THE EFFECTS OF A TART CHERRY SUPPLEMENT ON RECOVERY FROM EXHAUSTIVE EXERCISE

A Thesis By

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Abstract:
The aim of this study was to investigate the effects of a tart cherry supplement on recovery from exercise-induced muscle damage. Seventeen recreationally active women (mean age ± SD = 22.2 ± 3.3 years, height = 162.0 ± 6.0 cm, body mass = 65.1 ± 11.1 kg, BMI = 24.7 ± 3.5 kg·m²) supplemented with 2 powdered tart cherry capsules or a placebo for eight consecutive days. An overload protocol of 8 x 10 maximal effort knee extensions at a velocity of 60°·s⁻¹ was performed on the fourth day of supplementation. Testing sessions consisted of a muscle function test (MFT) to examine pre- and post-testing peak torque, peak power, total work, time to peak torque, mean power, muscle activation of the quadriceps, and muscle soreness at baseline and post-testing 0 h, 24 h, 48 h, and 72 h. A second trial of testing was repeated two weeks after using the opposite supplement than the one assigned for the first trial. No significant interaction for time × condition × velocity (p = 0.916) and no significant main effect for condition (p = 0.557) were demonstrated for peak torque. However, there were main effects for time and velocity for concentric quadriceps peak torque (p < 0.001). For muscle soreness, there was no two-way interaction for time x condition (p > 0.05) and no main effect of condition (p > 0.05), but there was a main effect for time (p < 0.001). In conclusion, a tart cherry supplement did not attenuate losses in isokinetic muscle peak torque, peak power, total work, time-to-peak torque, muscle soreness, or quadriceps muscle activation.
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CHAPTER 1
INTRODUCTION

Resistance exercise is commonly used for rapid muscle strength and muscle mass gains to improve athletic performance or decrease the demands of activities of daily living (Dominguez-Balmaseda et al., 2020; Hooper et al., 2021). However, unaccustomed, strenuous, high repetition eccentric training produces higher incidences of exercise-induced muscle damage (EIMD) (Abbott et al., 2020; Beals et al., 2017; Bowtell et al., 2011; Dominguez-Balmaseda et al., 2020; Hillman et al., 2017; Hooper et al., 2021; Lamb et al., 2019; Quinlan & Hill, 2020; Tufano et al., 2012). EIMD may arise due to mechanical stress or metabolic overload; however, its development is not completely understood (Hillman et al., 2017; Lamb et al., 2019; Quinlan & Hill, 2020). The mode, intensity, and duration of exercise as well as the training experience of an individual determine the severity of EIMD (Hyde et al., 2016). Common symptoms associated with EIMD include a reduction in muscle force, an increased inflammatory response in the bloodstream, a reduction in range of motion (ROM), a reduction in neuromuscular function, an increase in limb circumference, and the development of delayed-onset muscle soreness (DOMS) (Hillman et al., 2017; Lamb et al., 2019; Quinlan & Hill, 2020). Direct measurement of EIMD markers is invasive and includes blood draws to measure plasma creatine kinase and protein concentrations (West et al., 2020). Thus, increased muscle soreness, a reduction in joint ROM, increased tissue swelling, and loss of muscle strength are indirect measures of EIMD (Beck et al., 2007; West et al., 2020). Accordingly, DOMS and muscle strength are the most notable indirect markers used to evaluate EIMD (Nogueira et al., 2019).

DOMS is defined as a type I muscle strain; however, the exact mechanisms for its development are not completely understood (Cheung et al., 2003). Theories for the development of DOMS include increased lactic acid accumulation, tonic localized motor unit spasms, excessive strain of connective tissue, disruption of muscle tissue contractile components, inflammatory cell infiltration, and calcium accumulation outside of the sarcoplasmic reticulum (Cheung et al., 2003; Trombold et al., 2011). In particular, the soreness, tenderness, stiffness, and loss of muscle function associated
with DOMS peak between 24 and 72 hours (h) following eccentric training (Beals et al., 2017; Beck et al., 2007; Dominguez-Balmaseda et al., 2020; Trombold et al., 2011). Potential recovery methods following exercise training would be beneficial since the presence of DOMS can decrease exercise tolerance and increase perception of effort, which may then alter athletic performance or adherence to an exercise training program (Hillman et al., 2017).

Recovery may be defined as either the attenuation of muscle damage response to exercise or the return of performance measures to baseline levels (Gordon et al., 2017). A variety of recovery methods to attenuate EIMD and DOMS have been suggested and can be divided into the three following categories: therapeutic, pharmacological, and nutritional interventions (Beck et al., 2007). Passive stretching, foam rolling, and vibrating foam rolling are therapeutic interventions that have been researched (Howatson & van Someren, 2008; Lund et al., 1998; Nakamura et al., 2021; Romero-Moraleda et al., 2019). Meanwhile, non-steroidal anti-inflammatory drugs (NSAIDs) are an example of a pharmacological intervention used to treat muscle damage (Beck et al., 2007; Howatson & van Someren, 2008). impairs the formation of prostaglandin (Howatson & van Someren, 2008; Schoenfeld, 2012).

Nutritional interventions are an alternative to therapeutic and pharmacological interventions (Beck et al., 2007; Howatson & van Someren, 2008). Exercise can cause oxidative stress, which occurs when there is an imbalance between reactive oxygen species (ROS) production and antioxidant defenses (Martinez-Ferran et al., 2020). The oxidation of the ion transport systems, disruption of calcium ion (Ca$^2+$) homeostasis, impaired mitochondrial respiratory control, distortions in signal transduction pathways, and cell dysfunction are consequences that may arise with ROS production and may lead to muscle damage following vigorous exercise (Mastaloudis et al., 2006). Thus, antioxidant supplementation has gained popularity for its proposed ability to inhibit ROS production and reduce muscle damage following intense exercise (Bell et al., 2015; Howatson & van Someren, 2008). More specifically, vitamin C, vitamin E, pomegranates, and tart cherries have been studied as potential dietary supplements to aid recovery (Lamb et al., 2019; Martinez-Ferran et al.,
For example, Lamb et al. (2019) compared the effects of pomegranate juice and tart cherry juice following eccentric exercise of the elbow flexors and observed no accelerated recovery as measured via maximal voluntary isometric contractions (MVC), DOMS, ROM, and creatine kinase (CK) in non-resistance-trained men. Tart cherries, similar to pomegranates, are dietary supplements of interest since they are polyphenol-rich foods that may promote recovery from EIMD with their antioxidant and anti-inflammatory properties (Lamb et al., 2019). Flavonoids are a subclass of polyphenols while anthocyanins are a subclass of flavonoids that have garnered the most interest in research (Carey et al., 2021). Specifically, the properties of anthocyanins are understood to increase the expression of endogenous antioxidant enzymes while scavenging ROS and limiting their production (Quinlan & Hill, 2020). The mode of exercise is a factor that influences the efficacy of tart cherry supplementation on symptoms of EIMD (Hill et al., 2021). Studies focusing on recovery following participation in team sports have equivocal results (Abbott et al., 2020; McCormick et al., 2016; Quinlan & Hill, 2020). Abbott et al. (2020) and McCormick et al. (2016) did not observe accelerated recovery with tart cherry juice supplementation among professional male soccer players and male water polo players. Conversely, Quinlan & Hill (2020) had results showing that tart cherry juice supplementation did aid recovery after intermittent exercise among male and female team sport players. Tart cherry juice has also been found to reduce muscle pain, improve muscle function, and decrease symptoms of muscle damage after repeated sprints, marathon running, and long-distance running (Brown et al., 2019; Howatson et al., 2010; Kuehl et al., 2010). In addition, supplementing with 30 milliliters (mL) of Montmorency tart cherry concentrate twice a day attenuated oxidative stress and the inflammatory response, lowered blood pressure and improved end-sprint performance after cycling exercises (Bell et al., 2014; Bell et al., 2015; Keane et al., 2018).

Mixed results have been produced in research assessing the efficacy of tart cherry supplementation on recovery following plyometric exercise and resistance training (Beals et al., 2017; Bell et al., 2016; Bowtell et al., 2011; Connolly et al., 2006; Hillman et al., 2017; Hooper et al., 2021;
Lamb et al., 2019; Levers et al., 2015). Hillman et al. (2017) reported no significant differences in signs and symptoms of EIMD (i.e., CK levels, lactate dehydrogenase [LDH] levels and muscle soreness) but did observe significantly higher oxygen radical absorbance capacity (ORAC) values when supplementing with tart cherry and whey protein versus a placebo after plyometric exercise. Connolly et al. (2006) found that male college students supplementing with 12 oz of a cherry juice blend twice a day had significantly lower isometric elbow flexion strength loss and significantly different pain development in the elbow flexors following eccentric exercise compared to a placebo. In contrast, Lamb et al. (2019) found that non-resistance trained males supplementing with 250 mL of tart cherry juice twice a day did not exhibit accelerated recovery as measured by MVC, DOMS, ROM, and CK. Both 500 mg of Tart cherry extract supplementation and 480 mg of Montmorency tart cherry powder supplementation have been found to attenuate loss in performance markers and reduce oxidative stress among resistance trained males (Hooper et al., 2021; Levers et al., 2016). Two studies have examined the effects of tart cherry following eccentric training of knee extension muscles (Beals et al., 2017; Bowtell et al., 2011). Beals et al. (2017) found that a tart cherry beverage containing 733 mg of phenolic compounds ingested for 12 days may not reduce the pain and muscle tenderness associated with DOMS following a knee extension eccentric training protocol on a Biodex Multi Joint System among resistance trained men aged 18-50 years old. Bowtell et al. (2011) had well-trained males between the ages of 25-29 years of age supplement with 30 mL of cherry juice concentrate for 10 days and observed improved recovery of isometric knee extension muscle strength. Interestingly, most of the research to-date has used men or mixed-sex populations and there is very limited research investigating women populations exclusively (Brown et al., 2019).

Tart cherry supplementation in powdered form and the effects on performance and recovery, specifically isokinetic muscle peak torque, peak power, total work, time to peak torque, mean power, muscle soreness, and muscle activation, at velocities of 60°·s⁻¹, 180°·s⁻¹, and 300°·s⁻¹ among recreationally active college-aged women, have not been researched. Therefore, the purpose of this study is to investigate the effects of a tart cherry supplement on exercise-induced muscle damage for
improving recovery measured via isokinetic muscle peak torque, isokinetic muscle work, isokinetic muscle peak power, isokinetic mean power, muscle soreness and muscle activation.

**Hypothesis**

It is hypothesized that the tart cherry supplementation will improve recovery following an intense bout of resistance exercise measured via attenuated losses in isokinetic muscle peak torque, peak power, total work, time to peak torque, mean power, and muscle activation. It is also hypothesized that tart cherry supplementation will attenuate muscle soreness.

