EFFECT OF TEN WEEKS MAXIMAL ECCENTRIC AND CONCENTRIC RESISTANCE TRAINING ON MUSCLE FORCE IN PHYSICALLY ACTIVE YOUNG MEN IN ISOKINETIC BENCH PRESS

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ABSTRACT

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Introduction. It has been long known that there are differences in eccentric and concentric force productions. Moreover, it has been known that eccentric and concentric resistance training effects differently on force production. This thesis is part of a larger study. The purpose of this study was to investigate how maximal eccentric and concentric resistance training effects maximal eccentric and concentric force production and how maximal eccentric training effects maximal concentric force and maximal concentric training on maximal eccentric force production.

Methods. Participants were randomly selected for two intervention groups: one who trained eccentric only (N=11) and one who trained concentric only (N=12). Participants were physically active young men between 21-36 years old. The total number of participants in this study was 23 (N=23). Isokinetic bench press device was used for the trainings and measurements. Angular velocity of the isokinetic bench press was set to 0.2 milliseconds (ms) and the rest period of the bar was set to 2000 ms. Participants went through a ten-week training program. Sets varied from 2-4 and repetitions from 3-4 depending on the phase of the training protocol.

Results. Maximal eccentric force did not improve in this intervention by maximal eccentric resistance training (ecc/ecc). Decline was -146 newtons ($p = 0.01$; -10.3%) compared to pre measurement. This finding is not according to previous studies. Maximal concentric force increased 12.0%% (109 newtons; $p = 0.00$) among participants in the maximal concentric training group (con/con). Eccentric training had positive influence on maximal concentric force production (ecc/con) (14.1%; $p = 0.03$). Maximal concentric force increased 86 newtons in eccentric training group. Maximal eccentric force did not increase in concentric training group (con/ecc) (-31; -2.4%; $p = 0.69$). Statistically significant difference was observed between ecc/ecc vs. con/con training groups ($p = 0.00$).

Discussion. We hypothesized that maximal eccentric resistance training would be associated to increased maximal eccentric force production. This discovery is contradictory to previous studies. One possible explanation for this peculiar outcome can be that the participants were low responders in which strength does not develop as it normally enhances. Another explanation can be that the stimulus of the training protocol was not high enough to give responses in muscle force. This study gives us support that with maximal eccentric resistance training it is possible to enhance maximal concentric strength performance. In addition, maximal concentric resistance training does not enhance eccentric force production. As a practical application it can be said that sports coaches of different sport disciplines, personal trainers and other professionals of sport and health sciences can utilize the information and results of this study in their practical work for enhancing their athletes' physical performance and wellbeing. It is important to keep in mind that maximal eccentric training does not necessarily develop eccentric force production. Instead, e.g. for cyclists, it can be said that maximal concentric resistance training can enhance their endurance performance.

Key words: muscle force, maximal strength, eccentric, concentric, bench press, isokinetic

TIIVISTELMÄ

Aalto, A. 2020. Kymmenen viikkoa kestävän maksimaalisen eksentrisen ja konsentrisen voimaharjoittelun vaikutus fyysisesti aktiivisten nuorten miesten lihasvoimaan isokineettisessä penkkipunnerruksessa. Liikuntabiologia, Jyväskylän yliopisto. Valmennus- ja testausopin pro gradu -tutkielma. 49 sivua., 1 liite.

Johdanto. On ollut jo kauan tiedossa, että eksentrisessä ja konsentrisessa voimantuotossa on eroa. Lisäksi on tiedetty, että eksentrinen ja konsentrinen voimaharjoittelu vaikuttavat eri tavoin voimantuottoon. Tämä opinnäytetyö on osa laajempaa tutkimusta. Tämän tutkimuksen tarkoituksena oli selvittää kuinka maksimaalinen eksentrinen ja konsentrinen voimaharjoittelu vaikuttavat maksimaaliseen eksentriseen ja konsentriseen voimantuottoon ja kuinka maksimaalinen eksentrinen voimaharjoittelu vaikuttaa konsentriseen voimaan ja kuinka maksimaalinen konsentrinen voimaharjoittelu vaikuttaa maksimaaliseen eksentriseen voimantuottoon.

Menetelmät. Osallistujat valittiin satunnaisesti kahteen interventioryhmään: yksi, joka harjoitteli vain eksentrisesti (N = 11) ja toiseen, joka harjoitteli vain konsentrisesti (N = 12). Osallistujat olivat fyysisesti aktiivisia nuoria miehiä iältään 21–36-vuotiaita. Tutkimukseen osallistui yhteensä 23 (N = 23) henkilöä. Harjoituksiin ja mittauksiin käytettiin isokineettistä penkkipunnerruslaitetta. Isokineettisen penkkipunnerruslaitteen kulmanopeus säädettiin 0.2 millisekuntiin (ms) ja tangon lepoaika 2000 millisekuntiin. Osallistujille annettiin 10 viikkoa kestävä harjoitusohjelma. Sarjat vaihtelivat 2-4 välillä ja toistot 3-4 välillä riippuen harjoitusjakson vaiheesta.

Tulokset. Maksimaalinen eksentrinen voima ei parantunut tämän intervention aikana maksimaalisen eksentrisen voimaharjoittelun (eks/eks) avulla. Alenema oli -146 newtonia ($p = 0.01$; -10.3%) verrattuna ensimmäiseen mittaukseen. Tämä löydös ei ole aikaisempien tutkimustulosten mukainen. Maksimaalinen konsentrinen voima kasvoi 12.0 % (109 newtonia; $p = 0.00$) maksimaalisen konsentrisen voimaharjoitteluryhmän osallistujien keskuudessa (kon/kon). Eksentrisellä voimaharjoittelulla oli positiivinen vaikutus maksimaaliseen konsentriseen voimantuotoon (eks/kon) (14.1%; $p = 0.03$). Maksimaalinen konsentrinen voima lisääntyi 86 newtonia eksentrisellä voimaharjoitteluryhmällä. Maksimaalinen eksentrinen voima ei kasvanut konsentrisella voimaharjoitteluryhmällä (con/eks) (-31; -2.4%; $p = 0.69$). Tilastollisesti merkittävä ero havaittiin eks/eks vs. kon/kon harjoitteluryhmien välillä ($p = 0.00$).

Pohdinta. Hypoteesimme oli, että maksimaalinen eksentrinen voimaharjoittelu olisi yhteydessä lisääntyneeseen maksimaaliseen eksentriseen voimantuottoon. Tämä löydös on ristiriidassa aikaisempien tutkimustulosten kanssa. Yksi mahdollinen selitys tälle erikoiselle lopputulokselle voi olla se, että osallistujat olivat heikosti reagoivia, joilla voima ei kehity kuten se normaalisti kehittyisi. Toinen selitys voi olla se, että harjoitteluprotokollan ärsyke ei ollut tarpeeksi korkea antamaan vasteita lihasvoimaan. Tämä tutkimus antaa meille tukea siihen, että maksimaalisella voimaharjoittelulla on mahdollista parantaa maksimaalista konsentrista voimasuoritusta. Lisäksi maksimaalinen konsentrinen voimaharjoittelu ei paranna eksentristä voimantuottoa. Käytännön sovellutuksena voidaan sanoa, että eri urheilulajien urheiluvalmentajat, henkilökohtaiset valmentajat ja muut liikunta- ja terveystieteiden ammattilaiset voivat hyödyntää tämän tutkimuksen tietoa ja tuloksia käytännönläheisessä työssään parantaakseen urheilijoiden fyysistä suorituskykyä ja hyvinvointia. On tärkeää pitää mielessä, että maksimaalinen eksentrinen voimaharjoittelu ei välttämättä kehitä eksentristä voimantuottoa. Sen sijaan esim. pyöräilijöille voidaan sanoa, että maksimaalinen konsentrinen voimantuotto voi parantaa heidän kestävyyssuoritustaan.

Avainsanat: lihasvoima, maksimaalinen voima, eksentrinen, konsentrinen, penkkipunnerrus, isokineettinen

ABBREVIATIONS

ACMS	American college of sports medicine
BP	bench press
BMI	body mass index (kg/m^2)
CON	concentric (shortening muscle contraction)
CON/CON	concentric training / concentric strength
CON/ECC	concentric training / eccentric strength
DA	anterior deltoid
DAER	dynamic accentuated external resistance training
DCER	dynamic constant external resistance training
DOMS	delayed onset muscle soreness
ECC	eccentric (lengthening muscle contraction)
ECC/ECC	eccentric training / eccentric strength
ECC/CON	eccentric training / concentric strength
EMG	electromyography
GH	growth hormone
IGF-I	insulin-like growth factor-I
LD	latissimus dorsi
$MCSA_{max}$	maximal cross-sectional area
MVC	maximal voluntary contraction
MVMA	maximal voluntary muscle action
PM	pectoralis major
RFD	rate of force development
RT	resistance training
RTD_{max}	maximal rate of torque development
SEC	series of elastic component
SSC	stretch-shortening cycle
TB	triceps brachii
VO2	volume oxygen uptake
1 RM	one repetition
1 RM max	one repetition maximum

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1 INTRODUCTION

The purpose of the study was to measure the effects of maximal eccentric and concentric resistance training on maximal force production. First, we investigated how maximal eccentric and concentric resistance training effects maximal eccentric and concentric force production. Secondly, we wanted to investigate the training effect of maximal eccentric resistance training on maximal concentric force and how maximal concentric resistance training effects maximal eccentric force production. This study was part of a larger study.

Resistance training is popular among many people. Traditional resistance training is the most used method. This includes exercises in which muscles are doing both eccentric and concentric muscle action. In these exercises**,** stretch-shortening cycle is entirely utilized. However, it is possible to do resistance training by using strategies which are eccentric only or concentric only. These strategies use muscle actions in which muscles either lengthen or contract. (Walker et al. 2016.) Bench press can be classified as a multi-joint exercise. Elbow and shoulder joints are the primary movers in bench press (Ferreira et al. 2016.)

The main muscles that are affected in bench press**es** are triceps brachii (TB), latissimus dorsi (LD), deltoideus**,** and pectoralis major (PM). A normal bench press maneuver begins with a lowering phase in which the bar is lowered towards the performer's chest. This muscle action is called an eccentric activation (muscle elongation). Concentric phase (muscles shortening) occurs when the performer pushes the bar back to an upright position. The third muscle activation type is isometric which means that the muscle is neither shortening nor lengthening. (Hulmi 2002.)

Most studies have focused on the lower body. There also are many studies which have focused on combined eccentric and concentric resistance training. Based on previous studies, it is possible to expect that eccentric resistance training will produce more muscle mass than concentric resistance training. (Martino et al. 2017).

It is not very common to perform only eccentric or concentric resistance training exercises. Strength trainers typically exercise both types of motions when they train at gyms. Resistance training motions typically utilize whole stretch-shortening cycle (SSC). Most resistance training motions begin either by concentric phase (e.g. pull-up) or eccentric phase (bench press). Moreover, it is typical that both these phases occur in one exercise (e.g. squat). Long jumpers or high jumpers may want to exercise particularly the eccentric phase. Ability to produce rapid and maximal muscle force is crucial e.g. in these sport disciplines.

2 MUSCLE CHARACTERISTICS

There are three types of muscles: skeletal, cardiac, and smooth muscles. Origin and insertion of skeletal muscles are attached to bones. The origin of a muscle is the part that does not move, whereas insertion is the site that is in the movable section when muscle contraction takes place. Origin and insertion enable people to move their muscles. Origin is usually closer to the trunk or more immovable bone. Insertion is usually attached to the distal site of a muscle or has a mobile feature. In addition, skeletal muscles are able to contract voluntarily. The two other muscle types (cardiac and smooth) do not have this feature. About 40% of muscle mass consists of skeletal muscles. Flexors of the muscles pull sliding filaments together. Opposite to flexion is extension which makes muscles and its filaments lengthen. One flexion-extension pair is categorized as an antagonistic muscle group. One example of this type of pair is biceps brachii, which is a flexor, and triceps brachii, which acts as an extensor. Origin of biceps brachii is closer to the bones of the shoulder joint (Humerus and Clavicle). Origin is thus attached to the radius. (Silverthorn 2007, 397-398.). Agonist muscles are deltoid, pectoralis major, and triceps brachii in a bench press. An antagonist muscle is the biceps brachii. (Ojasto and Häkkinen 2009a.)

Strength consists of different segments. Strength is dependent from neural factors, muscle mass, and strength trainer’s dimensions. Architectural factor is one component in muscle strength. Muscle architecture includes volume of muscle, length of fascicle, muscle fiber type, and pennation angle. Muscle fiber types are classified as I [slow], IIa [intermediate slow], IIx and IIb [fast]. Muscle fibers are highly genetic and the training effect on muscle fiber type composition is mild. Neural factor is the second component. Muscle recruitment, firing frequency, muscles internal and between muscle coordination, performance and movement technique are considered neural factors. Functions of muscle recruitment, firing frequency, and muscles internal and between muscle coordination are based on motor units. Motor units consists of alpha motor neurons which recruits certain muscle group. Alpha motor neurons, which give the command to contract, work according to the all or nothing principle. (Kuukasjärvi 2019, 29-49.)

