EFFECTS OF ECCENTRIC AND CONCENTRIC ISOKINETIC BENCH PRESS TRAINING ON DYNAMIC STRENGTH, ISOMETRIC FORCE PRODUCTION AND TRICEPS BRACHII CROSS-SECTIONAL AREA.

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ABSTRACT

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Background. Engaging in resistance training programmes is an integral part of the physical preparation process for athletes. The neural and morphological mechanisms underpinning eccentric contractions are notably different from concentric and isometric contractions and remain less understood. Performing compound movements with an eccentric load greater than the individual's maximum strength capacity has become a popular interest in the quest to understanding how the neuromuscular system adapts acutely and chronically. Reversible physiological adaptations occur if there is a short-term insufficient training stimulus and thus, meticulous physical preparation planning is essential. The purpose of this study was to investigate the differences in strength and CSA between groups, and to compare the changes that occurred as a result of training between- and within-groups.

Methods. Subjects (n = 17) were randomly assigned to an eccentric overload (n = 9) or concentric (n = 8) training group. The males were physically fit and had engaged in recreational resistance training prior to the study. Training took place twice per week on non-consecutive days for a duration of 10 weeks, after which, five weeks of detraining. Contractions were performed in isolation with the volume and intensity ranging between three to four sets and repetitions. Maximum dynamic strength was found using a smith machine bench press in accordance to 1RM testing procedures; maximum isometric strength was performed on a bench press set-up with an immovable bar. Triceps brachii CSA was measured via panoramic ultrasonography. Strength and CSA was measured three times: pre-test, post-test and after detraining.

Results. There was a significant, within-group difference in absolute 1RM bench press strength for the eccentric training group ($p < .05$) from pre- to post-test, but not for the concentric group. Isometric strength increased to a greater extent for the concentric group, however, the mean change between groups was not significant ($p > .05$). A greater mean increase in combined triceps brachii CSA was found for the eccentric group which remained above baseline values after detraining unlike the concentric group. There was however a strong correlation ($r = 0.74$) between the change in combined CSA and change in isometric strength for the concentric group as a result of training.

Conclusion. This research contributes to an ongoing research interest of eccentric resistance training with eccentric overload, in particular, the upper extremity musculature. Each contraction type performed in isolation was not significantly different from one another, however, performing these can elicit significant changes in antagonist muscle cross-sectional area, dynamic and isometric strength with training.

Key words: hypertrophy, overload, accentuated, chest press, resistance training

ABBREVIATIONS

1 RM	One repetition maximum
CON	Isolated concentric-only training
CSA	Cross-sectional area
ECC+	Isolated eccentric overload training
FL	Fascicle length
iEMG	Integrated electromyography
MVC	Maximal voluntary contraction
PA	Pennation angle
RT	Resistance training

CONTENTS

ABSTRACT

1 INTRODUCTION

It has long been established that resistance training (RT) has a profound effect on neuromuscular qualities that contribute to successful athletic performance involving strength, power and endurance components (Beattie, Kenny, Lyons, & Carson, 2014; McGuigan, Wright, & Fleck, 2012). Concentric and eccentric contractions of human skeletal muscle can be described by shortening or lengthening of the muscle fibre with a concurrent increase in muscle tension (Franchi, Reeves, & Narici, 2017). More specifically, during concentric actions there is a dynamic shortening of the sarcomeres, whereas eccentric actions are attributed to active lengthening of the sarcomere (Schoenfeld, Ogborn, Vigotsky, Franchi, & Krieger, 2017).

One of the earliest studies of these muscle contraction types dates back to the sixties whereby isometric strength of the elbow flexors and knee extensors was measured following maximal isometric or eccentric contractions (Petersen, 1960). A second study comparing the effects of concentric and eccentric muscle contractions found that both methods were able to elicit significant increases in arm and leg strength, despite no significant differences the two methods of training (Johnson, Adamczyk, Tennoe, & Stromme, 1976). A few years later the research then focussed on the combination of contraction types and how this may influence maximal strength gains. Better increases in muscle force, as measured by leg extension forces, were reported for subjects that trained with combined concentric and eccentric contractions compared to concentric alone (Häkkinen, 1981).

Training effects are specific to the contraction type adopted in the exercise session (Morrissey, Harman, & Johnson, 1995). Remarkably contrasting training responses have been reported in the literature for interventions of different contraction-type specificity. Joint - torque angle relationships were found to change in a study that examined the Nordic hamstring exercise (Brockett, Morgan, & Proske, 2001). The authors reported that this was one of the first studies to show a sustained shift in optimal knee angle to longer muscle lengths for hamstring torque generation. Such changes were not found in a study that employed concentric training modes (Rees, Wolman, & Wilson, 2009).

Practitioners must be aware of the differences between training modes when planning for their athletes because each contraction type imposes stress on the physiological systems and can also alter the movement kinetics and technical execution. The SAID principle (specific adaptation to imposed demands) describes in basic terms that any physiological adaptation produced is dependent on the training stimulus and the form of overload it places on the body (Stone, Plisk, & Collins, 2002).

2 REVIEW OF THE LITERATURE

2.1 Methodological Approaches

2.1.1 Research Design

A minimum sample size of 30 subjects has been recommended for quantitative studies in the field of sports sciences in order for basic descriptive statistics to be performed (Gratton & Jones, 2014, p.114). A total of 54 subjects was reported in one study that examined heavy RT methods utilising different muscle contractions (Higbie, Cureton, Warren, & Prior, 1996). Many of the existing research has included over 30 subjects with an even distribution of subjects per group. As little as 12 subjects was reported in one study with only two equal groups of 6 subjects (Elmer, Hahn, McAllister, Leong, & Martin, 2012). A large proportion of the literature examining eccentric training modalities have involved untrained subjects as highlighted in a systematic review (Douglas et al., 2017). Improvements in strength and training induced morphological adaptations to the muscle is much more limited in previously well-trained subjects, such as strength athletes, compared to those with no RT experience (Häkkinen, 1994). One reason that can account for the popularity of untrained subjects is that the magnitude of adaptation will be greater and thus have greater statistical significance. The average intervention duration reported in the systematic review of the 40 studies included was 9.8 weeks (range 5-20) and an average weekly training frequency of 2.9 sessions per week (range 2.0 to 4.2).

2.1.2 Data Collection

The knee extensor muscles have been reported many times in the concentric and eccentric training intervention literature (Roig et al., 2009). Isokinetic devices that allow for control of angular velocity of movement are frequently reported; these are typically seated devices in which the subjects leg is attached to and controlled at a constant speed. Despite a greater proportion of the studies, there are known differences between upper and lower limb muscle morphology (Candow & Chilibeck, 2005). Another factor to consider is the speed of the limb movement which can also influence the magnitude of adaptive response. Studies using the isokinetic dynamometer have reported tempos of 30 and 60 degrees per second. It is apparent that the movement velocity during eccentric actions is an important element of the training stimulus. In a study of eccentric squat training at fast (< 1 second duration) and slow (4 seconds) durations, maximal smith machine half squat was found to increase by 14.5% for the fast group and 5.4% for the slow group (Stasinaki, Zaras, Methenitis, Bogdanis, & Terzis, 2019).

2.2 Influence of loading modality on neuromuscular function.

2.2.1 Neural Factors

Engaging in an appropriately designed RT programme will elicit neural adaptations which originate in the central nervous system. The ability to fully activate the agonist muscle during a specific movement, and to better coordinate the activation of relevant muscles for a given task are examples of changes that can be expected by engaging in resistance exercise (Hedayatpour & Falla, 2015). This in turn will result in a greater net force for a given movement when applied at the optimal direction during a movement. Neural adaptations to training and the improvement in muscle force are known to be dependent on the type of muscle contraction executed (Hedayatpour & Falla, 2015). Motor unit recruitment and firing frequency are the two primary mechanisms which influence the electrical activity of muscles within the active motor units and the tension that they develop (Bohannon, 1983).

Motor unit recruitment refers to the successive activation of the same, and additional motor units to accomplish an increase the contractile strength of the muscle. Generally, the motor units are recruited in order of size from smallest to largest as the contraction strength increases (Henneman, Somjen, & Carpenter, 1965). Data from one study suggests that during eccentric contractions there is a much less pronounced recruitment of motor units which may be attributed to better utilisation of elastic energy as tension develops during the lengthening phase (Moritani, Muramatsu, & Muro, 1987). In a study examining the plantar flexor muscles during lifting and lowering of loads equivalent to 15 to 20 percent of maximal voluntary contraction (MVC), only 15% of the soleus, and 50% of the gastrocnemius were found to be recruited during the muscles lengthening phase (Nardone, Romano, & Schieppati, 1989). The motor units recruited were those with high thresholds, and their activation was brought about by the de-recruitment of motor units active during the concentric phase of movement. Results from another study by the same author also found that voluntary triceps surae lengthening was accompanied by selective recruitment of motor units innervating fast muscle fibres (typically larger) and the decruitment of slow fibres and motor units (Nardone & Schieppati, 1988). These results, when taken together, indicate a reverse order of recruitment during eccentric contractions compared to concentric actions which follow the size principle to modulate force production during maximal efforts. During maximal eccentric contractions, other neural mechanisms appear to be more responsible in achieving higher muscle forces.

Firing rate, which is also termed rate coding, refers to the discharge of action potentials of motor units that are already active and plays a part in modulating the magnitude of muscle force produced (Enoka & Duchateau, 2017). The frequency of firing increases in proportion to the greater demand of the muscle to develop tension and thus firing happens continuously until the maximum force is achieved (Bohannon, 1983).