**Assumptions**

1. All participants will be under the assumption that they meet the inclusion criteria.
2. All participants will be assumed to be free from an injury or functional limitations that would prevent them from properly completing or participating in the testing procedures.
3. Participants will be assumed to have given maximal effort during the eccentric overload and muscle function test during each trial and for each session.
4. Participants will be assumed to have abstained from strenuous exercise prior to a testing session.
5. Participants will be assumed to have abstained from use of any nutritional supplements or NSAIDs for one month prior to the onset of the study and during the study.

**Delimitations**

1. Participants will be limited to recreationally active women of collegiate age.
2. Participants will be limited to those that completed the informed consent previously approved by California State University, Fullerton’s Institutional Review Board.
3. Participants will be limited to a 2-week washout period.
4. Participants will be limited to an 8-day supplementation period of both tart cherry and a placebo.
Exercise-induced muscle damage (EIMD) occurs following a novel, intense bout of unaccustomed exercise, especially exercise involving eccentric contractions (Hillman et al., 2017; Howatson & van Someren, 2008). Eccentric contractions occur when an external force greater than that of the contracting muscle causes the muscle to lengthen because of the increased tension (Hillman et al., 2017; Howatson & van Someren, 2008). Eccentric work has a lower metabolic cost and lower motor unit activation than concentric or isometric work, however that lower motor unit activation for the same force places greater mechanical stress on fewer muscle fibers (Howatson & van Someren, 2008; Owens et al., 2019). As a result, eccentric contractions lead to ultrastructural muscular disruptions, DOMS, elevated intramuscular protein circulation, limb swelling, reduced ROM, and weakened muscle force producing capacity (Owens et al., 2019). The development of EIMD is not completely understood, but a simplified two-phase process has been proposed to explain the mechanisms associated with EIMD (Lamb et al., 2019; Owens et al., 2019). The initial phase of the muscle damage process is believed to occur as a direct outcome of eccentric exercise while the secondary phase is believed to occur due to the disruption of intracellular Ca^{2+} homeostasis (Howatson & van Someren, 2008).

The initial development phase of EIMD, or primary muscle damage, corresponds with the structural disruption to sarcomeres and failure of the excitation-coupling process caused by the mechanical loading of the muscle (Lamb et al., 2019; Owens et al., 2019). During eccentric contractions, the mechanical loading on the sarcomeres is non-uniform, which means only some of the myofilaments are being stretched beyond the point of overlap (Howatson & van Someren, 2008). It has been suggested that the longest sarcomeres will be weakest and stretched more rapidly than others (Morgan & Proske, 2004). Once myofilaments within a sarcomere are stretched beyond the point of overlap, there’s an increase of tension on passive structures and sarcomeres experience
“popping” (Morgan & Proske, 2004; Owens et al., 2019). Popping results in the deformation of non-contractile proteins, shearing of myofibrils, Z-band streaming, and exposes T-tubules to large deformations (Howatson & van Someren, 2008; Morgan & Proske, 2004; Owens et al., 2019). Repeated eccentric contractions increase the number of disrupted sarcomeres until membrane damage occurs, leading to a loss of Ca$^{2+}$ homeostasis and failure of the excitation-coupling process becomes evident (Morgan & Proske, 2004; Proske & Morgan, 2001).

The secondary development phase of EIMD, or secondary muscle damage, arises after the initial phase as calcium ions enter the cytoplasm uncontrollably and disrupt intracellular Ca$^{2+}$ homeostasis (Howatson & van Someren, 2008; Owens et al., 2019). Changes in the sarcoplasmic reticulum is one explanation for the cause of Ca$^{2+}$ homeostasis disruptions with lengthening contractions (Howatson & van Someren, 2008; Nielsen et al., 2005). Consequently, the increase in intracellular Ca$^{2+}$ triggers proteolytic and phospholipase A2 pathways that degrade structural proteins, and the mitochondria must uptake additional Ca$^{2+}$ to maintain homeostasis (Howatson & van Someren, 2008; Owens et al., 2019). Excessive accumulation of Ca$^{2+}$ in the mitochondria can lead to structural damage of the mitochondria, cell membrane, and sarcolemma, cell infiltration and subsequent activation, production of ROS, fiber necrosis, fiber apoptosis, and fiber regeneration (Carey et al., 2021; Gissel & Clausen, 2001; Howatson & van Someren, 2008; Owens et al., 2019). In addition, leakage of ROS from the mitochondria is a source of oxidative stress (Mastaloudis et al., 2006). Secondary muscle damage is also characterized by the initiation of an inflammatory response due to apoptosis (Carey et al., 2021; Lamb et al., 2019). The inflammatory cascade is vital for clearing damaged tissue and initiating tissue repair; however, it results in the formation of ROS and further damage of proteins (Carey et al., 2021; Owens et al., 2019). DOMS, reduced ROM, and loss of strength arise with substantial interference of the excitation-contraction coupling (Carey et al., 2021).
Delayed Onset Muscle Soreness (DOMS)

DOMS, a notable indirect measure of EIMD, is experienced by individuals of all training levels (Cheung et al., 2003; Nogueira et al., 2019; Yu, 2003) and has a negative impact on exercise performance (Ortega et al., 2021). Eccentric contractions, rather than isometric or concentric contractions, produce higher levels of tension on muscle fibers and connective tissue, which leads to ultrastructural changes (Yu, 2003; Yu et al., 2004). Common symptoms associated with DOMS, including increased muscle soreness, reduced muscle strength, and decreased range of motion, begin 6-12 h post-exercise and peak at 48-72 h (Heiss et al., 2018). Exercise duration, exercise intensity, and the physiologic condition of the individual all play a role on the extent of DOMS (Cleary et al., 2006). The lactic acid theory, the muscle spasm theory, the connective tissue damage theory, the muscle damage theory, the inflammation theory, and the enzyme efflux theory have all been proposed to explain the pain stimulus associated with DOMS, but researchers agree that one theory alone cannot completely explain DOMS (Cheung et al., 2003). One proposed integration model for DOMS begins with high tensile forces from eccentric exercise damaging connective tissue and muscle tissue and is followed by the disruption of calcium homeostasis, elevation of circulating neutrophils, increased intracellular components, cellular necrosis, and activation of nociceptors (Cheung et al., 2003). While myofibrillar necrosis was included in the previous integration model, research by Yu (2003) suggests that Z-disc alterations associated with DOMS lead to myofibrillar remodeling and sarcomerogenesis, not myofibrillar necrosis. The evidence for myofibrillar remodeling and sarcomerogenesis helps explain why a second bout of similar eccentric exercise results in less soreness and damage, also known as the “second bout effect” (Morgan & Proske, 2004; Yu, 2003). Regardless, DOMS is a common and recurrent exercise-induced phenomenon and researchers have investigated various interventions to alleviate symptoms, restore muscle function, and limit the extent of the initial injury (Cheung et al., 2003). More specifically, therapeutic, pharmacological, and nutritional interventions for recovery have been investigated (Beck et al., 2007).
**Therapeutic Interventions**

Therapeutic interventions, such as stretching and massage, have been proposed for DOMS (Beck et al., 2007). Studies investigating passive stretching as a recovery tool following eccentric training have shown no difference in DOMS or muscle strength (Howatson & van Someren, 2008; Lund et al., 1998). Furthermore, it is proposed that massage may have a more psychological effect rather than a physiological effect on symptoms of DOMS (Beck et al., 2007). Additionally, vibrating foam rolling and non-vibrating foam rolling are two other therapeutic interventions that have been investigated (Nakamura et al., 2021; Romero-Moraleda et al., 2019). For instance, a 90 second (s) foam rolling intervention on the quadriceps after 6 sets of 10 knee extension repetitions on a dynamometer set at an angular velocity of $60^\circ \cdot s^{-1}$ has shown that foam rolling may help recover muscle strength loss, DOMS, and knee flexion ROM (Nakamura et al., 2021). Another study using a 300 s vibrating foam rolling (VFR) and non-vibrating foam rolling intervention (NVFR) on the quadriceps following 10 sets of 10 repetitions of parallel squats performed on an inertial flywheel device found that VFR produced better results in passive visual analog scale (VAS) perceived pain and passive hip joint extension ROM compared to the NVFR (Romero-Moraleda et al., 2019). In addition, the VFR and NVFR groups were both found to achieve similar results in pressure pain threshold, muscle oxygen saturation, countermovement jump, active hip extension ROM and active knee flexion ROM (Romero-Moraleda et al., 2019).

**Pharmacological Interventions**

Pharmacological interventions using nonsteroidal anti-inflammatory drugs (NSAIDs) have also been proposed and are one of the most widely known treatments of muscle damage to restore normal physical function (Beck et al., 2007; Howatson & van Someren, 2008; Schoenfeld, 2012). NSAIDs have been found to inhibit the metabolism of arachidonic acid through the cyclo-oxygenase (COX) pathway, which then impairs the formation of prostaglandin (Howatson & van Someren, 2008; Schoenfeld, 2012). Prostaglandins are lipids derived from arachidonic acid that play a key role in the creation of the inflammatory response (Ricciotti & FitzGerald, 2011). Cyclooxygenase-1 (COX-1)
activity subserves housekeeping functions while cyclooxygenase-2 (COX-2) activity is an important source of inflammation formation (Ricciotti & FitzGerald, 2011) To investigate the potential benefits of NSAIDs, Donnelly et al., (1990) had 40 untrained males consume 1,200 mg of ibuprofen or a placebo before completing two bouts of downhill running and then one 600 mg tablet every 6 h up to 72 h following the exercise bouts and found that dosage to be ineffective in reducing DOMS. A second study examined the effects of either 4,000 mg of acetaminophen, 1,200 mg of ibuprofen, or a placebo following 10 to 14 sets of 10 isotonic knee extension repetitions on a muscle dynamometer (Peterson et al., 2003). Peterson et al. (2003) found that neither ibuprofen nor acetaminophen influenced muscle inflammatory cell concentrations, muscle soreness, blood CK activity, and muscle prostaglandin E₂, however protein synthesis and prostaglandin F₂α were reduced. Overall, there’s equivocal evidence pertaining to the efficacy of NSAIDs to prevent or reduce symptoms of EIMD (Howatson & van Someren, 2008).