Muscle force production is based on Henneman’s size principle. According to the size principle, small motor units with low firing frequency are recruited before activation of larger motor units. Development of force production under tension occurs by recruiting new motor units or by increasing firing frequency of the already recruited motor units. One motor unit can recruit only one type of muscle fiber type (e.g. slow muscle fiber type). Recruitment is dependent on the intensity of the load. The closer a load is to maximal attempt**,** the more motor units are recruited. Length-tension ratio describes muscles force production in terms of muscle length. Muscles ability to produce force is dependent on the length of the muscle. Short muscle length usually produces more force than large muscle length. There are more formed cross bridges during small muscle lengths than in larger muscle lengths. This is one reason why during the end of a concentric muscle contraction force is produced more than in the early stages of a concentric contraction. Strength trainers can also experience that it is easy to produce force in short muscle lengths. This means that towards the end of eccentric contraction there is less force produced because there are fewer formed cross bridges. Formation of cross bridges are called active components in length-tension ration. Passive component consists of sarcomeres elastic elements which are capable of lengthening. Tension history also effects muscle strength. Tension history can lead to excessive force production. Force production is e.g. greater if the eccentric action has occurred before concentric muscle contraction. (Kuukasjärvi 2019, 29-49.)

Size principle was discovered in 1965 by American doctor Elwood Henneman and is thereafter referred as Henneman's size principle. When susceptibility threshold is reached**,** motor unit activation takes place. As a rule, slow twitch fibers are activated first, then type IIa and type IIx muscle fibers. Magnitude of the muscle force production is dependent on firing frequency. By increasing firing frequency**,** single motor unit**s** can increase muscle force production. The more frequent motor units are activated**,** the more they produce force. Maximal firing frequency in muscle contraction can be 10 Hz. This kind of firing frequency is possible only in a very short period of time in maximal muscle force production. (Kauranen 2014, 175-207.)

Sarcomere is classified as "the smallest functional unit of the muscle fiber". Interactions which occur between the thin and thick filaments are responsible for muscle contractions. When a muscle contraction takes place, width of the A band (thick filament) stays the same, but at the same time the Z disk move**s** closer to the A band and the I band gets smaller. Thin filament consists of actin. There are many sarcomeres consecutively in a myofibril. A protein called titin is the largest protein that is currently known. Titin has major role**s** in the regulation of muscle force. Titin's role is to bind calcium during muscle contraction and to bind actin molecules which are attached to thin filaments during cross-bridge attachment. Titin has been proven to increase strength during eccentric muscle contraction. Researcher**s**, however, do not fully understand the role of titin in muscle contractions. The sliding filament theory gives us an explanation for sarcomere contraction. In figure 1, a muscle sarcomere is presented. (Douglas et al. 2017; McArdle et al. 2007, 368-372; Martini & Bartholomew 2007, 184-194; Maughan & Gleeson 2010, 16-22).

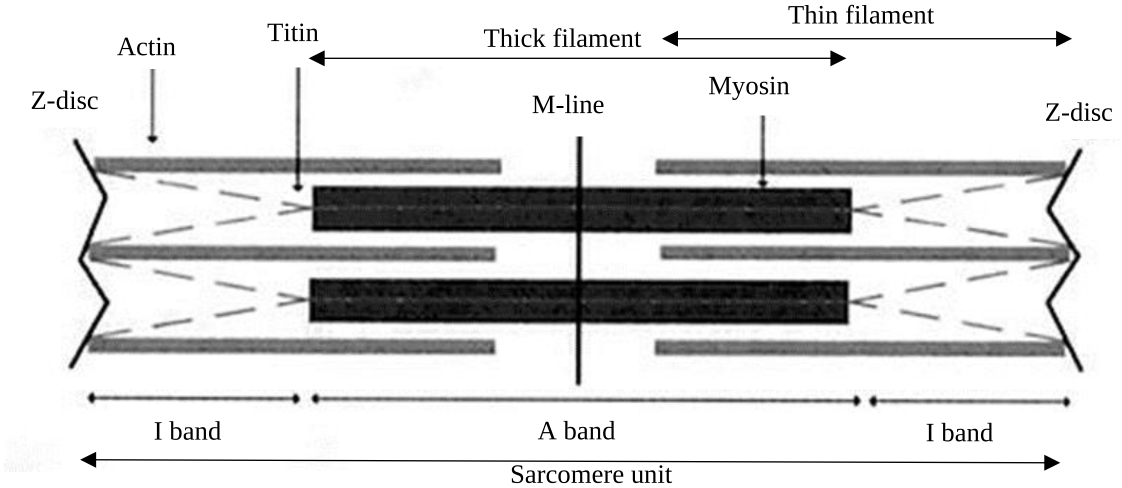


FIGURE 1. Muscle sarcomere is presented in this picture (modified from Douglas et al. 2017; McArdle et al. 2007, 368-372; Martini & Bartholomew 2007, 184-194; Maughan & Gleeson 2010, 16-22).

Traditional ways of practicing resistance training is to do all kinds of exercises: concentric, eccentric, and isometric. Concentric muscle force production can be a limiting factor for resistance trainers. If a resistance trainer is able to do the controlled lowering phase in a bench press, he/she is maybe not capable of lifting it up. In other words, it is usually possible to do eccentric actions with higher loads than concentric actions. Eccentric force production can be 20-50% higher than concentric force production. This means that resistance trainers are typically capable of lowering higher loads in a controlled manner than pushing them up again. The downside of eccentric resistance training is that it causes more muscle damage than other types of resistance training. Delayed onset muscle soreness (DOMS) is greater after eccentric actions. Eccentric resistance training exercises should be performed with constant velocity. (Secondary source from Parkkinen's 2019, 323-325 work.)

There is a link between pectoralis major muscle size and the ability to produce force in a bench press. It is important to understand that muscle size defines the level of muscle strength. EMG studies have indicated that pectoralis major, deltoid, and triceps brachii affect the bench press performance. It is shown in figure 2 how the maximal cross-sectional area (MCSA) of the pectoralis major muscle is affected by 1RM bench press strength. There is a link between the pectoralis major muscle size and the ability to produce force in a bench press. It is important to understand that muscle size defines the level of muscle strength. EMG studies have indicated that pectoralis major, deltoid, and triceps brachii affect the bench press performance. (Akagi et al. 2014.)

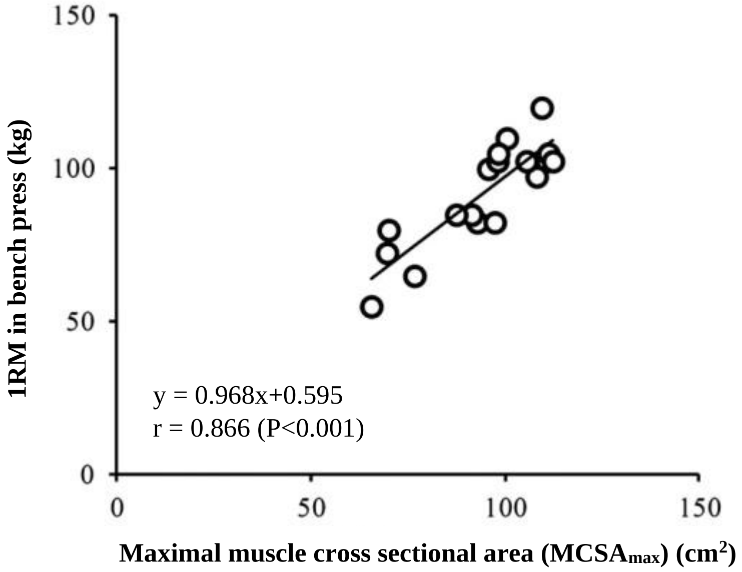


FIGURE 2. The effect of maximal muscle cross-sectional area ($MCSA_{max}$) of the pectoralis major muscle to one repetition maximum (1RM) is shown in this picture (modified from Akagi et al. 2014).

Rocha et al. (2007) compared EMG activity of pectoralis major (PM), anterior deltoidis and triceps brachii (TB) in bench press and peck deck. In this study subjects did 10 maximum repetitions in bench press and peck deck. In the end, there were no difference between the two different devices on PM and anterior deltoids (DA). Activity of the TB was higher in bench press compared to peck deck.

It is possible to expect that non-athletes will develop approximately 22-23 percentage maximal strength gain. Participants of Häkkinen's (1985) study did a squat exercise that is not directly comparable to the bench press exercise. However, this result will give us some kind of estimation of strength development. Non-athletes' development is greater than athletes' development. (Figure 3.)

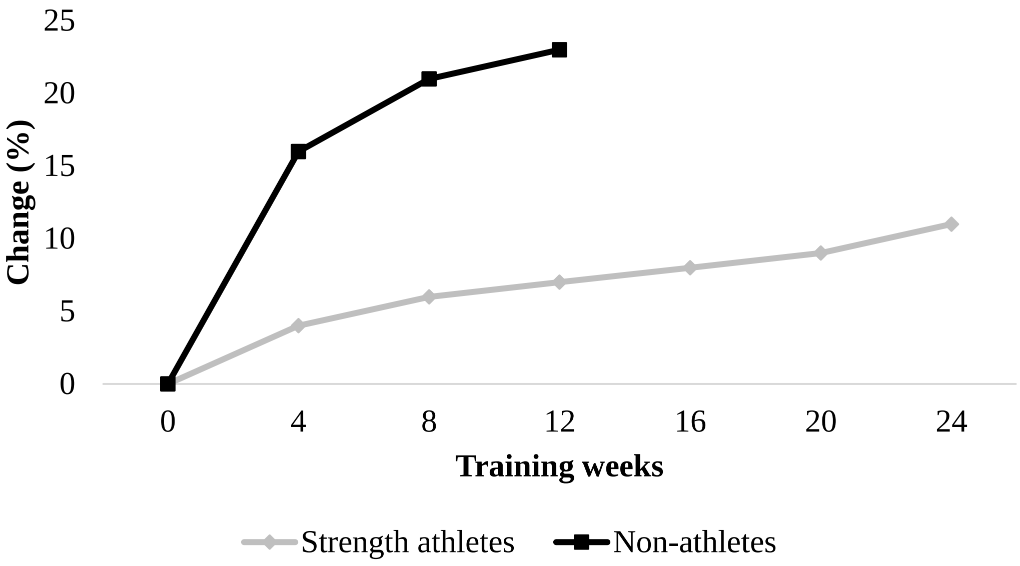


FIGURE 3. Non-athletes’ maximal strength improved approximately 22-23 % in a 12 weeks training period with a squad-lift exercise (modified from Häkkinen 1985).

There are presented characteristics that are common to all muscle tissues in figure 4. All muscles have the ability to do electrical activity, relaxation and contraction. Abilities of strech-shortening and exitability are counted in to the abilities. (Kauranen 2014, 40.)

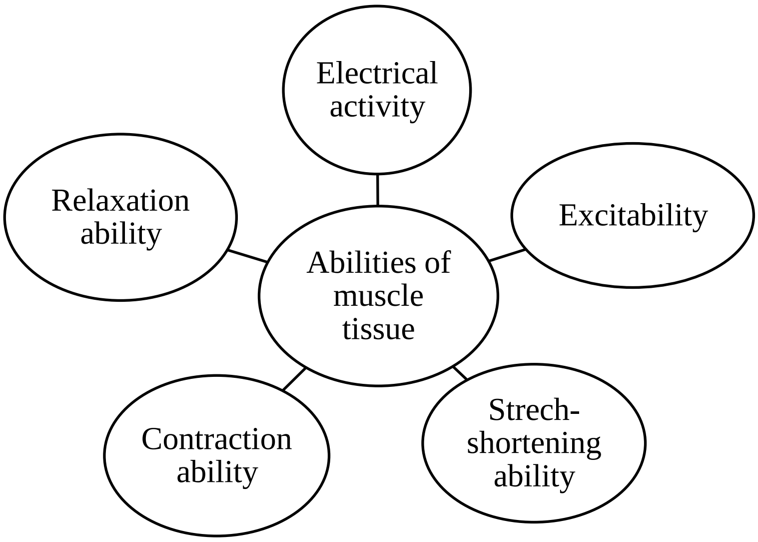


FIGURE 4. Common characteristics to all muscle tissues (modified from Kauranen 2014, 40).

Muscle strength can be divided into three categories: muscular (maximal) strength, power (speed) strength and endurance strength. Definitions of the muscle strengths are presented in figure 5. These areas overlap each other. These areas can be studied and measured separately. (ACMS 2018; Kauranen 2014, 172 and 231).

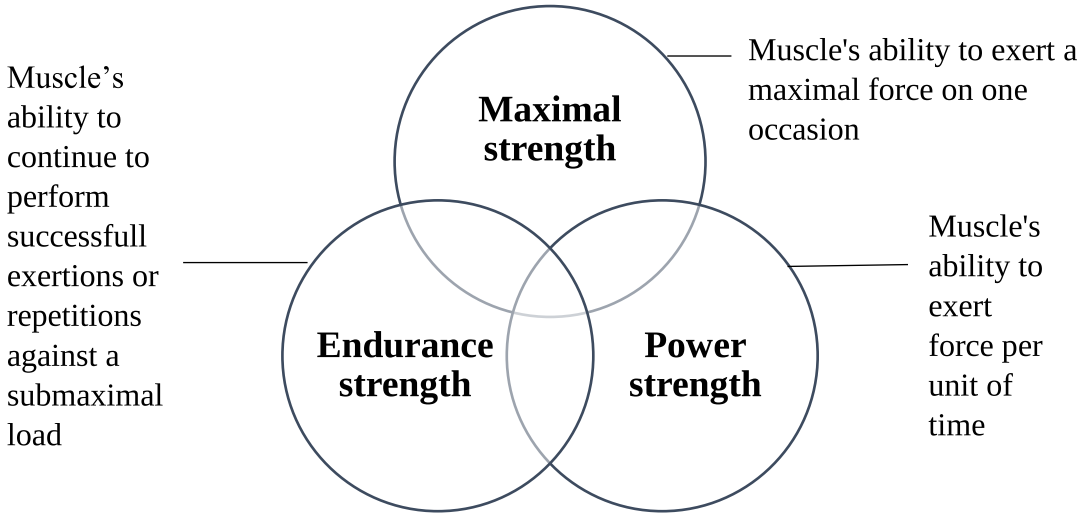


FIGURE 5. Different areas of muscle strength overlap each other (modified from ACSM 2018, 95; Kauranen 2014, 172.)