A study examined the firing rate of triceps brachii during voluntary rhythmic dynamic contractions (3 seconds concentric, 3 seconds eccentric at 40 degrees per second) at the highest intensity that the subject could exert at submaximal intensities (Del Valle & Thomas, 2005). Mean firing rate was found to increase proportionately with intensity for both contraction types, however, at each submaximal intensity, mean eccentric values were significantly lower than concentric. Contrary to these findings, firing rate was found to remain constant for the tibialis anterior muscle during the eccentric phase of movement and increase progressively from the start to the end of the concentric phase (Pasquet, Carpentier, & Duchateau, 2006). Slower firing rates of high threshold motor units were reported following eccentric overload RT of the knee extensors at intensities equivalent to the pre-determined maximal voluntary contraction (Balshaw, Pahar, Chesham, Macgregor, & Hunter, 2017). It is thought that the increase in firing rate during CON actions is to accommodate the lower force producing capacity of the muscle at shorter lengths (Enoka & Duchateau, 2017). Mean firing rates during maximal isometric contractions are similar to those found during maximal concentric actions (Del Valle & Thomas, 2005). In summary, lower firing rates occur during forceful eccentric contractions, perhaps because of the lesser metabolic demand and also to minimise muscle damage, thus serving as a protective mechanism.

2.2.2 Muscle Architecture Changes

In addition to neuromuscular adaptations, mechanical tension induced by heavy RT can elicit a number of acute responses and chronic adaptations for the body's systems. These include the metabolic, cardiorespiratory, hormonal and molecular systems, all of which contribute to the magnitude of force production and the ability to use these systems without early fatigue during competition performance (Douglas et al., 2017).

Muscle cross sectional area (CSA) can be defined as the total area of a transverse section of a muscle (Schantz, Randall-Fox, Hutchison, Tydén, & Åstrand, 1983). The primary mechanism attributed to a greater muscle CSA from training is an increase in the size of the existing fibres rather than the number of fibres in the muscle (Goldspink & Harridge, 1992). Mechanical tension, exercise induced muscle damage, and metabolic stress are three factors that mediate hypertrophic signalling in response to training (Douglas et al., 2017).

A compelling body of evidence supports that a muscle stretch combined with overload, is characterised by greater microlesions and mechanical tension compared to concentric and isometric contractions and thus, a more potent stimulus for muscle growth (Hedayatpour & Falla, 2015). The higher mechanical tension and muscle damage from eccentric training make this method superior because it induces a mechanochemical signal to upregulate anabolic molecular and cellular activity and enhance protein synthesis (Douglas et al., 2017). There appears to be a better relationship between eccentric loading on type II muscle fibre increases compared to concentric loading protocols, especially with higher intensities and velocities (Franchi et al., 2017). It is interesting and important to note that muscle CSA increases are located at different parts based on the contraction type that is performed. For the quadriceps muscle group, eccentric loading was found to increase CSA of the distal portion of the muscle compared to concentric RT training that elicited greater mid-belly increases (Seger et al., 1998).

The pennation angle (PA) of muscle is the angle between the fascicle's orientation and the tendon axis; this angle plays a significant role in the force production and CSA of skeletal muscle. The effect of an increased PA after training has been considered detrimental because of the reduced force transmission from muscles to tendons, thereby decreasing the tension generated per physiological cross-sectional area (Kawakami, 2005). Despite this loss of resolved force in the line of the tendon, within a certain muscle volume more contractile machinery can be packed together leading to an increased CSA and capacity to produce force (Kawakami, Abe, & Fukunaga, 1993). This is achieved by the addition of more sarcomeres in parallel arrangement, leading to a greater potential for actin and myosin head interaction; more force per cross bridge is related to the net force produced by the muscle (Fitts, McDonald, & Schluter, 1991).

Upper and lower limb RT has frequently been found to elicit increases in PA as a result of the muscle hypertrophy (Farup et al., 2012). Vastus lateralis PA was found to increase by 30% following 10 weeks on concentric RT leg press training (Franchi et al., 2014). An 11% change in PA of the same muscle was reported following eccentric RT using an isokinetic dynamometer (Guilhem, Cornu, Maffiuletti, & Guével, 2013). In a more recent review article, it was reported that for most eccentric RT studies, small if not no significant changes in PA are found compared to concentric RT modalities (Baroni, Pinto, Herzog, & Vaz, 2015). It appears that the concurrent increase in fascicle length (FL) from eccentric RT organises the sarcomeres in series, thereby hindering the ability for greater PA through parallel arrangement. Serial arrangement of sarcomeres as an adaptation to eccentric RT can serve as a protective mechanism when considering the length-tension relationship. As a muscle is lengthened the force generated decreases and any further lengthening of weak sarcomeres will result in them becoming so long that there is no myofilament overlap, causing them to pop to a long length (Morgan, 1990). This makes performing eccentric contractions at long muscle lengths particularly damaging to the muscle fibres.

Changes to a muscles fascicle length (FL) is another adaptation to RT modalities. Markedly greater increases in FL are associated with eccentric RT compared to other training modalities. A more than twofold increase in vastus lateralis FL was reported following eccentric RT (+12%) compared to concentric RT (+5%) using a modified leg press machine controlling performance of only one of the two contractions (Franchi et al., 2014). The mechanism of greater observed changes in FL with eccentric RT can be theoretically explained by the addition of sarcomeres in series; the smaller changes with concentric RT explained by increases in parallel arrangement. The most notable effect of more sarcomeres in series is an increase in contraction velocity, allowing for more powerful force production at longer muscle lengths (Vogt & Hoppeler, 2014). Increased length of muscle fibres has long been established a mechanism for post-natal growth of mammalian muscle (Goldspink, 1968). From a hypertrophy perspective, evidence does suggest that increases in CSA is linked to elongation of fascicles (Franchi et al., 2014). The authors reported an increase in anatomical CSA over a large portion of the muscle (central and distal regions) highlighting that sarcomeres form in series over a large portion of the muscle belly.

2.3 Maximal dynamic strength

2.3.1 Methods of testing

A variety of methods exist to assess an individual's maximal strength capacity. The one repetition maximum (1RM) is often considered the 'gold standard' test for assessing isoinertial strength capacity in laboratory and non-laboratory environments (Levinger et al., 2009). Lifting a maximal weight while maintaining correct form is a valid and reliable means to evaluate the effectiveness of a training intervention for a variety of populations (Ribeiro et al., 2014; Seo et al., 2012). Laboratory-based tests are typically performed using an isokinetic dynamometer device whereby the velocity of movement is controlled by the machine and the subject is instructed to exert maximally against a moving lever arm. Individuals isoinertial test scores will be somewhat limited by their experience and skill level of performing a certain strength movement (Abernethy, Wilson, & Logan, 1995).

2.3.2 Eccentric strength changes

The magnitude of eccentric strength gains within a substantial body of literature has varied between 9% and 59% increases from pre to post intervention (Baroni et al., 2015). Training volume and intensity of the studies varies substantially thus making it hard to draw strong conclusions as to what is most optimal. A review article reported that 3-5 sets of eight eccentric repetitions at an intensity of 100-120% 1RM was found to elicit the highest strength gains (Baroni et al., 2015; Guilhem et al., 2013). A trend exists towards greater eccentric strength gains following eccentric RT, with isometric and then concentric strength improving to a lesser degree (Higbie et al., 1996; Vikne et al., 2006). An early study examining eccentric elbow flexor strength reported a 16% eccentric strength increase after eccentric RT compared to a 7% with concentric RT, further supporting contraction type specificity (Komi & Buskirk, 1972). Contrary to these findings, eccentric RT of the rotator cuff muscles was found only to improve concentric strength during a functional test (Ellenbecker, Davies, & Rowinski, 1988). The test, markedly different from conventional strength tests, involved three maximal speed tennis serves which could explain the difference among results. It appears that eccentric RT at faster speeds (180° s^{-1}) is superior to slower speeds (30° s^{-1}) when assessing post-intervention elbow flexor isokinetic peak torque (Farthing & Chilibeck, 2003).

2.3.3 Concentric strength changes

A systematic review revealed that concentric RT was the preferred training modality to obtaining greater concentric strength, further supporting the specificity of strength gains in relation to contraction mode (Morrissey et al., 1995; Roig et al., 2009). Concentric strength gains between 14% and 53 % have been reported following concentric RT programmes when measured as MVC on an isokinetic dynamometer device (Colliander & Tesch, 1990; Hortobagyi et al., 1996). Both of these studies were matched for contraction speed (60°/s) and duration (12 weeks of 3 sessions) with only volume and intensity differing between them; 4.8 sets of 12 repetitions and 5.3 sets of 10 repetitions. The findings suggest that in order to improve concentric strength, fewer repetitions is most advantageous (Hortobagyi et al., 1996). Fast eccentric RT was found to improve concentric elbow flexor strength (MVC) by 23%, compared to fast concentric RT which elicited a 1% increase highlighting the influence of contraction velocity when the intensity is equal (Farthing & Chilibeck, 2003).

2.3.4 Coupled contraction strength tests

When measuring strength as a repetition maximum or series of repetitions, both contraction types when trained in isolation have been found to mediate strength gains (Colliander & Tesch, 1992; Kaminski, Wabbersen, & Murphy, 1998). When the intensity is similar, no significant differences in total strength can be expected from eccentric RT or concentric RT, as stated in a meta-analysis review comparing 1RM test results (Roig et al., 2009). In the study of Ben-Sira, Ayalon, & Tavi (1995), no significant differences in 1RM strength was found between eccentric RT and concentric RT groups when training intensity was set at 65% 1RM and increased 5% every two weeks. When training with eccentric overload at 138% of concentric maximum, a 20% improvement in post-test leg press 1RM was found compared to 13% for the group that trained eccentrically at 100% concentric 1RM (English et al., 2014). The same meta-analysis by Roig et al. (2009) reported statistically significant greater increases in 1RM strength when the intensity of eccentric RT is higher than that of concentric RT. Back squat and bench press 1RM were used as a testing modality for one study which compared progressive eccentric overload training at 100-121% 1RM, and traditional RT 52.5-75% 1RM (Yarrow et al., 2008). Similar increases in strength were found between both groups for the back squat (approx. 22%)

and bench press (approx. 10%) and thus, no significant difference was reported. The authors reported inconsistency with their strength results with other literature that had examined eccentric overload training. This study was one of the first to use large muscle group, multi-joint strength tests, demanding greater skill level and technical execution, which could be the reason for the discrepancies.