**Nutritional Interventions**

Since unaccustomed eccentric EIMD elicits an inflammatory response and increased ROS production, dietary antioxidants have been suggested to reduce ROS production, EIMD, and muscle soreness (Howatson & van Someren, 2008). Antioxidants are any substance that delays or prevents the oxidation of a substrate (Powers et al., 2011). Vitamins C (ascorbic acid) and E (tocopherol) have reported antioxidant properties that have been researched (Howatson & van Someren, 2008). One study by Shafat et al. (2004) had 12 male participants supplement with either 500 mg of vitamin C or 1200 IU vitamin E for 30 days before undergoing an eccentric muscle damage protocol consisting of 30 sets of 10 eccentric knee extension repetitions at a velocity of 0.52 rad·s⁻¹. This study found that the vitamin C and E group had a significantly lower decline in concentric peak torque, a significantly lower decline, a significantly lower reduction in maximal isometric force of the knee extensors, and a significant protection against decline in low frequency fatigue up to 2 days after the eccentric muscle contraction protocol (Shafat et al., 2004). The synergistic effects of vitamin C and vitamin E supplementation have also been studied (Martinez-Ferran et al., 2020). In the study, Mastaloudis et
al. (2006) found that vitamin C and vitamin E supplementation had no effect on plasma muscle damage markers, muscle torque production, or power deficits following a 50 (kilometer) km ultramarathon. Recently, research has focused on nutritional interventions with high concentrations of phenolic compounds (Ortega et al., 2021). Pomegranate and tart cherries are polyphenol-rich foods that have demonstrated the most potential for improving recovery from EIMD (Lamb et al., 2019). Connolly et al. (2006) was the first to report that tart cherry supplementation reduced post-exercise muscle soreness and loss of isometric strength following maximal eccentric contractions of the elbow flexors among untrained young men. Furthermore, Trombold et al. (2011) investigated the effects of pomegranate juice after a bout of eccentric elbow flexor and knee extensor exercises among resistance trained males and found that the supplementation diminished the loss in isometric strength and the rating of muscle soreness in the elbow flexors. However, there were no significant differences between knee extensor isometric strength and muscle soreness between the pomegranate juice group and the control group (Trombold et al., 2011). An overwhelming majority of the studies investigating the effects of polyphenol supplementation resulted in enhanced recovery of performance (Hooper et al., 2021)

**Polyphenols**

Polyphenols, a plant compound found in low concentrations in human blood but naturally high in fruits and vegetables, are another dietary supplement with antioxidant and anti-inflammatory properties that have garnered attention for their potential to enhance recovery from EIMD (Hooper et al., 2021; Lamb et al., 2019; Owens et al., 2019). As previously stated, increased ROS production is a characteristic of secondary muscle damage (Howatson & van Someren, 2008). ROS refers to oxygen centered free radicals and non-radical but reactive derivates of oxygen (Powers et al., 2011). Free radicals are molecules containing one or more unpaired electrons that make them unstable and reactive (Powers et al., 2011). Nitric oxide, superoxide, hydrogen peroxide and hydroxyl radicals are four specific ROS produced by contracting muscles (Brooks et al., 2008). ROS production, especially nitric oxide production, affects calcium regulation, myofilament function, and muscle force production
by lowering ATP production (Powers et al., 2011). While ROS can have a positive impact on muscle force production, elevated ROS levels decrease force production, therefore research has examined the role of antioxidant supplementation in delaying muscle fatigue during exercise (Powers et al., 2011). Polyphenols are radical scavengers that can donate an electron to stabilize free radicals (Bowtell & Kelly, 2019). Flavonoids, one of the four main families of polyphenols, and anthocyanins, a sub-class of flavonoids, have been the focus of research on polyphenols in performance and recovery (Bowtell & Kelly, 2019; Carey et al., 2021).

The high levels of anthocyanins and flavonoids with antioxidant and anti-inflammatory properties in tart cherries are prosed to scavenge ROS, limit ROS production, and increase expression of endogenous antioxidant enzymes (Quinlan & Hill, 2020). Muscle damaging exercise has been found to increase oxidative stress and inflammation and increase the sensitivity of nociceptors and mechanoreceptors to noxious chemicals, such as prostaglandins (Hill et al., 2021). Tart cherry supplementation may attenuate the inflammatory response associated with secondary muscle damage and improve recovery by reducing COX-1, COX-2, and phospholipase A2 enzyme activity which decreases the cyclooxygenase, prostaglandin and interleukin 6 pathway as well as the proteolytic and lipolytic response (Hill et al., 2021; Quinlan & Hill, 2020). Most of the research examining tart cherry supplementation has shown a reduction in inflammation and oxidative stress following endurance exercise; however, the efficacy of tart cherry supplementation on recovery following resistance, which primarily induces mechanical stress, have reported conflicting results (Hill et al., 2021).

**Tart Cherry and Sport Performance**

Studies have been conducted to examine the potential benefits those participating in sports could derive from tart cherry supplementation (McCormick et al., 2016). To illustrate, Abbott et al. (2020) recently studied the effects of tart cherry juice on recovery from a soccer match in professional male players. Twelve participants consumed 2 x 30 mL tart cherry juice gel servings, which had an equivalent of 100 sour cherries, 90-minutes before the match and 12 and 36 h after the match (Abbott
et al., 2020). The aim of this study was to investigate the effects of acute tart cherry juice after a real-world bout of an intermittent team sport activity (Abbott et al., 2020). Recovery was measured via muscle function (i.e., CMJ and reactive strength index[RSI]), muscle soreness, and subjective well-being (Abbott et al., 2020). All four measures demonstrated time effects following the soccer matches, with losses in CMJ and RSI peaking 12 h post-match and muscle soreness peaking at 12 h post-match (Abbott et al., 2020). Subjective well-being increased post-match for both the intervention and control group (Abbott et al., 2020). No group differences were observed for CMJ, muscle soreness, or subjective well-being (Abbott et al., 2020). Altogether, tart cherry juice was not found to speed the recovery after a professional soccer match (Abbott et al., 2020).

Another study by Bell et al., (2016) examined the effects of 2 x 30 mL of Montmorency tart cherry concentrate on recovery following prolonged, intermittent exercise among sixteen semi-professional male soccer players. Participants supplemented for 8 total days and performed an adapted version of the Loughborough Intermittent Shuttle Test (LIST ADAPT) on the fifth day (Bell et al., 2016). MVIC, 20 m sprint, CMJ, agility, and DOMS were measured 24, 48, and 72 h after the exercise bout as part of the functional performance test (Bell et al., 2016). Interleukin-1-beta (IL-1-β), interleukin-6 (IL-6), interleukin-8 (IL-8), tumour necrosis factor-alpha (TNF-α), and high-sensitivity C-reactive protein (hsCRP) were measures of inflammation, CK was the measure for muscle damage, and lipid hydroperoxides (LOOH) was the measure for oxidative stress (Bell et al., 2016). MVIC and CMJ both showed significant time, group, and interaction effects with MVIC scores being 19% higher in the tart cherry group at 48 h compared to the placebo group (Bell et al., 2016). The CMJ results in this study differ from those found by Abbott et al. (2020) who failed to observe significant group differences post-exercise bout. The tart cherry group also had an average 3% faster times on the 5-0-5 agility test across all post-testing time periods and 4% faster 20 m sprint times at 48 h (Bell et al., 2016). DOMS increased for both groups post-exercise; however, the tart cherry group had lower DOMS ratings as evidenced by significant group and interaction effects. IL-6 was the only inflammatory response marker to be significantly attenuated in the tart cherry group with significant
interaction effects (Bell et al., 2016). The other inflammatory response markers significantly increased post-exercise, but neither significant group nor interaction effects were found (Bell et al., 2016). CK and LOOH both significantly increased post-exercise as well however no significant group or interaction effects were observed (Bell et al., 2016). Tart cherry supplementation appeared to improve recovery after a prolonged, repeat sprint activity in semi-professional athletes, but unlike Abbott et al. (2020), the athletes were not tested in a real-world game activity (Bell et al., 2016).

Quinlan & Hill (2020) used similar performance measures as Bell et al. (2016) to assess the efficacy of tart cherry juice on recovery among male and female team sport players who completed the LIST ADAPT. Twenty participants consumed 2 x 30 mL servings of Montmorency tart cherry concentrate for 8 days with the sixth day assigned for the intermittent exercise protocol (Quinlan & Hill, 2020). CMJ, 20 m sprint, and MVIC had significant time, group, and interaction effects (Quinlan & Hill, 2020). The tart cherry group CMJ returned to baseline significantly faster than the placebo group at 24 h and 48 h post-exercise (Quinlan & Hill, 2020). In the 20 m sprint, the tart cherry group had sprint times 1.95% and 0.31% slower at 24 and 48 h while the placebo group sprint times were 5.94% and 3.84% slower at 24 and 48 h (Quinlan & Hill, 2020). The loss of speed was significantly lower among the tart cherry group at both time periods (Quinlan & Hill, 2020). Furthermore, both groups experienced decrements in MVIC 1 h post-LIST, but the tart cherry group had a significantly lower decrease in MVIC at 24 and 48 h (Quinlan & Hill, 2020). Both groups had significantly higher DOMS ratings at all time points with no observed significant differences between groups (Quinlan & Hill, 2020). Quinlan & Hill (2020) indicated that there were significant group and interaction effects on DOMS, but it could not be identified using post hoc analysis. CK was found to be significantly higher than pre-supplementation and pre-LIST levels in both groups across all time points without any group or interaction effects present (Quinlan & Hill, 2020). Lastly, C-reactive protein (CRP) had no significant time, group, or interaction effect (Quinlan & Hill, 2020). Quinlan & Hill (2020) and Bell et al. (2016) both found that tart cherry supplementation aided recovery when participants performed the LIST ADAPT as the fatiguing exercise protocol and not an actual or simulated team sport game activity.
Quinlan & Hill (2020) did include females in their study while the first two studies discussed only had male subjects (Abbott et al., 2020; Bell et al., 2016).

