strength after incremental number of isometric and forced lengthening contractions. *Journal of muscle research and cell motility*, 17(3), pp.335–341.

Herzog, W., Leonard, T.R., Joumaa, V. and Mehta, A. (2008). Mysteries of muscle contraction. *Journal of Applied Biomechanics*, 24(1), pp.1–13.

Highton, J.M., Twist, C. and Eston, R.G. (2009). The effects of exercise-induced muscle damage on agility and sprint running performance. *Journal of Exercise Science and Fitness*, 7(1), pp.24–30.

Ho, M.H.-K., Wong, W.H.-S. and Chang, C. (2014). Clinical Spectrum of Food Allergies: a Comprehensive Review. *Clinical Reviews in Allergy & Immunology*, 46(3), pp.225–240.

Hochwallner, H., Schulmeister, U., Swoboda, I., Spitzauer, S. and Valenta, R. (2014). Cow's milk allergy: From allergens to new forms of diagnosis, therapy and prevention. *Methods*, 66(1), pp.22–33.

Hoffman, J.R., Ratamess, N.A., Tranchina, C.P., Rashti, S.L., Kang, J. and Faigenbaum, A.D. (2010). Effect of a proprietary protein supplement on recovery indices following resistance exercise in strength/power athletes. *Amino Acids*, 38(3), pp.771–778.

Holt, N.C., Wakeling, J.M. and Biewener, A.A. (2014). The effect of fast and slow motor unit activation on whole-muscle mechanical performance: the size principle may not pose a mechanical paradox. *Proceedings of the Royal Society B: Biological Sciences*, 281(1783), pp.20140002–20140002.

Hough, T. (1902). Ergographic studies in muscular soreness. *American Journal of Physiology-Legacy Content*, 7(1), pp.76–92.

Howatson, G. and Milak, A. (2009). Exercise-induced muscle damage following a bout of sport specific repeated sprints. *Journal of strength and conditioning research*, 23(8), pp.2419–2424.

Howatson, G., Hoad, M., Goodall, S., Tallent, J., Bell, P.G. and French, D.N. (2012). Exercise-induced muscle damage is reduced in resistance-trained males by branched chain amino acids: a randomized, double-blind, placebo controlled study. *Journal of the International Society of Sports Nutrition*, 9(1), p.20.

Hulmi, J.J., Kovanen, V., Selänne, H., Kraemer, W.J., Häkkinen, K. and Mero, A.A. (2009). Acute and long-term effects of resistance exercise with or without protein ingestion on muscle hypertrophy and gene expression. *Amino Acids*, 37(2), pp.297–308.

Hulmi, J.J., Lockwood, C.M. and Stout, J.R. (2010). Effect of protein/essential amino acids and resistance training on skeletal muscle hypertrophy: A case for whey protein. *Nutrition & Metabolism*, 7.

Hulmi, J.J., Laakso, M., Mero, A.A., Häkkinen, K., Ahtiainen, J.P. and Peltonen, H. (2015). The effects of whey protein with or without carbohydrates on resistance training adaptations. *Journal of the International Society of Sports Nutrition*, 12.

Hyatt, J.P.K. and Clarkson, P.M. (1998). Creatine kinase release and clearance using MM variants following repeated bouts of eccentric exercise. *Medicine and Science in Sports and Exercise*, 30(7), pp.1059–1065.

Impellizzeri, F.M., Rampinini, E. and Marcora, S.M. (2005). Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, 23(6), pp.583–592.

Impellizzeri, F.M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S. and Wisloff, U. (2008). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine*, 42(1), pp.42–46.

Ispirlidis, I., Fatouros, I.G., Jamurtas, A.Z., Nikolaidis, M.G., Michailidis, I., Douroudos, I., Margonis, K., Chatzinikolaou, A., Kalistratos, E., Katrabasas, I., Alexiou, V. and Taxildaris, K. (2008). Time-course of changes in inflammatory and performance responses following a soccer game. *Clinical Journal of Sport Medicine*, 18(5), pp.423–431.

Jäger, R. *et al*. (2017). International Society of Sports Nutrition Position Stand: Protein and exercise. *Journal of the International Society of Sports Nutrition*, 14(20).

James, L.J., Clayton, D. and Evans, G.H. (2011). Effect of milk protein addition to a carbohydrate-electrolyte rehydration solution ingested after exercise in the heat. *British Journal of Nutrition*, 105(3), pp.393–399.

James, L.J., Gingel, R. and Evans, G.H. (2012). Whey Protein Addition to a Carbohydrate-Electrolyte Rehydration Solution Ingested After Exercise in the Heat. *Journal of Athletic Training (National Athletic Trainers' Association)*, 47(1), pp.61–66.

Jandal, J.M. (1996). Comparative aspects of goat and sheep milk. *Small Ruminant Research*, 22(2), pp.177–185.

Jenness, R. (1980). Composition and Characteristics of Goat Milk: Review 1968−1979. *Journal of Dairy Science*, 63(10), pp.1605–1630.

Johnston, M.J., Cook, C.J., Drake, D., Costley, L., Johnston, J.P. and Kilduff, L.P. (2016). The Neuromuscular, Biochemical, and Endocrine Responses to a Single-Session Vs. Double-Session Training Day in Elite Athletes. *Journal of Strength and Conditioning Research*, 30(11), pp.3098–3106.

Josse, A.R., Tang, J.E., Tarnopolsky, M.A. and Phillips, S.M. (2010). Body composition and strength changes in women with milk and resistance exercise. *Medicine and Science in Sports and Exercise*, 42(6), pp.1122–1130.

Kanda, A., Nakayama, K., Sanbongi, C., Nagata, M., Ikegami, S. and Itoh, H. (2016). Effects of whey, caseinate, or milk protein ingestion on muscle protein synthesis after exercise. *Nutrients*, 8(6).

Karlsson, K.R., Ko, R. and Blomstrand, E. (2006). Branched-Chain Amino Acids : Metabolism , Physiological Function , and Application Branched-Chain Amino Acids Activate Key Enzymes in Protein Synthesis. *The Journal of Nutrition*, 136(15), pp.269–273.

Karp, J.R., Johnston, J.D., Tecklenburg, S., Mickleborough, T.D., Fly, A.D. and Stager, J.M. (2006). Chocolate milk as a post-exercise recovery aid. *International Journal of Sport Nutrition and Exercise Metabolism*, 16(1), pp.78–91.

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicine and Science in Sports,* 20(2), pp.95-102.

Kendall, B. and Eston, R. (2002). Exercise-induced muscle damage and the potential protective role of estrogen. *Sports medicine (Auckland, N.Z.)*, 32(2), pp.103–123.

Kenney, W.L., Wilmore, J.H. and Costill, D.L. (2012). *Physiology of sport and exercise*. 6(1), pp.69-71.

Kenttä, G. and Hassmén, P. (1998). Overtraining and recovery. A conceptual model. *Sports Medicine*, 26(1), pp.1–16.

Kerksick, C.M., Rasmussen, C.J., Lancaster, S.L., Magu, B., Smith, P., Melton, C., Greenwood, M., Almada, A.L., Earnest, C.P. and Kreider, R.B. (2006). The effects of protein and amino acid supplementation on performance and training adaptations during ten weeks of resistance training. *J Strength Cond Res*, 20(3), pp.643–653.

Kingsley, M., Penas-Ruiz, C., Terry, C. and Russell, M. (2014). Effects of carbohydrate-hydration strategies on glucose metabolism, sprint performance and hydration during a soccer match simulation in recreational players. *Journal of Science and Medicine in Sport*, 17(2), pp.239–243.

Klapcińska, B., Iskra, J., Poprzęcki, S. and Grzesiok, K. (2001). The effects of sprint (300 m) running on plasma lactate, uric acid, creatine kinase and lactate dehydrogenase in competitive hurdlers and untrained men. *Journal of Sports Medicine and Physical Fitness*, 41(3), pp.306–311.

Koch, A., Pereira, R. and Machado, M. (2014). The creatine kinase response to resistance exercise. *Journal of musculoskeletal & neuronal interactions*, 14(1), pp.68–77.

Koopman, R., Saris, W.H.M., Wagenmakers, A.J.M., van Loon, L.J.C. and Wagenmakers, A.J.M. (2007). Nutritional interventions to promote post-exercise muscle protein synthesis. *Sports medicine (Auckland, N.Z.)*, 37(10), pp.895–906.

Kraemer, W.J., Spiering, B.A., Volek, J.S., Martin, G.J., Howard, R.L., Ratamess, N.A., Hatfield, D.L., Vingren, J.L., Ho, J.Y., Fragala, M.S., Thomas, G.A., French, D.N., Anderson, J.M., Häkkinen, K. and Maresh, C.M. (2009). Recovery From a National Collegiate Athletic Association Division I Football Game: Muscle Damage and Hormonal Status. *Journal of Strength and Conditioning Research*, 23(1), pp.2–10.

Kratz, A., Lewandrowski, K.B., Siegel, A.J., Chun, K.Y., Flood, J.G., Van Cott, E.M. and Lee-Lewandrowski, E. (2002). Effect of marathon running on hematologic and biochemical laboratory parameters, including cardiac markers. *American Journal of Clinical Pathology*, 118(6), pp.856–863.

Kreider, R.B. (2010). ISSN exercise & sport nutrition review: research & recommendations. *Journal of the International Society of Sports Nutrition*, 7(1), p.7.

Krustrup, P., Söderlund, K., Mohr, M., González-Alonso, J. and Bangsbo, J. (2004). Recruitment of fibre types and quadriceps muscle portions during repeated, intense knee-extensor exercise in humans. *European Journal of Physiology,* 449(1), pp.56-65.

Lamb, G.D. (2009). Mechanisms of excitation-contraction uncoupling relevant to activity-induced muscle fatigue. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme*, 34(3), pp.368–372.

Lanham-New, S.A., Stear, S.J., Shirreffs, S.M. and Collins, A.L. (2011). *Sport and Exercise Nutrition*.

Larson-Meyer, Wolfe, Burke. (2018). Assessment of Nutrient Status in Athletes and the Need for Supplementation. *International Journal of Sport Nutrition and Exercise Metabolism*. 28, pp. 139-158

Lauricella, S. and Koster, K. (2016). 'Refueling' athletes: Social media's influence on the consumption of chocolate milk as a recovery beverage. *American Communication Journal*, 18(1), pp.15–29.

Lavender, A.P. and Nosaka, K. (2008). Changes in markers of muscle damage of middle-aged and young men following eccentric exercise of the elbow flexors. *Journal of Science and Medicine in Sport*, 11(2), pp.124–131.

Layman, D.K., Anthony, T.G., Rasmussen, B.B., Adams, S.H., Lynch, C.J., Brinkworth, G.D. and Davis, T.A. (2015). Defining meal requirements for protein to optimize metabolic roles of amino acids. *American Journal of Clinical Nutrition*, 101(6).

Lecker, S.H., Solomon, V., Mitch, W.E. and Goldberg, A.L. (1999). Muscle protein breakdown and the critical role of the ubiquitin-proteasome pathway in normal and disease states. *The Journal of nutrition*, 129(1S Suppl), p.227S–237S.

Levenhagen, D.K., Gresham, J.D., Carlson, M.G., Maron, D.J., Borel, M.J. and Flakoll, P.J. (2001). Postexercise nutrient intake timing in humans is critical to recovery of leg glucose and protein homeostasis. *American journal of physiology. Endocrinology and metabolism*, 280, pp.E982–E993.

Lieber, R.L. and Fridén, J. (1999). Mechanisms of muscle injury after eccentric contraction. *Journal of Science and Medicine in Sport*, 2(3), pp.253–265.

Lillegaard, I.T.L. and Andersen, L.F. (2005). Validation of a pre-coded food diary with energy expenditure, comparison of under-reporters v. acceptable reporters. *British Journal of Nutrition*, 94(06), pp.998-999.

Lindstedt, S.L., LaStayo, P.C. and Reich, T.E. (2001). When Active Muscles Lengthen: Properties and Consequences of Eccentric Contractions. *Physiology*, 16(6), pp.256–261.

