# EFFECTS OF TWO DIFFERENT TAPER MODELS AFTER STRENGTH TRAINING ON CORTICOSPINAL EXCITABILITY AND MUSCLE STRENGTH

**Minttu Virtanen**

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Faculty of Sport and Health Sciences
University of Jyväskylä
Supervisor: Janne Avela

# ABSTRACT

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**Aim:** The aim of this study was to investigate if there are (1) differences between the effects of two taper models on strength performance, (2) changes in corticospinal excitability and inhibition as the effect of 8 week of strength training, and (3) changes in corticospinal excitability and inhibition following two different taper models. **Methods:** Two groups (n = 6 + 5) of recreationally active men first performed 8-week hypertrophic and maximum strength training period, and after that Group 1 performed two weeks of step taper and Group 2 two weeks of linear taper. Squat 1 RM, leg press MVIC, knee extension MVIC and the measurements of corticospinal excitability with transcranial magnetic stimulation were performed six time during the study: week before strength training (conrtol), before strength training, after 5 and 8 weeks of strength training and after one and two weeks of taper. **Results:** Squat 1 RM improved for both groups through the study whereas MVIC in leg press and knee extension did not change as clearly. There were not statistical differences between groups in any strength results. MEParea with different stimulation intensities, MEPsum and the slope of the I/O-curve remained constant or slightly decreased during the 8-week of strength training period, whereas during the first week of taper they slightly increased for group 1 and slightly decreased for group 2, and during the second week of taper vice versa. AMT and the duration of silent periods did not change significantly during the study. **Discussion & conclusion:** The results of this study suggest that there are not differences between the effects of step taper and linear taper on strength performance. During the 8-week hypertrophic and maximum strength training period corticospinal excitability remained constant or slightly decreased. During taper step taper corticospinal excitability first slightly increased and then slightly decreased whereas during linear taper appeared to happen vice versa.

**Keywords:** Strength training, step taper, linear taper, TMS, corticospinal excitability, MEP, silent period

# ABBREVIATIONS

| | |
|---|---|
| aEMG | Average electromyography |
| AMT | Active motor threshold |
| BF | m. biceps femoris |
| EMG | Electromyography |
| ES | Electrical stimulation |
| IEMG | Integrated electromyography |
| ITT | Interpolated twitch technique |
| MEP | Motor evoked potential |
| Mmax | Maximal M-wave |
| MSO | Maximal stimulating output |
| MT | Motor threshold |
| MVIC | Maximal voluntary isometric contraction |
| RMT | Resting motor threshold |
| SI | Stimulation intensity |
| SP | Silent period |
| TMS | Transcranial magnetic stimulation |
| VA | Voluntary activation |
| VL | m. vastus lateralis |
| 1 RM | One repetition maximum |

# CONTENTS

# 1 INTRODUCTION

Muscular strength is vital in different types of sports. Improvements in maximum strength are beneficial not only in strength based sports but also in endurance based and team sports. (e.g. Baker 2002; Hoff et al. 2002; Storen et al. 2008; IPF 2016; IWF 2018.) Thus it is reasonable that strength training has become as a popular form of exercise among athletes of different sports (Fleck & Kraemer 2014, 1).

When peaking or optimizing maximum strength for an important event like the main competition during the season the periodization of training is used (Fleck & Kraemer 2014, 258). The period just before the competition with short-term reduction in training load is commonly called as a taper (Gibala et al. 1994). The main purpose of the taper is to reduce negative effects and fatigue accumulated during preceding training period. The improving effect of the taper on performance is typically ranging between 0,5–6 % so it may have a critical role determining ranking between top level athletes in competitions. (Mujika & Padilla 2003.)

Taper can be performed with various different strategies (Mujika & Padilla 2003). To our knowledge, possible differences between the effects of different type of tapers on strength performance have not been investigated previously. It also seems that much information about neural mechanisms behind strength improvements during taper is not available. Changes in integrated surface electromyography (Häkkinen et al. 1991) and voluntary activation (VA) assessed with interpolated twitch technique (ITT) (Gibala et al. 1994) during taper has been studied earlier but there is a need for assessing neural changes with more sensitive method.