There are two types of muscle actions: dynamic and static. Dynamic muscle actions can be divided into concentric and eccentric muscle contractions. This division is kept as a basis in this thesis. Isokinetic means that the angular velocity does not change during concentric or eccentric activity. Isometric muscle action (muscle does not lengthen nor contract) is classified as static muscle activity. (Figure 6.) (Kauranen 2014, 218-220.)

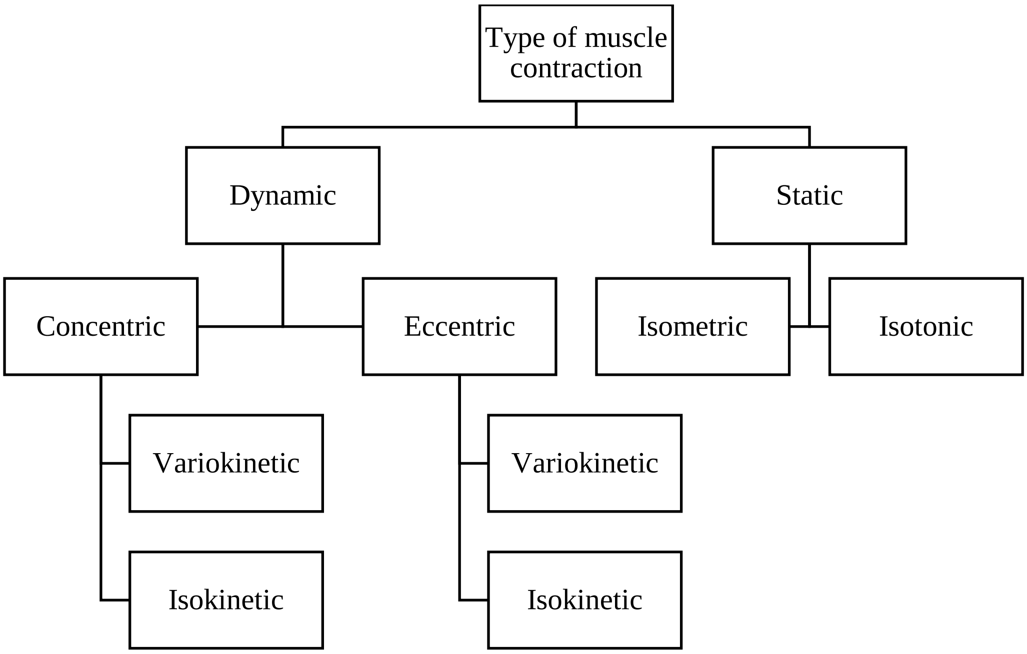


FIGURE 6. Concentric and eccentric muscle contractions are classified as dynamic movements whereas isometric is considered static muscle activity (modified from Kauranen 2014, 218-220).

In table 1 there are presented factors that affect muscle strength. Age, anatomical structure of the muscle and cross-sectional area (CSA) are some of these factors. (Kauranen 2014, 228.)

TABLE 1. Factors that affect to muscle strength (modified from Kauranen 2014, 228).

Factors of muscle strength
Age
Anatomical structure
Cross-sectional area (CSA)
Muscle cell distribution
Amount and quality of connective tissue
Muscle innervation
Maintenance systems of the muscle
Gender
Resistance training
Muscle length and part of trajectory
Type of muscle contraction

Gordon et al. (2019) found that isokinetic eccentric training improved strength significantly compared to traditional lower body resistance training. In this study subjects had a 13.7 % increase in strength on week two (2) and a 19.2 % increase on week four (4). The result of this study is according to previous findings from this area. It is commonly known that higher eccentric loads affect greater strength adaptations.

2.1 Muscle activity

Muscle activity can be detected by using electromyographic (EMG) method. EMG is detected from the surface of the skin. It is important to keep in mind that EMG always is an estimation of the muscle activity and that crosstalk from the muscles can occur which are not wanted to be detected (Saeterbakken et al. 2017).

It has been shown in previous studies that triceps brachii (TB) and pectoralis major (PM) are more active compared to the anterior deltoid (DA). TB and PM show greater EMG activity. In the bench press muscle activity changes can be measured in six factors: exercise intensity, velocity movement, fatigue, mental focus, movement phase and in stability conditions (bar vibration). Exercise intensity has been considered the most important factor. In the systematic review of the surface EMG on bench press, many studies have reported normalized muscle EMG. (Table 2.) (Stastny et al. 2017.)

TABLE 2. These studies have reported normal muscle surface EMG levels (Stastny et al. 2017).

Study	Intensity during BP; Normalized muscle activity; EMG units	Main result of study in EMG activity
Clark et. al. 2011 [9]	Max voluntary contraction 3 s isometry at 25% of movement; PM: 131± 30 group one, 141 ± 63 group two, TB: 140 ± 45 group one, 170± 72 group two; %MVIC mean	Training intervention did not have effect on muscle activity; TB had higher normalized activity in one group than PM.
Keogh et. al. 1999 [10]	Six repetitions isokinetics in ecc; PM: 85 ± 14.9, TB: 77 ± 11.2* Six repetitions isokinetics in con; PM: 88 ± 18.2, TB: 80 ± 11.2* Ecc six repetitions 110% RM; PM: 85 ± 13.1, TB: 74 ± 16.7* Func isometry at 160˚ elbow angle; PM: 70 ± 12.7, TB: 54 ± 17.8 Func isometry at 160˚ elbow angle; PM: 87 ± 16.4, TB: 94 ± 17.5 Super slow 5 s ecc 55% 1 RM; PM: 57 ± 20.4, TB: 42 ± 15.2* Super slow 5 s con 55% 1 RM; PM: 82 ± 15, TB: 74 ± 16.8*; %MVIC peak, iEMG	The eccentrics and isokinetics condition had significantly greater levels of integrated EMG than heavy weight training during the eccentric phase. Likewise, functional isometrics had significantly higher TB EMG than heavy weight training in the concentric phase. Super slow motion and maximal power training both recorded significantly lower levels of force and integrated EMG than heavy weight training in each phase.
Snyder and Fry 2012 [11]	50, 80% of 1RM; PM: 92.6, 147.9, AD: 71.1, 122.9, TB: 79.8*, 124.7*; %MVIC mean RMS	During 50% lift, the verbal instruction to focus on PM or TB can increased its activity. When 80% of 1 RM is used, only the focus on the chest has been found to increase PM and AD amplitude.
Moras et. al. 2010 [13]	180˚and 90˚elbow flexion; MVIC values has been reported as a graph; %MVIC from peak to peak amplitude	PM, TB and AD increases its activity along with vibration frequency. The %MVIC values point out that TB activity was bigger than PM and AD activity. Furthermore, PM (%MVIC) activity was bigger than AD when vibration was applied.
Sakamoto and Sinclair 2012 [15]	40, 50, 60, 80% of 1RM at speeds of 5.6 s, 2.8 s, 1.9 s per repetition; MVIC values has been reported as a graph; Measured each 20% of the lift. RMS amplitudes and median power frequencies were normalized to two repetitions of bench press at 60% 1RM under the medium speed (2.8 s per repetition).	The main effects of fatigue, speed, and intensity were all significant for PM and TB with the amplitude being greater for the speed-failure lift, faster speeds, and heavier (higher) intensities. During the fast condition PM produce greater frequencies than the medium and slow conditions. TB decline in frequency after fatigue was greater during slower speeds. Smith Machine.
Calatayud et. al 2015 [20]	Six RM; PM mean: (mean ± SEM) 53 ± 1.9 AD mean: 60 ± 3.5 PM peak: 140 ± 6.7 AD peak: 139 ± 7.7; mean and peak %MVIC	The normalized activity of PM and AD were similar. Smith Machine.
Calatayud et. al 2016 [21]	20, 40, 50, 60, 80% of 1 RM; PM: regular BP (95% confidence interval)/PM focus/TB focus at 20% - 21 (16–25)/28 (23–32)/20 (15–24) at 40% - 38 (34–43)/44 (39–48)/40 (35–44) at 50% - 52 (47–56)/57 (53–62)/55 (51–60) at 60% - 56 (52–61)/65 (61–70)/ 61 (57–66) at 80% - 81 (77–86)/80 (75–84)/82 (77–87), TB: regular BP/PM focus/TB focus at 20% - 31 (26–36)/32 (27–36)/ 42 (37–47) at 40% - 47 (42–52)/46 (41–50)/53 (48–58) at 50% - 55 (50–60)/54 (49–59)/59 (54–64) at 60% - 60 (55–65)/59 (54–64)/64 (60–69) at 80% - 80 (75–85)/81 (76–85)/82 (78–87); % MVIC in peak RMS (average of 3 reps)	In both muscles, focusing on using the respective muscles increased muscle activity at relative loads between 20 and 60% but not at 80% of 1RM. Both muscles show similar activity.
Schoenfeld et. al 2016 [22]	80, 50% of 1RM mean/peak; PM S: 121 ± 33, 103 ± 39/308 ± 121, 305 ± 179, PM C: 127 ± 45, 117 ± 53/321 ± 121, 329 ± 167, AD: 115 ± 39, 105 ± 44/275 ± 102, 272 ± 128, TB: 94 ± 30, 69 ± 23/ 237 ± 109, 202 ± 91; %MVIC, mean, peak, and iEMG muscle activation	The PM showed higher MVIC values than TB and AD.

ecc = eccentric, con = concentric, EMG = electromyography,
*highest value reported at condition,
iEMG = integrated electromyography, values are the mean ± standard deviation if not specified other, %MVIC = percentage of maximum voluntary isometric contraction, AD = deltoid anterior, PM = pectoralis major, TB = triceps brachii, SEM = standard error of measurement, RMS = route mean square,
RM = repetition maximum, S = sternal portion of PM, C = clavicular portion of PM, Func = functional.

In the same study Stastny et al. (2017) have presented a summary of the effects of bench press exercise conditions on muscle activity level. These are presented in table 3.

TABLE 3. A summary of how bench press exercise affects muscle activity (Stastny et al. 2017).

Parameter	Effect
BP exercise Intensity (load)	Increase in intensity is resulting in increased amplitude of PM [10, 11, 17, 21, 22], TB [11, 22], and AD [11, 17, 22].
Velocity of movement	EMG amplitude increases with increased speed of movement in PM, TB, [15].PM EMG frequency increases with increased speed [15].TB decline in EMG frequency after fatigue during slower speeds [15].
Stability condition	The PM, TB and AD increases its activity along with bar vibration frequency [13].RMS values increases with increasing instability in latissimus dorsi, erector spinae, biceps femoris, soleus, internal obliques, but not in rectus abdominis [19].
Fatigue	EMG amplitude increases in fatigue in PM, TB, [15].EMG median frequencies before fatigue is similar among speeds and intensities and decreases after fatigue in PM, TB, AD [15].TB decline in EMG frequency after fatigue during slower speeds [15].
Mental focus	Focus on PM or TB during 50% of 1RM BP can increases the activity of PM and TB [11, 21].Focus on PM during intensity of 80% of 1RM can increases the activity of PM and AD [11].Focusing on TB or PM (both parts) increase their EMG amplitude at relative loads between 20 and 60%, but not at 80% of 1RM [21].
Movement phase	The biceps activity was higher in the pre-sticking region compared with the other regions and the TB activity increases continuously from region to region in both conditions. TB and PM increases during sticking region [18].
Intervention	A 12-week intervention performing, two times a week, a regular BP in 4 sets or variable ROM BP in 5 sets resulted in no EMG change [9].
Compression sleeves	No positive performance effects or EMG change when wearing graduated compression sleeves during power exercise in young trained men [12].

ROM = range of motion, EMG = electromyography, RT = resistance training, RM = repetition maximum, min = minimum, PM = pectoralis major, TB = triceps brachii, AD = anterior deltoid, BP = bench press,

2.2 Stiffness

Some studies suggest that strength training increases stiffness. On the other hand, other studies suggest that there is no relationship between strength training and stiffness. Scientists are contradictory about the causes of stiffness. (Mero et al. 2016.) According to Wilson et al. (1994) strength training increases stiffness but, on the other hand, flexibility training declines musculotendinous stiffness. Two years earlier Wilson et al. (1992) studied how flexibility training affects the stiffness in bench presses. In this study they discovered that flexibility training (stretching) increased 13.1 % range of joint movement which was statistically significant ($p < 0.01$). In addition, series of elastic component (SEC) enhanced.

Stiffness can be measured by using oscillation techniques. In this method, the bar is held approximately 3 centimeters (cm) above the chest in isometric position. The subject is supposed to hold the bar for approximately 0.6 seconds. Next, there will be an approximately 100 Newton (N) load added for 150-200 millisecond (ms). There will be three trials. The loads are 15, 30, 45, 60 and 70 percent of the one repetition maximum (1RM). (Wilson et al. 1994.) Muscle stiffness affects all three different types of muscle action: eccentric, isometric and concentric muscle work. In isometric and concentric muscle actions its role is significant. Muscle stiffness is not as important of a role in eccentric muscle activation. (Wilson et al. 1994.)