Lomer, M.C.E., Parkes, G.C. and Sanderson, J.D. (2008). Review article: Lactose intolerance in clinical practice – myths and realities. *Alimentary Pharmacology & Therapeutics*, 27(2), pp.93–103.

Lunn, W.R., Pasiakos, S.M., Colletto, M.R., Karfonta, K.E., Carbone, J.W., Anderson, J.M. and Rodriguez, N.R. (2012). Chocolate milk and endurance exercise recovery: Protein balance, glycogen, and performance. *Medicine and Science in Sports and Exercise*, 44(4), pp.682–691.

Lynch, C.J. and Adams, S.H. (2014). Branched-chain amino acids in metabolic signalling and insulin resistance. *Nature Reviews Endocrinology*, 10(12), pp.723–736.

MacDougall, J.D. *et al*. (1998). Muscle performance and enzymatic adaptations to sprint interval training. *Journal of applied physiology (Bethesda, Md. : 1985)*, 84(6), pp.2138–42.

MacIntyre, D.L., Reid, W.D. and McKenzie, D.C. (1995). Delayed Muscle Soreness. *Sports Medicine*, 20(1), pp.24–40.

MacIntyre, D.L., Sorichter, S., Mair, J., Berg, A. and McKenzie, D.C. (2001). Markers of inflammation and myofibrillar proteins following eccentric exercise in humans. *European Journal of Applied Physiology*, 84(3), pp.180–186.

MacNamara, Á., Button, A. and Collins, D. (2010). The Role of Psychological Characteristics in Facilitating the Pathway to Elite Performance Part 1: Identifying Mental Skills and Behaviors. *The Sport Psychologist*, 24(1), pp.52–73.

Macnaughton, L.S., Wardle, S.L., Witard, O.C., Mcglory, C., Hamilton, D.L., Jeromson, S., Lawrence, C.E., Wallis, G.A. and Tipton, K.D. (2016). The response of muscle protein synthesis following whole-body resistance exercise is greater following 40 g than 20 g of ingested whey protein. *Physiol Rep*, 4(15).

Mair, J., Dienstl, F. and Puschendorf, B. (1992). Cardiac Troponin T in the Diagnosis of Myocardial Injury. *Critical Reviews in Clinical Laboratory Sciences*, 29(1), pp.31–57.

Malm, C., Nyberg, P., Engstrom, M., Sjodin, B., Lenkei, R., Ekblom, B. and Lundberg, I. (2000). Immunological changes in human skeletal muscle and blood after eccentric exercise and multiple biopsies. *The Journal of physiology*, 529 Pt 1, pp.243–262.

Malone, S., Hughes, B., Doran, D.A., Collins, K. and Gabbett, T.J. (2018). Can the workload–injury relationship be moderated by improved strength, speed and repeated-sprint qualities?. *Journal of Science and Medicine in Sport*, 2018.

Manninen, A.H. (2006). Hyperinsulinaemia, hyperaminoacidaemia and post-exercise muscle anabolism: the search for the optimal recovery drink. *British journal of sports medicine*, 40(11), pp.900–5.

Marchesseau, S., Mani, J.C., Martineau, P., Roquet, F., Cuq, J.L. and Pugnière, M. (2002). Casein interactions studied by the surface plasmon resonance technique. *Journal of dairy science*, 85(11), pp.2711–21.

Marginson, V. and Eston, R. (2001). The relationship between torque and joint angle during knee extension in boys and men. *J Sports Sci*, 19(11), pp.875–880.

Marginson, V., Rowlands, A. V, Gleeson, N.P. and Eston, R.G. (2005). Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of

plyometric exercise in men and boys. *Journal of applied physiology (Bethesda, Md. : 1985)*, 99(3), pp.1174–81.

Margaritelis, N. V., Theodorou, A.A., Baltzopoulos, V., Maganaris, C.N., Paschalis, V., Kyparos, A. and Nikolaidis, M.G. (2015). Muscle damage and inflammation after eccentric exercise: Can the repeated bout effect be removed?. *Physiological Reports*, 3(12).

Mastaloudis, A., Traber, M.G., Carstensen, K. and Widrick, J.J. (2006). Antioxidants did not prevent muscle damage in response to an ultramarathon run. *Medicine and Science in Sports and Exercise*, 38(1), pp.72–80.

Maughan, R.J. and Shirreffs, S.M. (2012). Nutrition for sports performance: issues and opportunities. *The Proceedings of the Nutrition Society*, 71(1), pp.112–9.

Maughan, R.J. and Shirreffs, S.M. (2011). IOC Consensus Conference on Nutrition in Sport, 25–27 October 2010, International Olympic Committee, Lausanne, Switzerland. *Journal of Sports Sciences*, 29(sup1), pp.S1–S1.

McGlory, C., Devries, M.C. and Phillips, S.M. (2017). Skeletal muscle and resistance exercise training; the role of protein synthesis in recovery and remodelling. *Journal of Applied Physiology*, 2017, 122(3). pp.541-548.

McHugh, M.P., Connolly, D.A.J., Eston, R.G., Kremenic, I.J., Nicholas, S.J. and Gleim, G.W. (1999). The Role of Passive Muscle Stiffness in Symptoms of Exercise-Induced Muscle Damage. *The American Journal of Sports Medicine*, 27(5), pp.594–599.

McHugh, M.P. (2003). Recent advances in the understanding of the repeated bout effect: The protective effect against muscle damage from a single bout of eccentric exercise. *Scandinavian Journal of Medicine and Science in Sports*, 13(2), pp.88–97.

McLellan, C.P., Lovell, D.I. and Gass, G.C. (2010). Creatine kinase and endocrine responses of elite players pre, during, and post rugby league match play. *Journal of Strength and Conditioning Research*, 24(11), pp.2908–2919.

Meek, S.E., Persson, M., Ford, G.C. and Nair, K.S. (1998). Differential regulation of amino acid exchange and protein dynamics across splanchnic and skeletal muscle beds by insulin in healthy human subjects. *Diabetes*, 47(12), pp.1824–1835.

Mendez-Villanueva, A., Hamer, P. and Bishop, D. (2008). Fatigue in repeated-sprint exercise is related to muscle power factors and reduced neuromuscular activity. *European Journal of Applied Physiology*, 103(4), pp.411-419.

Meyer, G.A. and Lieber, R.L. (2012). Skeletal muscle fibrosis develops in response to desmin deletion. *American Journal of Physiology-Cell Physiology*, 302(11), pp.C1609–C1620.

Mike, J.N., Cole, N., Herrera, C., Vandusseldorp, T., Kravitz, L. and Kerksick, C.M. (2017). The Effects of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump, and Soreness. *Journal of Strength and Conditioning Research*, 31(3), pp.773–786.

Miller, P.E., Alexander, D.D. and Perez, V. (2014). Effects of whey protein and resistance exercise on body composition: a meta-analysis of randomized controlled trials. *Journal of the American College of Nutrition*, 33(2), pp.163–75.

Miller, S.L., Tipton, K.D., Chinkes, D.L., Wolf, S.E. and Wolfe, R.R. (2003). Independent and combined effects of amino acids and glucose after resistance exercise. *Medicine and Science in Sports and Exercise*, 35(3), pp.449–455.

Mills, E.N.C., Moreno, J., Sancho, A., Jenkins, J.A. and Wichers, H.J. (2004). Processing approaches to reducing allergenicity in proteins. In: *Proteins in Food Processing*. pp.396–418.

Minehan, M.R., Riley, M.D. and Burke, L.M. (2002). Effect of flavor and awareness of kilojoule content of drinks on preference and fluid balance in team sports. *International journal of sport nutrition and exercise metabolism*, 12(1), pp.81–92.

Mitchell, C.J., McGregor, R.A., D'Souza, R.F., Thorstensen, E.B., Markworth, J.F., Fanning, A.C., Poppitt, S.D. and Cameron-Smith, D. (2015). Consumption of milk protein or whey protein results in a similar increase in muscle protein synthesis in middle aged men. *Nutrients*, 7(10), pp.8685–8699.

Molfino, A., Aronis, A., Zanetti, M. and Phillips, S.M. (2017). Current Concepts and Unresolved Questions in Dietary Protein Requirements and Supplements in Adults. , 4.

Molina, R. and Denadai, B.S. (2012). Dissociated time course recovery between rate of force development and peak torque after eccentric exercise. *Clinical Physiology and Functional Imaging*, 32(3), pp.179–184.

Moore, D.R., Tang, J.E., Burd, N.A., Rerecich, T., Tarnopolsky, M.A. and Phillips, S.M. (2009). Differential stimulation of myofibrillar and sarcoplasmic protein synthesis with protein ingestion at rest and after resistance exercise. *Journal of Physiology*, 587(4), pp.897–904.

Moore, D.R.D., Robinson, M.J.M., Fry, J.L.J., Tang, J.E., Glover, E.I., Wilkinson, S.B., Prior, T., Tarnopolsky, M.A. and Phillips, S.M. (2009). Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. *American Journal of Clinical Nutrition*, 89(1), pp.161–168.

Morgan, D.L. (1990). New insights into the behavior of muscle during active lengthening. *Biophysical Journal*, 57(2), pp.209–221.

Morgan, D. (1994). An explanation for residual increased tension in striated muscle after stretch during contraction. *Experimental Physiology*, 79(5), pp.831–838.

Morgan, D.L. and Allen, D.G. (1999). Early events in stretch-induced muscle damage. *Journal of applied physiology (Bethesda, Md. : 1985)*, 87(6), pp.2007–15.

Morton, R.W., McGlory, C. and Phillips, S.M. (2015). Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy. *Frontiers in Physiology*, 6(SEP).

Newham, D.J., Jones, D.A. and Edwards, R.H.T. (1983). Large delayed plasma creatine kinase changes after stepping exercise. *Muscle & Nerve*, 6(5), pp.380–385.

Newham, D.J., McPhail, G., Mills, K.R. and Edwards, R.H.T. (1983). Ultrastructural changes after concentric and eccentric contractions of human muscle. *Journal of the Neurological Sciences*, 61(1), pp.109–122.

Nichols, A.W., Hetzler, R.K., Villanueva, R.J., Stickley, C.D. and Kimura, I.F. (2008). Effects of combination oral contraceptives on strength development in women athletes. *Journal of Strength and Conditioning Research*, 22(5), pp.1625-1632.

Nosaka, K. and Kuramata, T. (1991). Muscle soreness and serum enzyme activity following consecutive drop jumps. *Journal of Sports Sciences*, 9(2), pp.213–220.

Nosaka, K. and Clarkson, P.M. (1995). Muscle damage following repeated bouts of high force eccentric exercise. *Medicine and science in sports and exercise*, 27(9), pp.1263–9.

Nosaka, K. and Clarkson, P.M. (1996). Variability in serum creatine kinase response after eccentric exercise of the elbow flexors. *International Journal of Sports Medicine*, 17(2), pp.120–127.

Nosaka, K., Newton, M. and Sacco, P. (2002). Delayed-onset muscle soreness does not reflect the magnitude of eccentric exercise-induced muscle damage. *Scandinavian Journal of Medicine and Science in Sports*, 12(6), pp.337–346.

Nosaka, K., Sacco, P. and Mawatari, K. (2006). Effects of amino acid supplementation on muscle soreness and damage. *International Journal of Sport Nutrition and Exercise Metabolism*, 16(6), pp.620–635.

Nurenberg, P., Giddings, C.J., Stray-Gundersen, J., Fleckenstein, J.L., Gonyea, W.J. and Peshock, R.M. (1992). MR imaging-guided muscle biopsy for correlation of increased signal intensity with ultrastructural change and delayed-onset muscle soreness after exercise. *Radiology*, 184(3), pp.865–869.

Owasoyo, J.O., Neri, D.F. and Lamberth, J.G. (1992). Tyrosine and its potential use as a countermeasure to performance decrement in military Sustained Operations. *Aviation Space and Environmental Medicine*, 63(5), pp.364–369.