Table 1. Pre- and post-testing characteristics for the traditional (TRAD) and eccentric enhanced (ECC+) training groups, adapted from Yarrow et al. (2008).

	Body mass (kg)		Body fat (%)		Chest press 1RM (kg)		Squat 1RM (kg)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TRAD	78.8 ± 2.9	78.5 ± 2.7	19.5 ± 2.1	19.9 ± 2.1	76.9 ± 4.4	84.7 ± 4.8*	101.5 ± 7.6	127.3 ± 7.1*
ECC+	81.1 ± 3.0	82.1 ± 3.2	19.5 ± 2.5	19.8 ± 2.3	75.5 ± 4.9	82.3 ± 5.0*	102.7 ± 4.6	121.8 ± 5.8*

Data are mean ± SE.

*Different from corresponding pretesting value ($p < .05$).

Pre = pre-testing Post = post-testing

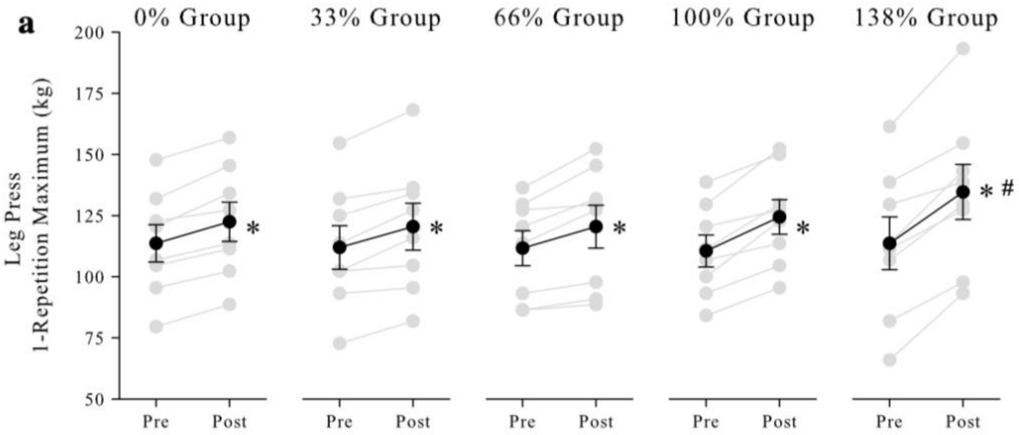

Figure 1. Pre to post leg press 1RM strength after eight weeks of training with a constant concentric load and accentuated eccentric load (100-138% concentric 1RM). * = significant difference from pre to post test (*p* < .05). # = significantly different from 0, 33, and 66% training groups, adapted from English et al. (2014).

2.3.5 Changes in dynamic strength following a detraining period

An expected loss in dynamic muscle strength can be expected following detraining for a variety of populations including sedentary adults, old aged adults and children (Faigenbaum et al., 1996; Tokmakidis, Kalapotharakos, Smilios, & Parlavantzas, 2009). A short-term detraining period of 4 weeks was found to significantly decrease maximal bench press strength by nine percent (17% increase was found after 16 weeks heavy RT) for Basque ball players with a mean training age of 12.5 years (Izquierdo et al., 2007). A similar study examining the bench press exercise found bench press 1RM to significantly increase after six weeks of training; after six weeks detraining, only the eccentric RT group lifted greater than baseline load, with the concentric RT returning to baseline (Coratella & Schena, 2016). Studies have reported a smaller loss in dynamic strength among previously untrained subjects. Housh, Housh, Weir, & Weir (1996) found that increases in dynamic constant external RT after eight weeks of training were maintained across eight weeks of detraining. Similarly, bench press 1RM was retained after six weeks of detraining which further supporting that recreationally trained subjects can maintain or suffer a small loss of strength after training cessation (Kraemer et al., 2002).

2.3.6 Summary

Taken together, these findings suggest that the specificity of training is important when aiming to increase dynamic strength for that muscle action. Eccentric training at faster speeds is most optimal to increase eccentric strength; concentric RT at higher intensities and fewer repetitions is most optimal. Concerning dynamic strength performance, a variety of factors must be considered when comparing the magnitude of changes as a result of detraining, including the training age of the subjects, and programme factors such as intensity and duration.

2.4 Maximal isometric strength

2.4.1 Methods of testing

During an isometric strength test a force is generated through muscle contraction and exerted against a static object with no movement at the joint. The most common upper-body measures of isometric strength are the hand grip strength test, measured using a handheld dynamometer and the biceps brachii MVC, performed with the elbow braced at 90° to equipment with a torque or force transducer (Gąsior, Pawłowski, Williams, Dąbrowski, & Rameckers, 2018; Rainoldi et al., 1999). As depicted in figure 2, a common set up for testing isometric bench press strength is to place a bench upon a high sampling frequency (1000Hz) strain gauge force plate (Tillaar, Saeterbakken, & Ettema, 2012). Similar testing procedures have shown good reliability (r = .82 to .92) when performing the isometric bench press at elbow angles of 90° and 120° (Murphy, Wilson, Pryor, & Newton, 1995). Contraction duration must be greater than two seconds for each trial in order for subjects to attain true maximal force (Drake, Kennedy, & Wallace, 2017).

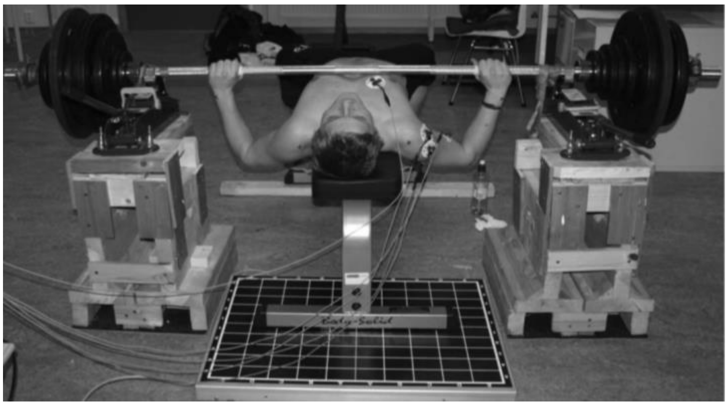

Figure 2. Experimental isometric bench press set up showing a bench placed upon a force plate, adapted from Tillaar et al. (2012).

2.4.2 Improvements with submaximal and maximal training

The literature supports that isometric strength can be enhanced with eccentric RT and concentric RT, however, there are equivocal findings and no prominent assertions as to which is a more optimal modality (Baroni et al., 2015; Douglas et al., 2017). One study reported increases in maximal isometric strength following eccentric RT (+9.7%) and concentric RT (12.5%) at submaximal intensities (greatest intensity: 90% of pretraining maximum), performed on an isokinetic dynamometer (Blazevich, Horne, Cannavan, Coleman, & Aagaard, 2008). Despite both groups significantly increasing isometric strength after 10 weeks, there was no between-group differences in the magnitude of improvement. Pavone & Moffat (1985) reported similar findings whereby isokinetic knee extensor strength increased significantly for eccentric RT and concentric RT training groups. Nevertheless, neither contraction mode was superior when training involved 10 repetitions at 50% 10RM, followed by 75% 10RM, then 100% 10 RM.

2.4.3 Improvements with eccentric overload training

Overloaded eccentric RT has been found to produce similar outcomes to the aforementioned research findings. A study by Johnson et al. (1976) found that overloaded eccentric RT (6 reps, 2 sets, 120% concentric 1RM) statistically improved isometric strength, however, the gain was not significantly different from the concentric RT group (10 reps, 2 sets, 80% 1RM) who also significantly improved. Another study utilised similar loading (concentric RT: 80% 1RM;

overloaded eccentric RT: 145% concentric 1RM) and found isometric force to improve 11% following overloaded eccentric RT and 15% following concentric RT; the differences between groups were not significant (Jones & Rutherford, 1987). One study reported eccentric RT a superior method, however, the leg was completely immobilised in a cast for three weeks reducing the baseline strength by 47% (Hortobágyi et al., 2000). The authors reported greater increases in type IIa and type IIx muscle fibre enlargements following the 12-week intervention, providing evidence for the greater strength gains.

2.4.4 Changes to isometric strength following a detraining period

Skeletal muscle adapts to the functional demands of training, which, when the stimulus is removed, results in muscle detraining and a reduced capacity to perform the same levels of strength as in a trained muscle state (Mujika & Padilla, 2001). The time course of isometric strength loss following an isokinetic knee extensor training programme was reported to be similar to the increases seen from pre to post measurements (Narici, Roi, Landoni, Minetti, & Cerretelli, 1989). The results are consistent with the findings of Tran et al. (2017), who reported an isometric mid-thigh pull decrease of – 5.5% and relative isometric peak force loss of -7.3% after four weeks of detraining; the strength programme duration was seven weeks. Within the literature there appears to be no study that has examined the effect of a detraining period on isometric strength when training either eccentrically or concentrically alone.