In table 4 we can see that musculotendinous stiffness varies between stiff and compliant subjects. Stiff subjects tend to have higher N/m values than compliant subjects. According to Wilson et al. (1994) stiff subjects' stiffness is 12,848.2 (mean) ± 2,867.0 (SD) N/m whereas compliant subjects' stiffness is 8,302.3 (mean) ± 1,636.2 (SD) N/m which is statistically significant ($P < 0.05$). Eccentric force is 1,306.7 ± 157.1 N in stiff subjects. Compliant subjects produce less force (1,119.9 ± 123.5 N).

TABLE 4. Oscillation and performance test results of stiff and compliant subjects is seen in this picture (modified from Wilson et al. 1994).

	Stiff subjects (mean ± SD)	**Compliant subjects** (mean ± SD)
Musculotendinous stiffness (N/m)	12.848.2 ± 2.867.0	8.302.3 ± 1.636.2*
Concentric force (N)	981.3 ± 83.3	872.4 ± 180.2
Concentric RFD (N/s)	14.478.8 ± 1.229.2	11.028.8 ± 2.896.2*
Work done bench press throw (J)	230.9 ± 30.3	179.2 ± 25.1*
Eccentric force (N)	1.306.7 ± 157.1	1.119.9 ± 123.5
Eccentric RFD (N/s)	16.871.0 ± 3.500.3	13.811.8 ± 1.273.4
Isometric force (N)	1.535.4 ± 166.6	1.152.4 ± 179.0**
Isometric force RFD (N/s)	16.091.6 ± 4.372.3	8.207.6 ± 1.524.4**

Statistically significant * $P<0.05$; ** $P<0.01$.

The effects of maximal musculotendinous stiffness has been studied previously to eccentric performance (table 5). Maximal musculotendinous stiffness is 0.27 in maximum eccentric performance whereas maximum eccentric rate of force development (RFD) is 0.15. Maximal musculotendinous stiffness value is 0.38 in maximum concentric force. Statistically significant finding in maximum concentric RDF indicates that there is association on maximal musculotendinous stiffness. In addition, we can see from this table that the level of force and RFD is smaller in eccentric performance compared to concentric and isometric performances. (Wilson et al. 1994.)

TABLE 5. In this study, stiffness and its effect to eccentric, isometric, and concentric performance have been examined (modified from Wilson et al. 1994).

Performance variable	Maximal musculotendinous stiffness
Maximum concentric force	0.38
Maximum concentric RFD	0.65*
Work done concentric bench press throw	0.57*
Maximum eccentric force	0.27
Maximum eccentric RFD	0.15
Maximum isometric force	0.63*
Maximum isometric RFR	0.78**

Statistically significant: * $P<0.05$; ** $P<0.01$

Elastic components can be used if concentric and eccentric phases alternate. If only concentric or eccentric phase is done, elasticity cannot be used. In a few sport disciplines either only eccentric or concentric phase is needed.

2.3 Muscle fatigue and delayed onset muscle soreness (DOMS)

There are a number of factors that affect neuromuscular fatigue. In figure 7 are six factors presented. There are, e.g., sensitivity of muscle receptors, metabolic substances, and temperature that affect muscle fatigue.

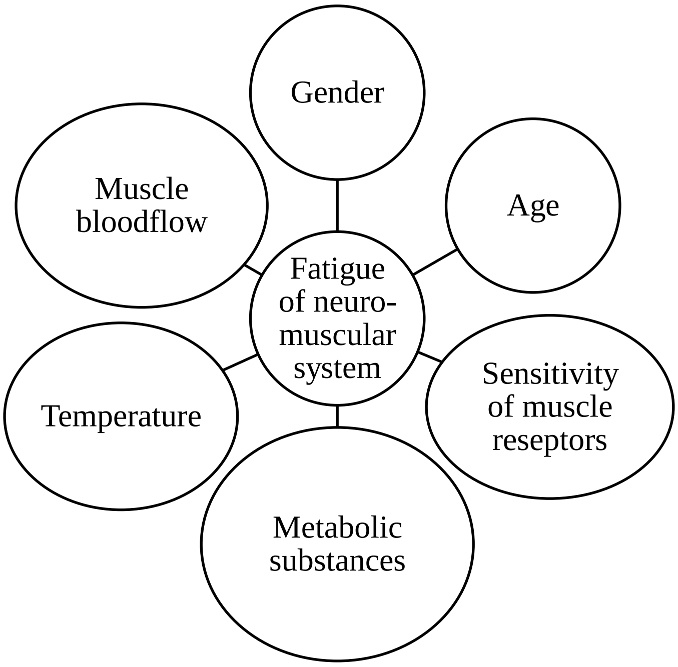


FIGURE 7. Factors that affect neuro-muscular fatigue (modified from Kauranen 2014, 212).

Muscle fatigue has a crucial role in resistance training and it affects differently in eccentric and concentric exercises. A common consequence of muscle fatigue is reduction in muscle force. There is also an increased risk for injuries during fatigued conditions. Cadore et al. (2019) studied muscle fatigue after concentric and eccentric muscle contractions. They had two intervention groups: eccentric and concentric. Both intervention groups did concentric and eccentric protocol. Eccentric and concentric intervention groups were stressed to concentric and eccentric muscle fatigue. As a conclusion of this study, it can be kept that muscle fatigue, which was induced by concentric and eccentric protocols, was similar in pre and post training despite of contraction type. Peak torque is similar when pre training and post training conditions are compared. The study focused to measure knee flexors and extensors. Muscle fatigue can be divided into central and peripheral fatigue. Part of peripheral fatigue is due to central factors. Blood lactate varies approximately 7-8 mg/dL in eccentric and concentric training. In eccentric training protocol blood lactate concentration is a little higher than what it is in concentric training. (Cadore et al. 2019.)

Morawetz et al. (2019) have compared gender differences after a single maximal bout of eccentric exercise in a meta-analysis. This systematic review was focused on acute effects. In table 6 we can see that men exhibited 10.1-40.7 % strength loss after eccentric exercise for the lower body. There can be seen higher strength loss for the upper body in both genders. Up to 62 % of strength loss results have been reported for men's upper body extremities. Women's strength loss in the same studies has varied between 11.9-38.1 % for the lower body. Four of six studies have reported higher strength loss and two studies lower strength loss than men. Almost all women's results indicate higher strength loss compared to men regarding upper extremities. (Table 6.)

TABLE 6. There can be seen a large variation in strength loss on men and women after eccentric resistance training (modified from Morawetz et al. 2019).

Author	**Strength loss male (%)**	**Strength loss female (%)**
Hicks et al. 2016	22.5 ± 8.5	27.1 ± 13.1
Kerksick et al. 2008	10.6	11.9
Fredsted et al. 2008	17	25
Mac Intyre et al. 2000	10.1	13.5
Joyce et al. 2014	22.9 ± 7.6	15.5 ± 4.5
Lee et al. 2017	40.7 ± 21.1	38.1 ± 22.8
Weighted mean lower extremities	**20.6**	**21.9**

Continue		
Hubal et al. 2008	32	39
Dannecker et al. 2005	50.4	57.8
Sayer and Clarkson 2001	54	60
Rinard et al. 2000	62	69
Weighted mean upper extremities	**54.5**	**31**

In figure 8 we can see relative values of isokinetic peak torque of PM and TB in six different phases in bench press. Pre value means phase before training. From this picture we can see that isokinetic peak torque declined immediately after the training. It will come to baseline after 96 hours after the training. (Ferreira et al. 2016.)

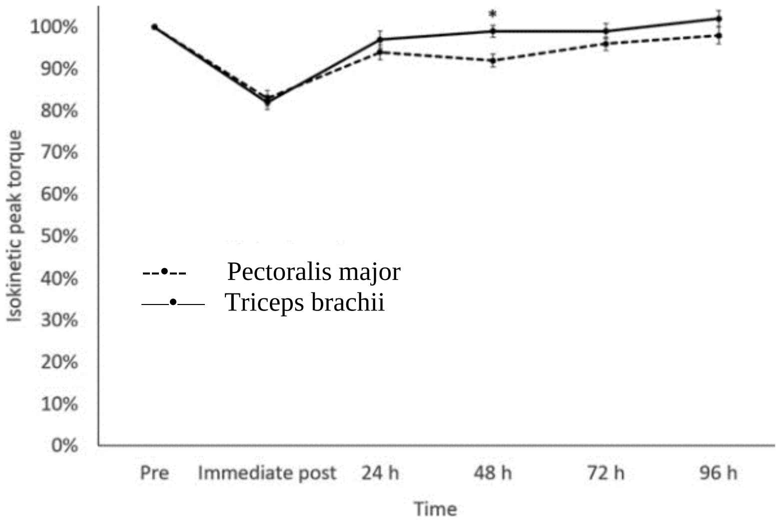


FIGURE 8. Isokinetic peak torque (relative) of PM and TB results are seen in this figure (modified from Ferreira et al. 2016). *Significant difference (P<0.05) between pectoralis major and triceps brachii muscles.

It takes 72 hours when relative value of total work is on baseline after bench press exercise. It is important to notice that the total work value is reduced between 24 and 72 hours after the training. Reduction continues from 72 hours up to 96 hours. (Figure 9.) (Ferreira et al. 2016.)

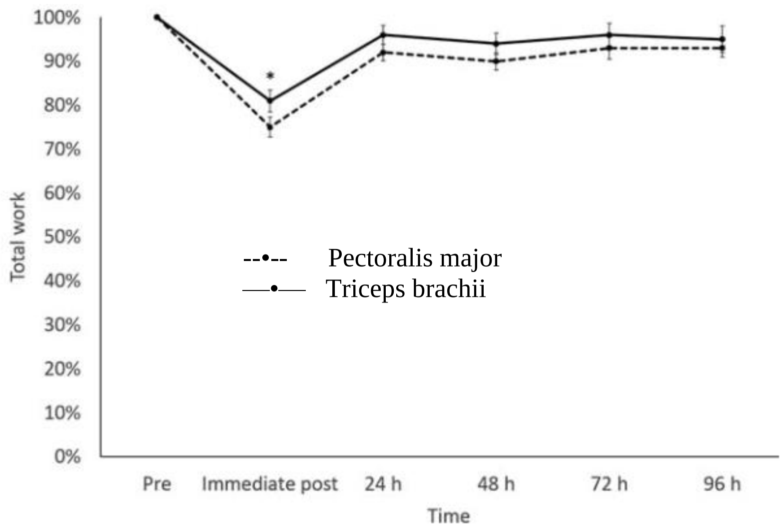


FIGURE 9. Relative total work value of PM and TB (modified from Ferreira et al. 2016). *Statistically significant ($P<0.05$).

From figure 10 we can see how bench press affect the experience of delayed onset muscle soreness (DOMS). DOMS effect is greater in pectoralis major (PM) than in triceps brachii (TB) but the magnitude is similar. We can see from figure 10 that TB recovered faster than PM. After 72 hours DOMS effect is almost completely vanished. PM is still at this phase significantly elevated. (Ferreira et al. 2016.)

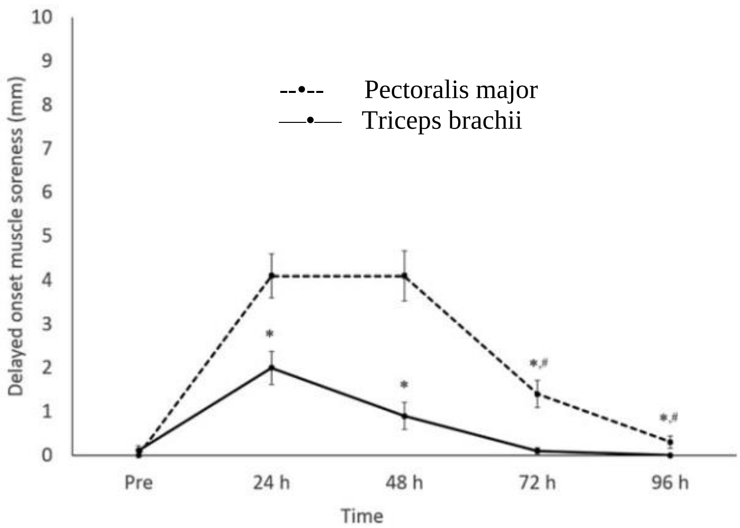


FIGURE 10. DOMS effect 24, 48, 72 and 96 hours after bench press exercise (modified from Ferreira et al. 2016). *Statistically significant ($P<0.05$).

3 RESISTANCE TRAINING

Resistance training can be classified as so called conventional resistance training or it can be done with some kind of modification of conventional resistance training. Rocha Junior et al. (2007) have compared muscle activity of the following muscles: pectoralis major (PM) anterior deltoid (DA) and triceps brachii (TB) in bench press and peck deck. They found that prime movers in the bench press are anterior deltoids and pectoralis major. According to Rocha Junior and his colleagues (2007), the bench press and peck deck recruit pectoralis major and anterior deltoids in the same way. However, muscle activity is higher in all the three studied muscles in bench press.

There are many principles that affect the resistance training programs. In table 7 there are eleven (11) of these principles presented. All of these are also taken into account in our study. (Fleck & Kraemer 2014, 1-14.)

TABLE 7. Basic principles when designing a resistance training program (modified from Fleck & Kraemer 2014).