Overgaard, K., Fredsted, A., Hyldal, A., Ingemann-Hansen, T., Gissel, H. and Clausen, T. (2004). Effects of Running Distance and Training on Ca2+ Content and Damage in Human Muscle. *Medicine & Science in Sports & Exercise*, 2004, pp.821–829.

Pal, S., Woodford, K., Kukuljan, S. and Ho, S. (2015). Milk intolerance, beta-casein and lactose. *Nutrients*, 7(9), pp.7285–7297.

Park, Y.W., Mahoney, A.W. and Hendricks, D.G. (1986). Bioavailability of iron in goat milk compared with cow milk fed to anemic rats. *Journal of dairy science*, 69(10), pp.2608–15.

Park, Y.W. (1991). Relative buffering capacity of goat milk, cow milk, soy-based infant formulas, and commercial nonprescription antacid drugs. *Journal of Dairy Science*, 74, pp.3326–3333.

Park, Y.W. (1992). Comparison of buffering components in goat and cow milk. *Small Ruminant Research*, 8(1–2), pp.75–81.

Park, Y.W. (1994). Hypo-allergenic and therapeutic significance of goat milk. *Small Ruminant Research*, 14(2), pp.151–159.

Park, Y.W. (2007). Rheological characteristics of goat and sheep milk. *Small Ruminant Research*, 68(1–2), pp.73–87.

Park, Y.W., Juárez, M., Ramos, M. and Haenlein, G.F.W. (2007). Physico-chemical characteristics of goat and sheep milk. *Small Ruminant Research*, 68(1–2), pp.88–113.

Pasiakos, S.M., Lieberman, H.R. and McLellan, T.M. (2014). Effects of protein supplements on muscle damage, soreness and recovery of muscle function and physical performance: A systematic review. *Sports Medicine*, 44(5), pp.655–670.

Pasiakos, S.M. and Carbone, J.W. (2014). Assessment of skeletal muscle proteolysis and the regulatory response to nutrition and exercise. *IUBMB Life*.

Passe, D.H., Horn, M., Stofan, J. and Murray, R. (2004). Palatability and voluntary intake of sports beverages, diluted orange juice, and water during exercise. *International Journal of Sport Nutrition and Exercise Metabolism*, 14(3), pp.272–284.

Paulin, D. and Li, Z. (2004). Desmin: A major intermediate filament protein essential for the structural integrity and function of muscle. *Experimental Cell Research*, 301(1), pp.1–7.

Peake, J., Nosaka, K. and Suzuki, K. (2005). Characterization of inflammatory responses to eccentric exercise in humans. *Exerc Immunol Rev*, 11, pp.64–85.

Peake, J.M., Suzuki, K., Wilson, G., Hordern, M., Nosaka, K., MacKinnon, L. and Coombes, J.S. (2005). Exercise-induced muscle damage, plasma cytokines, and markers of neutrophil activation. *Medicine and Science in Sports and Exercise*, 37(5), pp.737–745.

Pennings, B., Boirie, Y., Senden, J.M.G., Gijsen, A.P., Kuipers, H. and Van Loon, L.J.C. (2011). Whey protein stimulates postprandial muscle protein accretion more effectively than do casein and casein hydrolysate in older men. *American Journal of Clinical Nutrition*, 2011.

Pennings, B., Koopman, R., Beelen, M., Senden, J.M.G., Saris, W.H.M. and Van Loon, L.J.C. (2011). Exercising before protein intake allows for greater use of dietary protein-derived amino acids for de novo muscle protein synthesis in both young and elderly men. *American Journal of Clinical Nutrition*, 93(2), pp.322–331.

Phillips, S.M., Tipton, K.D., Aarsland, A., Wolf, S.E. and Wolfe, R.R. (1997). Mixed muscle protein synthesis and breakdown after resistance exercise in humans. *The American journal of physiology*, 273(1 Pt 1), pp.E99^{-1}07.

Phillips, S.M. and Van Loon, L.J.C. (2011). Dietary protein for athletes: From requirements to optimum adaptation. *Journal of Sports Sciences*, 29(sup1), pp.S29–S38.

Poortmans, J.R., Carpentier, A., Pereira-Lancha, L.O. and Lancha, A. (2012). Protein turnover, amino acid requirements and recommendations for athletes and active populations. *Brazilian Journal of Medical and Biological Research*, 45(10), pp.875–890.

Powers, S.K. and Jackson, M.J. (2008). Exercise-induced oxidative stress: cellular mechanisms and impact on muscle force production. *Physiological Reviews*, 88(4), pp.1243-1276.

Power, O., Hallihan, A. and Jakeman, P. (2009). Human insulinotropic response to oral ingestion of native and hydrolysed whey protein. *Amino Acids*, 37(2), pp.333–339.

Phillips, S.M. (2014). A Brief Review of Higher Dietary Protein Diets in Weight Loss: A Focus on Athletes. *Sports Medicine*, 44.

Phillips, S.M. (2016). The impact of protein quality on the promotion of resistance exercise-induced changes in muscle mass. *Nutrition & Metabolism*, 13(1), p.64.

Prasartwuth, O., Taylor, J.L. and Gandevia, S.C. (2005). Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. *The Journal of Physiology*, 567(1), pp.337–348.

Pritchett, K.L., Pritchett, R.C., Edd, P.B. and Pritchett, K. (2011). Nutritional strategies for post-exercise recovery : a review. *Sajsm*, 23(1), pp.20–25.

Pritchett, K.L., Pritchett, R.C., Green, J.M., Combs, B., Eldridge, M., Bishop, P. and Education, P. (2011). Comparisons of Post-Exercise Chocolate Milk and a Commercial Recovery Beverage following Cycling Training on Recovery and Performance. *Journal of Exercise Physiology*, 14(6), pp.29–39.

Proske, U. and Morgan, D.L. (2001). Muscle damage from eccentric exercise: Mechanism, mechanical signs, adaptations and clinical applications. *Journal of physiology*, 537(2), pp.333–345.

Proske, U. and Allen, T.J. (2005). Damage to skeletal muscle from eccentric exercise. *Exercise and Sport Sciences Reviews*, 33(2), pp.98–104.

Raastad, T., Owe, S.G., Paulsen, Gø., Enns, D., Overgaard, K., Crameri, R., Kiil, S., Belcastro, A., Bergersen, L. and Hallén, J. (2010). Changes in calpain activity, muscle structure, and function after eccentric exercise. *Medicine and Science in Sports and Exercise*, 42(1), pp.86–95.

Rampinini, E., Bosio, A., Ferraresi, I., Petruolo, A., Morelli, A. and Sassi, A. (2011). Match-related fatigue in soccer players. *Medicine and Science in Sports and Exercise*, 43(11), pp.2161–2170.

Rangel, A.H. do N., Sales, D.C., Urbano, S.A., Galvao Júnior, J.G.B., Andrade Neto, J.C. de and Macedo, C. de S. (2016). Lactose intolerance and cows milk protein allergy. *Food Science and Technology, Campinas*, 36(2), pp.179–187.

Rankin, P., Stevenson, E. and Cockburn, E. (2015). The effect of milk on the attenuation of exercise-induced muscle damage in males and females. *European Journal of Applied Physiology*, 2015.

Rankin, P., Landy, A., Stevenson, E. and Cockburn, E. (2018). Milk: An effective recovery drink for female athletes. *Nutrients*, 10(2), pp. E228.

Rechichi, C. and Dawson, B. (2009). Effect of oral contraceptive cycle phase on performance in team sport players. *Journal of Science and Medicine in Sport,* 12(1), pp.190-195

Reilly, T. and Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of Sports Sciences*, 23(6), pp.619–627.

Reimer, T., Park, E.S. and Hinsz, V.B. (2006). Shared and coordinated cognition in competitive and dynamic task environments: An information-processing perspective for team sports. *International Journal of Sport and Exercise Psychology*, 4(4), pp.376–400.

Rennie, M.J. and Tipton, K.D. (2000). Protein and amino acid metabolism during and after exercise and the effects of nutrition. *Annual review of nutrition*, 20, pp.457–483.

Rinard, J., Clarkson, P.M., Smith, L.L. and Grossman, M. (2000). Response of males and females to high-force eccentric exercise. *Journal of Sports Sciences*, 18(4), pp.229–236.

Robson-Ansley, P.J., Blannin, A. and Gleeson, M. (2007). Elevated plasma interleukin-6 levels in trained male triathletes following an acute period of intense interval training. *European Journal of Applied Physiology*, 99(4), pp.353–360.

Robson-Ansley, P.J., Gleeson, M. and Ansley, L. (2009). Fatigue management in the preparation of olympic athletes. *Journal of Sports Sciences*, 27(13), pp.1409–1420.

Rodenburg, J.B., Bar, P.R. and De Boer, R.W. (1993). Relations between muscle soreness and biochemical and functional outcomes of eccentric exercise. *J Appl Physiol*, 74(6), pp.2976–2983.

Rodriguez, N.R., DiMarco, N.M., Langley, S. and American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Nutrition and athletic performance. *Med Sci Sports Exerc*, 109(3), pp.509–527.

Romagnoli, M., Sanchis-Gomar, F., Alis, R., Risso-Ballester, J., Bosio, A., Graziani, R.L. and Rampinini, E. (2016). Changes in muscle damage, inflammation, and fatigue-related

parameters in young elite soccer players after a match. *The Journal of sports medicine and physical fitness*, 56(10), pp.1198–1205.

Rouch, C., Meile, M.J. and Orosco, M. (2003). Extracellular hypothalamic serotonin and plasma amino acids in response to sequential carbohydrate and protein meals. *Nutritional Neuroscience*, 6(2), pp.117–124.

Rumbold, P., Shaw, E., James, L. and Stevenson, E. (2015). Milk Consumption Following Exercise Reduces Subsequent Energy Intake in Female Recreational Exercisers. *Nutrients*, 7(1), pp.293–305.

Rushall, B.S. (1990). A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sport Psychology*, 2(1), pp.51–66.

Russell, M., Sparkes, W., Northeast, J., Cook, C.J., Love, T.D., Bracken, R.M. and Kilduff, L.P. (2016). Changes in acceleration and deceleration capacity throughout professional soccer match-play. *Journal of Strength and Conditioning Research*, 30(10), pp.2839–2844.

Russell, M., Sparkes, W., Northeast, J., Cook, C.J., Bracken, R.M. and Kilduff, L.P. (2016). Relationships between match activities and peak power output and Creatine Kinase responses to professional reserve team soccer match-play. *Human Movement Science*, 45, pp.96–101.

Rustad, P.I., Sailer, M., Cumming, K.T., Jeppesen, P.B., Kolnes, K.J., Sollie, O., Franch, J., Ivy, J.L., Daniel, H. and Jensen, J. (2016). Intake of protein plus carbohydrate during the first two hours after exhaustive cycling improves performance the following day. *PLoS ONE*, 11(4).

Sainani, K.L. (2018). The Problem with “Magnitude-Based Inference”. *Medicine & Science in Sports & Exercise*, 2018, 50(10), pp. 2166-2176.

Saka, T., Akova, B., Yazici, Z., Sekir, U., Gür, H. and Ozarda, Y. (2009). Difference in the magnitude of muscle damage between elbow flexors and Knee extensors eccentric exercises. *Journal of Sports Science and Medicine*, 8(1), pp.107–115.

Salinas-García, M.E., Martínez-Sanz, J.M., Urdampilleta, A., Mielgo-Ayuso, J., Norte Navarro, A. and Ortiz-Moncada, R. (2014). [Effects of branched amino acids in endurance sports: a review]. *Nutrición hospitalaria*, 31(2), pp.577–89.

Saunders, M.J.; Luden, N.D. (2018). Protein Supplementation During or Following a Marathon Run Influences Post-Exercise Recovery. Nutrients; Vol. 10 Issue 3, p1^{-1}4.

Sawka, M.N., Burke, L.M., Eichner, E.R., Maughan, R.J., Montain, S.J. and Stachenfeld, N.S. (2007). American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and science in sports and exercise*, 39(2), pp.377–90.