The effects of tart cherry juice on recovery and next day performance following a simulated water polo game was also researched (McCormick et al., 2016). In this study, well-trained water polo players were asked to consume 90 mL of tart Montmorency cherry juice for 6 days (McCormick et al., 2016). The fatiguing simulated game took place on day 6 and recovery and performance measures were tested on day 1, pre-exercise day 6, post-exercise day 6, and day 7 (McCormick et al., 2016). Vertical jump (VJ), the Water Polo Intermittent Shuttle Test (WIST), repeat sprint test (RST), 10 m sprint, total quality of recovery (TQR), DOMS, and blood marker measures were tested (McCormick et al., 2016). VJ, WIST, RST, and 10 m sprint had no significant condition, time, or interaction effects (McCormick et al., 2016). Regarding the blood variables measured, IL-6 had a significant time effect with levels significantly higher on day 6 post-exercise compared to day 6 pre-exercise or day 7 post-exercise (McCormick et al., 2016). CRP levels were found to be significantly higher on day 7 compared to day 6 pre- and post-exercise indicating a significant time effect (McCormick et al., 2016). F2-isoprostanates (F2-IsoP) also had a significant time effect with scores significantly lower on day 7 compared to day 6 measures (McCormick et al., 2016). There were no condition or interaction effects for IL-6, CRP, or F2-IsoP (McCormick et al., 2016). Uric acid (UA), a fourth blood marker, had no significant condition, time, or interaction effects (McCormick et al., 2016). There were no condition, time, or interaction effects observed for ratings of DOMS or TQR (McCormick et al., 2016). In summary, McCormick et al. (2016) concluded that the demands imposed by the simulated water polo game may not have produced a significant inflammatory response or sufficient oxidative stress to deteriorate performance, therefore potential benefits from tart cherry supplementation were failed to be found. Research surrounding tart cherry and sport performance have garnered mixed results even though they used similar dosages (Abbott et al., 2020; Bell et al., 2016; McCormick et al., 2016; Quinlan & Hill, 2020).
Tart Cherry and Running

Long distance running activities tend to produce muscle damage, inflammation, and oxidative stress (Howatson et al., 2010). Research has been conducted on tart cherry supplementation as a potential nutritional intervention to help improve pain, muscle function, inflammation, and oxidative stress after exhaustive running activities (Brown et al., 2019). For example, Howatson et al. (2010) studied the effects supplementing with two 8 fluid ounce (fl oz) bottles of tart cherry juice for 8 days would have on recovery. Male and female participants ran a marathon on day 5 of supplementation with recovery and performance markers measured 6 days before the marathon, immediately after the marathon, and at 24 and 48 h post-marathon (Howatson et al., 2010). Serum CK, LDH, DOMS, MVIC, CRP, IL-6, UA, total antioxidant status (TAS), thiobarbituric acid reactive species (TBARS), and protein peroxidation, the measured blood markers, all demonstrated a significant time effect (Howatson et al., 2010). MVIC was the only muscle damage marker with a significant group effect indicating that the tart cherry group experienced a more significantly rapid recovery of strength through the 48 h post-marathon (Howatson et al., 2010). Serum IL-6, serum CRP, and serum UA were each found to have significant group and group by time interaction effects with the tart cherry group having significantly smaller elevations in IL-6 and CRP and no increase in UA post-marathon (Howatson et al., 2010). TAS was significantly higher in the tart cherry group both pre-marathon and post-marathon when compared to the placebo group (Howatson et al., 2010). The placebo group had significantly higher TBARS scores than the tart cherry juice group at 48 h post-marathon however there were no group differences in the protein carbonyls (PC) scores (Howatson et al., 2010). Howatson et al. (2010) concluded that tart cherry juice supplementation improved recovery following a marathon by improving antioxidative capacity, lipid peroxidation, and inflammation.

Kuehl et al. (2010) examined the effects of tart cherry juice in reducing muscle pain after long distance running by assessing muscle soreness using a VAS and participant satisfaction. Healthy male and female runners supplemented with two bottles of 355 mL of either tart cherry juice or a placebo 7 days before the running activity and on the day of the running activity (Kuehl et al., 2010).
Kuehl et al. (2010) found significant main effects of drink, time, and interaction. There were no differences in mean VAS scores pre-race between the groups and while both groups reported higher VAS scores post-exercise, the cherry juice group had significantly lower increases in muscle soreness (Kuehl et al., 2010). The participants assigned to the cherry juice group also reported significantly higher participant satisfaction than the placebo group (Kuehl et al., 2010). The findings of this study indicate that tart cherry juice supplementation may aid recovery but the authors did mention that the subjective nature of assessments used are a limitation (Kuehl et al., 2010).

Instead of using longer distance running, Brown et al. (2019) used a repeated-sprint protocol with healthy university-aged females to investigate whether Montmorency tart cherry supplementation could aid recovery. Studies with females and tart cherry supplementation are limited because oestrogen may influence outcome variables (Brown et al., 2019). As a result, participants in this study had data collection completed during the early to mid-luteal phase of their menstrual cycle or 14 days before a withdrawal bleed (Brown et al., 2019). Participants were asked to supplement with 2 x 30 mL of cherry concentrate or with a placebo for 8 days (Brown et al., 2019). This study had participants supplement for 4 days before the repeated-sprint protocol (Brown et al., 2019). Indices of muscle damage and inflammation were measured pre-, immediately post- (0 h), and 24, 48, and 72 h post-exercise (Brown et al., 2019). Both groups reported higher levels of DOMS post-exercise, but the Montmorency cherry group was found to have a trend and moderate effect for lower DOMS (Brown et al., 2019). The Montmorency cherry group also reported a trend and moderate effect for higher pain pressure threshold (PPT) at the rectus femoris when compared to the placebo group and there were no group differences in PPT at the vastus lateralis and gastrocnemius (Brown et al., 2019). There were no group differences in thigh and calf girth as well as flexibility post-exercise (Brown et al., 2019). Out of the four muscle function measures assessed (CMJ, RSI, MVIC, and 30 m sprint time), only CMJ had an observed group effect (Brown et al., 2019). Total CK increased in both groups while hsCRP levels remained unaffected post-exercise, yet no group differences were observed in either marker (Brown et al., 2019). Overall, Brown et al. (2019) had data demonstrating that tart cherry juice
supplementation can be a nutritional intervention following repeated-sprint protocol, not just longer
distance running, in females.

**Tart Cherry and Cycling**

Exercise completed using cycle ergometry has a low eccentric component and leads to stress
mainly through metabolic pathways (Bell et al., 2014). Research on the impact of tart cherry
supplementation on metabolically induced stress from repeated days of high-intensity stochastic
cycling was completed by Bell et al. (2014). Well-trained male cyclists supplemented with 30 mL of
either Montmorency cherry or a placebo for 4 days pre-exercise and during each trial day (Bell et al.,
2014). LOOH were measured to assess oxidative stress (Bell et al., 2014). LOOH had significant
time, group, and interaction effects with the Montmorency cherry group demonstrating 29.8%
significantly lower LOOH after trial 3 (Bell et al., 2014). TNF-α, IL-1-β, IL-6, IL-8, and hsCRP were
measured indices of inflammation (Bell et al., 2014). IL-6 and hsCRP both had significant time, group,
and interaction effects (Bell et al., 2014). IL-6 was significantly lower in the Montmorency cherry
group following trials 2 and 3 while hsCRP was significantly lower in the Montmorency cherry group
across all three trials (Bell et al., 2014). There were no group differences found between IL-1-β or
TNF- α and only a main effect of time was found for IL-8 (Bell et al., 2014). Muscle damage was
measured via serum CK (Bell et al., 2016). A significant main effect for time was found for serum CK,
but there were no group differences (Bell et al., 2014). Thus, Bell et al. (2014) suggested that
Montmorency cherry may attenuate oxidative stress and inflammatory response following repeated
days of stochastic cycling.

A similar study was conducted by Bell et al. (2015), but a 109-minute cycle trial was used as
the fatiguing protocol instead of using a repeated-days of high-intensity stochastic cycling protocol.
The primary purpose of this study was to determine the effect of 2 x 30 mL Montmorency cherry
supplementation for 8 days on muscle function in trained male cyclists (Bell et al., 2015). Muscle
function indices were measured pre-trial, immediately post-trial, and 1, 3, 5, 24, 48, and 72 h post-trial
(Bell et al., 2015). MVIC values among the Montmorency cherry group were attenuated and did not
fall below baseline levels, indicating a significant group effect when compared to the placebo group (Bell et al., 2015). Cycling efficiency was significantly 4% lower in the Montmorency cherry group at the 24 h time period (Bell et al., 2015). There were no group or interaction effects for 6-s sprint time, but there was a significant effect for time (Bell et al., 2015). IL-6 demonstrated a significant group effect with the IL-6 response significantly reduced in the Montmorency cherry group throughout all time periods (Bell et al., 2015). There were significant differences in hsCRP between the groups, specifically at 24 h post-trial (Bell et al., 2015). IL-8, TNF-α, CK, and LOOH demonstrated main effects for time but no group or interaction effects (Bell et al., 2015). IL-1-β was the only marker that had no observable effects for group, time, or interaction (Bell et al., 2015). No significant group differences in total work done were found (Bell et al., 2015). As such, Bell et al. (2015) concluded that Montmorency cherries could improve recovery and reduce exercise-induced inflammation.

Keane et al., (2018) also performed a study on trained male cyclists and used moderate- and severe-intensity cycling bouts as the exercise tests. In this study, 60 mL of Montmorency cherry concentrate was ingested 90 minutes before each cycling bout (Kuehl et al., 2010). No significant differences were observed in blood lactate, oxygen consumption (VO₂), tissue oxygenation, plasma nitrate concentrations or time to exhaustion between the Montmorency cherry group and the placebo group (Keane et al., 2018). The Montmorency cherry group did demonstrate a 9.5% increase in peak power output and 10% increase in total work during a 60 s all-out sprint test following the 6-minute severe-intensity bout, indicating a significant main effect for supplement (Keane et al., 2018). Systolic blood pressure (SBP) was significantly lower 1.5 h after Montmorency cherry supplementation, however there were no group differences in diastolic blood pressure (DBP), mean arterial pressure (MAP), pulse wave velocity (PWV), augmentation index (AIx), and AIx corrected for heart rate (HR) at 75 bpm (Keane et al., 2018). This study demonstrates that Montmorency cherry supplementation may improve some aspects of performance, but not all (Keane et al., 2018). Additionally, Keane et al. (2018) did highlight that the improvement in end-sprint performance observed could be an advantage in sporting scenarios.
Tart Cherry and Plyometric Exercise

Plyometric exercise in training programs may lead to musculoskeletal pain, a common symptom of EIMD, and increase dropout rates among those who view it as a barrier to exercise (Hillman et al., 2017). Consequently, Hillman et al. (2017) had healthy males and females between the ages of 18-28 years of age supplement with two bottles of 240 mL of tart cherry with whey protein or a placebo for 10 days. Participants started supplementing 6 days before completing the 5 sets of 20 repetitions of drop jumps (DJ) (Hillman et al., 2017). The signs and symptoms of EIMD used to assess recovery included muscle soreness using VAS, ROM of the knee, CMJ, thigh circumference, and thigh temperature (Hillman et al., 2017). Data collected showed no group differences in muscle soreness, ROM, thigh temperature, thigh circumference, or CMJ (Hillman et al., 2017). Muscle soreness, thigh temperature, and thigh circumference did significantly increase over time in both groups, indicating that the plyometric exercise protocol did produce EIMD (Hillman et al., 2017). Blood samplings were taken to measure myeloperoxidase (MPO), ORAC, CK, and LDH (Hillman et al., 2017). MPO, CK, and LDH significantly increased by 85%, 45%, and 10%, respectively, in the tart cherry with whey protein group, however no group differences were observed (Hillman et al., 2017). ORAC significantly increased for both groups, but it was significantly higher by an average 67% in the tart cherry with whey protein group (Hillman et al., 2017). Hillman et al. (2017) determined that training programs incorporating plyometric exercise can produce mild signs and symptoms of EIMD and tart cherry juice with whey protein could increase ORAC and reduce muscle soreness measured via VAS. A limitation to this study was that the tart cherry juice was combined with whey protein, so research using only tart cherry juice on plyometric exercise is lacking (Hillman et al., 2017).