Principle	What does the principle mean?
Maximal voluntary muscle actions (MVMA)	Sets to failure (e.g. 1 RM)
Intensity	Percentage of 1 RM
Training volume	A measure of the total amount of work (in joules) performed (e.g. in a training session, a week, a month or some other period of time)
Rest period	A time between sets of an exercise, between exercises or training sessions
Velocity spesificity	Velocity means the speed at which exercise is performed
Muscle action specificity	Strength gain is specific to the type of used muscle action (e.g. eccentric, concentric)
Muscle group specificity	Adaptation and strength gain can occur only on those muscles that are activated
Energy source specificity	There exists two anaerobic (for high power, short duration) and one aerobic (longer duration) sources of energy supply for the muscles
Periodization	Include variation in volume and intensity, exercise options, length of rest period between sets
Progressive overload	Can take place by increasing number of repetitions, sets, exercise or by changing rest period length, training frequency.
Safety aspects	Include belts, technique, breathing, spotting, clothes etc.

Eccentric and concentric resistance training is possible to perform with different loads which are typically expressed as percentages of a subject’s 1 RM result. It is possible to determine the appropriate load for each individual. It is very often inevitable to determine 1 RM before the percentage of 1 RM is known. When 1 RM is known, it is possible to calculate percentage of 1 RM. In addition, it is important to keep in mind that as the training continues, progression occurs. This means that 1 RM changes over time (typically increases if resistance training has positive influences on muscle force production and overall muscle characteristics). If a change occurs in 1 RM, the percentage of 1 RM must be re-calculated. If a subject's 1 RM is e.g. 100 kg, 70 percentage of 1 RM is 70 kg.

One advanced resistance training method is to do dynamic accentuated external resistance (DAER) training. This training method use loading patterns in which eccentric phase is immediately followed by a lower load in concentric phase. DAER method is suitable for enhancing maximal strength as well as for explosive training. The main benefit from DAER training is that it may provide extra potential for gaining strength. In the maximal DAER training, loads that are over 100 % of 1 RM must be used. There have been used loads up to 50 % of 1 RM in the eccentric phase. Concentric phase can be done with loads which are maximal (100 % of 1 RM). If someone is keen on enhancing explosive strength abilities, eccentric phase can be performed with loads which are 50-90 % of 1 RM and concentric phase with load of 50 % of 1 RM. (Ojasto & Häkkinen 2009a; Ojasto & Häkkinen 2009b.)

There can be different indicators which tell us if muscle hypertrophy has occurred. Measuring the muscle cross-sectional area is one of the means to measure muscle hypertrophy. Another way is to measure muscle fiber type II. Muscle thickness, muscle volume and muscle lean mass/fat free mass can also be considered as an index of muscle hypertrophy. (Franchi et al. 2017.)

As a basic principle large muscle groups should be performed before small muscle groups. In addition, multi-joint exercises should be done before single-joint exercises. These are the guidelines that American College of Sports Medicine (ACSM 2018) recommends. It is typical in resistance training that there are more repetitions performed at earlier stages. Senna et al. (2019) found in their research that exercise order (multi- to single-joint or reverse order) does not affect bench press results.

In figure 11 we can see an overview of the shortening, isometric and lengthening muscle actions. The upper lines in the picture indicate percentage of muscle fiber length (% L_f) when muscle is at a resting state. The lower lines indicate percentage of maximal force (% $F_{m,o}$). This phenomenon can be known as short-range stiffness which can be explained by the function of the muscle cross-bridges. (Enoka 2015, 246-248.)

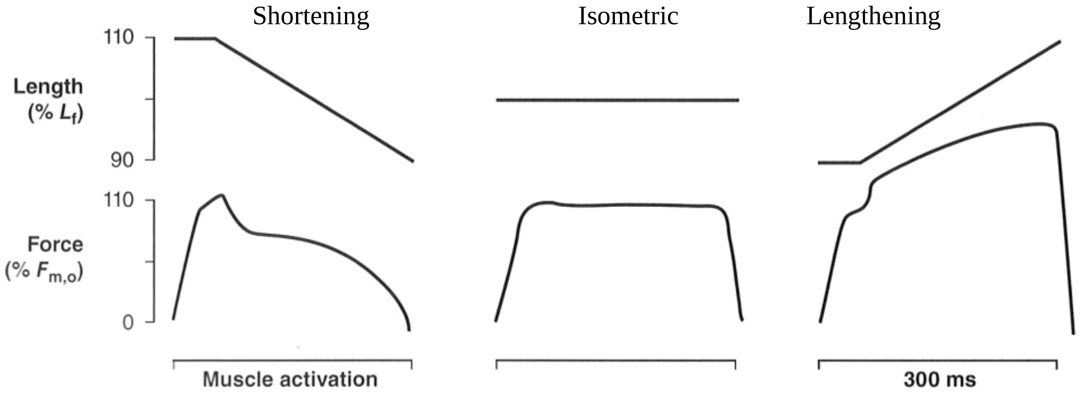


FIGURE 11. Change in muscle force of shortening, isometric and lengthening contractions (modified from Enoka 2015, 246-248).

In figure 12 is the classical view from eccentric, isometric and concentric muscle contractions. We can see that strength decreases as the muscle is lengthening. Lengthening nor shortening occurs in the isometric contractions. When the concentric muscle action occurs, the muscle is shortening and velocity increases. (Avela, Mero & Kyröläinen 2016, 95.)

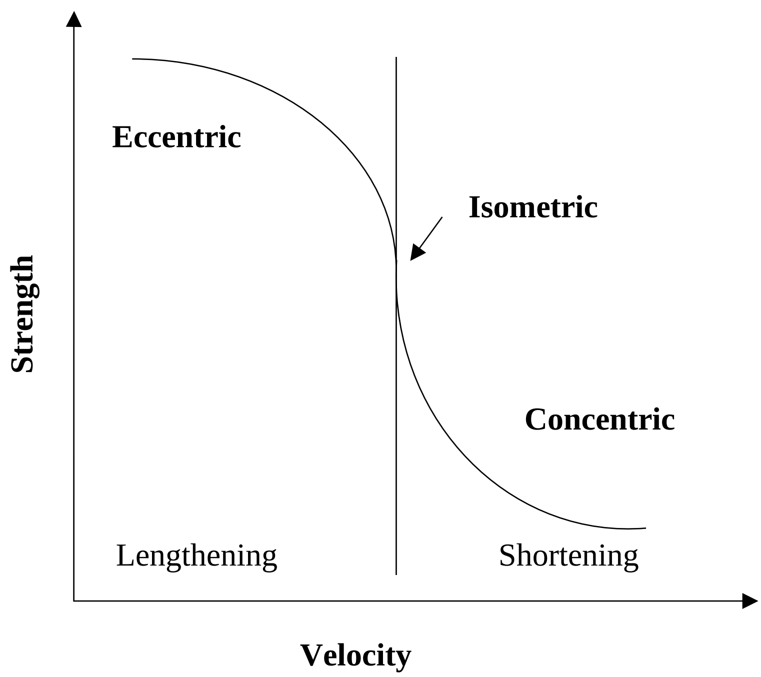


FIGURE 12. Classical style to present eccentric, isometric and concentric muscle contractions (modified from Avela, Mero & Kyröläinen 2016, 95).

There are many benefits that people gain from resistance trainings. In table 8 there are some of these beneficial effects. Most common benefits are improved muscular strength, power and endurance and improvements in cardiorespiratory fitness. Less known or controversial effects are changes in blood pressure and blood lipid profile. (Visich & Ehrman 2009, 102.)

TABLE 8. Some of the beneficial effects of resistance training are seen in this picture (modified from Visich & Ehrman 2009, 102).

Effects of resistance training
Improved muscular strength and power
Improved muscular endurance
Improvements in cardiorespiratory fitness
Reduced effort for activities of daily living as well as leisure and vocational activities
Improved flexibility
Reduced skeletal muscle fatigue
Elevated skeletal density and improved connective tissue integrity
Reduced risk of falling
Improved body composition
Possible reduction of blood pressure values
Improved glucose tolerance
Possible improvement in blood lipid profile

3.1 Biomechanics of bench press

The main muscles that is affected in bench press are triceps brachii (TB), latissimus dorsi (LD), deltoideus and pectoralis major (PM). A normal bench press maneuver starts with a lowering phase in which the bar is lowered towards the chest. Muscle action during descendent phase is called concentric muscle action (muscles are shortening). Eccentric muscle activation (muscle elongation) occurs during the incremental phase. The third muscle activation type is isometric which means that the muscle is neither shortening nor lengthening. (Hulmi 2002.)

There are several issues to be considered in the right bench press technique. Width of the grip is one. As a general principle it can be said that the wider the grip the better it is. With the help of a wide grip, it is possible to activate the muscles in the best possible way. However, too wide of a grip is not good. In figure 13, the effects of narrow and medium grip compared to a wider grip is presented. We can see that muscle force production is greater in pectoralis major (clavicular part) and triceps brachii with a wider grip. Force production of latissimus dorsi is about the same level when medium and narrow grip widths are compared. Anterior and posterior deltoids as well as biceps brachii are activated better with a narrow grip. (Saeterbakken et al. 2017.)

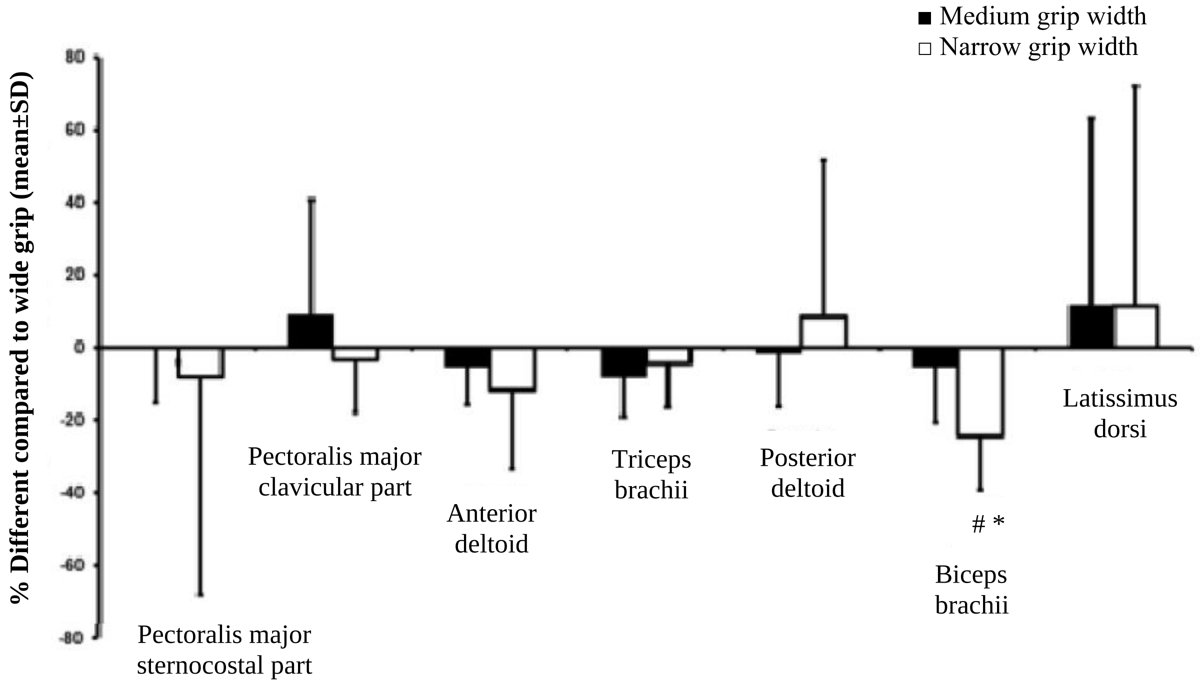


FIGURE 13. Effect of the grip width on force production is seen in this picture (modified from Saeterbakken et al. 2017). #Statistically significant difference between inclined and declined condition (P<0.05). *Statistically significant difference from all other bench positions (P<0.05).

As a practical procedure, especially if the resistance trainer is not familiar with good upper body posture, it can be good to learn how to get a proper posture before bench press. It may be good to take a good deep breath and rotate shoulders back when trainer is still standing beside the bench press chair. Scapula should be held tightly together and chest slightly pushed forwards. The idea of this maneuver is to give the idea of a good posture before the bench press. When the trainer is lying on the bench press chair and proper hold of the bar is taken, it can be good to advise the trainer to bring the chest close to the bar and strongly supinate the scapula together.

Scapula (shoulder blade) should be kept tightly together during the bench press. Before raising the bar, air should be inhaled, and breathing should be avoided during the lift. Wrists and elbows should be kept right under the bar. Palms should be in a vertical position. Legs can assist the lift. The bar should be lowered as fast as possible and stop over the chest should be as short as possible. There should occur the explosive start from the chest. (Hulmi 2002.) When subject is lying on the bench there should be a 120° angle in the arms. Elbow-shoulder angle should be 90° just before the push takes place. (Wilson et al. 1994.)

3.2 Motor control

In figure 14, a system of motor control as we understand it today is presented. Motor control gives us answers on how, for example, a weight can be lifted. Motor control system also gives feedback to the trainer. Higher centers can receive either an external or internal stimulus from where signals are transmitted to muscles. (Enoka 2015, 288.)