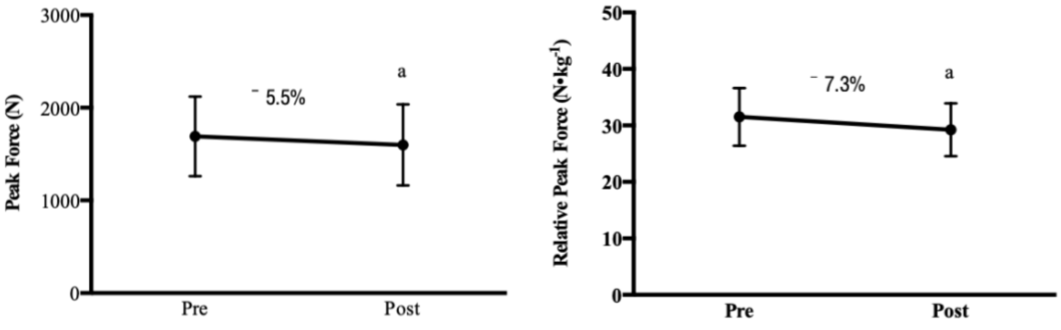

Figure 3. Isometric mid-thigh pull percentage changes for absolute force (N) and relative peak force (N•kg$_{-1}$) after a 4-week detraining period for adolescent surfers, adapted from Tran et al. (2017).

2.4.5 Summary

It appears that isolated concentric and eccentric contractions at varying intensities, including that greater than 100% of maximum, evoke a similar increase in isometric strength. Changes to the muscle's architecture influences the magnitude of isometric strength increase, and thus a programme with a hypertrophic focus may appear superior to a maximal strength programme. Isometric strength can be expected to decrease in a similar magnitude to what it is gained, as reported in traditional RT studies. It is possible that the strength loss following agonist muscle training in isolation is greater than that of traditional training because there is less antagonist muscle activation.

2.5 Muscle cross sectional area

2.5.1 Methods of testing

An important determinant of muscle mechanical function is the muscles anatomical CSA and thus, this is a common measure in strength training intervention studies (Noorkoiv, Nosaka, & Blazevich, 2010). Magnetic resonance imaging (MRI) and computed tomography (CT) can be considered the 'gold standard' method to assess CSA, however, ultrasound (US) is more accessible and less costly (Bierig & Jones, 2009). When measured as intraclass correlation coefficient (ICC), high repeatability (ICC of 0.997) between pre and post intervention intra-day US measurements has been reported (Ahtiainen et al., 2010). A validity test of US against the MRI method revealed an ICC of 0.905; the standard error of measurement was 0.87 cm^2 for the US method as reported by the same authors. The findings support that US is a valid means to detect changes in CSA and that the repeatability of measurements is high.

2.5.2 Improvements in CSA with submaximal and maximal training

Increases in muscle CSA following eccentric RT and concentric RT interventions ranging from eight to twenty weeks has been reported in the literature (Baroni et al., 2015; Roig et al., 2009). It is evident that all muscle fibre types increase in CSA more with eccentric RT than concentric RT when training at maximal voluntary contraction (Hortobágyi et al., 2000). The authors reported that after training, CSA increase of type I, type IIa and type IIx fibres relative to baseline was 10, 16 and 16% for eccentric RT and 4, 5 and 5% for concentric RT subjects.

Significantly greater quadriceps CSA was reported after eccentric RT (+ 6.6%) compared to concentric RT (+5%) following isokinetic training (Higbie et al., 1996). Similarly, isokinetic training (intensity: MVC) was found to only increase significantly following eccentric RT (+4%); the concentric RT group's CSA increased by 3% (Seger et al., 1998). The results from these studies can be explained by the preferential recruitment of type II fibres during eccentric contractions; just one study has found greater type II fibre CSA after concentric RT compared to eccentric RT (Mayhew, Rothstein, Finucane, & Lamb, 1995).

2.5.3 Improvements in CSA with eccentric overload training

Factors that contribute to a greater CSA following eccentric RT include increased muscle fibre recruitment, capacity to produce muscle tension and greater damage to fast twitch muscle fibres (Douglas et al., 2017). One can therefore assume that by increasing the intensity of eccentric RT above maximal, that is above 100% MVC or 1RM, proportional increases in muscle growth will occur. Most of the positive effects of eccentric overload training reported in the literature have used traditional RT protocols. Low intensity-high repetition (25 reps) leg extension training involving a concentric phase 30% 1RM, and an eccentric phase 70% of concentric 1RM was found to elicit a tendency ($p = .092$) towards greater CSA increase compared to those training at only 30% 1RM (Friedmann et al., 2004). High intensity leg extensor training, performed at the 8RM was found to elicit a greater and significant increase in type IIx fibre CSA only for the group that had overload during the eccentric phase (Friedmann-Bette et al., 2010). No significant changes in elbow flexor or extensor CSA was found when an intensity of 120% was employed during a preacher curl and supine elbow extension training intervention; the concentric phase was 75% 1RM for both groups (Brandenburg & Docherty, 2002). The subjects were reported to be actively involved in RT programmes which may have explained the non-significant increase in CSA.

Table 2. Distribution of muscle fibre types (%) before and after six weeks of knee extension exercise, adapted from Friedmann-Bette et al. (2010).

Fibre type	CON/ECC+			CON/ECC		
	25%	Median	75%	25%	Median	75%
I						
Before	38.5	50.7	56.6	25.9	40.2	54.8
After	33.3	45.7	57.9	30.5	39.4	51.8
II A						
Before	30.5	34.7	37.2	31.6	47.1	51.0
After	28.0	37.7	44.5	37.2	50.7	58.3
II X						
Before	7.7	9.6	26.9	4.0	11.1	20.3
After	5.1	13.6	20.4	7.3	12.1	15.1

CON/ECC+ = concentric-eccentric overload CON/ECC= concentric-eccentric

2.5.4 Changes to muscle CSA following a detraining period

The effects of detraining on muscle fibre properties has been reported for some time in the literature. During the 80’s, a study found that 12 weeks of detraining following high intensity strength training resulted in a significant decrease in mean areas of slow and fast twitch muscle fibres for males accustomed to strength training (Häkkinen, Alén, & Komi, 1985). One study suggested that changes in CSA from detraining have a similar time course to those of training; daily percentage comparisons revealed a 0.14% increase per day with 60 days of training and 0.10% decline during the 40-day training cessation (Narici et al., 1989). Fast-twitch type IIb fibres of the quadriceps were found to increase in CSA by 18% following 12 weeks of training and decrease by 12% after 10 weeks in the study of (Houston, Froese, Valeriote, Green, & Ranney, 1983). This is indicative of a slower CSA loss compared to the findings of Narici et al. (1989). Losses in knee extensor CSA after 10 weeks of detraining were not statistically significant, and the loss was also found not statistically different from baseline values for both subjects that trained concentric-only or eccentric-only (Blazevich, Cannavan, Coleman, & Horne, 2007). The detraining changes between groups did not reach statistical significance. Contrary to this finding, isolated eccentric RT increased chest circumference from baseline to post-test but not for concentric RT; after detraining only the eccentric RT group maintained a circumference above baseline with the concentric RT returning to baseline (Coratella & Schena, 2016).

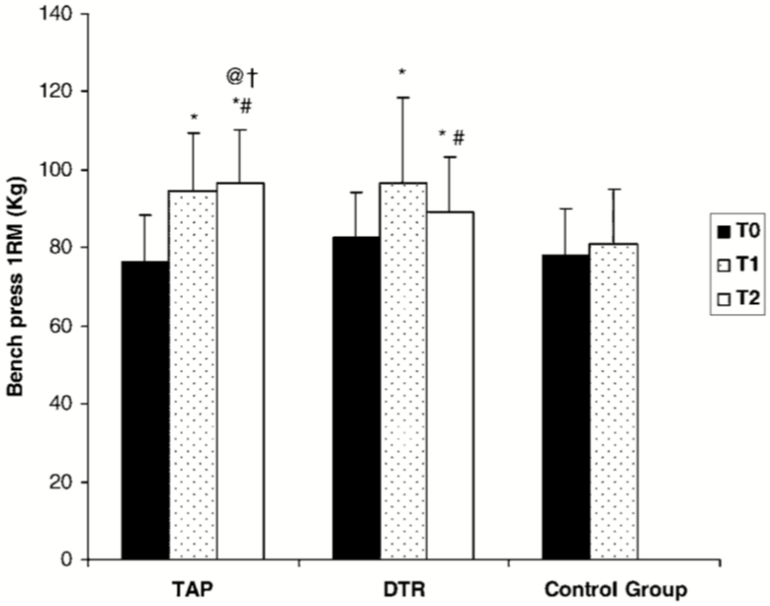

Figure 4. Changes in bench press strength at baseline (T0), after 16 weeks of heavy resistance training (T1) and after 4 weeks of either a tapering (TAP) or detraining (DTR) period (T2). * *p* < .05 from timepoint T0. # *p* < .05 from timepoint T1, adapted from Izquierdo et al. (2007).

2.5.5 Summary

Collectively, the findings from these studies suggest that eccentric loading at an intensity greater than the concentric maximum is superior to lifting weights at the same relative intensity when aiming to increase CSA. Fewer repetitions with eccentric overload may be more favourable when aiming to increase CSA. Upper and lower extremity differences in CSA gains have been found when overloading the eccentric phase, and thus must be considered from an injury prevention viewpoint. Detraining will inevitably cause muscle atrophy; however, the magnitude depends on the trained status of the subjects, the duration of training cessation and the intensity of the training programme. Eccentric overload training of the upper extremity musculature can be considered better at maintaining muscle size following a detraining period.

3 RESEARCH QUESTIONS AND HYPOTHESIS

The aim of this research was to investigate the difference in absolute dynamic and isometric muscle strength, in addition to cross sectional area changes of the triceps brachii muscle group, between males that trained either with eccentric overload or concentrically. The second aim was to compare the changes in these variables with training (pre to post) and also training cessation (5 weeks of no RT) and see if there were any relationships between these changes.

Question 1: Will eccentric RT be superior to concentric RT when aiming to increase dynamic 1RM bench press strength?

Hypothesis: Yes, eccentric training will elicit greater increased in dynamic strength.

Rationale: Meta-analysis results revealed significantly greater increases in total strength for subjects that trained with a higher eccentric intensity than concentric. Furthermore, when the intensity of the two contraction types are comparable no significant differences in total strength was observed, as reported in the same analysis (Roig et al., 2009). Leg press 1RM was found to increase more with an overloaded eccentric phase in one study, indicating that strength gains are dependent on training intensity (English, Loehr, Lee, & Smith, 2014).