Tart Cherry and Resistance Exercise

Resistance training can be a powerful driver of strength and hypertrophy gains, but it can also cause substantial amounts of muscle damage, oxidative stress, and inflammation as well as acute losses in performance that left untreated could lead to overtraining (Hooper et al., 2021; Levers et al., 2015). Tart cherry, a polyphenol-rich food source, has become popular in exercise-based research as
a potential mediator for signs and symptoms of EIMD, oxidative stress, and inflammation (Hooper et al., 2021; Lamb et al., 2019; Levers et al., 2015). For example, Connolly et al. (2006) had male college students supplement with two 12 fl oz bottles containing 600 mg of phenolic compounds and 40 mg of anthocyanins for 8 days. The participants performed 2 x 20 eccentric elbow flexion contractions on a modified preacher curl apparatus on the fourth day of supplementation (Connolly et al., 2006). Tart cherry supplementation led to significantly lower pain values than the placebo as pain peaked at 24 h following tart cherry supplementation while peaking at 48 h following the placebo (Connolly et al., 2006). Isometric elbow flexion strength loss was also significantly greater with the placebo than with tart cherry supplementation (Connolly et al., 2006). The strength loss between the placebo and the tart cherry trials were all significantly different with the placebo resulting in greater strength loss (Connolly et al., 2006). There were no group differences in loss of range of motion with the elbow relaxed or muscle tenderness, so it was proposed that those measures may be insensitive to differences or represent other components of muscle damage (Connolly et al., 2006). Overall, Connolly et al. (2006) was the first study to find that tart cherry may attenuate the signs and symptoms of EIMD.

More recently, Lamb et al., (2019) investigated the effects of tart cherry juice or pomegranate juice supplementation on recovery from exercise-induced muscle damage on the elbow flexors in non-resistance trained men, but the results suggest that neither juice could improve recovery. The participants in this study supplemented with 2 x 250 mL of either tart cherry juice, pomegranate juice, or a fruit flavored placebo drink 5 days before the muscle damaging protocol and 4 days after the protocol (Lamb et al., 2019). Lamb et al., (2019) had participants perform 5 sets of 10 maximal eccentric contractions of the non-dominant elbow flexors on an isokinetic dynamometer at an angular velocity of 60 °·s⁻¹ for the muscle damaging protocol. CK, MVIC, maximal elbow extension and flexion of the non-dominant arm, and elbow flexion soreness using a 100 mm VAS were measured (Lamb et al., 2019). CK increased significantly in all groups and peaked at 96 h, but there were no significant group or interaction of group by time effects (Lamb et al., 2019). There were significant
differences in MVIC from pre-exercise to immediately post, 24 h, 48 h, and 72 h but not 96 h in all groups, however there was no significant difference between the groups (Lamb et al., 2019). The muscle damaging protocol also produced significant increases in elbow flexor soreness in all groups across all time points post-exercise, with soreness peaking at 48 h, however there no significant group differences (Lamb et al., 2019). Finally, all groups experienced a significant decrease in maximal elbow extension and flexion after the muscle damaging protocol at all times post-exercise, but there were no significant group differences (Lamb et al., 2019). Unlike Connolly et al., (2006), this study concluded that tart cherry juice and pomegranate juice had no effect on recovery following EIMD (Lamb et al., 2019).

Two studies used barbell back squats for the muscle damaging protocol (Hooper et al., 2021; Levers et al., 2015). First, Levers et al. (2015) had healthy, resistance-trained men supplement with either 480 mg of freeze-dried Montmorency tart cherry skin powder or a placebo for 7 days prior to completing the resistance training protocol, the day of the protocol, and 2 days after the protocol. The resistance training protocol consisted of 10 sets of 10 repetitions of barbell back squats at 70% one repetition maximum (1RM) with 3 minutes of rest in between sets (Levers et al., 2015). The resistance training protocol resulted in increased muscle soreness in both groups over time and peaked at 48 h post-lift, however the tart cherry group had significantly lower muscle soreness perception in the vastus lateralis and vastus medialis soreness 24 and 48 h post-lift, respectively (Levers et al., 2015). Isokinetic knee flexion and extension maximal voluntary contraction (MVC) results showed significant changes over time but no significant group effect over time was found (Levers et al., 2015). On average, MVC for flexion and extension and total work decreased 2, 16, and 10% for the tart cherry group and 5, 9, and 14% for the placebo group (Levers et al., 2015). Markers of mechanical damage and physiological stress, such as UA, total bilirubin, creatinine, total protein, CK, and aspartate aminotransferase (AST), significantly changed over time (Levers et al., 2015). Creatinine and total protein also demonstrated significant group differences over time and group by time changes as well as significant differences across groups (Levers et al., 2015). CK level
increases post-lift were also significantly lower for the tart cherry group versus the placebo group (Levers et al., 2015). Levers et al. (2015) also assessed ROS, reactive nitrogen species (RNS), TBARS, TAS, and superoxide dismutase (SOD) but no significant main effects for time or group differences were found. No significant group differences were observed for TNF-α, IL-6, IL-8, interleukin-4 (IL-4), or interleukin-7 (IL-7), but they had significant main effects for time (Levers et al., 2015). Lymphocytes, mid-range absolute count (MID), granulocytes (GRAN), and white blood cell counts (WBC) levels were measured as clinical markers of immune-related complete blood counts (Levers et al., 2015). Significant changes over time were observed in all four markers while only lymphocytes, MID, and WBC had significant group effects over time (Levers et al., 2015). Levers et al. (2015) concluded that powdered tart cherry supplementation may effectively reduce muscle soreness perception and markers of muscle catabolism but may not be as effective on markers of oxidative damage or inflammation (Levers et al., 2015).

Similar to the previous study, Hooper et al. (2021) used the barbell back squat to fatigue the lower body in their acute resistance exercise protocol. Thirteen resistance-trained men performed 6 x 10 repetitions of the barbell squat at 80% 1RM after supplementing with 500 mg of tart cherry powder with a low calorie content 7 days before the exercise protocol (Hooper et al., 2021). PC, a marker of oxidative stress, and CK, a marker of muscle damage, had significantly higher increases in the placebo condition compared to the tart cherry condition (Hooper et al., 2021). Creatine kinase myocardial band (CK-MB), another marker of muscle damage, showed a statistically significant increase in the placebo condition versus the tart cherry condition at 1 h post-exercise, but there were no other statistically significant differences (Hooper et al., 2021). Muscle soreness significantly increased for both conditions, but there were no significant main effects for supplement or supplement by time interaction (Hooper et al., 2021). As for the performance markers, there was a statistically significant increase in hand grip strength in the tart cherry condition compared to the placebo but no significant differences in CMJ (Hooper et al., 2021). This study concluded that tart cherry powder with a low-calorie content can reduce oxidative stress, muscle and cardiac damage,
and central fatigue (Levers et al., 2015). Moreover, Hooper et al. (2021) speculated that the study’s 60 repetition exercise protocol may not have created as substantial a performance decrement and muscle damage as the 100 repetition protocol used by Levers et al. (2015) since CMJ performance was not attenuated.

Another study conducted by Bowtell et al. (2011) used an intensive leg exercise to investigate if oxidative stress and muscle function could be reduced with Montmorency tart cherry juice supplementation. More specifically, 10 well-trained male overnight-fasted athletes consumed 2 x 30 mL of either a Montmorency cherry juice concentrate or a placebo 8 days prior to the experimental protocol and 2 days after the protocol (Bowtell et al., 2011). The experimental protocol consisted of 10 sets of 10 single-leg knee extension repetitions at 80% 1RM with a 3 second eccentric phase and 2 minutes of rest in between sets (Bowtell et al., 2011). There were no differences in the relative amount of work completed by both groups, but force recovery was significantly faster with the Montmorency cherry supplementation than with the placebo (Bowtell et al., 2011). Absolute change and absolute MVC force were significantly higher in the Montmorency group as well (Bowtell et al., 2011). PPT of the rectus femoris, vastus lateralis, and vastus medialis were significantly reduced through 48 h post-experimental protocol but there were no significant group differences (Bowtell et al., 2011). CK activity significantly increased in both groups post-experimental protocol, however there were no significant group differences (Bowtell et al., 2011). PC also significantly increased in both groups but was significantly lower with Montmorency cherry supplementation (Bowtell et al., 2011). No significant time or condition effects were found for nitrotyrosine concentration or hsCRP (Bowtell et al., 2011). Lastly, there was no significant time effect for total antioxidant capacity (Bowtell et al., 2011). This study’s results, like those found by Connolly et al. (2006) and Howatson et al. (2010), suggest that maximum isometric muscle force recovery can be improved through Montmorency tart cherry supplementation (Bowtell et al., 2011). Nevertheless, Bowtell et al. (2011) found that Montmorency tart cherry supplementation could not reduce PPT or any other marker of muscle damage or inflammation besides PC.
Beals et al. (2017) also found that tart cherry juice supplementation did no enhance recovery after a fatiguing knee extension protocol on a Biodex Multi Joint System. In this study, 29 recreationally active 18–50-year-old male and females consumed 2 x 60 mg freeze-dried tart cherry powder mixed drink or a placebo 4 days prior to the fatiguing protocol and 7 days after the protocol (Beals et al., 2017). Sets of 45, 45, and 90 isokinetic concentric/eccentric knee extensions at $60^\circ \cdot s^{-1}$ with 30 seconds of rest were performed until the participant reached the fatigue threshold, which was defined as 3 consecutive eccentric quadriceps torque production below 50% of the participant’s peak eccentric torque production (Beals et al., 2017). No significant main effect of group or interaction between group and time were observed for proximal tenderness, thigh circumference, ROM, and strength (Beals et al., 2017). There was no significant main effect of time on thigh circumference, however there were significant main effects of time for ROM, proximal tenderness, and strength (Beals et al., 2017). There were also no significant differences in VAS (Beals et al., 2017). None of the cytokines measured as markers of inflammation demonstrated a significant interaction effect between group and time (Beals et al., 2017). Lastly, CK had no significant interaction between group and time (Beals et al., 2017). Since CK and cytokines did not significantly change, Beals et al. (2017) suggested that the eccentric protocol used may not have produced enough muscle damage to induce an inflammatory response, even though the total number of repetitions fall within the 40-300 repetition range published by other research to elicit DOMS. Further research on tart cherry supplementation in powdered form using a fatiguing protocol with higher number of sets with lower repetitions and measuring recovery using performance markers on college-age, resistance trained males could fill the gaps in literature.
CHAPTER 3
METHODS
Participants

Seventeen women participated in this study (mean age ± SD = 22.18 ± 3.32 years, height ± SD = 162.03 ± 6.02 cm, weight ± SD = 65.11 ± 11.08 kg, BMI ± SD = 24.71 ± 3.52 kg · m²).