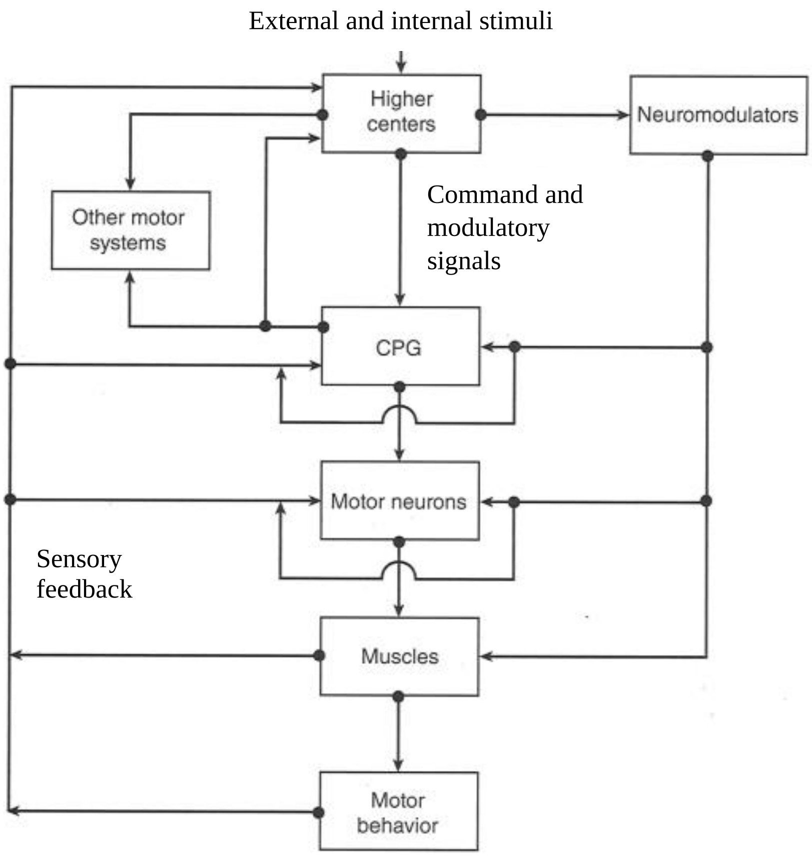


FIGURE 14. Motor control system (modified from Enoka 2015, 288).

Skeletal muscles have all the elements (e.g. sarcomeres and its components) that are needed for a muscle contraction. If there is no motor control, the muscles are not able to contract. (Komi 2011, 1-14.) Motor control has an essential role in a bench press. Without motor control, the trainer is not able to get feedback on how a lift is performed. In the experimental design of this study, the trajectory of the bench press motion is controlled. Vertical bars at both sides of the isokinetic machine ensures that not as much motor control is needed as in a normal bench press motion. In a laboratory setting it is possible to minimize the need of motor control. Isokinetic machines enable that the subject can focus only on maximal voluntary contraction without paying so much attention on how the motion is performed. In addition, head and horizontal position of the subject were controlled. In a normal bench press situation, the trainer has to e.g. make sure that there is not so much horizontal vibration upon a lift. In the end motor control can be associated to learning on how, in this case, a bench press movement can or should be performed.

3.3 Eccentric and concentric resistance training

We know from previous studies (e.g. Vikne et al. 2006) that eccentric muscle actions can produce more forces than in concentric type of muscle contractions. In addition, we know that eccentric training will affect positively to eccentric strength. This means that if concentric training is performed, eccentric muscle force will not develop to the same magnitude. Moreover, there is evidence that eccentric training will produce more hypertrophy than concentric training. (Vikne et al. 2006.)

Hypertrophy does not necessarily occur in the whole length of a muscle fiber. There can be found regional growth in hypertrophy. Franchi et al. (2017) have studied regional hypertrophy during eccentric and concentric resistance training. Muscle cross-sectional area was an index of muscle hypertrophy. This method is suitable for taking samples from different parts of a muscle length. They have found that eccentric resistance training will produce more hypertrophy in distal part of a muscle. In contrast, concentric resistance training will induce more hypertrophy in the mid portion of a muscle. (Franchi et al. 2017.)

If eccentric training is performed at high intensity, total strength increases more than in concentric resistance training. Eccentric training can lead to greater adaptations than concentric training. According to Roig et al. (2008) meta-analysis, eccentric training appears to be superior to concentric training in terms of strength gains. In addition, eccentric training seems to be highly specific to the type of muscle contraction. There is also evidence that strength gain is velocity dependent. (Roig et al. 2008.)

Both, Morawetz et al. (2019) and Roig et al. (2008), meta-analyses suggest that eccentric training seems to be a more effective way to increase strength than concentric training. Resistance training has been proven to have an effect on endocrine responses. Concentric training induces greater growth hormone (GH) levels than eccentric training. On the contrary eccentric training has induced higher insulin and glucose levels. (Kraemer & Castracane 2015.)

Douglas and his colleagues (2017) studied acute responses of eccentric muscle contractions. Many acute responses exist and in table 9 are the presented responses that have an influence on neural, cardiorespiratory, fatigue, hormonal and molecular functions. It is well-known that eccentric force production exceeds concentric force production (neural response) as discussed earlier. It is less known that volume oxygen uptake (VO2) is up to three times lower during eccentric than concentric muscle action. With eccentric resistance training, it is possible to perform loads which are over 30 % of the trainer's concentric 1RM result. There, sets of three to four with 4-6 repetitions per set can be done. We can speculate that this is possible e.g. due to the fact that eccentric training is less fatiguing than concentric resistance training. Eccentric resistance training induces lower testosterone and growth hormone (GH) levels. Insulin and growth hormone levels are not remarkably different from what acute concentric resistance training has been found to evoke.

TABLE 9. Some of the acute responses of eccentric resistance training are presented here (modified from Douglas et al. 2017).

Response	**Content**
Neural responses	Eccentric force production is greater than concentric force production
Cardiorespiratory responses	VO2 can be three times lower during eccentric contraction than concentric
Fatigue responses	Eccentric is less fatiguing than concentric
Hormonal responses	Eccentric: lower testosterone and growth hormone (GH) levels; insulin and cortisol not notably different when compared to concentric; IGF-1 is elevated 48h following ecc rt
Molecular responses	1 RM ecc is found to increase significantly satellite cell activity in type II muscle fibers

Mota et al. (2017) studied concentric muscle activation and muscle fatigue in the bench press. They found that muscle activation in the bench press was higher in anterior deltoid and pectoralis major compared to pullover exercise. In this study subjects performed bench press with 70 % load of 1 RM. (Mota et al. 2017.) Motor units are recruited differently in eccentric and concentric actions. Muscle fibers, motor units and motoneurons all take part in voluntary actions. In the eccentric actions fast-twitch units are recruited first. These motor units have faster relaxation time. These motor units also give good control for the motions. (Gardiner 2011, 1, 38-44, 171-173.)

There are more studies that have investigated the effect of eccentric overload on concentric performance and vice versa. Motor unit recruitment, rate coding and greater activity of the muscle spindles are some of the possible mechanisms that elicit improvements in concentric performance by eccentric training. (Munger et al. 2017.) It is seldom required for only eccentric or concentric muscle activity in sports. Rapid force development is requirement in many sport disciplines. Sheppard and Young (2010) has studied the effect of different loads on rate of force development (RFD) in bench press. Eccentric and concentric force production was efficient when there was used 66 % load of 1 RM.

4 RESEARCH QUESTIONS AND HYPOTHESES

It is important to study eccentric and concentric force production for the reason that we do not have enough knowledge about the mechanisms beyond the force production nor the consequences of eccentric and concentric resistance training on force production.

Research question 1: Is there a difference between maximal eccentric and concentric strength training on the magnitude of maximal eccentric and concentric force production?

Hypothesis 1: Yes.

Explanation 1: Maximal eccentric training is more effective to gain strength than maximal concentric training. There are meta-analyses that have come to a conclusion that eccentric strength is developed by maximal eccentric strength. Same phenomenon occurs in concentric training according to which concentric strength is induced by maximal concentric training. (Vikne et al. 2006; Franchi et al. 2017; Roig et al. 2008; Morawetz et al. 2019). Hollander et al. (2007) discovered that eccentric strength increased by 40 % in bench press training when compared to concentric resistance training.

Research question 2: Is there a difference between the effect of maximal eccentric training on maximal concentric force and maximal concentric training on maximal eccentric force production?

Hypothesis 2: Yes.

Explanation 2: It is expected that maximal eccentric resistance training will affect maximal concentric force production positively whereas maximal concentric training is not associated to increase the level of eccentric force production. There are studies (e.g. Munger et al. 2017) that have come to a conclusion that by eccentric training it is possible to enhance concentric velocity and power performance. (Roig et al. 2008; Martino et al. 2017.) Study result of Sheppard and Young (2010) indicates that eccentrically loaded training can increase concentric performance. Brandenburg and Docherty (2002) discovered in their study that eccentrically performed dynamic accentuated external resistance training (DAER) improved significantly the elbow extensor muscles compared to concentrically performed dynamic constant external resistance training (DCER). However, there are studies (e.g. Ojasto & Häkkinen 2002a) that did not get significant effect on maximum concentric strength by eccentrically loaded training.

5 METHODS

5.1 Subjects

Total number of subjects in this study is 23 (N = 23). Subjects were randomly divided into two (2) training groups: concentric and eccentric training groups. Eleven men (N=11) belonged to eccentric training group and twelve men (N=12) were in the concentric training group. All the participants were between 21 and 36 years old. Only one male subject withdrew from this study due to personal reasons. (Table 10.)

TABLE 10. Here is presented the intervention groups.

Two training groups (N = 23)	
Group 1.	Group 2.
Eccentric training group N = 11	Concentric training group N = 12

All participants were volunteers and they had the chance to withdraw from this study at any point without consequences. Before attending this study, the participants had to have a minimum of one year's experience in resistance training. Participants were physically fit. We searched for people who were between 18-35 years old. Participants had to be free from any upper body injury within six (6) months prior to the study. Participants were so called recreational strength trainers. This means that they did not compete at any sport. Participants had to describe what kind of resistance training and aerobic training they usually had done six months prior to the study (e.g. how many times a week, what kind of exercises, which kind of sets, amount of repetitions or duration of aerobic training). In addition, participants had to be able to commit to the whole study period. It was told to the participants that they should maintain their normal diet during the whole intervention period. Participants were not allowed to do resistance training on their own during the ten (10) week resistance training program. Aerobic training was allowed.

Physical characteristics of the participants are presented in table 14. All the variables are measured from the time when they started the study. The following equation was used to calculate body mass index (BMI): Weight : $Heigth^2$ after which was Weight : x. This equation can also be written into weight : height x height. Weight is divided by the sum of weight : height^2 equation.

Central tendencies of all participants is presented in table 11. We can see from the table that participants were on average 30.9 years old (sd ± 4.0; 21-36 years). Average height of the participants was 179 cm (sd ± 5.9; 171-193 cm). Participants weighed on average 79.3 kg (sd ± 9.9; 63-105 kg). Body mass index (BMI) varied between 18.6-32.4 kg/m^2 (mean 24.5; sd ± 3.0).

TABLE 11. Physical characteristics of all male subjects (N = 23).

	Age (years)	**Heigth** (cm)	**Weight** (kg)	**BMI** (kg/m^2)
Mean ± SD	30.9 ± 4.0	179 ± 5.9	79.3 ± 9.9	24.5 ± 3.0
Range (min-max)	21-36	171-193	63-105	18.6-32.4

Comparison between group physical characteristics can be seen in the next table. Participants in the concentric training group were on average 31.5 years old (sd ± 3.1; range 25-36) and they were on average 179.2 cm (sd ± 7.3; 171-193) height. Average weight was 78.8 kg (sd ± 10.2; 63-98 kg) and BMI 24.2 kg/m^2 (sd ± 3.1; 18.6-29.0 kg/m^2). Participants in the eccentric training group were little younger (mean 30.1 years; sd ± 4.8; 21-35). They were on average 178.9 cm (sd ± 4.3; 174-186) height and weighed on average 79.7 kg (sd ± 10.0; 65-105). Average body mass index (BMI) for eccentric group is 24.9 kg/m^2 (sd ± 3.1; 21.4-32.4). (Table 12.)

TABLE 12. Comparison between the concentric and eccentric training groups.

	Age (years)		**Heigth** (cm)		**Weight** (kg)		**BMI** (kg/m^2)	
	CON	**ECC**	**CON**	**ECC**	**CON**	**ECC**	**CON**	**ECC**
Mean	31.5	30.1	179.2	178.9	78.8	79.7	24.2	24.9
SD ±	3.1	4.8	7.3	4.3	10.2	10.0	3.1	3.1
Range (min-max)	25-36	21-35	171-193	174-186	63-98	65-105	18.6-29.0	21.4-32.4

Participants were recruited for this study from Jyväskylä and its surroundings. Posters were put on bulletin boards of e.g. library, fitness centers and University buildings. Participants were also recruited by an email that was sent to all University students who studied in the University of Jyväskylä. One advertisement was published in a local newspaper which was delivered to all households in Jyväskylä.

The ethical committee approved the study design of this intervention. The staff of University of Jyväskylä submitted a request for this study from the ethical committee. This study is conducted according to the guidelines that are stated in the Declaration of Helsinki (WMA 2013). Before the subjects were eligible to participate in this study, they were given informed consent to be read and signed. This study can be classified as experimental design. The quantitative research method is used in this study.

5.3 Design

In figure 15 we can see an overview of the length of each training period. The study begun by a familiarization week. Control measurement was done on the control week. We can see from the figure that the duration of the training period was ten weeks. Pre measurement was done on the first week of the intervention and post measurement on the last week of the intervention.