Transcranial magnetic stimulation (TMS) can be used to evaluate the excitability and inhibition of the corticospinal tract (Barker et al. 1985; Avela & Gruber 2011, 115). Changes in corticospinal excitability and inhibition have been detected following strength and motor skill training (e.g. Perez et al. 2004; Jensen et al. 2005; Beck et al. 2007; Griffin & Carafelli 2007; Kidgell & Pearce 2010; Kidgell et al. 2010). To our knowledge, the effects of taper on corticospinal excitability has not been investigated previously. There

is a possibility that changes in corticospinal excitability and inhibition occurs also during taper and that those changes are partly explaining the changes in strength performance.

In this study two groups of recreationally active men performed 8 weeks of strength training followed either by 2 weeks of step taper or 2 weeks of linear taper. The aim of this study was to investigate if there are (1) differences between the effects of two taper models on strength performance, (2) changes in corticospinal excitability and inhibition as the effect of 8 week of strength training, and (3) changes in corticospinal excitability and inhibition following two different taper models.

# 2 NEUROMUSCULAR SYSTEM

## 2.1 Nervous system

The central nervous system consist of two main parts: the brain and the spinal cord. The brain is composed of six major parts: the medulla oblongata, pons, cerebellum, midbrain, diencephalon and cerebrum (Figure 1). These regions have several different functions concerning for example vital autonomic functions, senses, learning of motor skills and regulation of movements. (Kandel et al. 2013, 8–9.)

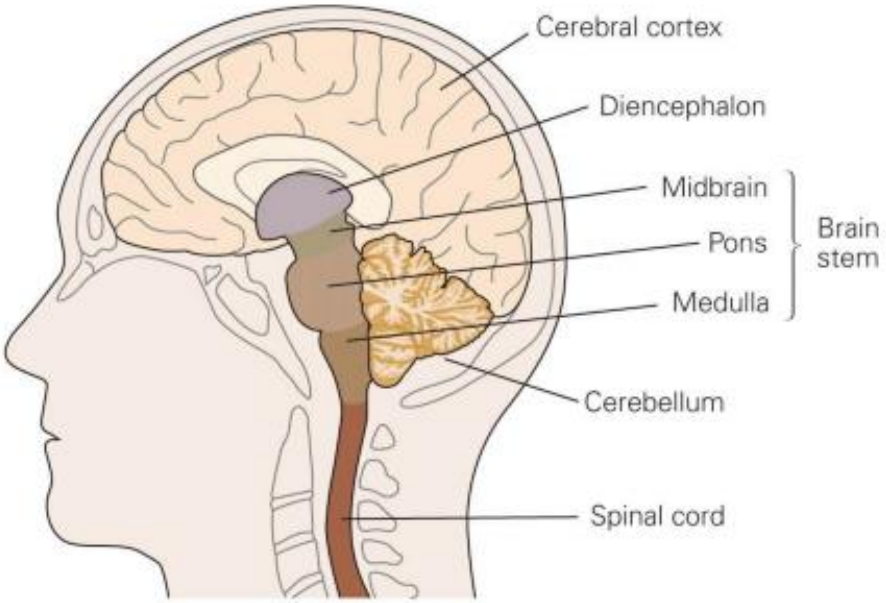



FIGURE 1. Central nervous system can be divided in the brain and the spinal cord. The brain is composed of six main parts. (Kandel et al. 2013, 340.)

The spinal cord extends from the base of the skull all the way to the first lumbar vertebra. It contains motor neurons responsible for voluntary and reflex movements, and sensory neurons receiving and delivering sensory information from periphery to the brain. The motor neurons in the spinal cord form the final common pathway so the higher brain levels controlling motor activity are acting through the spinal cord. That is, through these descending pathways motor commands and modulatory signals are delivered from the brain to the muscles. (Lorenz & Campello 2001, 127–132; Kandel et al. 2013, 339–340.)

Cerebral cortex is a part of cerebrum and can be divided in four smaller lobes: frontal, parietal, occipital and temporal lobe. Large areas of the cerebral cortex participate in voluntary motor control and one of them is the primary motor cortex which is located in the frontal lobe of the cerebral cortex (Figure 2). The primary motor cortex mediates voluntary movements of the limbs and trunk by generating signals providing information about desirable movements before those movements are executed. The primary motor cortex is organized somatotropically so activity in specific area of the primary motor cortex leads to the activity in the specific muscle groups in periphery. The relative areas of primary motor cortex corresponding to each muscle groups are represented in Figure 2. (Kandel et al. 2013, 341–344; 364–366; 835-852.)