Participants were recreationally active and collegiate age. Recreationally active was defined as participating in physical activity at least 3 days per week, for at least 30 minutes each session, for at least 3 months (Hillman et al., 2016). Participants who had previous resistance training experience were included in the definition of recreationally active. Resistance trained was defined as participating in resistance training at least 3 per week, for at least 30 minutes, for the past 6 months (Ruggieri et al., 2021). All participants were free of any lower extremity injury within the last 6 months of their participation in the study (Madoni et al., 2018). Participants had no reported aversion or inability to tolerate intense, soreness inducing resistance training exercises, a history of medical events (i.e., exercise-induced rhabdomyolysis, cardiovascular disease, metabolic, renal, hepatic, or musculoskeletal disorders) that may significantly affect the study outcome or use medicine or nutritional supplements that may affect the study outcome for one month prior to the onset of the study (Beals et al., 2017). During the loading phases of this study, participants were asked to refrain from consuming supplemental protein or branched-chain amino acids in quantities greater than 2 servings per week, antioxidant or anti-inflammatory supplements or drugs, grapefruit and grapefruit juice, steroids, caffeine, marijuana, and alcohol (Brown et al., 2019; Connolly et al., 2006; Lamb et al., 2019). Furthermore, participants were asked to not seek any treatment to aid with muscle soreness (Brown et al., 2019), such as massage, foam rolling, topical analgesics, and ice therapy. Lastly, participants were asked to refrain from partaking in any lower body exercise throughout the duration of the study (Connolly et al., 2006).
Research Design

This research is a randomized, double-blind, placebo-controlled crossover design. Participants visited the laboratory in nine separate occasions (Figure 1). The first visit was a familiarization session where participants completed the Informed Consent, filled out a “Pre-Exercise Testing Health and Exercise Status Questionnaire,” and set a schedule for the remaining laboratory visits. Participants were also familiarized with the isokinetic dynamometer, EMG sensors, and testing environment by completing a preliminary trial of the muscle function test (MFT), and overload protocol. Once that was completed, each participant was randomly assigned the first of two deidentified “supplements” (tart cherry supplement or placebo) and were instructed to begin taking the supplement on this day to mark the start of Trial 1 and day 1 of the loading phase. They were asked to consume this supplement daily for a 4-day loading phase. The loading phase was followed by Visit 1 in which the participant underwent an overload protocol, consisting of a series of lengthening muscle actions of the randomly selected quadriceps in an isokinetic dynamometer. It was documented whether the randomly selected limb was dominant or non-dominant. Participants continued to supplement on the day of the overload protocol and 24, 48, and 72 h post-eccentric overload. Testing occurred at pre-overload and 0 (immediately after), 24, 48, and 72 h post-overload. Testing consisted of isokinetic muscle peak torque, isokinetic muscle work, and isokinetic muscle power using 3 concentric/concentric knee extension repetitions at speeds of $60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$, and $300^\circ \cdot s^{-1}$ as well as muscle activation using EMG. The overload protocol consisted of 8 sets of 10 concentric/eccentric leg extension repetitions at $60^\circ \cdot s^{-1}$. A 14-day wash-out began after the completion of Trial 1 testing, and the 4-day loading phase of the next product occurred after the washout. All protocols were repeated on the contralateral lower limb for the second product to avoid the impact of the repeated bout effect (Connolly et al., 2006).
Procedures

All testing sessions were conducted in the exercise physiology laboratory at California State University, Fullerton. During the familiarization visit, participants read and signed the Informed Consent, and filled out a health and exercise questionnaire. Each participant’s anthropometrics were also measured. Body mass was measured using a digital scale (Ohaus ES Series scale, Parsippany, NJ, USA) and height was measured using a stadiometer (SEXA stadiometer, Chino, CA, USA). Participants were then familiarized with EMG sensor locations and became comfortable with the isokinetic dynamometer by completing a preliminary MFT trial and a set of 10 repetitions of the overload protocol. The preliminary MFT trial consisted of three maximal effort knee extension repetitions at three different velocities ($60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$, and $300^\circ \cdot s^{-1}$) after a separate warm-up for each velocity. The overload protocol preliminary trial consisted of one set of 10 knee extension repetitions at $60^\circ \cdot s^{-1}$ to reduce any potential learning effects since the proceeding visits were testing days. At the end of the familiarization visit, a 10-point VAS, which was used to measure muscle soreness while at rest, walking downstairs, and performing a squat, was explained to each participant. Participants were then assigned to one of the two deidentified supplements and asked to begin the 4-day loading phase and visit the lab on day 5 of supplementation to perform the overload protocol.
On Visit 1 of Trial 1, participants completed three separate parts. The first part was a pre-test, which began with baseline VAS and MFT performed via the isokinetic dynamometer on the randomly assigned quadriceps to establish muscle soreness, concentric peak torque, concentric peak power, concentric average power, concentric time to peak torque, concentric total work, and muscle activation. EMG sensors were used to detect and measure muscle activation. The participant was then asked to remain in the isokinetic dynamometer to complete the overload protocol to elicit significant quadriceps muscle damage. Immediately after the overload protocol, participants repeated the VAS and MFT to assess muscle soreness, peak torque, peak power, average power, time to peak torque, total work, and muscle activation. Visits 2, 3, and 4 correlate to post-test 24 h, post-test 48 h, and post-test 72 h. The participant was asked to complete a post-VAS and post-MFT on each of those visits. Trial 1 was completed in 8 days.

After visit 4, participants commenced a 14-day washout phase and were asked to continue to refrain from any prohibited supplementation or activity. The participant arranged a time and day to acquire the second supplement to prepare for Trial 2. Trial 2 was a repeat of the procedures outlined for Trial 1. The participant underwent a loading phase with the second deidentified supplement and the contralateral lower limb underwent the overload protocol and was tested.

At the same time as testing, participants were asked to record a 5-day food, exercise, and sitting log using MyFitnessPal (MyFitnessPal, Inc, San Francisco, CA, USA), an application and web-based dietary tracking system. Subjects were then asked to replicate diets from the initial Trial 1 on Trial 2.

**Supplementation Protocol**

Participants began consuming the first of the two randomly assigned deidentified supplements after the familiarization visit. Each participant consumed the supplement 4 days prior to the overload protocol, the day of the overload protocol, and 3 days after the overload protocol. Previous research had participants supplement for a total of eight days (Bell et al., 2016; Bell et al., 2015; Brown et al., 2019; Howatson et al., 2010; Kuehl et al., 2010; Quinlan & Hill, 2020). Daily polyphenol
supplementation for 3 or more days before and after exercise has been shown to improve recovery (Hooper et al., 2021). The experimental tart cherry supplement used in this study was the highly concentrated Toniiq Tart Cherry Capsules (Toniiq LLC, Chicago, IL, USA). Each participant consumed two Toniiq Tart Cherry Capsules, which contain 1,000 mg total of concentrated tart cherry extract for eight total days. For the placebo, subjects consumed two capsules of dextrose and natural red food coloring (Muscle Feast, Nashport, OH, USA) that resembled the tart cherry capsules for eight total days. A 14-day washout phase was completed in between each trial (Hooper et al., 2021).

**Muscle Function Test Protocol**

The muscle function test (MFT) protocol was completed using an isokinetic dynamometer (Humac Norm CSMi, Stoughton, MA, USA) to analyze concentric and eccentric peak torque, peak power, average power, time to peak torque and total work at the velocities of 60°·s⁻¹, 180°·s⁻¹, and 300°·s⁻¹ (Ruggieri et al., 2021). Isometric extension was measured at 50% of the participants measured knee extension range of motion (ROM) to establish MVCs for EMG normalization (Ruggieri et al., 2021). Subjects were seated on the isokinetic dynamometer and straps were fastened over the participant’s shoulders, across their lap, and the shin of the testing leg to ensure it was isolated and secured (Ruggieri et al., 2021). The axis of the dynamometer was aligned to meet the knee rotation axis of the secured leg (Costa et al., 2013; Ruggieri et al., 2021). Each MFT session began with warm-up kicks and pulls at increasing intensities of 25%, 50%, 75%, and 100% followed by a 1-minute rest period (Costa et al., 2013; Madoni et al., 2018; Ruggieri et al., 2021). Participants performed three maximal effort repetitions of the concentric extension and flexion actions at the three different velocities and the highest value of each of the three maximal repetitions was recorded (Ruggieri et al., 2021). All other dependent variables were recorded based on the best repetition at each velocity. A 1-minute rest period was provided between each velocity (Ruggieri et al., 2021). Participants were given verbal prompts and encouragement, such as “kick,” “pull,” and “push” (Madoni et al., 2018; Ruggieri et al., 2021).
Electromyography (EMG) Protocol

EMG electrodes were placed on the participant’s testing limb (Figure 2) as they perform the MFT and overload protocol to measure muscle activation. Three pre-amplified bipolar surface electrodes (EL254S; Biopac Systems Inc., Santa Barbara, CA, USA) were placed over the rectus femoris (RF) and vastus lateralis (VL) of the quadriceps and the biceps femoris (BF) of the hamstrings (Madoni et al., 2018; Ruggieri et al., 2021). The electrode on the rectus femoris was placed at the mid-point of the anterior superior iliac spine and the superior part of the patella (Madoni et al., 2018). The electrode on the vastus lateralis was placed at 2/3 the distance between the anterior superior iliac spine and the lateral portion of the patella (Ruggieri et al., 2021). The electrode for the biceps femoris was placed halfway between the ischial tuberosity and lateral epicondyle (Madoni et al., 2018; Ruggieri et al., 2021). To ensure the EMG placements are identical for each session, the rectus femoris, vastus lateralis, and biceps femoris EMG locations were marked during the first day of each deidentified supplement trial. The reference electrode was placed over the spinous process of the seventh cervical vertebra (Madoni et al., 2018; Ruggieri et al., 2021). All the electrodes were placed on the skin after shaving, abrading, and cleaning with isopropyl alcohol each session (Madoni et al., 2018; Ruggieri et al., 2021). Raw EMG scores of muscle activation for the three muscles were collected using a Biopac data collection system (MP150WSW; Biopac Systems Inc, Santa Barbara, CA, USA). All EMG were recorded at a frequency of 1,000 (hertz) Hz during the completion of the MFT and overload protocol. EMG values were filtered with signal bandpass at 10-500 Hz, and data were measured and recorded as root mean square and normalized to the maximum voluntary contractions (MVCs). All signals were recorded on a personal computer (Dell, Red Rock, TX, USA) and analyzed using AcqKnowledge (version 5.0, Biopac Systems Inc, Santa Barbara, CA, USA).
Overload Protocol

The overload protocol aimed to induce muscle damage was completed using the isokinetic dynamometer (Humac Norm CSMi, Stoughton, MA, USA). The protocol consisted of 8 sets of 10 repetitions of maximal effort knee extensions at a velocity of $60^\circ \cdot s^{-1}$ with one-minute rest periods in between sets. Beals et al. (2017) had participants perform concentric/eccentric knee extension contractions at $60^\circ \cdot s^{-1}$ using sets of 45, 45, and 90 repetitions but found no significant increase in CK, indicating that the protocol may not have induced enough muscle damage to produce an inflammatory response. This protocol intended to elicit significant quadriceps muscle damage using a higher number of sets with a lower number of repetitions per set as suggested by previous research (Beals et al., 2017).