Question 2: Will eccentric training evoke a greater change in triceps brachii CSA than concentric trained subjects?

Hypothesis: Yes, eccentric training will bring about a greater change in CSA.

Rationale: Despite the muscle shortening during the eccentric bench press movement, greater activation and mechanical tension with the movement will elicit a greater change. In addition, type IIx fibre CSA was found to increase more when the eccentric phase was overloaded compared to performed at the same intensity as the concentric phase during traditional RT (Friedmann-Bette et al., 2010). Significant increases in CSA only occurred among the eccentric RT subjects and not for the concentric RT subjects when training at the same intensity (maximal isokinetic) in the study of (Seger, Arvidsson, & Thorstensson, 1998). Overloaded eccentric training is therefore hypothesised to increase CSA to a greater extent.

Question 3: Will differences between groups exist following the 10-week training?

Hypothesis: Yes, there will be a significant difference between post-test scores if there are no significant differences at baseline (pre-test). Eccentric RT will increase CSA and dynamic strength more than concentric RT; there will be no difference in post-test isometric strength.

Rationale: A meta-analysis by Roig et al. (2009) stated that eccentric RT at high intensities is related to better increases in total strength than concentric RT. Also, no differences in isometric strength can be expected after training eccentrically or concentrically at equal or different intensities. Finally, increased recruitment, tension-generating capacity and damage to fast twitch muscle fibres with eccentric RT exerts a unique influence on the hypertrophy of fast twitch type IIa and type IIx fibres (Douglas, Pearson, Ross, & McGuigan, 2017).

Question 4: Will detraining cause a greater loss in strength and CSA for the concentric group than for the eccentric group?

Hypothesis: Yes, losses will be greater for the concentric training group.

Rationale: Similar to the findings of Coratella and Schena (2016), dynamic strength will decrease closer to baseline for the concentric group with the eccentric group being able to maintain strength better. Because no difference between groups is hypothesised for isometric strength, the decline associated with detraining will be similar and not statistically different. Concerning CSA losses, it is hypothesised that the size loss will be greater for the concentric group and that only the eccentric group will remain above baseline as similarly reported in the study of Coratella and Schena (2016).

4 METHODS

4.1 Subjects

A total of 17 males recruited from the local area, volunteered to participate in this study. Subject characteristics are displayed in Table 3. Each had a minimum of one year's upper extremity RT experience, were physically active and reported no injuries at the time of testing. Prior to any study related testing procedures, subjects who had agreed to take part were invited to an introduction talk lead by the university researchers and students. Here they received information concerning the purpose of the research and the required expectations from them taking part. Engaging in their own RT was not permitted, however, general physical activity exercises and endurance exercise was.

Table 3. Subject characteristics expressed as (mean ± standard deviation)

	n	Age	Height (cm)	Body mass (kg)	BMI (m$_2$ / kg)
All	17	31.1 ± 4	178.7 ± 5.5	78.4 ± 10.4	24.3 ± 3.4
Eccentric	9	30.9 ± 4.9	179.2 ± 4.5	79.2 ± 11.2	24.6 ± 3.4
Concentric	8	31.4 ± 3	178.1 ± 6.7	77.4 ± 10.2	24.0 ± 3.6

Training and testing sessions were conducted at the Neuromuscular Research Centre, Jyväskylä, Finland. Written informed consent was obtained from each subject along with a completed health-screening questionnaire. Those with a history of musculoskeletal injury, or neurological disorders of the upper extremity were excluded from the study. The training and testing protocols adhered to the World Medical Association Code of Ethics (Declaration of Helsinki, 2003) and were approved by the University of Jyväskylä Ethical Committee.

4.2 Study Design

An individual repeated measures design was used to determine the muscle size and strength qualities at each time point. The first week of the study was a familiarisation period, later followed by a control week, and 10 weeks of their respective training (figure 5). A five-week detraining period concluded the study. Measurements were taken during the control week, week one (pre-test), week ten (post-test) of training, then after the five-week detraining period. Subjects were randomly assigned to their respective isokinetic training group; either overloaded isolated eccentric (ECC+) RT or isolated concentric (CON) RT.

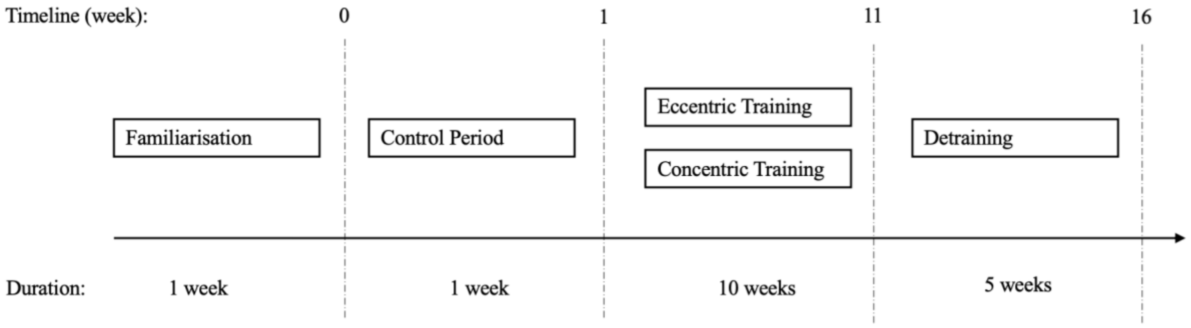

Figure 5. Study design timeline.

4.3 Procedures

A standardised warm-up was performed at the start of each session under the one of the student's supervision (table 4). Heart rate was raised by pedalling on a cycle ergometer for five minutes followed by a series of low-intensity exercises targeting the upper-extremity musculature that were to be used in the isokinetic bench press training.

During the familiarisation week's first session, the subject's anatomical landmarks needed for the ultrasound were found and noted. The midpoint between the acromion and olecranon process determined the triceps brachii marker. Firstly, the distance between the two landmarks was found then 50% of this value was found by moving the tape measure proximally towards the acromion. The tattoo or marker was placed on the muscle belly.

Table 4. Standardised warm-up protocol

Exercise	Sets	Load (kg)	Reps / Duration
Cycle ergometer pedalling	1	-	5 minutes
Arm circles forwards	2	-	15
Arm circles backwards	2	-	15
Arm circles back to front	2	-	15
Shoulder press	2	1.25 / 2.5	15
Lateral shoulder raises	2	1.25 / 2.5	15
Anterior shoulder raises	2	1.25 / 2.5	15
Bent over rear shoulder raises	2	1.25 / 2.5	15
Rotator cuff abduction	2	Elastic	15
Rotator cuff abduction	2	Elastic	15
Scapula push-ups	2	-	15
Push-ups	2	-	5 – 10

4.3.1 Isokinetic bench press training

A custom-made isokinetic barbell machine specifically made for the university was used for measurements and training. The subjects lied down on the bench, positioning their feet on the edge in a knees-bent position. The little finger and head position were the same for each trial performed in the study; tape with numbers on was attached to the bar and edge of the bench. Furthermore, the upper and lower position of the bar were determined before any training took place; the upper position was with an elbow angle of 120 degrees and the lower position, approximately 5 centimetres away from the chest. The machine was controlled by a researcher who gave verbal encouragement in an equal manner to each subject. Barbell velocity was set at 0.2 m/s with a 2000ms pause in the pre-determined, individual upper and lower positions.

Figure 6. The custom-made isokinetic bench press machine with the operating panel positioned in front.

Subjects each completed two sets of three repetitions on the isokinetic bench press during the first session of the familiarisation week; the contraction type was eccentric. Concentric contractions were performed during the second session of the familiarisation week for the same number of sets and repetitions. The following week for the control measurements, two sets of two repetitions were performed eccentrically then the same concentrically

From weeks one to ten, the subjects trained twice per week on the isokinetic barbell machine, performing either eccentric or concentric contractions depending on which group they were assigned to. The volume and intensity changed during the weeks and are displayed in table 5.

Table 5. Overview of the isokinetic bench press training volume

	Sets	Reps	Day Reps	Week Reps	Contraction type
Familiarisation S1	2	3	6	12	ECC+
Familiarisation S2	2	3	6	12	CON
Control	2	2	8	8	Both
Weeks 1-3	3	3	9	18	TGC
Weeks 4-7	4	4	16	32	TGC
Weeks 8-10	3	4	12	24	TGC

CON: concentric, ECC+: eccentric S1: Session one, S2: Session 2, TGC: training group contraction

4.3.2 Smith Machine Bench Press

A one repetition maximum (1RM) test was performed after the isokinetic barbell machine for the familiarisation, control and measurement weeks. All trials were performed using a smith machine (Kraftwerk, Finland). The test followed normal 1RM testing procedures previously reported in the literature (Faigenbaum, Milliken, & Westcott, 2003). Tape markers were placed on the bar to ensure the hand position remained consistent during each measurement. The head position was also controlled by tape placed on the side of the bench and eye position used when looking at the ceiling. The researchers assisted the subjects in unloading the bar from the pegs, after which instructions and verbal encouragement was given during the movement. The bar was required to touch the chest for one second before the concentric phase was attempted.

Figure 7. Set-up for the 1RM smith machine test.

4.3.3 Isometric Bench Press

Peak force (N) was determined via a maximal horizontal push test against a stationary bar, collected on a bench (Kraftwerk, Finland). Subjects lied supine on the bench with their feet positioned on the bench, an elbow angle of 90 degrees and the head and hands in the same place for each trial. Three trials were performed with approximately one-minute rest period between trials, during which the Subjects remained lying down. Verbal encouragement was given by the student operating the computer. The computer software used (Signal version 4.10, Cambridge Electronic Design Ltd.) produced numerical data which was inputted into an excel spreadsheet (Microsoft Excel 2019 Version 16.0). Raw and filtered data was also obtained.