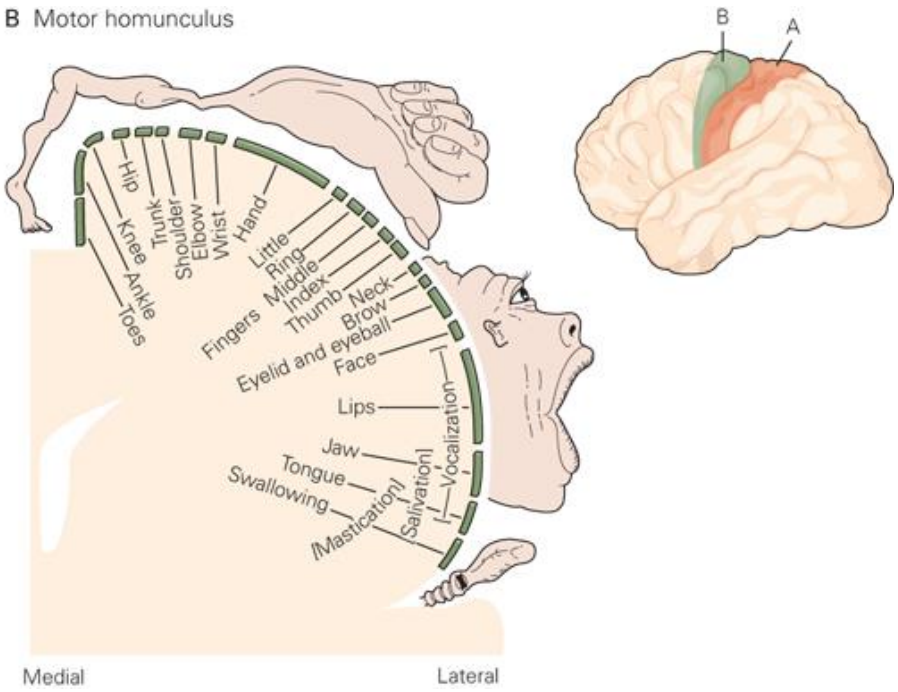



FIGURE 2. Primary motor cortex (B) is located in the frontal lobe of the cerebral cortex and is organized somatotropically. (Kandel et al. 2013, 364.)

Neurons that originate from the primary motor cortex terminate in the ventral horn of the spinal cord (Figure 3). Those neurons activate somatic motor neurons directly and form a significant part of the corticospinal tract. Most of the corticospinal neurons cross the midline in the medulla as illustrated in Figure 3. That means that each hemisphere is acting primarily contralaterally so motor commands from the left hemisphere activates muscles on the right side of the body and vice versa. (Kandel et al. 2013, 10; 364–366; 835-852.)