Visual Analog Scale (VAS) Protocol

Quadriceps muscle soreness was assessed using a 10-point VAS. A rating of 0 on the VAS would signify no soreness while a 10 would signify worse possible soreness (Ruggieri et al., 2021). For this test, participants will be asked for a rating of soreness while resting (Hillman et al., 2016), walking downstairs (Heiss et al., 2018; Nicol et al., 2015), and performing a squat (Quinlan & Hill, 2020). The resting VAS measure was assessed while the participant is seated on a chair. The walking downstairs VAS was taken while the participant walked down 13 steps with a height of 20.5...
centimeters (cm), width of 30.4 cm, and length of 42 cm. To perform the squat, each participant stood with hands on hips and feet shoulder-width apart, squat to 90° while flexing at the knees, and then stand back to the start position (Hillman et al., 2017). The VAS is a reliable method to assess perceived muscle pain after eccentric exercise (Cleary et al., 2006).

**Statistical Analysis**

The statistical analysis for this randomized, double-blind, placebo-controlled, crossover design included repeated measures ANOVAs. VAS was analyzed through a two-way repeated measures ANOVA (time [pre vs. 0 h post vs. 24 h post vs. 48 h post vs. 72 h post] × condition [placebo vs. supplement]). Peak torque, peak power, average power, time to peak torque, total work, RF EMG, and VL EMG were analyzed using a three-way repeated measures ANOVA (time [pre vs. 0 h post vs. 24 h post vs. 48 h post vs. 72 h post] × condition [placebo vs. supplement] × velocity [60°·s⁻¹ vs. 180°·s⁻¹ vs. 300°·s⁻¹]). *T* tests, post hoc with a Bonferroni correction, and one-way ANOVAs were used if necessary and appropriate. Data was reported as mean ± SE. Results were considered significant at *p* ≤ 0.05. IBM SPSS Statistics was used for statistical analysis (version 28, IBM Corp, Armonk, NY, USA).
CHAPTER 4
RESULTS

Peak Torque

There was no three-way interaction for time × condition × velocity ($p = 0.916$), and no two-way interactions for time × condition ($p = 0.853$), time × velocity ($p = 0.157$), or condition × velocity ($p = 0.114$). However, there were main effects for time and velocity ($p < 0.001$). Peak torque decreased from pre- to post-test 0 h ($p < 0.001$) and increased post-test 24 h ($p < 0.001$), post-test 48 h ($p = 0.011$), and post-test 72 h ($p = 0.007$) from post-test 0 h (Figure 3). In addition, peak torque decreased as angular velocity increased ($p < 0.001$).

![Figure 3](image-url)

*Figure 3. Mean ± SE of peak torque. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference from pre- and post-test 24, 48 and 72 h*
**Peak Power**

There was no three-way interaction for time $\times$ condition $\times$ velocity ($p = 0.648$), and no two-way interactions for time $\times$ condition ($p = 0.665$) or condition $\times$ velocity ($p = 0.258$). However, there was a two-way interaction for time $\times$ velocity ($p < 0.001$). Simple main effects were found for $180^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$ ($p < 0.001$) but not for $60^\circ \cdot s^{-1}$ ($p = 0.421$). At $180^\circ \cdot s^{-1}$, peak power decreased from pre- to post-test 0 h ($p = 0.018$) and increased at post-test 24 h ($p = 0.039$), post-test 48 h ($p = 0.011$), and post-test 72 h ($p < 0.001$) from post-test 0 h. At $300^\circ \cdot s^{-1}$, peak power decreased from pre- to post-test 0 h ($p = 0.016$) and increased at post-test 24 h ($p = 0.004$), post-test 48 h ($p = 0.009$), and post-test 72 h ($p < 0.001$) from post-test 0 h (Figure 4).

![Figure 4. Mean ± SE of peak power. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. * Denotes significant difference from pre- and post-test 24, 48, and 72 h.](image-url)
There was no three-way interaction for time × condition × velocity ($p = 0.951$), and no two-way interactions for time × condition ($p = 0.473$) or condition × velocity ($p = 0.456$). However, there was a two-way interaction for time × velocity ($p = 0.001$). Simple main effects were found for all three velocities ($p < 0.001$). At $60^\circ\cdot s^{-1}$ total work decreased from pre- to post-test 0 h ($p < 0.001$) before increasing at post-test 24 h ($p = 0.009$), post-test 48 h ($p = 0.011$), and post-test 72 h ($p = 0.015$). At $180^\circ\cdot s^{-1}$, total work decreased from pre- to post-test 0 h ($p = 0.020$) and increased at post-test 24 h ($p = 0.009$), post-test 48 h ($p = 0.005$), and post-test 72 h ($p < 0.001$) from post-test 0 h. At $300^\circ\cdot s^{-1}$, total work decreased from pre- to post-test 0 h ($p = 0.020$) and increased at post-test 24 h ($p < 0.001$), post-test 48 h ($p = 0.003$), and post-test 72 h ($p < 0.001$) from post-test 0 h (Figure 5).

Figure 5. Mean ± SE of total work. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. * Denotes significant difference from pre- and post-test 24, 48, and 72 h.
Time-to-Peak Torque

There was no three-way interaction for time × condition × velocity ($p = 0.779$), and no two-way interactions for time × condition ($p = 0.498$), time × velocity ($p = 0.400$), or condition × velocity ($p = 0.527$). In addition, there were no main effects for time ($p = 0.158$) or condition ($p = 0.746$), but there was a main effect for velocity ($p < 0.001$) (Figure 6). Time-to-peak torque decreased as angular velocity increased ($p < 0.001$).

![Figure 6. Mean ± SE of time-to-peak torque. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference among velocities.](image)

Mean Power

There was no three-way interaction for time × condition × velocity ($p = 0.487$), and no two-way interactions for time × condition ($p = 0.456$), time × velocity ($p = 0.319$), or condition × velocity ($p = 0.316$). However, main effects for time ($p = 0.033$) and velocity ($p < 0.001$) were found. Post hoc analysis did not find any significant differences among the time points ($p > 0.05$) (Figure 7). In addition, there were significant differences between the velocities of $60^\circ \cdot s^{-1}$ and $180^\circ \cdot s^{-1}$ ($p < 0.001$) as well as between $180^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$ ($p < 0.001$). However, there was no difference in mean power between $60^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$ ($p = 0.414$).
**Figure 7.** Mean ± SE of mean power. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference compared to 60°·s⁻¹ and 300°·s⁻¹

**Muscle Soreness at Rest**

There was no two-way interaction for time × condition (p = 0.082). In addition, there was no main effect for condition (p = 0.507), but there was a main effect for time (p < 0.001). Muscle soreness at rest increased from pre- to post-test 0 h (p < 0.001) and post-test 24 h (p = 0.039) (FIGURE 8).

**Muscle Soreness While Walking Downstairs**

There was no two-way interaction for time × condition (p = 0.063). In addition, there was no main effect for condition (p = 0.936), but there was a main effect for time (p < 0.001). Muscle soreness while walking downstairs increased from pre- to post-test 0 h (p < 0.001), post-test 24 h (p < 0.001), and post-test 48 h (p = 0.012) (FIGURE 8). There was also a decrease at post-test 48 h (p = 0.031) and post-test 72 h (p = 0.003) from post-test 0 h.

**Muscle Soreness While Performing a Squat**

There was no two-way interaction for time × condition (p = 0.147). In addition, there was no main effect for condition (p = 0.874), but there was a main effect for time (p < 0.001). Muscle
soreness while performing a squat increased from pre- to post-test 0 h ($p < 0.001$) (Figure 8). There was also a decrease at post-test 72 h from post-test 0 h ($p = 0.009$).

Figure 8. Mean ± SE of muscle soreness. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference from pre-test. † Denotes significant difference from post-test 0 h

**Rectus Femoris Muscle Activation**

There was no three-way interaction for time × condition × velocity ($p = 0.167$), and no two-way interactions for time × condition ($p = 0.866$), time × velocity ($p = 0.747$), or condition × velocity ($p = 0.466$). However, there was a main effect for velocity ($p = 0.005$). For velocity, post hoc analysis found a difference in muscle activation between $60^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$ ($p = 0.029$) and between $180^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$ ($p = 0.003$) (Figure 9).
Figure 9. Mean ± SE of concentric rectus femoris muscle activation. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference compared to 60° · s⁻¹ and 180° · s⁻¹

Vastus Lateralis Muscle Activation

There was no three-way interaction for time × condition × velocity (p = 0.495), and no two-way interactions for time × condition (p = 0.877), time × velocity (p = 0.200), or condition × velocity (p = 0.466). However, there was a main effect for velocity (p = 0.015). There was a difference in muscle activation between 180° · s⁻¹ to 300° · s⁻¹ (p = 0.024) (Figure 10).

Figure 10. Mean ± SE of vastus lateralis muscle activation. Pre: Pre-test. Post 0 h: Post-test 0 h. Post 24 h: Post-test 24 h. Post 48 h: Post-test 48 h. Post 72 h: Post-test 72 h. *Denotes significant difference compared to 180° · s⁻¹
CHAPTER 5
DISCUSSION

The primary results of the present study indicate that there were no supplement-related
differences in isokinetic muscle peak torque, peak power, total work, time-to-peak torque, mean
power, muscle soreness, and muscle activation between the supplement and placebo conditions.
Peak torque decreased from pre- to post-test 0 h, but then increased in the subsequent post-test 24 h, 48 h, and 72 h. Peak torque also decreased as angular velocity increased. Peak power had a two-way interaction for time × velocity. At $180^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$, peak power decreased from pre-test to post-test 0 h, but it increased at post-test 24 h, 48 h, and 72 h. Similarly to peak power, total work had a two-way interaction for time × velocity and simple main effects for all three velocities. At $60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$, total work decreased from pre- to post-test 0 h, but increased at post-test 24 h, 48 h, and 72 h. Time-to-peak torque decreased as angular velocity increased. Mean power had main effects for time and velocity. Post hoc analysis did not find any differences in mean power between the pre- and post-tests. As for velocity, mean power increased as angular velocity increased from $60^\circ \cdot s^{-1}$ to $180^\circ \cdot s^{-1}$ and decreased as angular velocity increased from $180^\circ \cdot s^{-1}$ to $300^\circ \cdot s^{-1}$. Muscle soreness was measured using a visual analog scale at rest, while walking downstairs, and while performing a squat. Results indicated a pre- to post-test 0 h increase followed by a decrease at later post-testing sessions. Lastly, RF and VL muscle activation both had main effects for velocity.