Saw, A.E., Main, L.C. and Gastin, P.B. (2016). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *British Journal of Sports Medicine*, 50(5), pp.281–291.

Schwab Reese, L.M., Pittsinger, R. and Yang, J. (2012). Effectiveness of psychological intervention following sport injury. *Journal of Sport and Health Science,* 26(1), pp.71-79.

Schwane, J.A., Johnson, S.R., Vandenakker, C.B. and Armstrong, R.B. (1983). Delayed-onset muscular soreness and plasma CPK and LDH activities after downhill running. *Med Sci Sports Exerc*, 15(1), pp.51–56.

Seeley, M., Huang, W., Chen, Z., Wolff, W.O., Lin, X. and Xu, X. (2007). Depletion of zebrafish titin reduces cardiac contractility by disrupting the assembly of Z-discs and A-bands. *Circulation Research*, 2007, 100(2), pp.238-245.

Sell, K.M. and Ledesma, A.B. (2016). Heart Rate and Energy Expenditure in Division i Field Hockey Players during Competitive Play. *Journal of Strength and Conditioning Research*, 30(8), pp.2122–2128.

Sharp, C.P.M. and Pearson, D.R. (2010). Amino acid supplements and recovery from high-intensity resistance training. *Journal of Strength and Conditioning Research*, 24(4), pp.1125–1130.

Shirreffs, S.M., Watson, P. and Maughan, R.J. (2007). Milk as an effective post-exercise rehydration drink. *British Journal of Nutrition*, 98(1), pp.173–180.

Silva, J.R., Rebelo, A., Marques, F., Pereira, L., Seabra, A., Ascensão, A. and Magalhães, J. (2014). Biochemical impact of soccer: an analysis of hormonal, muscle damage, and redox markers during the season. *Applied Physiology, Nutrition, and Metabolism*, 39(4), pp.432–438.

Sirotic, A.C. and Coutts, A.J. (2007). Physiological and performance test correlates of prolonged, high-intensity, intermittent running performance in moderately trained women team sport athletes. *Journal of Strength and Conditioning Research*, 21(1), pp.138–144.

Sorichter, S., Mair, J., Koller, A., Muller, E., Kremser, C., Judmaier, W., Haid, C., Calzolari, C. and Puschendorf, B. (2001). Creatine kinase, myosin heavy chains and magnetic resonance imaging after eccentric exercise. *Journal of sports sciences*, 19(9), pp.687–691.

Sorichter, S., Puschendorf, B. and Mair, J. (1999). Skeletal muscle injury induced by eccentric muscle action: Muscle proteins as markers of muscle fiber injury. *Exercise Immunology Review*, 1999, pp.5–21.

Spencer, M.R. and Gastin, P.B. (2001). Energy system contribution during 200-to 1500-m running in highly trained athletes. *Medicine and Science in Sports and Exercise*, 33(1), pp.157–162.

Spencer, M., Bishop, D., Dawson, B. and Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities:specific to field-based team sports. *Sports medicine (Auckland, N.Z.)*, 35(12), pp.1025–1044.

Spriet, L.L., Matsos, C.G., Peters, S.J., Heigenhauser, G.J. and Jones, N.L. (1985). Effects of acidosis on rat muscle metabolism and performance during heavy exercise. *The American journal of physiology*, 248(3 Pt 1), pp.C337-47.

Staples, A.W., Burd, N.A., West, D.W.D., Currie, K.D., Atherton, P.J., Moore, D.R., Rennie, M.J., MacDonald, M.J., Baker, S.K. and Phillips, S.M. (2011). Carbohydrate does not augment exercise-induced protein accretion versus protein alone. *Medicine and Science in Sports and Exercise*, 43(7), pp.1154–1161.

Stupka N, Lowther S, Chorneyka K. (2000). Gender differences in muscle inflammation after eccentric exercise. Journal of Applied Physiology; 89: 2325-32

Takekura, H., Fujinami, N., Nishizawa, T., Ogasawara, H. and Kasuga, N. (2001). Eccentric exercise-induced morphological changes in the membrane systems involved in excitation-contraction coupling in rat skeletal muscle. *J Physiol*, 533(Pt 2), p.571–83.

Tang, J.E., Moore, D.R., Kujbida, G.W., Tarnopolsky, M.A. and Phillips, S.M. (2009). Ingestion of whey hydrolysate, casein, or soy protein isolate: effects on mixed muscle protein synthesis at rest and following resistance exercise in young men. *Journal of Applied Physiology*, 107(3), pp.987–992.

Tee, J.C., Bosch, A.N. and Lambert, M.I. (2007). Metabolic consequences of exercise-induced muscle damage. *Sports medicine (Auckland, N.Z.)*, 37(10), pp.827–836.

The National Dairy Council. Food for Health Ireland. DN Forum. Dairy and Performance Nutrition 2015; 7. [Online] Available at http://www.ndc.ie/downloads/dn-forums/2015/Dairy%20and%20Performance%20Nutrition.pdf [accessed on 09/04/18]

Thomas, D.T., Erdman, K.A. and Burke, L.M. (2016). Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. *Journal of the Academy of Nutrition and Dietetics*, 116(3), pp.501–528.

Thomas, K., Morris, P. and Stevenson, E. (2009). Improved endurance capacity following chocolate milk consumption compared with 2 commercially available sport drinks. *Applied Physiology, Nutrition, and Metabolism*, 34(1), pp.78–82.

Thompson, D., Nicholas, C.W. and Williams, C. (1999). Muscular soreness following prolonged intermittent high-intensity shuttle running. *Journal of sports sciences*, 17(5), pp.387–395.

Thorning, T.K., Raben, A., Tholstrup, T., Soedamah-Muthu, S.S., Givens, I. and Astrup, A. (2016). Milk and dairy products: good or bad for human health? An assessment of the totality of scientific evidence. *Food & Nutrition Research*, 60(1), p.32527.

Tipton, K.D., Ferrando, A.A., Phillips, S.M., Doyle, D. and Wolfe, R.R. (1999). Postexercise net protein synthesis in human muscle from orally administered amino acids. *American Journal of Physiology - Endocrinology And Metabolism*, 276(4), pp.E628-E634.

Tipton, K.D., Rasmussen, B.B., Miller, S.L., Wolf, S.E., Owens-Stovall, S.K., Petrini, B.E. and Wolfe, R.R. (2001). Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. *American journal of physiology. Endocrinology and metabolism*, 281(2), pp.E197–E206.

Tipton, K.D., Elliott, T.A., Cree, M.G., Wolf, S.E., Sanford, A.P. and Wolfe, R.R. (2004). Ingestion of casein and whey prosteins result in muscle anabolism after resistance exercise. *Medicine and Science in Sports and Exercise*, 36(12), pp.2073–2081.

Tipton, K.D., Elliott, T.A., Cree, M.G., Aarsland, A.A., Sanford, A.P. and Wolfe, R.R. (2006). Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. *AJP: Endocrinology and Metabolism*, 292(1), pp.E71–E76.

Tipton, K.D. (2011). Efficacy and consequences of very-high-protein diets for athletes and exercisers. *The Proceedings of the Nutrition Society*, 70(2), pp.205–214.

Tipton, K.D., Hamilton, D.L. and Gallagher, I.J. (2018). Assessing the Role of Muscle Protein Breakdown in Response to Nutrition and Exercise in Humans. *Sports Medicine*, 48, pp.53–64.

Tomotake, H., Okuyama, R., Katagiri, M., Fuzita, M., Yamato, M. and Ota, F. (2006). Comparison between Holstein cow's milk and Japanese-Saanen goat's milk in fatty acid composition, lipid digestibility and protein profile. *Bioscience, biotechnology, and biochemistry*, 70(11), pp.2771–2774.

Townsend, R., Elliott-Sale, K.J., Currell, K., Tang, J., Fraser, W.D. and Sale, C. (2017). The effect of postexercise carbohydrate and protein ingestion on bone metabolism. *Medicine and Science in Sports and Exercise*, 49(6), pp.1209–1218.

Trabulsi, J. and Schoeller, D.A. (2001). Evaluation of dietary assessment instruments against doubly labeled water, a biomarker of habitual energy intake. *American Journal of Physiology - Endocrinology and Metabolism*, 281(5 44-5).

Tsabouri, S., Douros, K. and Priftis, K. (2014). Cow's Milk Allergenicity. *Endocrine, Metabolic & Immune Disorders-Drug Targets*, 14(1), pp.16–26.

Tsampoukos, A., Peckham, E.A., James, R. and Nevill, M.E. (2010). Effect of menstrual cycle phase on sprinting performance. *European Journal of Applied Physiology*, 109(4), pp.659-667.

Tseng, K.-W., Tseng, W.-C., Lin, M.-J., Chen, H.-L., Nosaka, K. and Chen, T.C. (2016). Protective effect by maximal isometric contractions against maximal eccentric exercise-induced muscle damage of the knee extensors. *Research in Sports Medicine*, 24(3), pp.228–241.

Twist, C. and Eston, R. (2005). The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. *European Journal of Applied Physiology*, 94(5–6), pp.652–658.

Twist, C., Gleeson, N. and Eston, R. (2008). The effects of plyometric exercise on unilateral balance performance. *Journal of sports sciences*, 26(10), pp.1073–80.

Twist, C. and Sykes, D. (2011). Evidence of exercise-induced muscle damage following a simulated rugby league match. *European Journal of Sport Science*, 11(6), pp.401–409.

Twist, C., Waldron, M., Highton, J., Burt, D. and Daniels, M. (2012). Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *Journal of Sports Sciences*, 30(4), pp.359–367.

Van Cutsem, M., Duchateau, J. and Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *Journal of Physiology*, 513(1), pp.295–305.

Van Loon, L.J.C. (2014). Is there a need for protein ingestion during exercise?. *Sports Medicine*, 44(SUPPL.1).

Van Vliet, S., Burd, N.A. and van Loon, L.J. (2015). The Skeletal Muscle Anabolic Response to Plant- versus Animal-Based Protein Consumption. *Journal of Nutrition,* 145(9), pp.1981-1991.

Van Vliet, S., Beals, J.W., Martinez, I.G., Skinner, S.K. and Burd, N.A. (2018). Achieving optimal post-exercise muscle protein remodeling in physically active adults through whole food consumption. *Nutrients*, 10(2).

Volek, J.S. (2013). Whey Protein Supplementation During Resistance Training Augments Lean Body Mass. *Journal of the American College of Nutrition*, 32(2).

Wal, J.M., Bernard, H., Yvon, M., Peltre, G., David, E.D.E., Creminon, C., Frobert, Y. and Grassi, J. (1995). Enzyme Immunoassay of Specific Human IgE to Purified Cows' Milk Allergens. *Food and Agricultural Immunology*, 7(2), pp.175–187.

Warren, G., Lowe, D. and Armstrong, R. (1999). Measurement tools used in the study of eccentric contraction – induced injury. *Sports Medicine*, 27(1), pp.43–59.

Warren, G.L., Ingalls, C.P., Lowe, D.A. and Armstrong, R.B. (2001). Excitation-Contraction Uncoupling: Major Role in Contraction-Induced Muscle Injury. *Exercise and Sport Sciences Reviews*, 29(2), pp.82–87.

Warren, G.L., Lowe, D.A., Hayes, D.A., Karwoski, C.J., Prior, B.M. and Armstrong, R.B. (1993). Excitation failure in eccentric contraction-induced injury of mouse soleus muscle. *The Journal of Physiology*, 468(1), pp.487–499.

Weinert, D.J. (2009). Nutrition and muscle protein synthesis: a descriptive review. *The Journal of the Canadian Chiropractic Association*, 53(3), pp.186–93.

West, D.W.D., Burd, N.A., Coffey, V.G., Baker, S.K., Burke, L.M., Hawley, J.A., Moore, D.R., Stellingwerff, T. and Phillips, S.M. (2011). Rapid aminoacidemia enhances myofibrillar protein synthesis and anabolic intramuscular signaling responses after resistance exercise. *American Journal of Clinical Nutrition*, 94(3), pp.795–803.