Figure 8. Isometric Bench press set-up

4.3.4 Ultrasound

All CSA data was obtained using a B-mode axial-plane ultrasound machine (model SSD-α10, Aloka Co Ltd., Tokyo, Japan). Panoramic ultrasound measurements of the triceps brachii long head and lateral head were performed in the morning (between 6am and 10am) of the measurement day. Each measure was taken of the subject's right triceps brachii as they laid prone on a bench with the arm at a 90-degree angle to the body; the forearm was perpendicular to the ground. A supporting piece of foam was positioned under the right elbow for comfort and prevention of any movement during the analysis. For those subjects who did not get a tattoo point in the familiarisation week, a tape measure was used to determine the midpoint of the triceps brachii in the same way as previously discussed.

A line was drawn around the arm which intersected with the tattoo/marker point. The probe (10 MHz linear-array, 60mm width, 23Hz sampling frequency) was placed on this line and two more lines were drawn the same width of the foam pad surrounding the probe; this was to provide guidance when moving the probe to maximise the validity of each measurement.

Before starting the actual measurement, the machine was configured to the subject's own settings including brightness of the measurement. Gel was placed on the end of the probe and then spread over the skin. During the measurement, the probe was moved superiorly around the arm towards the subject's head. Three to five panoramic imaged were obtained and used for the analysis.

4.3.5 Gym Training

The 10-week training programme started after the familiarisation and control weeks, whereby the subjects trained twice-weekly in the university gym. For the first training session, the subjects warmed up then underwent an acute loading protocol which consisted of three sets of four repetitions on the isokinetic bench press machine with a two-minute rest period and the isometric bench press test in which three trials were performed. This acute loading was also performed during the tenth week of training. The gym exercised performed are presented in table 6; these remained consistent for all training weeks; only the volume and intensity changed. From week one to five, three sets of eight to ten repetitions were performed which served as a hypertrophy stimulus. The focus from week six to ten was maximum strength; the subjects performed six to eight repetitions for each exercise. Greater repetitions for the core exercises (Russian twist and back extensions) were performed if the subject could execute the movement with the heaviest weight in the gym (25kg) with sound movement. The load for each exercise was progressively increased if the subject could demonstrate sound lifting technique for the exercise. The gym was supervised by experienced trainers who also judged whether an increase in load was appropriate.

Table 6. Gym training protocol

	Weeks 1-5		Weeks 6-10	
	Sets	Reps	Sets	Reps
Lat Pulldown	3	8-10	3	6-8
Seated leg press	3	8-10	3	6-8
Hip thrust	3	8-10	3	6-8
Knee extension	3	8-10	3	6-8
Biceps curl	3	8-10	3	6-8
Russian twist	3	8-12	3	6-12
Back extension	3	8-12	3	6-12

4.4 Data Analysis

The average peak isometric bench press force was calculated by averaging the three best trials at each measurement timepoint. This value, along with the bench press 1RM values were inputted into a Microsoft Excel spreadsheet for further calculations.

Image-J (National institute of health, USA, version 1.37) software was used for analysing the ultrasound images. The triceps brachii long head and lateral head were analysed separately. The best image obtained from each individual measurement session was used for the analysis. Each image was analysed twice and the average of the two values used for the statistical analysis. The combined CSA was calculated by adding together the lateral and long head values.

4.5 Statistical Analysis

Descriptive statistics for each test were calculated for the both groups using SPSS ® (V.21. Chicago Illinois) software. A two samples (independent) t-test was performed to determine the interaction (time x group) between the groups average test scores at the timepoints: pre, post and detraining. A paired-samples t-test was used to determine within-group differences between pre and post, and post and detraining tests; a non-parametric Willcoxon matched pairs test was used for the data that did not show a normal distribution.

Changes (post minus pre and detraining minus post) were calculated using the absolute, raw data. To determine the difference between group changes (time x group) a two samples (independent) t-test was performed. A Mann Whitney U test was used if the data was not normally distributed. A paired-samples t-test was used to determine within-group differences between the changes for each dependent variable; a Willcoxon matched pairs test was used for the data that did not show a normal distribution. The relationship between changes in strength and CSA was determined using a Pearson's R correlation test and if the change was not normally distributed, a Spearman's p (rho) test was used. The level of significance was set at alpha level $p < .05$.

5 RESULTS

5.1 Absolute training values

Descriptive statistics including the mean and standard deviation for each of the variable test scores are displayed in table 7. The two groups showed similar performance for the post-test 1RM despite the ECC+ group having a lower (7.5 %) baseline group average. Combined triceps CSA was similar at baseline for both groups, with the ECC+ group making superior gains after the ten weeks of training. The proportionate increase for the long head and lateral head was similar and greater than that of the CON group. The mean increase in isometric strength was greater among the CON trained subjects (5 %) than the ECC+ group (2.7%), however, following the detraining period both averages were similar to one another. There were no significant between group effects for each of the measured variables at each measured timepoint as showed in table 7.

Table 7. *Mean and standard deviation values for absolute test values*

Variable	Eccentric group	Concentric group	p-value between groups
	Mean ±	Mean ±	
Dynamic strength (1RM)			
Pre-test	69.33 ± 14.19	74.59 ± 11.90	0.424
Post-test	76.69 ± 12.79*	76.93 ± 11.89	0.968
Detraining	72.94 ± 11.42*	73.18 ± 11.91*	0.966
Isometric strength			
Pre-test	728.11 ± 190.70	698.75 ± 146.03	0.729
Post-test	748.11 ± 126.78	734.00 ± 117.40	0.816
Detraining	705.11 ± 140.49*	704.25 ± 118.36	0.989
Combined CSA			
Pre-test	18.30 ± 3.79	18.30 ± 4.73	1.0
Post-test	20.10 ± 3.69*	18.87 ± 4.56	0.550
Detraining	19.04 ± 3.57*	18.12 ± 4.61	0.651
Long head CSA			
Pre-test	8.54 ± 2.34	8.4 ± 2.14	0.897
Post-test	8.95 ± 2.22*	8.6 ± 2.06	0.738
Detraining	8.72 ± 2.23*	8.21 ± 1.95*	0.626
Lateral head CSA			
Pre-test	9.77 ± 2.00	9.88 ± 2.73	0.925
Post-test	11.14 ± 2.04*	10.25 ± 2.62	0.443
Detraining	10.34 ± 1.76*	9.92 ± 2.77	0.712

*= significant within-group difference between the preceding test. $p < .05$.

Dynamic 1RM strength

A paired samples t-test revealed a significant (t = -6.02, p < .05) within-group difference in strength at pre to post tests for the ECC+ group. A significant difference in strength was found from the same group from post-test to detraining (t = 3.75, p < .01). The CON trained subjects only showed a significant difference in strength between the post-test and detraining measurements (t = 3.310, p = 0.01).

Isometric Strength

A paired samples t-test revealed a significant difference in mean isometric force from post-test to detraining test for the ECC+ training group (t = 3.65, p < .01). The difference between pre- and post-test differences were found not to be significant (p > .05), as for the CON group. Neither the post-test nor detraining absolute values for the CON group were statistically different (p > .05).

Triceps brachii cross sectional area

There was a significant within-group effect of ECC+ training on the combined triceps brachii CSA from pre to post test (t = -8.050, p < .01), and from post-test to detraining test (t = 6.52, p < .01). The differences in mean values for the CON group did not reach statistical significance.

Secondly, a significant within-group difference in triceps brachii long head CSA from pre-test to post test for only the ECC+ group (t = -2.840, p < .05). The difference in mean CSA from post-test to detraining test was significant for the ECC+ group (t = 3.21, p < .05), and for the CON group (t = 2.42, p < .05).

There was a significant difference in lateral head CSA for the ECC+ group from pre-test to post-test (t = -11.264, p < .01), and from post-test to detraining test (t = 5.90, p < .01). The differences in absolute CSA for the CON trained subjects did not reach significance.

5.2 Training induced changes

Table 8 displays the changes from each of the testing sessions. Only pre- to post-test differences between groups were found to be significant for combined, and lateral head triceps brachii CSA (*p* < .05).

Table 8. *Mean and standard deviation values for the change values.*

Variable	Eccentric group	Concentric group	p-value between groups
	Mean ±	Mean ±	
Dynamic strength (1RM)			
Pre to post	7.36 ± 3.66	2.34 ± 14.72	0.376
Post to detraining	-3.75 ± 2.99	-3.75 ± 3.20	0.673
Isometric strength			
Pre to post	20 ± 92.61	35.25 ± 79.00	0.722
Post to detraining	-43 ± 35.32	-29.75 ± 62.73	0.594
Combined CSA			
Pre to post	1.80 + 0.67	0.57 + 1.33	0.028
Post to detraining	-1.05 + 0.48	-0.75 + 1.15	0.503
Long head CSA			
Pre to post	0.41 ± 0.43	0.20 ± 0.56	0.396
Post to detraining	-0.23 ± 0.21	-0.38 ± 0.45	0.375
Lateral head CSA			
Pre to post	1.36 ± 0.36	0.36 ± 0.90	0.008*
Post to detraining	-0.8 ± 0.40	-3.2 ± 0.8	0.139

* significant between groups at the level of *p* <.05

Strength changes in response to training and detraining

A greater increase in 1RM strength was shown for the ECC+ group following 10 weeks of training, however, the difference between groups did not reach significance ($p > .05$). There was no effect of training group on isometric strength changes from pre- to post-test ($t = -0.363$, $p > .05$). There was a significant within-group difference from post- to detraining tests for both groups and strength tests. After five weeks of detraining, the changes for each of the variables between groups were also found statistically non-significant ($p > .05$).