One of the major differences between the present study and previous research is the quantity
and form of tart cherry supplement used. In this present study, the tart cherry supplement was in
capsule form and contained 1,000 mg total of concentrated tart cherry extract per serving, with a
serving consisting of 2 capsules. The tart cherry supplement reportedly contained *Prunus cerasus*
(fruit) extracted at a 52:1 ratio, which is equivalent to 52,000 mg of tart cherry. One of the first studies
to report the efficacy of tart cherry in attenuating strength loss following muscle damage had
participants supplement with a 12-oz bottle cherry juice blend with at least 600 mg of phenolic
compounds and at least 40 mg, or the equivalent of 50-60 cherries (Connolly et al., 2016). Another demonstrated tart cherry juice could reduce muscle pain during long distance running used a similar 10.5 oz cherry juice blend containing at least 600 mg of phenolic compounds and at least 40 mg of anthocyanins or the equivalent of 45-50 cherries, which is similar to the content in the cherry juice used by Connolly et al. (2006). Brown et al., (2019), who reported that supplementing with cherry may help attenuate the symptoms of muscle damage and improve recovery among women used a cherry juice blend containing a 30 mL dose of concentrate containing a total anthocyanin content of 73.5 mg L\(^{-1}\) of cyanidin-3-glucoside, a total phenolic content of 178.8 gallic acid equivalent L\(^{-1}\) and an antioxidant capacity of 0.58 trolox equivalents L\(^{-1}\), or the equivalent of 90 cherries. One study that did not report any improvements in recovery following tart cherry supplementation had participants consume 60 mg of a tart cherry powder mixed with unsweetened Black Cherry Kool-Aide that provided 64 mg anthocyanins and 733 mg phenolic compounds. One study purposely examining whether polyphenol supplementation in the form of powdered tart cherry extract reduced markers of oxidative stress, skeletal and cardiac muscle damage, and muscle soreness had participants supplement with a 500 mg proprietary broad spectrum powder with total polyphenols 5-6% w/w tested via F-C assay (Hooper et al., 2021). Hooper et al. (2021) found that tart cherry supplementation could reduce oxidative stress and markers of muscle and cardiac damage. Overall, the differences in polyphenol and anthocyanins as well as the form in which the tart cherry was consumed could explain some of the differences in the results reported by research.

The findings of the present study are consistent with those of Beals et al. (2017) who reported no significant differences in isokinetic concentric quadriceps strength after consuming a tart cherry blend for four days before and eight days following an exhaustive bout of eccentric exercise. This particular study investigated the effects of the tart cherry blend on both recreationally active men and women (Beals et al., 2017). In the present study, time-to-peak was also analyzed and no group differences were found. These results are in contrast with Connolly et al. (2006) whose study demonstrated that the placebo trial had a greater loss in isometric elbow flexion compared to the
cherry juice trial. The participants in Connolly et al., (2006), who were all male college students, were asked to consume either the placebo or cherry juice blend drinks for eight days and performed the eccentric exercise protocol on the fourth day of supplementation. The present study, along with the previously two aforementioned studies, had participants supplement acutely with either the placebo or tart cherry before, during, and after the exercise protocol when conducting the post-testing (Beals, et al., 2016, Connolly et al., 2006). Previous research has shown that supplementing with polyphenols daily for 3 or more days prior to and following exercise may improve recovery (Connolly et al., 2006); however, the results of the current study failed to show improvements in muscle function after supplementing for four days before and after an overload protocol. Decreases in CK suggest that antioxidant supplements may be able to reduce the amount of biomechanical damage placed on muscle proteins by scavenging for reactive oxygen species (Hooper et al.2021). Since the present study did not measure blood markers of muscle damage, it is unclear whether there were any improvements in damage to the muscle proteins. At least for muscle function, particularly peak torque and time-to-peak torque, no improvements were observed.

Hillman et al. (2017) used a countermovement jump (CMJ) to assess muscle power among men and women after 10 days of consuming either a tart cherry whey beverage or placebo and found there to be no differences in CMJ over time or between groups. It was suggested that the use of the CMJ may not have been sensitive enough to evaluate neuromuscular performance (Hillman et al., 2017). Moreover, McCormick et al. (2016) also used a vertical jump (VJ) as a performance variable in a study looking at the effects of tart cherry juice on recovery and next day performance in well-trained male water polo players and found no effects for condition, time, or an interaction. Hooper et al. (2021) deemed it important to demonstrate enhanced improvement in physical performance resulting from reduced oxidative stress following polyphenol supplementation and used VJ as the physical performance marker. Results from Hooper et al. (2021) showed a non-significant main effect for supplement and time, but there was a significant supplement × time interaction. In contrast, Brown et al. (2019) did find a group effect with CMJ after a repeated-sprint protocol of 15 x 30 m maximal
sprints with a rapid 10 m deceleration phase among physically active females. In this present study, an isokinetic dynamometer was used to measure isokinetic peak power. Still, no differences in conditions for peak power were found but there was a two-way interaction for time × velocity with peak power decreasing from pre-test to post-test 0 h before increasing once again at the following post-tests. Mean power was also measured in the present study, but again, no differences in condition were found. However, mean power did have main effects for time and velocity. Possibly, the overload protocol used in the present study did not induce enough fatigue in the lower limbs to produce performance decrements.

Botwell et al. (2011) analyzed biomechanical recordings in well-trained male participants who completed 10 sets of 10 single-leg knee extensions at 80% of their 1RM with a 3 s elongated eccentric phase after supplementing with either cherry juice or a placebo for 10 days. Work, one of the biomechanical recordings, was determined by integrating the force over time trace, and data were normalized to the corresponding 1RM value to eliminated interindividual and inter-leg variability (Botwell et al., 2011). Botwell et al., (2011) found no differences in relative work between the two trials. The present study found no difference between conditions for total work, but there was a two-way interaction for time × velocity and simple main effects for all three velocities. Total work decreased from pre- to post-test 0 h before increasing at the subsequent post-tests of 24 h, 48 h, and 72 h. More research using total work as a marker for recovery may be needed as it is a unique performance measure.

The present study found that muscle soreness assessed at rest, while walking downstairs, and while performing a squat had a main effect for time, but no main effect for condition or two-way interaction for time x condition. In addition, the reported muscle soreness values were not large, perhaps influencing the lack of significant results for the supplement condition. Hillman et al. (2017) and Quinlan & Hill et al. (2020) also measured muscle soreness in the lower body by having participants perform a squat. Both aforementioned studies reported an increase in muscle soreness over time with no significant group effects after completing 5 x 20 drop jumps and an adapted version
of the Loughborough Intermittent Shuttle Test (LIST) (Hillman et al., 2017, Quinlan & Hill et al. 2020). Interestingly, Quinlan & Hill et al. (2020) did find a significant group by time interaction but did not find where the differences were with further post hoc analysis. Another study by Hooper et al. (2021) also found a significant main effect for time but a non-significant main effect for supplement and supplement x time. One difference between this latter study and the former three studies was how muscle soreness was assessed. For example, Hooper et al. (2021) had subjects report their muscle soreness using a marked line on a 10 cm scale as a researcher firmly palpated their upper, middle, and lower quadriceps while the subject was in a seated position with legs elevated. Moreover, one of the first studies to investigate the effects of a tart cherry juice blend in preventing symptoms of muscle damage following 40 maximal eccentric contractions of the elbow flexors found pain values to be significantly higher among the placebo trial compared to the cherry juice trial (Connolly et al., 2016). For instance, Connolly et al. (2006) reported muscle soreness in the placebo trial peaked post-test 48 h with the mean of approximately 5 using a 0-10 pain scale whereas the cherry trial had muscle soreness peaking at post-test 24 h with the mean approximately of 4. In that study, subjects reported pain values as the overall discomfort during active elbow flexion and extension with activities of daily (Connolly et al., 2006). Intriguingly, Botwell et al. (2011) opted to use pressure pain threshold on the belly of the rectus femoris, vastus lateralis, and vastus medialis to measure muscle soreness to reduce subjectivity associated with using a VAS but still found no significant differences between a cherry juice concentrate and an isoenergetic fruit concentrate placebo. Perhaps, differences in results may be due to the different muscles assessed, exercise protocols, and the manner in which muscle soreness was measured.

Previous research on semi-professional male soccer players reported no decline in MVC of the dominant knee extensors measured using a strain gauge in a group supplementing with tart cherry compared to a placebo group whose MVC did not return to basal levels at post-test 72 h (Bell et al., 2016). In addition, Botwell et al. (2011) found knee extension isometric MVC force normalized to pre-exercise values recovered significantly faster when supplementing with tart cherry. In contrast, Brown
et al. (2019) who also measured the isometric MVC of the right knee extensors among physically active females supplementing with a tart cherry or a placebo for four days prior to muscle-damaging protocol, the day of exercise, and for three days of recovery and found no group effect. While these studies used isometric MVC to assess muscle function, the present investigation is unique because it is one of the first to use EMG to analyze muscle function following tart cherry supplementation. The current study found no differences in RF and VL EMG muscle activation between conditions but there was a main effect for velocity. It is possible that the previous training of the participants may have impacted the results. For example, although the participants were recreationally active, some of them may have previous resistance training experience, which may attenuate their response to a bout of exhaustive exercise compared to those who have no experience with resistance training. In contrast, the current study found no differences in RF and VL muscle activation between conditions but there was a main effect for velocity.

One limitation of this study was the lack of oxidative stress biomarkers. Therefore, it is unclear whether those measures would have revealed different results. However, a variety of isokinetic measures more reflective of performance were analyzed. Additionally, the population used may have limited exposure to maximal effort exercise training, such that the results may be different when investigating the effects on resistance trained women or athletes compared to recreationally active females. Another limitation to this study is the lack of menstrual cycle tracking and consideration during testing. It has been suggested that EIMD and recovery may vary throughout the different phases of the menstrual cycle (Brown et al., 2019). Lastly, based on the low muscle soreness values reported and the peak of muscle soreness occurring at post-test 0 h, it is likely the overload protocol used in this study did not induce enough exercise-induced muscle damage for the supplement to have an effect. Future research could follow a similar protocol to investigate the differences in women who meet specific strength requirements. Another future alternative could be to compare the effects tart cherry supplementation on performance and recovery between men and women. Future research could also investigate the effects of more acute tart cherry supplementation where subjects load with
the supplement for less than 3 days. In summary, when compared to a placebo, tart cherry taken four days before, the day of, and three days after 8 sets of 10 maximal effort knee extension repetitions at 60°·s⁻¹ on an isokinetic dynamometer was unable to demonstrate reduced attenuation of muscle function, specifically isokinetic peak torque, peak power, total work, time-to-peak torque, and mean power, as well as muscle soreness and muscle activation of the quadriceps.
REFERENCES