West, D., Abou Sawan, S., Mazzulla, M., Williamson, E. and Moore, D. (2017). Whey Protein Supplementation Enhances Whole Body Protein Metabolism and Performance Recovery after Resistance Exercise: A Double-Blind Crossover Study. *Nutrients*, 9(7), p.735.

Wilborn, C.D., Taylor, L.W., Outlaw, J., Williams, L., Campbell, B., Foster, C.A., Smith-Ryan, A., Urbina, S. and Hayward, S. (2013). The effects 0f pre- and post-exercise whey

vs. Casein protein consumption on body composition and performance measures in collegiate female athletes. *Journal of Sports Science and Medicine*, 12(1).

Wilkinson, S.B., Tarnopolsky, M.A., MacDonald, M.J., MacDonald, J.R., Armstrong, D. and Phillips, S.M. (2007). Consumption of fluid skim milk promotes greater muscle protein accretion after resistance exercise than does consumption of an isonitrogenous and isoenergetic soy-protein beverage. *American Journal of Clinical Nutrition*, 85(4), pp.1031–1040.

Wilkinson. M. (2014). Distinguishing between statistical significance and practical/clinical meaningfulness using statistical inference. Sports Med. 44(3). pp :295-301.

Williams, M.B., Raven, P.B., Fogt, D.L. and Ivy, J.L. (2003). Effects of recovery beverages on glycogen restoration and endurance exercise performance. *Journal of Strength and Conditioning Research,* 17(1), pp.12-19.

Willoughby, D.S., Taylor, M. and Taylor, L. (2003). Glucocorticoid Receptor and Ubiquitin Expression after Repeated Eccentric Exercise. *Medicine and Science in Sports and Exercise*, 35(12), pp.2023–2031.

Wilson, A. and Lichtwark, G. (2011). The anatomical arrangement of muscle and tendon enhances limb versatility and locomotor performance. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1570), pp.1540–1553.

Witard, O.C., Jackman, S.R., Kies, A.K., Jeukendrup, A.E. and Tipton, K.D. (2011). Effect of increased dietary protein on tolerance to intensified training. *Medicine and Science in Sports and Exercise*, 43(4), pp.598–607.

Witard, O.C., Jackman, S.R., Breen, L., Smith, K., Selby, A. and Tipton, K.D. (2014). Myofibrillar muscle protein synthesis rates subsequent to a meal in response to increasing doses of whey protein at rest and after resistance exercise. *American Journal of Clinical Nutrition*, 99(1), pp.86–95.

Witard, O.C., Wardle, S.L., Macnaughton, L.S., Hodgson, A.B. and Tipton, K.D. (2016). Protein considerations for optimising skeletal muscle mass in healthy young and older adults. *Nutrients*, 8(4).

Wolfe, R.R. (2017). Branched-chain amino acids and muscle protein synthesis in humans: Myth or reality?. *Journal of the International Society of Sports Nutrition*, 14(1).

Wurtman, R.J., Hefti, F. and Melamed, E. (1980). Precursor control of neurotransmitter synthesis. *Pharmacological reviews*, 32(4), pp.315–35.

Yang, Y., Churchward-Venne, T.A., Burd, N.A., Tarnopolsky, M.A. and Phillips, S.M. (2012). Greater stimulation of myofibrillar protein synthesis with ingestion of whey protein isolate v. micellar casein at rest and after resistance exercise in elderly men. *British Journal of Nutrition*, 108(6), pp.958–962.

Yang, J., Deng, Y., Chu, H., Cong, Y., Zhao, J., Pohl, D., Misselwitz, B., Fried, M., Dai, N. and Fox, M. (2013). Prevalence and Presentation of Lactose Intolerance and Effects on Dairy Product Intake in Healthy Subjects and Patients With Irritable Bowel Syndrome. *Clinical Gastroenterology and Hepatology*, 11(3).

Young, W., McLean, B. and Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. *Journal of Sports Medicine and Physical Fitness*, 35(1), pp.13–19.

Young, W.B. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics*, 10(1), pp.89–96.

Yu, J.G., Carlsson, L. and Thornell, L.E. (2004). Evidence for myofibril remodeling as opposed to myofibril damage in human muscles with DOMS: An ultrastructural and immunoelectron microscopic study. *Histochemistry and Cell Biology*, 121(3), pp.219–227.

Zahalak, G.I. (1997). Can muscle fibers be stable on the descending limbs of their sarcomere length-tension relations?. *Journal of Biomechanics*, 30(11–12), pp.1179–1182.

Zeng, S.S. (1996). Comparison of goat milk standards with cow milk standards for analyses of somatic cell count, fat and protein in goat milk. *Small Ruminant Research*, 21(3), pp.221–225.

CHAPTER 7

APPENDIX

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Appendix A: PARTICIPANT INFORMATION SHEET

Participant name: _____ Participant code: _____

1. Study title

The effects of cows milk, goats milk, whey protein and an energy-matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask the researcher if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part in this research study or not. Thank you for reading this.

3. What is the purpose of the study?

To determine and compare the effects of cows milk, goats milk, whey protein and an energy-matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes. High-intensity repeated sprinting and jumping in team sport performance, have been associated with increased muscle damage and oxidative stress, which reduces the ability of the muscle to produce force and causes increased muscle fatigue, leading to reduced performance. It has been shown that the consumption of milk post-eccentric exercise can attenuate the negative effects of exercise-induced muscle damage (Cockburn *et al*., 2010, 2012; Rankin *et al*., 2015). It is possible, but unknown, if goats milk can offer the same benefits for recovery. Furthermore, given that some individuals have an intolerance to cows milk, or may have a preference for the

consumption of goats milk, it would be worthwhile investigating goats milk as a post-exercise recovery drink. The aim of this study is to determine if goats milk can be utilised as an effective recovery drink following exercise that replicates the demands of team sport performance.

4. Why have I been chosen?

It is important that the researcher assesses as many participants as possible, and you have indicated that you are interested in taking part in this study. You fulfil the following requirements for participants:

Gender: Male/Female

Age: 18-30years

Sport: Involved in a team sport training/competing at least three times per week.

Also, you do not meet any of the exclusion criteria - lower limb or back injury in previous 3 months, surgery in previous 6 months, intolerance to dairy or lactose products, known coronary disease, uncontrolled metabolic disorder or respiratory disease, hepatitis, HIV, pregnancy, post-partum.

5. Do I have to take part?

It is up to you to decide whether to take part in this research study or not. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason. If you do decide to withdraw from the study then please inform the researcher as soon as possible, and they will facilitate your withdrawal. If, for any reason, you wish to withdraw your data please contact the researcher within a month of your participation. After this data, it may not be possible to withdraw your individual data as the results may have already been published. However, as all data are anonymised, your individual data will not be identifiable in any way. A decision to withdraw at any time, or a decision not to take part, will not affect your status as a student in any way.

6. What will I have to do?

- You will be invited in this research project for 7^{-1}0days.
- You will be asked to attend room C156 (Physiology Laboratory) at the Institute of Technology, Carlow on six separate occasions. The table at the end of this section summarises your involvement.
- On attending the first session (familiarisation) you will be met by the investigator and invited to ask any questions concerning what you will later be asked to do. You will be asked to complete a health screening questionnaire to find out about your current health status and your health history, and sign a consent form. You will then perform several assessments (see below) to allow you to become familiar with the protocols. This visit will take approximately one hour.
- The second visit will be for the conduction of baseline measurements (see below) and will take approximately 40min.
- On visit 3, following a warm-up, you will be asked to perform 15 x 20m maximal sprints, with a 10m deceleration or 'stopping' zone after the finish line. You will have a rest after each sprint. You will then be asked to complete 8 sets of 10 plyometric jumps, followed by a cool-down. After the cool down you will be provided with 500mL of cows milks, 500mL of goats milk, 500mL of whey protein shake or 500mL of an energy-matched carbohydrate drink to consume after completion and you will be free to leave. Following the consumption of your allocated drink you will be asked to fast for 2h, then return to the laboratory to provide a blood sample.
- Visits 4, 5 and 6 will take place 24h, 48h and 72h after the exercise session, during which the baseline measurements will be repeats. These visits will take approximately 40min each

Measurements you will be asked to complete during each visit are listed below. Please note, the researcher will provide a written record of any abnormality discovered during this which will be addressed to your nominated GP stated on your health screening form and you will be handed a referral.

1. Provide a venous blood sample (BS) from a vein on your forearm.
2. Peak Torque (Nm) will be determined by completing three bilateral maximal effort knee flexion repetitions at 60°.s-1 and180°.s-1, with sixty seconds' recovery between speeds and approximately three minutes between legs on a Biodex System3 Isokinetic dynamometer.
3. Rate of force development (RFD) – this assessment will measure how quickly you can develop force in your leg muscles using a computer controlled strength testing device (isokinetic machine). You will be asked to straighten your leg against the immovable arm of the machine as hard as possible. You will complete three repetitions.
4. Countermovement Jump test (CMJ) - from a standing position you will be asked to squat down to approximately 90 degrees and jump upwards as high as you can. Your jump height will be recorded. You will complete three jumps.
5. Reactive Strength Index (RSI) – from a standing position on a step you will be asked to step off and upon contact with the ground, jump upwards as high as you can. Your time in contact with the ground and your jump height will be recorded. You will complete three jumps.
6. Twenty metre sprint test (20mSp) - you will be asked to run 20m as fast as you can. Your sprint time will be recorded. You will complete three sprints with a two-minute rest between sprints.
7. Soreness (S) and Tiredness (T) - you will be shown a scale and asked to indicate how sore you feel, and how tired you feel when completing a squatting exercise.
8. Perception of recovery- you will be asked to complete a short questionnaire asking you about how you feel you are recovering from the exercise trial with regard to the physical recovery, your energy levels and your enthusiasm and motivation.
9. Palatability - will be measured with a 'Likert Scale' (Flint *et al*. 2000) in which you will describe your gut comfort after the ingestion of supplied beverages.

- For 24h prior to the exercise session and for the 72h after, you will be asked to record your food and fluid intake. You will be provided with a weighing scale, measuring jug and recording sheet for this purpose.
- You will be asked to refrain from strenuous physical activity for the duration of the investigation, and from treating the symptoms of muscle fatigue or soreness with interventions such as massage, ice or medication, or consuming any nutritional supplements (eg anti-oxidants, HMB, casein/whey protein).
- A summary of your involvement can be seen in the following table.

Table 1: Participant involvement

Visit	Duration	What I will do
Visit 1: Familiarisation	I hour	Health screening questionnaire; consent form; BS, PkTq, RFD, CMJ, RSI, Sp, S/T
Visit 2: Baseline measures	40min	BS, PkTq, RFD, CMJ, RSI, Sp, S/T
Visit 3: Exercise Protocol	3 hours in total. (1hr for Exercise protocol & return 2hrs later for blood sample)	10min warm up 15 x 20m maximal sprints 8 sets of 10 plyometric jumps 10min cool down Consumption of fluid 2-hour fast Provision of blood sample
Visits 4-6	30min	BS, PkTq, RFD, CMJ, RSI, Sp, S/T, PR, P

BS: blood sample; RFD: Rate of force development; PkTq: peak torque; CMJ: countermovement jump; RSI: Reactive Strength Index; Sp: 20m sprint; S/T: soreness/tiredness; PR: perception of recovery. P: Palatability

7.Will I have to provide any bodily samples (i.e. blood/saliva/urine)?

Yes, you will be asked to provide a venous blood sample from a vein on your forearm. The researcher has been trained in venepuncture. You will be allowed to lie down for the procedure. Your skin will be cleaned, the needle inserted and stabilised with minimal discomfort to you. The correct volume of blood will be obtained in a blood collection tube and the needle will be removed. You will be asked to apply pressure with a cotton swab to the puncture site to minimise bruising and bleeding.

Should the tests reveal an abnormality the researcher will recommend to you that you seek further medical advice from your GP. Bear in mind though that a single test may not always provide an accurate reflection of your health status.

8.What are the possible disadvantages and risks of taking part?