Changes in triceps brachii CSA in response to training and detraining

After the 10-week training intervention there was a significant difference in the combined triceps brachii CSA between the two groups ($t = 0.24$, $p = .028$). Furthermore, a significant between group difference was found for the CSA change of the triceps brachii lateral head (t = 3.079, $p = .008$). Difference between groups for the triceps brachii long head CSA was found to be statistically non-significant.

The change in combined triceps brachii CSA was significant for the ECC+ group from pre-test to post-test ($t = 12.33$, $p < .01$) and from post-test to the detraining test ($t = 16.38$, p < .01). Results also indicate a significant change in CSA for the CON group from pre-test to post-test ($t = 9.563$, $p < .01$) and from post-test to the end of the detraining period ($t = 11.54$, $p < .01$).

For the ECC+ group there was a significant change in triceps brachii long head CSA ($t = 9.598$, $p < .01$) and lateral head CSA ($t = 12.39$, $p < .01$) from pre-test to post-test. After 5 weeks of detraining, there was a significant change in the triceps brachii long head ($t = 12.37$, $p < .01$) and triceps brachii lateral head ($t = 15.20$, $p < .01$) for the ECC+ group.

The CON training resulted in a significant change in long head CSA from pre-test to post-test ($t = 9.84$, $p < .01$) and a significant loss following the detraining period ($t = 11.22$, $p < .01$). Results also revealed a significant within-group change in the lateral head CSA from pre-test to post-test ($t = 8.67$, $p < .01$) and from the post-test to detraining test ($z = -2.52$, $p < .05$).

Muscle strength and CSA change correlations from pre-test to post-test

Figure 9 shows that the CON group had a significant correlation between the change in isometric strength and the change in combined triceps brachii CSA ($r = 0.74$, $p < .05$). The positive correlation was consistent for the lateral head change and isometric change ($r = 0.73$, $p < .05$) however the change in long head CSA was weaker ($r = 0.61$, $p > .05$). There were no significant correlations between strength and CSA for the ECC+ group ($p > .05$).

Muscle strength and CSA change correlations as a result of detraining

The CON group showed a significant correlation between the change in 1RM and the change in lateral head CSA ($r = 0.71$, $p < .05$). Combined CSA change and isometric strength were also significantly correlated ($r = 0.68$, $p < .05$). The lateral head change was significantly correlated with the change in isometric strength ($r = 0.73$, $p < .05$).

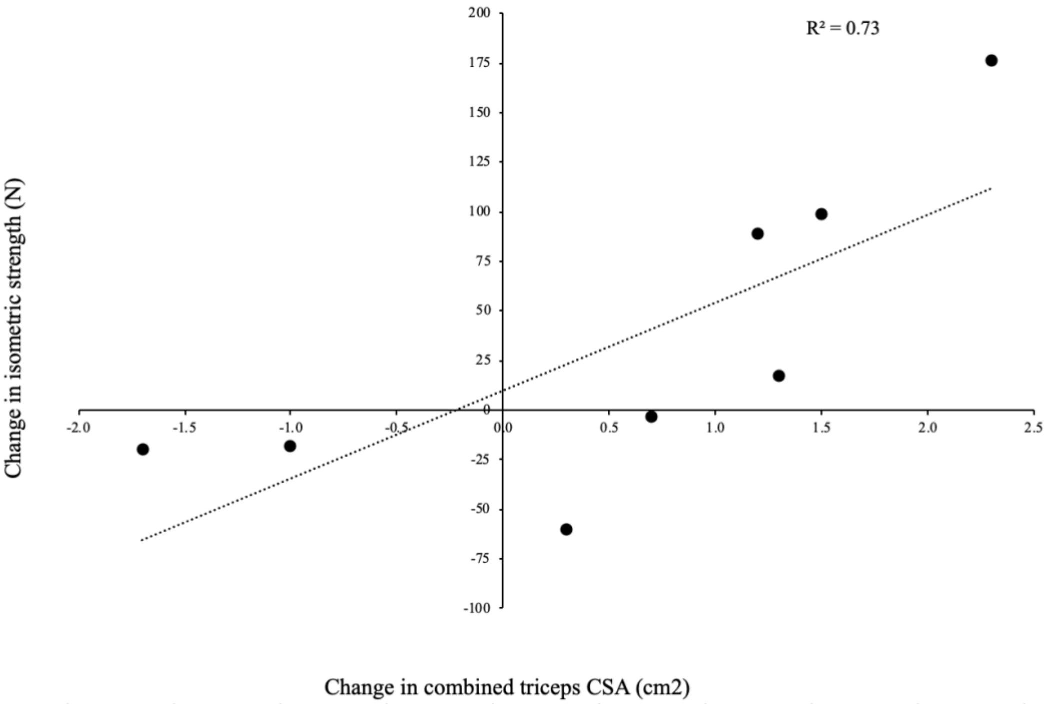

Figure 9. Scatter graph showing the relationship between pre to post isometric and CSA changes for concentric trained subjects.

6 DISCUSSION

The main result of this study was that ECC+ has a better effect on increasing dynamic 1RM strength than CON RT. Results revealed that ECC+ RT is also more optimal at increasing the combined and individual head CSA of the triceps brachii during bench press training. No significant differences between groups for post-test results were found for all variables tested. Significant changes from post-test to detraining were found for all variables, and for both groups, however, between group changes were not significant. This data is novel as it is one of very few studies that used upper extremity musculature to examine the effects of eccentric overload training.

Dynamic Strength

The baseline 1RM measurement obtained at the pre-test was 69.3 kg for the ECC+ group and 74.6 for CON. The difference in baseline strength between groups was not statistically different indicating that the changes occurred as a result of the training programme. This was expected because the only strenuous and physically demanding exercise the subjects engaged in from the start to end of the study was the training programme. Excess sports training would have interfered with the training response and caused additional fatigue thus affecting the capacity to train and perform at maximal intensity.

The ECC+ group significantly increased 1RM from pre-test to post-test, however, the strength increases for the CON group did not reach significance ($p > .05$). This finding is in accordance with the conclusions drawn from a meta-analysis that when the intensity of eccentric RT is greater than concentric RT intensity, a greater increase in dynamic strength can be expected (Roig et al., 2009). When the intensity of eccentric RT is higher than 100% of concentric 1RM, greater strength increases are known to occur than training with a 100% intensity (English et al., 2014). Bench press 1RM improvements were found to be similar in the study of Yarrow et al. (2008) who compared traditional RT and eccentric enhanced (40% 1RM concentric and 100% eccentric 1RM) traditional RT methods. If the eccentric phase was greater than 100% of 1RM there may have been a greater increase in strength found for the ECC+ group. Despite this, identical training intensities have been reported and proven effective at increasing 1RM strength more for eccentric trained (+29%) than concentric trained (+19%) subjects (Kaminski et al., 1998). The duration of the training intervention in the study of Yarrow et al. (2008) was only five weeks which was quite short; the main changes in dynamic strength in the present study may have changed to a greater extent from weeks give to ten, not during the first five weeks.

There was no relationship found between the change in triceps brachii CSA and dynamic 1RM strength as there was found with isometric strength. The correlation between muscle CSA and dynamic strength is well established, however, the consensus that RT induced hypertrophy directly influences force producing capability has recently been examined (Vigotsky, Schoenfeld, Than, & Brown, 2018). The correlation in this study was performed between each subject in the group; within-subject correlations appear to elicit different variations in correlations. The analysis paper by Vigotsky et al. (2018) also stated that how the muscle size is assessed can ultimately affect the strength of the correlation. For example, studies have measured RT induced hypertrophy as muscle thickness, volume, anatomical and physiological CSA, however, these methods do not account for inter- and intra- individual differences in muscle architecture. Stronger correlations between triceps brachii CSA and dynamic strength may have been found in this study if the muscle was examined at the distal end of the muscle. Previous research has found distinct differences in where hypertrophy occurs in the muscle, with distal growth associated with eccentric RT and increased mid muscle anatomical CSA associated with concentric RT (Franchi et al., 2014).

The detraining period was found to elicit a significant difference between post-test and detraining test bench press 1RM for both groups. In addition, the change in 1RM strength was also found significant. When comparing the change in strength, the mean change for both groups was – 3.75 kg which is equivalent to a 5% loss after 5 weeks. The percentage decline of 5% is similar to the 9% reported in the study of Izquierdo et al. (2007), despite differences in the trained status of the subjects. The findings of this study indicate that our subjects suffered only a slight reduction in neuromuscular performance and that the better conditioned Basque players were subject to a greater relative performance decrement. Häkkinen and Komi (1983) found that after four weeks of detraining, weight trained male's 1RM back squat decreased by 10%. This provides evidence that weight trained individuals are perhaps more vulnerable to training cessation than the recreationally trained. The findings of the present study do not agree with those of Lemmer et al. (2000) who found a much slower rate of decline in 1RM strength among young (25 ± 1 years) untrained subjects. The total decline was 8 ± 2% after 31 weeks of detraining with the greatest loss (6 ± 2%) between weeks 12 and 31. The slower initial strength loss up to week 12 may be attributed to the training intervention which did not include contractions performed in isolation, nor with eccentric overload. Furthermore, the 1RM leg extension test started with a concentric shortening of the muscle compared to the bench press which involves muscle lengthening first. This may have some effect on dynamic strength performance when the intensity is maximal.

Isometric Strength

A greater pre to post increase in isometric strength was found for the CON group compared to the ECC+ group, however, there were no significant differences between the changes. The mean increase for the ECC+ group was 20 newtons compared to 35 newtons for the CON group. Blazevich et al. (2008) also examined the effect of isolated contractions on isometric strength with the results similar to those in this study. Their study found a greater increase in leg extensor strength among the CON group (+ 12.5%) compared to the ECC+ group (+9.7%). Similarly, another study found concentric trained subjects increased isometric strength by 15% compared to 11% for those that trained eccentrically (Jones & Rutherford, 1987). There was quite a large training intensity difference between groups in the study of (Jones & Rutherford, 1987) whereby eccentric RT was reported 50% greater. In the present study the intensity difference was approximately 30% greater for the ECC+ group. It is known that high mechanical stress is a required stimulus for strength adaptation, however, the nonsignificant difference between groups suggests that other factors are more involved in mediating strength increases. These include hypertrophy of the agonist muscle fibres, sarcoplasmic activity involving calcium (Ca_{2+}) activity and neural activation, all of which were beyond the scope of this study.