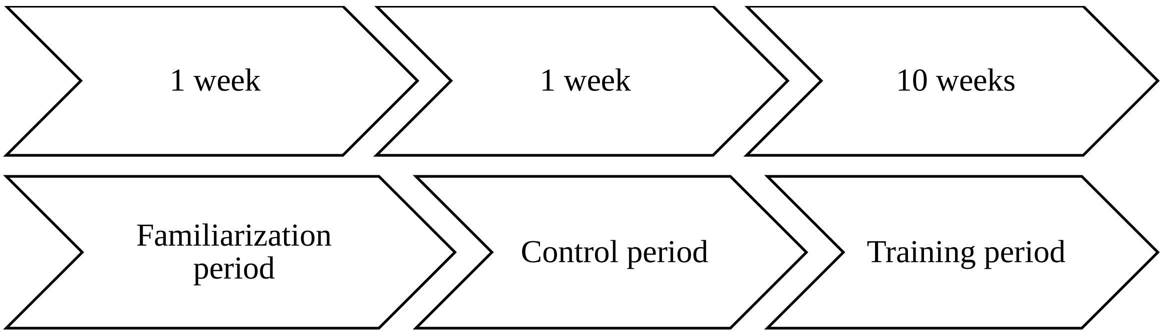


FIGURE 15. Length of each period can be seen from this picture.

An overview of the experimental design is presented in table 13. Number of sets and repetitions of the trainings and measurements are presented in this table. The study begun with a familiarization week which was followed by a control week. Both groups did 2x3 concentric and 2x3 eccentric muscle actions in the control week. Participants performed first opposite muscle action, which means that concentric training group first did eccentric and vice versa. The first number in the table indicates sets and the second number the amount of repetitions per set. Pre-measurements were done on the first week of the study. Mid-measurements were done on the sixth week. Pre- and mid-measurements were done in the first training of each week. Post measurement was done in the second training of the week. There were two training sessions per week. In the measurements, the eccentric training group did concentric muscle action and concentric training group did eccentric muscle action. In other words, we measured the opposite muscle force.

TABLE 13. Number of sets and repetitions in the measurements and trainings are presented here.

Week	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Familiarization	Control*	**Pre-Measurement**	Trainings				**Mid-Measurement**	Trainings			**Post-Measurement**
Ecc	2x3	2x3 + 2x3	2x3	3x3	3x3	4x4	4x4	2x3	4x4	4x4	3x4	2x3
Con	2x3	2x3 + 2x3	2x3	3x3	3x3	4x4	4x4	2x3	4x4	4x4	3x4	2x3

*Participants did 2x3 concentric and 2x3 eccentric

Pre and post measurements for the determination of eccentric and concentric muscle force were done differently from control and mid measurements. Eccentric and concentric muscle force were not measured according to the table above. This is a small deviation from the original study plan. In order to minimize, this small deviation was done using the following procedure: eccentric and concentric pre and post muscle force were detected from acute measurements. Acute measurements were done with three sets of four repetitions but the determination of muscle force was accepted only from the first two sets. The last set was excluded from the analyses due to accumulating muscle fatigue.

There are at least two protocols on how legs can be placed in bench press. In some protocols, legs are kept on the floor. Some protocols prefer keeping the legs on the bench. In this study legs are kept on the bench or up in the air. This procedure ensures that participants can not ease the bench press with their legs. With the help of legs, it is possible to get force to the lift. We want to ensure that the bench press is done purely without lower body forces.

Participants participated in familiarization sessions which were organized one week before control measurements. Actual measurements started two weeks after the familiarization week. The right settings were made to each participant during the familiarization week. The settings were written in a laboratory diary. In the familiarization week measurements were not necessarily done with maximal force. The main idea was that subjects got acquainted with equipment and methods. In addition, subjects had a chance to ask if they had questions about the methods or practical issues.

5.4 Resistance training program

Length of the training program was ten (10) weeks. All of the trainings were guided. Exercises of the training program are presented below. There are altogether eight exercises in this training protocol. During the first five (5) weeks hypertrophic training was done which means that there were 10-12 repetitions per set. Weeks 6-10 consisted of maximal strength training which means repetitions of 6-8 per set. All the sets were done three times in every exercise. Abdominal and back extensions were done with 10-12 repetitions during the whole protocol. Loads of each exercise were increased in the second half of the training protocol. Loads were individually set for every practice. Some of the subjects had not much experience on resistance training which meant that it was inevitable to estimate the appropriate load for each exercise. Participants did this training program twice a week. Training days were not consecutive days. There was a minimum of 48 hours of rest between resistance training sessions. Exercises were done in the order of appearance in the table. (Table 14.)

TABLE 14. Exercises of the training protocol, number of sets and repetitions are presented in this table.

Exercise	**Weeks 1-5**	**Weeks 6-10**
Lateral pull down	3x10	3x6-8
Leg press	3x8-10	3x5-8
Hip trust	3x10	3x6-8
Knee extension	3x10	3x6-8
Barbell curl	3x10	3x6-8
Abdominals (Russian twist)	3x10-12	3x10-12
Back extension	3x10-12	3x10-12

We used standardized warm-up protocol in this study. First, the participants pedaled on a bicycle ergometer for five (5) minutes. Participants rotated their arms forward and backwards (2 x 15 full rotations). Thereafter, the participants swung their hands by extending both hands backwards and crossing hands to front (15 repetitions). In addition, participants did vertical push-up as well as backward, side and front lateral raise with either 1.25 kg or 2.5 kg external weights. There were two rounds and 15 repetitions in each exercise. In addition, the participants did shoulder push-ups and normal push-ups. These were done twice with ten (10) repetitions.

Participants were able to decide from three options which training days were best for them. Optional training days were either Monday and Thursday, Tuesday and Friday or Wednesday and Saturday. In addition, participants were able to suggest the best training time for them. Possible training times on weekdays were between 15-21 pm and 12-18 pm for Saturday.

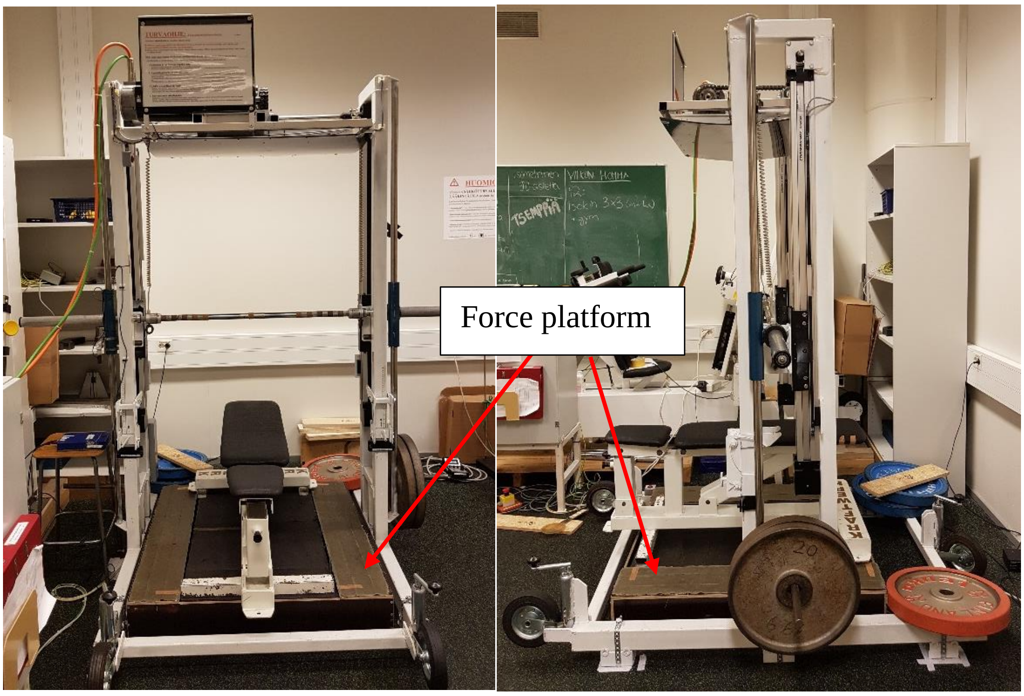
5.6 Measurements

All the measurements were done in a controlled manner in the laboratory of University of Jyväskylä, Finland. All the measurements were conducted by students who had gotten instructions on using the machines and who were acquainted with the methods.

Results were stored on the computer that did not have Internet connection. Each subject had their own ID code which was used in saving. Participants were verbally encouraged to do their best in every measurement. There was used equipment that the University of Jyväskylä offered.

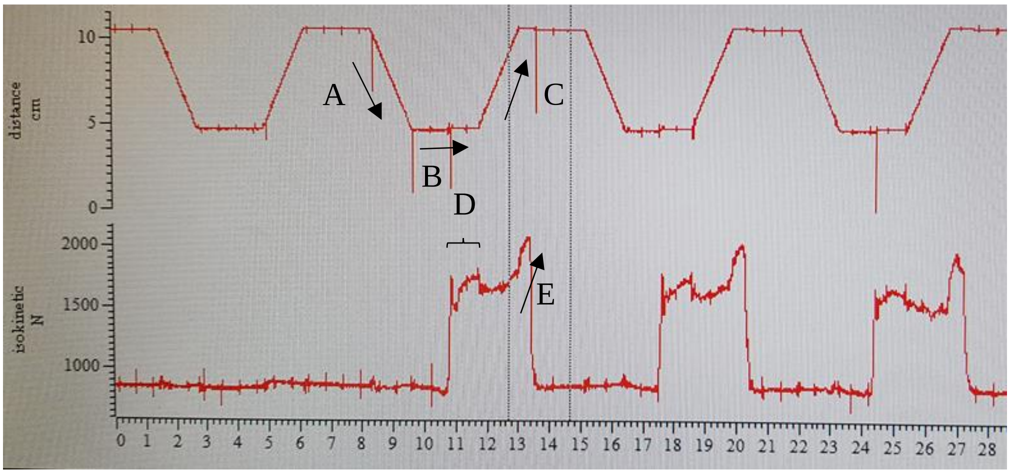
5.6.1 Isokinetic machine

An isokinetic barbell machine (Kraftwerk, bench David, force platform University of Jyväskylä) is equipped with electricity. Angular velocity of the bar was set to move at the speed of 0.2 milliseconds (ms). The bar stayed still for 2000 ms before downward or upward motion. Maximum force of the isokinetic barbell machine was 5000 newtons (approximately 509 kilograms). Rest period between sets was set to three (3) minutes in the trainings and to two (2) minutes in the measurements. (Picture 1.)



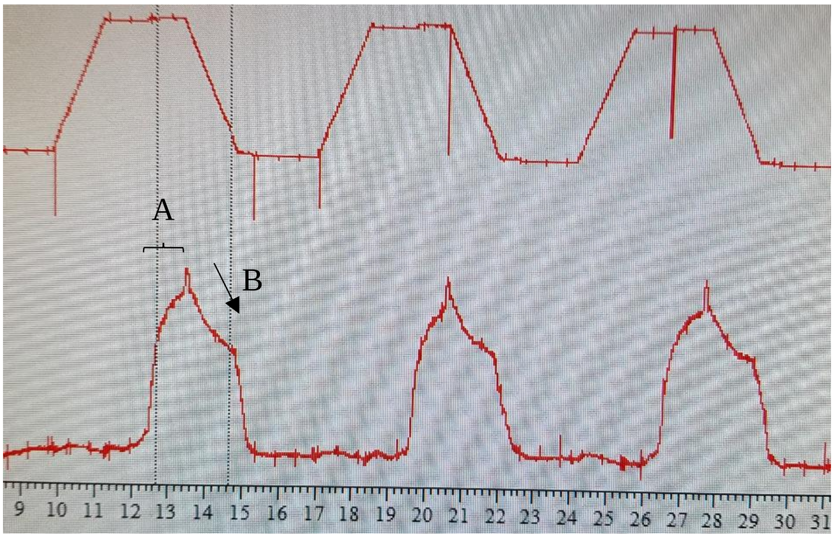
PICTURE 1. Isokinetic bench press machine.

In picture 2 there is a view from Signal program which was seen on the computer screen. The upper line in the picture indicates the displacement of the bar during the isokinetic bench press. Displacement is indicated by arrows. There was one displacement of the bar before the actual measurement. Decline means that the bar is moving downwards (A). Straight arrow indicates that the bar is not moving at all (B). Upward motion points out that the bar is moving back to an upright position (C). The lower line tells us the amount of produced muscle force in newtons. We can see from the picture that force production began before the bar went ahead upwards (D). In the concentric action force production increases as the bar moves upwards (E).



PICTURE 2. A view from concentric muscle activation on the computer screen.

The lower graph tells us the force that is produced in eccentric muscle action. We can see from the picture that the greatest force is produced when the bar is not moving (A). Force begins to decline right after the bar has started to move (B). This decline continues to the point when the bar stops again in the lower position. In the horizontal axis we can see time in seconds. (Picture 3.)



PICTURE 3. View of eccentric muscle contraction on the computer screen.

5.6.2 Safety procedures

There were many safety procedures with the machines. There were upper and lower limits set to the isokinetic machine. Bar of the isokinetic machine moved between the lower and the upper limiters. Lowest possible height in the measuring tape was 95 cm. There was not an upper limit. Grip length, horizontal position and elbow angel were written down in every participant's laboratory diary (appendix 1).

The bar of the isokinetic machine did not move unless thumb was not placed to hold the switch. Elbow angle was the main indicator when the upper limit of the was bar set. For some participants it was necessary to put blocks under the bench press chair. There were blocks of 18 mm, 28 mm and 36 mm. These blocks were placed under both ends of the bench chair.