Participation in this project will involve some physical discomfort.

The research project has been designed to induce muscle soreness and oxidative damage having you sprint and jump with maximal effort. You may experience feelings of exertion and local tiredness in your legs and it is likely you will experience delayed muscle soreness and stiffness afterwards. However, this discomfort is short-term and will dissipate after approximately five days.

When having your blood sample collected by a researcher trained in venepuncture, you will feel a needle prick in your arm. Every care will be taken to ensure that minimal discomfort is felt during the blood draw using standardised venepuncture techniques. In rare cases bruising may be apparent, but this should subside with days.

The sprint and jump tests require you to work at high intensities though they are of short duration. You may feel dizzy and tired. These feelings are temporary and are expected to subside within minutes of completing the exercise.

Appropriate risk assessments for all procedures have been conducted, and will be followed throughout the duration of the study.

9. What are the possible benefits of taking part?

We hope that participating in the study will help you. However, this cannot be guaranteed. The information we get from this study may help to provide researchers, coaches and players with specific guidelines regarding the benefits of nutritional supplementation for team sports athletes following high intensity training sessions or competition.

10. Will my taking part in this study be kept confidential?

The research team has put several procedures in place to protect the confidentiality of participants. You will be allocated a participant code that will always be used to identify any data you provide. Your name or other personal details will not be associated with your data, for example, the consent form that you sign will be kept separate from your data. All paper records will be stored in a locked filing cabinet, accessible only to the research team, and all electronic data will be stored on a password protected computer.

11.What will happen to the results of the research study?

The results of the research study will be used as part of a master thesis. The results may also be presented at conferences or in journal articles. However, the data will only be used by members of the research team and at no point will your personal information or data be revealed.

12.Who has reviewed the study?

The study has been reviewed by the Irish Research Council.

13.Contact for further information

If you require further information, have any questions or would like to withdraw your data then please contact:

Mary Curristin, Department of Science and Health, 087 2777215,
C00153237@itcarlow.ie

Thank you for taking part in this study. You should keep this participant information sheet as it contains your participant code, important information and the research teams contact details.

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Appendix B: CONSENT FORM

Title of research project: The effects of cows milk, goats milk, whey protein and energy-matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes.

Name of Researcher: Mary Curristin

1. I confirm that I have read and understand the information sheet dated ..... for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
3. I agree that this form that bears my name and signature may be seen by a designated auditor.
4. I agree that my non-identifiable research data may be stored in National Archives and be used anonymously by others for future research. I am assured that the confidentiality of my data will be upheld through the removal of any personal identifiers.
5. I agree to take part in the above study.

_____	_____	_____...
Name of participant	Date	Signature
_____	_____	_____
Name of person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

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Appendix C: HEALTH SCREENING FORM

STRICTLY CONFIDENTIAL

Participant name:

Height:

Weight:

Please answer these questions truthfully and completely. The sole purpose of this questionnaire is to ensure that you are fit and healthy to follow the proposed research programme.

1. How would you describe your present level of activity?

Less than once per month

Once a month

Once a week

Two/three times a week

Four/five times a week

More than five times a week

2. Are you currently taking any form of medication? If yes, please give brief details.

Yes ☐ No ☐

---

3. Have you suffered from a bacterial or viral infection in the last two weeks?

   Yes ☐ No ☐

4. Have you had cause to suspend physical activity in the last two weeks for any reason? Yes ☐ No ☐

---

5. If you currently suffer from or have previously suffered from any of the following conditions, you will be unable to take part in the study. Please inform the researcher (without specifics) if as a result you will now be unable to take part in the study.
   - heart complaint/condition
   - asthma
   - diabetes (Type 1 or 2)
   - high blood pressure
   - blood borne disease or infection
   - current or recent use of nutritional supplements (creatine, whey/casein protein, HMB etc)
   - known allergy or intolerance to dairy or lactose products
   - lower limb or back injury in previous three months
   - surgery in previous six months
   - known coronary disease
   - pregnancy

6. Is there any reason why you should not embark on the proposed research programme? Yes ☐ No ☐

Please provide details of your GP for referral in the unlikely event of discovering any abnormalities during the research study.

Name: _____

Address: _____

Contact no: _____

You are not required to provide specifics of any condition that precludes you from taking part in the study. However, if you are not sure if any such condition will affect your ability to participate, please feel free to discuss this with the research team, although you are not obliged to do so.

Signature: _____

Date: _____

Researcher: _____

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Participant code _____

Appendix D: FOOD AND FLUID RECORD

This food diary is designed to provide the researcher with information that will help provide individual nutrition advice, specifically tailored to your sporting needs.

Make a note of everything you eat and drink for _4_ days.

Things to remember

- Do not change what you eat just because you are filling in this diary. Be honest.
- Do not record a day when you are ill.
- Fill in as much detail as is possible (see sample diary on page 4). If you can, make a note of the weight of any of the foods you eat.
- State whether food is boiled, fried, stewed, grilled, baked, steamed or cooked in the microwave.
- If fat is used in cooking, please state the amount and type used.
- Note down the brand name of all foods e.g. Alpen muesli, Twix chocolate bar etc.
- Make sure to include all drinks and to state if sugar and milk are added.
- Include all foods and snacks – even if it's just a handful of crisps or nuts.

The more accurate your recording, the more accurate the results.

Write down everything and write clearly

Examples of some common foods and description to write down

Bread	⟶	white, brown, wholemeal, plain or soda
Milk	⟶	whole, low fat (semi-skimmed) or skimmed
Cheese	⟶	cheddar, edam, cottage cheese etc
Spread	⟶	butter, margarine, low fat spread
Biscuits	⟶	name the brand and if chocolate covered
Sweets/chocolate	⟶	give the name and size or weight
Gravy/sauces	⟶	write down if included with a meal

Please fill in the sections on the next few pages to give general information on your current lifestyle habits.

SAMPLE DIARY

Date: _____

Training day ☐ **Competition day** ☐ **Rest day** ☐

Time of meal snack/drink	Food and Drink	Quantity	Training (time, type and duration)
7am	Cornflakes Milk, semi skimmed Toast, white bread, large loaf Butter Jam Tea with SS milk Sugar	Large bowl 1/3 pint 2 rounds thinly spread thickly spread 1 mug 2 teaspoons	
10.30am	Coffee with SS milk Sugar Fruit scone Butter	1 mug 1 teaspoon 1 average thinly spread	
1pm	Diluted fruit squash during training	500mLs	1pm 5 mile run (7-minute mile) 50 minutes including warm up and warm down
2pm	Wholemeal rolls Ham Lettuce Tomato Bananas Water	2 large 4 thin slices 2 leaves 1 2 medium 500mLs	
4pm	Chocolate biscuit (digestive)	3	
6pm	Water during training	750mLs	6pm weights session (high intensity, 1 hour) 7pm swim (20 lengths, 35 mins)
8pm	Chicken breast with skin, roast Potatoes, boiled with skins Potato wedges, baked in oven Mixed vegetables Gravy Diluted orange squash	1 breast 3 medium 4 medium ½ plate 5 tablespoons 1 pint	
10.30pm	Cornflakes Milk, SS Sugar	large bowl 1/3 pint 1 dessertspoon	

Date: _____

Training day ☐ **Competition day** ☐ **Rest day** ☐

Time of meal snack/drink	Food and Drink	Quantity	Training (time, type and duration)

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Appendix E: MUSCLE SORENESS

Rate your level of soreness based on the scale below with 0 indicating no soreness and 10 indicating as sore as it could be

I_____I

0 **10**

No soreness **As sore as it could be**

Appendix F: MUSCLE TIREDNESS

Rate your level of tiredness based on the scale below with 0 indicating no tiredness and 10 indicating as tired as it could be

I_____I

0 10

No tiredness As tired as it could be

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Appendix G: Daily Analysis of Life Demands for Athletes Questionnaire (DALDA)

24-hour post exercise protocol **Participant code _____**

	Normal	Worse than normal	Better than normal
PART A			
Diet			
Home life			
College/Work			
Friends			
Sport Training/Exercise			
Climate			
Sleep			
Recreation			
Health			
	Normal	**Worse than normal**	**Better than normal**
PART B			
Muscle Pains			
Techniques			
Tiredness			
Need for a rest			
Supplementary work			
Boredom			
Recovery time			
Irritability			
Weight			
Throat			
Internal			
Unexplained aches			
Technique power			
Enough sleep			
Between sessions recovery			
General Weakness			
Interest			
Arguments			
Skin rashes			
Congestion			
Training effort			
Temper			
Swellings			
Running nose			

48-hour post exercise protocol **Participant code_____**

	Normal	Worse than normal	Better than normal
PART A			
Diet			
Home life			
College/Work			
Friends			
Sport Training/Exercise			
Climate			
Sleep			
Recreation			
Health			
	Normal	**Worse than normal**	**Better than normal**
PART B			
Muscle Pains			
Techniques			
Tiredness			
Need for a rest			
Supplementary work			
Boredom			
Recovery time			
Irritability			
Weight			
Throat			
Internal			
Unexplained aches			
Technique power			
Enough sleep			
Between sessions recovery			
General Weakness			
Interest			
Arguments			
Skin rashes			
Congestion			
Training effort			
Temper			
Swellings			
Likeability			
Running nose			

72-hour post exercise protocol **Participant code _____**

	Normal	Worse than normal	Better than normal
PART A			
Diet			
Home life			
College/Work			
Friends			
Sport Training/Exercise			
Climate			
Sleep			
Recreation			
Health			
	Normal	**Worse than normal**	**Better than normal**
PART B			
Muscle Pains			
Techniques			
Tiredness			
Need for a rest			
Supplementary work			
Boredom			
Recovery time			
Irritability			
Weight			
Throat			
Internal			
Unexplained aches			
Technique power			
Enough sleep			
Between sessions recovery			
General Weakness			
Interest			
Arguments			
Skin rashes			
Congestion			
Training effort			
Temper			
Swellings			
Likeability			
Running nose			

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Appendix H: Palatability Scale

Participant code: _____

Scale 1 – 5

(1 = Good/None, 5 = Bad/Much)

Smell

Good _____Bad

Taste

Good _____Bad

Aftertaste

None _____Much

Pleasure on the palate

Good _____Bad

How comfortable does your stomach feel at the moment?

1. Very comfortable
2. Comfortable
3. Average comfortable
4. Uncomfortable
5. Very uncomfortable

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Appendix I: PARTICIPANT DEBRIEF SHEET

Title of research project: The effects of cows milk, goats milk, whey protein and an energy-matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes

Researcher details:

Mary Curristin

Department of Science and Health, IT Carlow

Email: C00153237@itcarlow.ie

Telephone: 0872777215

1. **What was the purpose of the study?**

   To investigate, determine and compare cows milk, goats milk, whey protein and an energy-matched carbohydrate drink on recovery from repeated sprinting and jumping in team sport athletes. Recovery is a challenge for athletes who are undertaking two or more sessions a week, training for prolonged periods, or competing in a programme that involves multiple training and games/matches. Between each training session, the body needs to adapt to the induced physiological stress. Prolonged and high intensity exercise causes a substantial breakdown of muscle protein. Recent research has been shown that the consumption of milk post-eccentric exercise can attenuate the negative effects of exercise-induced muscle damage (Cockburn *et al*., 2010, 2012; Rankin *et al*., 2015). It is possible, but unknown, if goats milk can offer the same benefits for recovery. Furthermore, given that some individuals have an intolerance to cows milk, or may have a preference for the consumption of goats milk, it would be worthwhile investigating goats milk as a post-exercise recovery drink. The results of this study should provide researchers, coaches and players with specific

guidelines regarding the benefits of milk consumption for team sports athletes during high intensity training periods.

2. **How will I find out about the results?**

   Once all the study has been completed and all the data analysed the researcher will email you a summary of the results.

3. **What will happen to the information I have provided?**

   All the information provided will be treated in accordance with the Data Protection Act. All the information that you provided and all data collected will be stored safely for the duration of the study on a password protected computer. Coding of participants will be kept in a separate area to ensure anonymity. Confidentiality and anonymity will be maintained always and any published work will use group data that is generalised so that no individual can be identified.