The second finding was that no significant difference between the baseline (pre-test) and post-test absolute values were apparent within each of the groups despite a mean increase in force. The mean change from pre- to post-test was however significant for both groups; the change was not significantly different between ECC+ and CON groups. Roig et al. (2009) stated in their meta-analysis that there are no differences in isometric strength when intensity is similar between eccentric and concentric training. This study utilised a greater intensity for eccentric training and found a smaller mean change in isometric strength compared to the CON group. This finding supports previous research that has found significant isometric strength gains with eccentric RT and concentric RT, despite no one method being superior (Pavone & Moffat, 1985).

Detraining was found to elicit a greater mean decrease in isometric force for the ECC+ group (-43 N) than the CON group (-29.75 N), however the difference between groups was not significant. The strength decline expressed as a percentage is 5.7% for the ECC+ group and 4% for the CON group. The percentage decrease is similar to the 5.5% in mid-thigh pull peak isometric force reported in the study of (Tran et al., 2017). Those authors examined the effects of four weeks detraining after seven weeks of periodized upper- and lower-body RT involving some explosive movements. Although the subjects in this study were older than the mean age of 14 years old in the study of Tran et al. (2017), it is known that people with a lower RT age have a greater capacity for CSA and strength adaptation than strength trained individuals (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2003). The magnitude of RT improvements appears to be lost quickly during detraining which could be influenced by the neuromuscular system. Adaptations to RT in children are principally neural based, not morphological, and in newly trained teenagers and adults the early strength increases are attributed to the neural system (Carroll, Riek, & Carson, 2001). Considering that a similar percentage decrease was found with ECC+ in this study and traditional RT in the Tran et al. (2017) study, concentric muscle contractions appear superior when aiming to preserve isometric force following a detraining period. The neural system may have an important influence on force production after detraining.

There was a significant difference between the post-test and detraining absolute isometric force only for the ECC+ group. Furthermore, this decline resulted in a mean value below baseline which was not found for the CON group. Isometric strength losses have been previously reported to decline at the same rate at which they are gained (Narici et al., 1989). This study found a greater change from detraining for the ECC+ group than for the training period; it is important to note that there was a large standard deviation (92.6 N) for the pre- to post-test change. Maintaining strength after not engaging in RT is attributed to the neural adaptations from training and whether they remain unchanged for the detraining period; this has been suggested because there is a quicker rate of change towards pre-training values for muscle size (Blocquiaux et al., 2020). Following a detraining period, losses in isometric strength have been found highly correlated with decreases in integrated EMG (iEMG) of the leg extensors (Häkkinen et al., 1985). Highly significant correlations between isometric force production and iEMG have been found in the study of (Moritani & deVries, 1978). This finding, taken together with the changes to neural properties may underpin the isometric strength losses for both groups in this study.

Muscle cross sectional area

The combined triceps brachii CSA increased to a greater extent for the ECC+ group when comparing pre-test and post-test absolute values. The mean CSA was 18.3 cm$_2$ for both groups at the pre-test and increased by 9.8% to 20.1 cm$_2$ for ECC+ and by 3.1% to 18.8 cm$_2$ for CON. This difference in mean CSA from training was however only significant for the ECC+ group. This study did not examine fibre type distribution of the triceps brachii, however it has previously been reported that approximately 50% of the triceps brachii is composed of slow twitch and 50% fast twitch fibres (Schantz et al., 1983). Collectively, it can be assumed that each of the fibre types increased in size for both groups, however the magnitude was greater for ECC+ as similarly found in the study of (Hortobágyi et al., 2000). These findings contradict those of Mayhew et al. (1995) who found greater type II fibre CSA following concentric training. The eccentric RT and concentric RT groups in their study trained at the same relative power level, which in this study eccentric loading was greater than concentric.

A significant within-group change from pre- to post-test in all CSA measures (combined, lateral head, long head) was found, however, no significant differences between the two groups. The mean change for each CSA measure was more than twofold greater for the ECC+ group. This supports the consensus that heavier loading involving the generation of high tension levels per motor unit, subsequently causing greater EIMD, has the ability to enhance the hypertrophic training response (Douglas et al., 2017). These results contradict those of Brandenburg and Docherty (2002) who found no significant changes in elbow extensor CSA after overloaded eccentric RT. Perhaps their intervention whereby the muscles were trained until failure, produced overtraining and neural fatigue such that fatigue cumulated and muscle regeneration was not sufficient. A second explanation may be that the subjects were accustomed to RT and that the nine-week programme wasn’t a sufficient duration to increase triceps brachii CSA. For RT subjects, gains in CSA may not start to occur until after eight weeks of heavy RT as found in the study of (Häkkinen et al., 1985). The results of the present study suggest that the stimulus was better suited to increasing CSA for ECC+ subjects, despite being adequate for the CON group also.

For the CON group, the change in combined triceps brachii CSA was found significantly correlated with the isometric bench press strength change from training (*r* = 0.74). These two changes were also significantly correlated for the following the detraining period (*r* = 0.68) further supporting that isometric force is dependent on the muscle size. Interestingly, a weaker correlation was found between the triceps brachii long head (r = 0.61) highlighting that the change in lateral head CSA contributed most to the combined CSA. Anatomical CSA of the elbow flexors and isometric MVC have previously been found to correlate (*r* = 0.637) for similar age subjects in this study (Akagi et al., 2009). Weaker correlations have been reported in other studies. The percentage gains in elbow flexor muscle volume was found significantly correlated (r = 0.527, p = 0.002) with the change in isometric maximum voluntary force as reported by (Erskine, Fletcher, & Folland, 2014). These findings contradict those of Davies, Parker, Rutherford and Jones (1988), who found elbow flexor CSA to increase 5.4 ± 3.8% after isometric training, but this was smaller than, and not significantly correlated with the increase in isometric strength. Perhaps if the training involved dynamic muscle contractions there would have been a stronger correlation. Finally, a muscles whole CSA does not reflect its fibre activation patterns or the velocity-dependent nature of activation and thus, it has been suggested that a weaker relationship between changes in muscle CSA and strength should not be surprising (Higbie et al., 1996).

A greater combined CSA change was found after detraining for the ECC+ group (mean: -1.05) than for the CON group (mean: -0.75), however the CSA was only above baseline (pre-test) for the ECC+ group after detraining. The percentage increase in combined CSA was 9.8% for the ECC+ group which then declined by 5.3% with detraining; the CON group increased CSA by 3.1% and declined by 4% respectively. Narici et al. (1989) reported a similar time course of CSA loss to which it is gained. In this study the CON RT group's CSA had declined below baseline after five weeks detraining indicating a fast loss of muscle size. The ECC+ group on the other hand declined at a slower rate and following detraining and remained above baseline which was also found in the study of (Coratella & Schena, 2016). Understanding muscle size retention and the underlying mechanisms is complex, as stated by Coratella and Schena (2016) who compared concentric and eccentric RT modalities.

Limitations of the research

It is a limitation of the present study that the chest size (either muscle thickness or CSA) was not examined because this was the primary muscle which was used during the bench press training. This study found weak correlations (*r* = 0.071 – 0.191) between the changes in combined triceps brachii CSA, isometric strength and bench press 1RM for the ECC+ group from pre- to post-tests. It would have been interesting to know whether the greater increase in 1RM strength for the ECC+ group was attributed to a greater CSA of the pectorals or whether this increase occurred due to neural changes.

Strengths of the research

One major strength was that the duration of the intervention and the frequency of weekly sessions was in conformity with other studies in this research area. Douglas et al. (2017) reported in their systematic review of 40 studies that the mean intervention duration was 9.8 weeks (range 5-20 weeks) and weekly sessions averaged at 2.9 sessions (range 2.0-4.2). The training stimulus was adequate enough to elicit training related changes. A second strength would be that the subjects were fairly homogeneous when examined for physical characteristics such as age, body mass and BMI. Furthermore, the baseline CSA measurements were similar and baseline strength was comparable between groups.

Conclusion

This study further contributes to a field of research that has had undulating interest since the 1960's. More specifically, the research provides novel findings on overloaded eccentric RT of the upper extremity which has received less attention than isokinetic training of the knee extensor muscles. There were no significant differences between the two training groups for the absolute 1RM strength, isometric strength or triceps brachii CSA, neither for the changes that occurred from training or detraining for the groups. Greater increases in 1RM occur with ECC+, however, the decline is proportional to that of CON. Conversely, CON was found the superior modality in increasing isometric force after training, and this change showed a high correlation with the changes in combined triceps brachii CSA. Both groups showed significant changes in CSA from pre to post, however, the only within-group difference between absolute values was significant for the ECC+ group. Concerning the changes with detraining, losses in CSA below baseline values can be expected if training with concentric RT methods.

Practical applications

The results of this study indicate that ECC+ is an effective training modality at increasing dynamic 1RM and triceps brachii CSA among males that have some RT experience. Additionally, gains in CSA can be better preserved after ECC+ and thus, must be taken into consideration during periodisation planning, particularly mesocycles. The findings suggest that performing eccentric contractions in isolation at intensities greater than 100% 1RM is a suitable alternative to traditional RT and concentric RT methods as this will elicit a greater strength gain within a given time period. Training age and RT experience of the athlete is critical and must not be overlooked. Movements such as the bench press must be performed with sound technique and the athlete must demonstrate competent movement patterns prior to any additional loading beyond their strength producing capabilities. The associated muscular fatigue with eccentric RT must be carefully considered when session planning and must be monitored efficaciously to prevent overtraining syndrome.

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