5.2 Timetable

Timetable of the study is presented in figure 16. Preparations included familiarization of the design, methods etc. These were made during April-May in 2019. During this period of time all the main decisions for the study were made. The last updates concerning the design was made in August 2019. Actual measurements started in September 2019 and lasted to the middle of December 2019. Analysis of the measurements were done when all the measurements were completed.

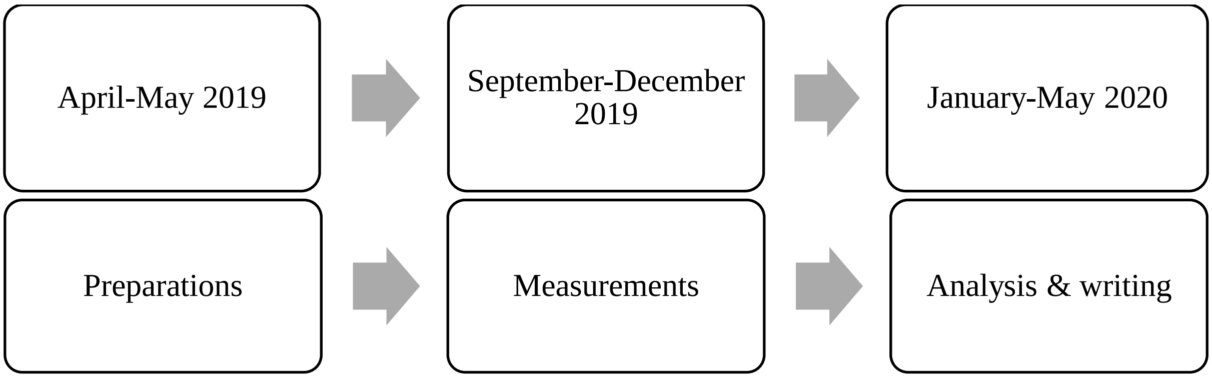


FIGURE 16. Timetable of the study.

5.8 Data collection

All the data from the laboratory measurements were collected and stored to a computer (Dell Optiplex 9010). This computer was stationary. There was installed Windows 7 Enterprise (version 6.1) software on the computer. There were two Acer Screens (models AL1917 F and AL1917 A). These were located in the same laboratory room where the measurements were done. Signal program (version 4.10) was used for the isokinetic measurements.

All the forms that we collected from the participants were stored in a locked closet which was located in the laboratory room. All the participants got an ID number that was used in forms as well as saving e.g. isokinetic data to the computer. In addition, there were used initials which were created from the participant’s first letters of the first and last names. In the end, when all analyses were done, all data was destroyed.

5.9 Statistical analysis

Results were first analyzed with Microsoft Office Excel (2016). There was imputation used for the missing numerical values. Missing numbers were replaced by the average number of the parameter. For example, if a pre measurement was missing, it was replaced by the average of all pre measurements of the group. Thus, the effect of one participant's missing measurement is as negligible as possible and does not adversely nor beneficially affect the statistical analyses.

Unit of the isokinetic data is newton (N). This can be classified as a continuous variable because it can take any value within a great range. Therefore, it was chosen as the scale of measurement unit for statistical analyses. IBM® SPSS (version 26) (Statistical Product and Service Solutions; originally Statistical Package for the Social Sciences) were used for the statistical analyses. Normal distribution of the data was tested on Shapiro-Wilk's test. For the statistical analyses, a non-parametric method was used because the sample size is small. Wilcoxon's paired sample t-test was used for analyzing the difference between two measurement points (pre vs. post). Statistical analysis was done between groups by Mann-Whitney's non-parametric test. Independent samples t-test was used for between group analysis. In the statistical analyses, significance level of $p < 0.05$ was used.

6 RESULTS

Summary of the main results are presented in table 15. Eccentric training group (ecc/ecc) lifted on average 1327 (sd ± 335) newtons in pre measurement. In post measurement this value was 1181 (sd ± 300) newtons. Decline during the intervention was -146 newtons (p=0.01). Concentric group's (con/con) mean value was 799 (sd ± 197) newtons in pre situation and 908 (sd ± 220) newtons in post condition. Maximal concentric training increased maximal strength by 109 newtons (p=0.00).

Eccentric training affected concentric force production (ecc/con) in the following way: mean pre value was 842 (sd ± 217) newtons and post value 928 (sd ± 202) newtons. Maximal eccentric training increased maximal concentric strength by 86 newtons (p=0.03). The effect of concentric training on eccentric force (con/ecc) decreased from pre (mean 1388 ± sd 191) to post (mean 1357 ± sd 341). Maximal concentric training did not improve maximal eccentric force (-31 newton; p=0.69).

TABLE 15. The main results of the study.

Training group	**Strength**	**Pre** (mean ± sd)	**Post** (mean ± sd)	**P-value**	**Δpre-post** (N)	**Δpre-post%** (mean ± sd)
ecc	ecc	1327 ± 335	1181 ± 300	0.01	-146	-10.3 ± 10.8
	con	842 ± 217	928 ± 202	0.03	86	14.1 ± 13.8
con	con	799 ± 197	908 ± 220	0.00	109	12.0 ± 16.1
	ecc	1388 ± 191	1357 ± 341	0.69	-31	-2.4 ± 18.5

Summary of the percentages changes between group measurements are presented in figure 19. There is statistically significant difference between ecc/ecc vs. con/con training groups (p = 0.00). Statistical significance was not observer between ecc/con vs. con/ecc groups (p = 0.69). Mean decrease of eccentric training on eccentric force production (ecc/ecc) was -10.3 % (sd ± 10.8). The effect of eccentric training on concentric force (ecc/con) was on average 14.1 % (sd ± 13.8). Concentric training improved maximal concentric strength (con/con) by 12.0 percentages (sd ± 16.1). There was on average -2.4 % (sd ± 18.5) decrease in the concentric training group on maximal eccentric force (con/ecc).

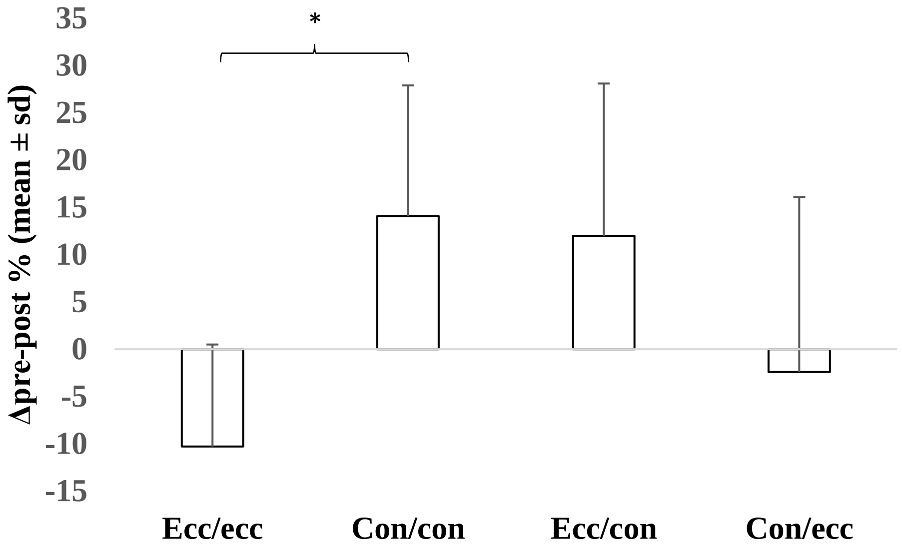


FIGURE 19. Percentage of change and standard deviation between pre and post measurements. Ecc/ecc, eccentric training/eccentric force; ecc/con, eccentric training/concentric force; con/con, concentric training/concentric force; con/ecc, concentric training/eccentric force. * Statistically significant difference between group measurements (p<0.05).

7 DISCUSSION

7.1 Main findings

The main finding for the first study question is that maximal eccentric strength did not increase in this intervention, but maximal concentric strength enhanced. Between group comparison (ecc/ecc vs. con/con) revealed that there is statistically significant difference. The main finding for the second study question is that maximal eccentric training improved maximal concentric strength. Maximal concentric training did not improve maximal eccentric strength.

The aim of this study was to investigate how maximal eccentric and concentric resistance training effects maximal eccentric and concentric force production, and secondly, the training effects of maximal eccentric and concentric training on maximal eccentric and concentric force production. It can be said now that this aim is fulfilled. However, the phenomenon of the effects of maximal eccentric and concentric training remains unsolved. The results of this study are partly controversial to previous studies. Some previous studies have come to a conclusion that maximal eccentric training has improved maximal eccentric strength. In this study the result is opposite. Maximal eccentric strength did not increase by maximal eccentric resistance training. Reason for this outcome is unclear. One possible explanation can be that participants were co called low responders. This means that strength does improve with these participants as it improves with those who are so called high responders.

The results of this study give us support that eccentric overload training can enhance concentric performance abilities. Very often a plateau occurs in resistance training programs at some point. In concentric resistance training performances, it is not possible to put loads that are above 1 RM but in eccentric resistance training it is possible. Based on this study, plateau in concentric performance can be bypassed by eccentric overload training. Concentric phase in bench press can be a limiting factor for 1 RM lift. Even though the eccentric lowering phase in bench press can be performed by over concentric 1 RM load, it is not possible to lift again up. If maximal concentric training is done in bench press, it has a negative influence on eccentric performance.

This study confirms some the understanding that we have had about the effects of eccentric and concentric resistance training on force production but the results are partly inconsistent to previous studies. It can be said based on the findings that there is a difference between eccentric and concentric strength training on maximal force production but the direction and magnitude of the eccentric resistance training on eccentric force production was not what we were anticipating.

Validity of the study can be assessed to a high level. All the devices that were used in this study were manufactured and calibrated for the purpose that they were designed. All the measurements were repeated similarly with the same equipment in a laboratory environment. The reliability of the study was influenced on few occasions in which isokinetic force could not be recorded to the computer. Bench press was performed even if there was a problem in recording or saving the measurement. This caused small bias to the results. Number of participants is common in this kind of study. Both groups had quite equal number of participants (11 and 12). All in all, reliability can be classified to a high level.

It would have been interesting to analyze detraining effects, the effects of eccentric and concentric resistance training on other parameters such as 1RM max or EMG activity etc. In the larger study design, detraining effect was measured but it was excluded from this thesis. There is more research needed from this area. As a future development, the suggestion can be given that muscle architecture from fascicles and pennation angles perspective should be investigated more precisely.

7.2 Strengths and weaknesses of the study

One strength of this study is that the measurements were done in a laboratory and all the measurements were done similarly during the whole intervention period. This kind of standardization allows us to investigate muscles effectively. In addition, there was an isokinetic bench press available which is a special device to measure the effects of eccentric and concentric strength. Position of head and grip were controlled in this study. Participants were asked to do their maximal output in every measurement, and performances were also verbally encouraged.

A limitation of this study can be kept that time of measurements were not controlled. This may have had an effect especially on endocrine functions and thus also on strength results. There are studies that suggest that time of day may influence strength gain and hypertrophy (Chtourou & Souissi 2012). On the other hand, it can be considered as a positive issue that the participants had the chance to decide when they arrived at the laboratory. We can also discuss what is the role of motivation. If the study period is long it may be inevitable that participants lose their interest towards the measurements. We did not have any kind of goal discussions with the participants. This would be a natural discussion in real life competitive sports coaching. There may have occurred adaptation during the intervention period. However, stimuli may have not been high enough to develop strength. There may have been required frequent training in order to increase the level of stimulus.

7.3 Scientific conclusion

A scientific conclusion can be stated that maximal eccentric resistance training did not have positive influence on maximal eccentric force production. This finding is contradictory to previous studies. However, maximal concentric resistance training had positive influence on maximal concentric force production. Statistically significant difference is seen between the effect of eccentric and concentric resistance training on force production.

It can also be stated that maximal eccentric resistance training is associated with elevated maximal concentric force. Maximal concentric resistance training does not induce greater adaptation in maximal eccentric force.

7.4 Practical applications

There are many professions that can benefit from the information and findings that are discussed in this study. Coaches of multiple disciplines can expand their knowledge about the effects of eccentric and concentric resistance training. They can use this information when they plan resistance training programs for their athletes. It is important to keep in mind that eccentric training may not necessarily develop eccentric strength. In some sports eccentric, concentric or both force production types can be a limiting factor for development. Therefore, it is important for coaches to do sport analysis which consider how force is produced and can be gained. In addition, personal trainers can also benefit from this information. It may be important for them to know that there are differences between concentric and eccentric resistance training. For students and professionals of sport and health sciences, this study may give new and current insights around the impact of maximal eccentric and concentric resistance training on force production.

One sport specific practical application can be given to a cyclist. Cyclists can try to increase their pedaling performance by maximal concentric resistance training. In cycling concentric phase has a crucial role. Eccentric phase should be done slowly whereas concentric phase as quickly as possible. (Halme 2019; Malmstedt 2019; Heggelund et al. 2013.) Maximal strength training can develop strength more than so called conventional resistance training. (Heggelund et al. 2013).

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APPENDICES

APPENDIX 1

ISOKINEETTINEN PENKKIPUNNERRUS

Yläasento	Ala-asento	Yläasennon kyynärkulma

Käsienpaikka (pikkurillistä)	Päänpaikka (silmistä)	Palkit	Jalkojen paikka (penkillä)