4. **How will the results be disseminated?**

   Data might be published in a scientific journal or may be presented at a conference, but the data will be presented in a generalised way. At no stage, will your personal information be presented. Your data will not be identifiable.

5. **Have I been deceived in any way during the project?**

   No, you have not been deceived. Some participants receive cows milk after the exercise, some receive goats milk, some receive whey protein shake and others receive a carbohydrate drink, but this is obvious to all participants at the time.

6. **If I change my mind and wish to withdraw the information I have provided, how do I do this?**

   If you wish you may withdraw your data by contacting the researcher, but you should do this within a month of your participation. After that, it may not be possible to withdraw your individual data as the results may already have been published. As all data are anonymised, your individual data will not be identifiable in any way.

Appendix J: Within-group Analysis

A summary of the statistical analysis for within group effects can be seen in Table 4.22.

Table 4.22 Breakdown analysis of within-group effects

VARIABLE	TIMEFRAME	MEAN EFFECT, ±90% CI	QUALITATIVE INFERENCE	EFFECT SIZE
CMJ				
Within Cow	B - 24	-4.3, ± 2.9	Likely Trivial	Trivial (0.10)
	B - 48	-3.6, ± 3.6	Very likely Trivial	Trivial (0.08)
	B - 72	-0.3, ± 3.4	Likely Trivial	Trivial (0.02)
Within Cho	B - 24	-8.3, ± 4.0	Likely Harmful	Small (0.26)
	B - 48	-6.3, ± 3.2	Likely Harmful	Trivial (0.19)
	B - 72	-1.6, ± 3.4	Likely Trivial	Trivial (0.03)
Within Whey	B - 24	-1.7, ± 7.9	Likely Trivial	Trivial (0.10)
	B - 48	-1.6, ± 4.7	Possibly Harmful	Trivial (0.05)
	B - 72	-4.1, ± 8.3	Possibly Harmful	Trivial (0.06)
Within Goat	B - 24	-3.6, ± 7.2	Possibly Harmful	Trivial (0.15)
	B - 48	-6.3, ± 4.8	Possibly Harmful	Small (0.23)
	B - 72	-4.0, ± 7.1	Likely Trivial	Trivial (0.15)
RSI				
Within Cow	B - 24	-5.4, ± 7.2	Possibly Harmful	Trivial (0.18)
	B - 48	-7.2, ± 8.1	Possibly Harmful	Small (0.25)
	B - 72	-1.8, ± 10.5	Possibly Harmful	Trivial (0.06)
Within Cho	B - 24	-9.6, ± 13.2	Possibly Harmful	Small (0.33)
	B - 48	-16.2, ± 12.1	Likely Harmful	Moderate (0.60)
	B - 72	-6.7, ± 16.5	Unclear	Small (0.20)
Within Whey	B - 24	-3.9, ± 9.0	Possibly Harmful	Trivial (0.14)
	B - 48	-11.0, ± 12.3	Likely Harmful	Small (0.38)
	B - 72	-4.4, ± 4.2	Possibly Harmful	Trivial (0.16)
Within Goat	B - 24	-7.5, ± 11.7	Possibly Harmful	Small (0.26)
	B - 48	-6.8, ± 16.0	Possibly Harmful	Trivial (0.14)
	B - 72	-14.3, ± 18.3	Possibly Harmful	Small (0.44)
RFD Dominant				
Within Cow	B - 24	-2.4, ± 25.5	Unclear	Trivial (0.02)
	B - 48	-17.3, ± 8.4	Very Likely Harmful	Small (0.55)
	B - 72	-19.1, ± 14.8	Likely Harmful	Small (0.55)
Within Cho	B - 24	-10.5, ± 17.8	Possibly Harmful	Trivial (0.09)
	B - 48	-5.3, ± 21.2	Possibly Harmful	Trivial (0.02)
	B - 72	-4.9, ± 24.2	Possibly Harmful	Trivial (0.01)

Within Whey	B - 24	-1.6, ± 8.5	Likely Trivial	Trivial (0.06)
	B - 48	-4.7, ± 12.3	Possibly Harmful	Trivial (0.09)
	B - 72	-7.4, ± 12.9	Unclear	Trivial (0.13)
Within Goat	B - 24	-17.1, ± 13.0	Likely Harmful	Small (0.29)
	B - 48	-14.8, ± 7.2	Likely Harmful	Small (0.27)
	B - 72	-16.0, ± 9.5	Likely Harmful	Small (0.29)
RFD Non Dominant				
Within Cow	B - 24	-21.4, ± 10.0	Very Likely Harmful	Moderate (0.83)
	B - 48	-25.8, ± 9.7	Very Likely Harmful	Moderate (0.89)
	B - 72	-18.3, ± 10.2	Very Likely Harmful	Moderate (0.64)
Within Cho	B - 24	-16.9, ± 22.7	Likely Harmful	Small (0.36)
	B - 48	-18.8, ± 24.0	Likely Harmful	Small (0.41)
	B - 72	-16.9, ± 18.6	Likely Harmful	Small (0.42)
Within Whey	B - 24	-2.8, ± 17.1	Possibly Trivial	Trivial (0.12)
	B - 48	-14.2, ± 11.2	Likely Harmful	Small (0.28)
	B - 72	-10.4, ± 13.3	Possibly Harmful	Small (0.23)
Within Goat	B - 24	-13.5, ± 21.1	Possibly Harmful	Small (0.21)
	B - 48	-11.4, ± 19.8	Possibly Harmful	Small (0.21)
	B - 72	-11.2, ± 22.6	Possibly Harmful	Small (0.21)
Peak Torque 60◦/s Dominant Extension				
Within Cow	B - 24	-12.0, ± 6.8	Likely Harmful	Small (0.37)
	B - 48	-10.7, ± 5.0	Likely Harmful	Small (0.33)
	B - 72	-8.2, ± 7.7	Possibly Harmful	Small (0.24)
Within Cho	B - 24	-10.9, ± 11.9	Possibly Harmful	Small (0.26)
	B - 48	-13.7, ± 10.7	Likely Harmful	Small (0.31)
	B - 72	-9.5, ± 10.5	Possibly Harmful	Small (0.24)
Within Whey	B - 24	-1.6, ± 5.8	Likely Trivial	Trivial (0.03)
	B - 48	-2.0, ± 6.7	Likely Trivial	Trivial (0.04)
	B - 72	-4.7, ± 6.3	Possibly Beneficial	Trivial (0.14)
Within Goat	B - 24	-12.5, ± 4.5	Likely Harmful	Small (0.23)
	B - 48	-7.9, ± 5.2	Possibly Harmful	Trivial (0.14)
	B - 72	-4.8, ± 4.4	Likely Trivial	Trivial (0.09)
Peak Torque 60◦/s Non Dominant Extension				
Within Cow	B - 24	-13.0, ± 6.0	Very Likely Harmful	Small (0.44)
	B - 48	-11.2, ± 5.7	Very Likely Harmful	Small (0.36)
	B - 72	-9.3, ± 7.0	Likely Harmful	Small (0.29)
Within Cho	B - 24	-15.3, ± 8.3	Very Likely Harmful	Small (0.38)
	B - 48	-15.7, ± 10.8	Likely Harmful	Small (0.40)
	B - 72	-11.9, ± 8.1	Likely Harmful	Small (0.32)

Within Whey	B - 24	-2.6, ± 7.2	Unclear	Trivial (0.11)
	B - 48	-3.1, ± 6.8	Possibly Harmful	Trivial (0.09)
	B - 72	-3.5, ± 7.3	Unclear	Trivial (0.12)
Within Goat	B - 24	-5.8, ± 6.1	Possibly Harmful	Trivial (0.10)
	B - 48	-7.9, ± 4.5	Possibly Harmful	Small (0.20)
	B - 72	-7.3, ± 8.2	Possibly Harmful	Trivial (0.15)
Peak Torque 60◦/s Dominant Flexion				
Within Cow	B - 24	-10.7, ± 8.1	Likely Harmful	Small (0.32)
	B - 48	-8.0, ± 9.2	Possibly Harmful	Small (0.22)
	B - 72	-3.0, ± 9.2	Unclear	Small (0.40)
Within Cho	B - 24	-14.9, ± 9.5	Likely Harmful	Small (0.31)
	B - 48	-15.4, ± 10.2	Likely Harmful	Small (0.30)
	B - 72	-0.6, ± 6.1	Likely Trivial	Trivial (0.19)
Within Whey	B - 24	-1.9, ± 7.7	Likely Trivial	Trivial (0.05)
	B - 48	-10.4, ± 8.0	Likely Harmful	Small (0.22)
	B - 72	-8.6, ± 4.4	Likely Harmful	Trivial (0.18)
Within Goat	B - 24	-11.1, ± 9.1	Likely Harmful	Small (0.27)
	B - 48	-16.0, ± 9.9	Likely Harmful	Small (0.29)
	B - 72	-5.6, ± 8.3	Possibly Harmful	Small (0.25)
Peak Torque 60◦/s Non Dominant Flexion				
Within Cow	B - 24	-12.2, ± 9.3	Likely Harmful	Small (0.36)
	B - 48	-13.2, ± 16.8	Likely Harmful	Small (0.31)
	B - 72	-1.2, ± 13.8	Possibly Trivial	Small (0.22)
Within Cho	B - 24	-10.1, ± 9.5	Likely Harmful	Small (0.22)
	B - 48	-10.2, ± 16.2	Possibly Harmful	Trivial (0.16)
	B - 72	-0.1, ± 9.6	Possibly Trivial	Small (0.26)
Within Whey	B - 24	-4.4, ± 10.5	Possibly Harmful	Trivial (0.12)
	B - 48	-8.4, ± 12.3	Possibly Harmful	Small (0.20)
	B - 72	-4.2, ± 7.9	Possibly Harmful	Small (0.23)
Within Goat	B - 24	-14.1, ± 10.5	Likely Harmful	Small (0.36)
	B - 48	-12.1, ± 10.7	Likely Harmful	Small (0.28)
	B - 72	-2.4, ± 6.0	Likely Trivial	Small (0.20)
Peak Torque 180◦/s Dominant Extension				
Within Cow	B - 24	-9.6, ± 11.1	Possibly Harmful	Small (0.28)
	B - 48	-6.9, ± 14.3	Possibly Harmful	Trivial (0.18)
	B - 72	-2.1, ± 8.8	Possibly Trivial	Trivial (0.08)
Within Cho	B - 24	-11.3, ± 5.9	Likely Harmful	Small (0.27)
	B - 48	-10.9, ± 6.5	Likely Harmful	Small (0.25)
	B - 72	-8.1, ± 6.4	Possibly Harmful	Small (0.22)

Within Whey	B - 24	-2.2, ± 3.1	Very Likely Trivial	Trivial (0.07)
	B - 48	-1.2, ± 8.7	Likely Trivial	Trivial (0.03)
	B - 72	-5.2, ± 9.2	Unclear	Trivial (0.10)
Within Goat	B - 24	-7.6, ± 4.5	Possibly Harmful	Trivial (0.15)
	B - 48	-3.8, ± 9.7	Likely Trivial	Trivial (0.03)
	B - 72	-5.1, ± 8.3	Possibly Trivial	Trivial (0.09)
Peak Torque 180◦/s Non Dominant Extension				
Within Cow	B - 24	-12.0, ± 8.2	Likely Harmful	Small (0.34)
	B - 48	-7.9, ± 7.4	Possibly Harmful	Small (0.22)
	B - 72	-2.0, ± 8.4	Possibly Trivial	Trivial (0.05)
Within Cho	B - 24	-12.6, ± 5.9	Likely Harmful	Small (0.32)
	B - 48	-14.7, ± 7.4	Very Likely Harmful	Small (0.35)
	B - 72	-10.4, ± 5.3	Likely Harmful	Small (0.26)
Within Whey	B - 24	-4.8, ± 6.1	Possibly Harmful	Trivial (0.12)
	B - 48	-6.0, ± 3.0	Possibly Harmful	Trivial (0.13)
	B - 72	-4.5, ± 6.5	Possibly Harmful	Trivial (0.12)
Within Goat	B - 24	-7.7, ± 7.1	Possibly Harmful	Trivial (0.14)
	B - 48	-8.2, ± 6.4	Possibly Harmful	Trivial (0.15)
	B - 72	-3.2, ± 7.8	Likely Trivial	Trivial (0.00)
Peak Torque 180◦/s Dominant Flexion				
Within Cow	B - 24	-7.7, ± 9.5	Possibly Harmful	Small (0.23)
	B - 48	-3.7, ± 10.2	Likely Trivial	Trivial (0.12)
	B - 72	-3.1, ± 8.7	Likely Trivial	Trivial (0.13)
Within Cho	B - 24	-4.9, ± 11.0	Possibly Harmful	Trivial (0.13)
	B - 48	-0.6, ± 12.6	Likely Trivial	Trivial (0.01)
	B - 72	-0.8, ± 12.4	Likely Trivial	Trivial (0.05)
Within Whey	B - 24	-2.1, ± 10.0	Possibly Trivial	Trivial (0.04)
	B - 48	-12.0, ± 7.8	Likely Harmful	Small (0.26)
	B - 72	-4.7, ± 10.6	Possibly Harmful	Trivial (0.13)
Within Goat	B - 24	-11.5, ± 13.8	Possibly Harmful	Small (0.23)
	B - 48	-13.5, ± 14.8	Possibly Harmful	Small (0.22)
	B - 72	-11.6, ± 16.0	Possibly Harmful	Small (0.21)
Peak Torque 180◦/s Non Dominant Flexion				
Within Cow	B - 24	-9.0, ± 12.7	Possibly Harmful	Small (0.27)
	B - 48	-8.3, ± 20.2	Possibly Harmful	Trivial (0.18)
	B - 72	-3.4, ± 14.0	Unclear	Trivial (0.07)
Within Cho	B - 24	-1.3, ± 8.0	Likely Trivial	Trivial (0.01)
	B - 48	-6.0, ± 10.6	Possibly Harmful	Trivial (0.10)
	B - 72	-1.7, ± 9.9	Likely Trivial	Trivial (0.00)

Within Whey	B - 24	-4.2, ± 12.9	Possibly Harmful	Trivial (0.11)
	B - 48	-4.9, ± 12.4	Possibly Harmful	Trivial (0.08)
	B - 72	-3.1, ± 14.1	Possibly Harmful	Trivial (0.04)
Within Goat	B - 24	-9.6, ± 16.1	Possibly Harmful	Trivial (0.18)
	B - 48	-10.6, ± 17.2	Possibly Harmful	Trivial (0.10)
	B - 72	-1.5, ± 13.2	Possibly Trivial	Trivial (0.00)
5m Sprint				
Within Cow	B - 24	-1.2, ± 3.9	Possibly Harmful	Trivial (0.16)
	B - 48	-2.5, ± 4.1	Possibly Harmful	Small (0.35)
	B - 72	-3.6, ± 5.4	Likely Harmful	Small (0.42)
Within Cho	B - 24	-1.0, ± 2.0	Likely Trivial	Trivial (0.10)
	B - 48	-1.4, ± 3.2	Possibly Harmful	Trivial (0.12)
	B - 72	-1.8, ± 3.7	Possibly Harmful	Trivial (0.15)
Within Whey	B - 24	-0.6, ± 5.0	Unclear	Trivial (0.05)
	B - 48	-0.7, ± 5.3	Possibly Harmful	Trivial (0.07)
	B - 72	-5.8, ± 7.1	Likely Harmful	Small (0.41)
Within Goat	B - 24	-0.0, ± 3.6	Possibly Trivial	Trivial (0.01)
	B - 48	-1.6, ± 4.1	Possibly Harmful	Trivial (0.17)
	B - 72	-5.0, ± 4.2	Likely Harmful	Small (0.30)
10m Sprint				
Within Cow	B - 24	-0.6, ± 2.9	Possibly Harmful	Trivial (0.07)
	B - 48	-1.1, ± 3.3	Possibly Harmful	Trivial (0.14)
	B - 72	-1.4, ± 4.3	Possibly Harmful	Trivial (0.18)
Within Cho	B - 24	-0.4, ± 1.5	Likely Trivial	Trivial (0.04)
	B - 48	-0.1, ± 2.4	Likely Trivial	Trivial (0.01)
	B - 72	-0.5, ± 1.8	Likely Trivial	Trivial (0.06)
Within Whey	B - 24	-0.6, ± 4.0	Unclear	Trivial (0.07)
	B - 48	-0.1, ± 4.4	Possibly Harmful	Trivial (0.00)
	B - 72	-1.5, ± 3.7	Possibly Harmful	Trivial (0.18)
Within Goat	B - 24	-1.2, ± 3.7	Unclear	Trivial (0.12)
	B - 48	-1.4, ± 3.5	Possibly Harmful	Trivial (0.15)
	B - 72	-1.8, ± 4.3	Possibly Harmful	Trivial (0.19)
20m Sprint				
Within Cow	B - 24	-3.1, ± 6.1	Possibly Harmful	Small (0.35)
	B - 48	-0.3, ± 2.5	Possibly Trivial	Trivial (0.06)
	B - 72	-0.8, ± 2.4	Possibly Harmful	Trivial (0.09)
Within Cho	B - 24	-0.9, ± 1.0	Possibly Harmful	Trivial (0.08)
	B - 48	-1.7, ± 1.5	Possibly Beneficial	Trivial (0.17)
	B - 72	-0.3, ± 1.4	Very Likely Trivial	Trivial (0.03)

Within Whey	B - 24	-0.8, ± 2.5	Unclear	Trivial (0.11)
	B - 48	-0.4, ± 2.9	Unclear	Trivial (0.07)
	B - 72	-1.3, ± 3.4	Possibly Harmful	Trivial (0.16)
Within Goat	B - 24	-1.7, ± 2.6	Unclear	Trivial (0.14)
	B - 48	-1.7, ± 2.7	Unclear	Trivial (0.15)
	B - 72	-0.1, ± 2.9	Likely Trivial	Trivial (0.00)
CK				
Within Cow	B - 2	-2.9, ×/÷ 1.8	Very Likely Increase	Very Large (2.28)
	B - 24	-4.0, ×/÷ 2.2	Very Likely Increase	Extremely Large (4.48)
	B - 48	-3.1, ×/÷ 2.1	Very Likely Increase	Very Large (2.84)
	B - 72	-2.7, ×/÷ 1.9	Very Likely Increase	Very Large (2.62)
Within Cho	B - 2	-1.6, ×/÷ 1.5	Likely Increase	Small (0.56)
	B - 24	-2.1, ×/÷ 1.7	Very Likely Increase	Large (1.50)
	B - 48	-1.6, ×/÷ 1.5	Likely Increase	Moderate (0.83)
	B - 72	-1.3, ×/÷ 1.5	Possible Increase	Small (0.46)
Within Whey	B - 2	-1.4, ×/÷ 1.5	Likely Increase	Large (1.44)
	B - 24	-1.4, ×/÷ 1.5	Likely Increase	Moderate (1.00)
	B - 48	-1.2, ×/÷ 1.4	Possible Increase	Small (0.48)
	B - 72	-1.0, ×/÷ 1.4	Unclear	Trivial (0.03)
Within Goat	B - 2	-2.1, ×/÷ 1.3	Most Likely Increase	Moderate (0.98)
	B - 24	-2.1, ×/÷ 1.3	Most Likely Increase	Moderate (0.91)
	B - 48	-1.3, ×/÷ 1.3	Likely Increase	Small (0.36)
	B - 72	-1.3, ×/÷ 1.3	Likely Increase	Small (0.26)
Soreness (isokinetic)				
Within Cow	B - 24	-5.5, ± 1.1	Most Likely Harmful	Large
	B - 48	-4.1, ± 1.3	Most Likely Harmful	Moderate
	B - 72	-3.6, ± 1.4	Most Likely Harmful	Moderate
		-		
Within Cho	B - 24	-4.5, ± 1.6	Most Likely Harmful	Moderate
	B - 48	-5.1, ± 2.2	Most Likely Harmful	Large
	B - 72	-2.9, ± 2.0	Very Likely Harmful	Small
Within Whey	B - 24	-5.4, ± 1.1	Most Likely Harmful	Large
	B - 48	-4.9, ± 1.5	Most Likely Harmful	Moderate
	B - 72	-4.3, ± 1.2	Most Likely Harmful	Moderate
Within Goat	B - 24	-5.9, ± 1.8	Most Likely Harmful	Large
	B - 48	-4.6, ± 1.3	Most Likely Harmful	Moderate
	B - 72	-3.8, ± 1.5	Most Likely Harmful	Moderate
Soreness (squat)				
Within Cow	B - 24	-5.6, ± 1.0	Most Likely Harmful	Large
	B - 48	-3.8, ± 1.5	Most Likely Harmful	Moderate
	B - 72	-2.3, ± 1.3	Very Likely Harmful	Small

Within Cho	B - 24	-5.8, ± 1.2	Most Likely Harmful	Large
	B - 48	-5.0, ± 1.7	Most Likely Harmful	Large
	B - 72	-2.9, ± 1.6	Very Likely Harmful	Small
Within Whey	B - 24	-4.3, ± 1.2	Most Likely Harmful	Moderate
	B - 48	-4.3, ± 1.3	Most Likely Harmful	Moderate
	B - 72	-2.8, ± 1.4	Very Likely Harmful	Small
Within Goat	B - 24	-5.1, ± 1.2	Most Likely Harmful	Large
	B - 48	-3.4, ± 0.8	Most Likely Harmful	Moderate
	B - 72	-2.5, ± 1.2	Very Likely Harmful	Small
Tiredness				
Within Cow	B - 24	-5.6, ± 1.0	Most Likely Harmful	Large
	B - 48	-3.8, ± 1.5	Most Likely Harmful	Moderate
	B - 72	-2.3, ± 1.3	Very Likely Harmful	Small
Within Cho	B - 24	-5.8, ± 1.2	Most Likely Harmful	Large
	B - 48	-5.0, ± 1.7	Most Likely Harmful	Large
	B - 72	-2.9, ± 1.6	Very Likely Harmful	Small
Within Whey	B - 24	-4.3, ± 1.2	Most Likely Harmful	Moderate
	B - 48	-4.3, ± 1.3	Most Likely Harmful	Moderate
	B - 72	-2.8, ± 1.4	Very Likely Harmful	Small
Within Goat	B - 24	-5.1, ± 1.2	Most Likely Harmful	Large
	B - 48	-3.4, ± 0.8	Most Likely Harmful	Moderate
	B - 72	-2.5, ± 1.2	Very Likely Harmful	Small
DALDA				
Within Cow	B - 24	-4.5, ± 1.2	Most Likely Harmful	Small
	B - 48	-4.1, ± 1.5	Most Likely Harmful	Small
	B - 72	-2.1, ± 1.5	Very Likely Harmful	Trivial
Within Cho	B - 24	-7.9, ± 5.3	Most Likely Harmful	Moderate
	B - 48	-7.5, ± 4.6	Most Likely Harmful	Moderate
	B - 72	-3.8, ± 1.6	Very Likely Harmful	Small
Within Whey	B - 24	-5.9, ± 3.1	Very Likely Harmful	Small
	B - 48	-4.8, ± 1.9	Most Likely Harmful	Small
	B - 72	-3.3, ± 1.7	Very Likely Harmful	Small
Within Goat	B - 24	-4.8, ± 1.6	Most Likely Harmful	Small
	B - 48	-3.9, ± 1.8	Very Likely Harmful	Small
	B - 72	-2.8, ± 1.9	Very Likely Harmful	Small

Qualitative Inference represents the likelihood that the true value will have the observed magnitude. Mean effect refers to the first group minus the second group. ± 90% CI: add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Effect size is a quantitative measure of the magnitude.