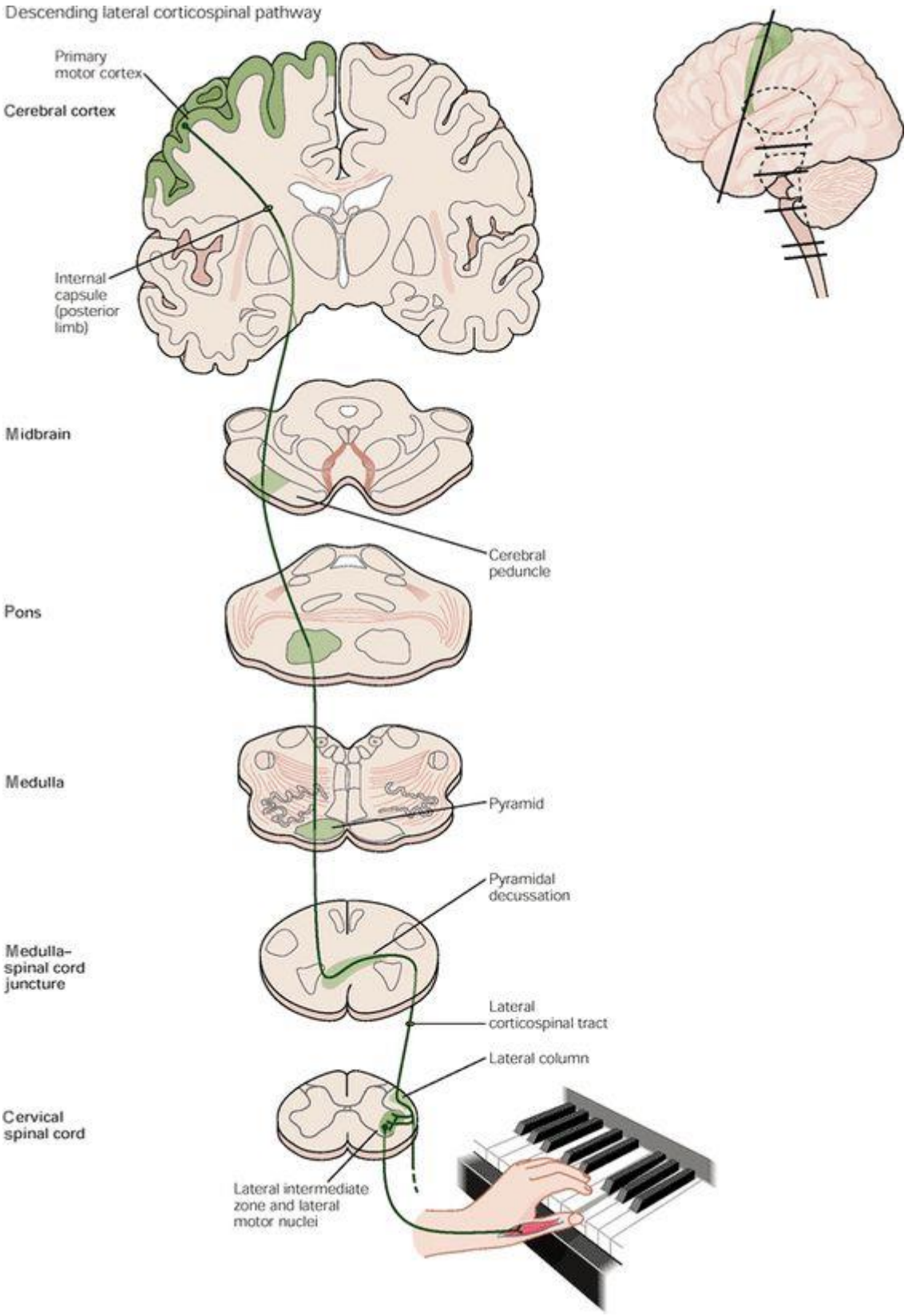



FIGURE 3. Neurons originating from the primary motor cortex terminate in the ventral horn of the spinal cord and activate motor neurons from the contralateral side directly. (Kandel et al. 2013, 366.)

Neurons transmitting the signals are both electrically and chemically excitable. Formation and transmission of neural signals is based on temporary changes in flow of positive and negative ions through the neuron's membrane causing rapid changes in membrane potentials of the neuron. If the resting membrane potential is reduced enough occurs the depolarization which leads to a formation of an action potential. Action potentials are those signals by which brain delivers and receives information. (Enoka 2008, 179–182; Kandel et al. 2013, 23; 31; 71; 126–127.)

Neural commands, or motor outputs, that motor neurons on the spinal cord transmit from the brain to the muscle cause the contraction of the muscle. The axons of motor neurons innervating limb muscles exit the spinal cord in the ventral root and continues in a peripheral nerve to the muscle. (Kandel et al. 2013, 744; 768.) The synapse between motor nerve and muscle fiber is called as a neuromuscular junction (Enoka 2008, 190). One motor neuron can innervate from few to several thousand muscle fibers by its axon's branches. Motor neuron and muscle fibers it innervates form a motor unit which is the basic functional unit used in the control of the movement. (Kandel et al. 2013, 744; 768.)

## 2.2 Muscle contraction and force production

Following strong enough depolarization of the motor neuron membrane potential the action potential travels to the neuromuscular junction, or synapse, locating between the end of the axon and the muscle fiber. Action potential is transmitted over the synaptic cleft by a chemical neurotransmitter and then travels along the membrane of the muscle fiber causing a tetanic contraction of the fiber. During the contraction of the muscle fiber the contractile proteins (actin and myosin) in sarcomere, that is the small contractile unit of the muscle fiber, are sliding in relative to each other and forming cross bridges between each other. Thus during the sliding the cross bridges are in a way pulling the endplates of sarcomere towards each other. Whereas the muscle is consisted of muscle fibers, muscle fibers are consisted of myofibrils in parallel and myofibrils are consisted of a sarcomeres in series, the shortening of sarcomeres is shortening the whole muscle and force is exerted (Figure 4). (Lorenz & Campello 2001, 149–153; Kandel et al. 2013, 769–777.)

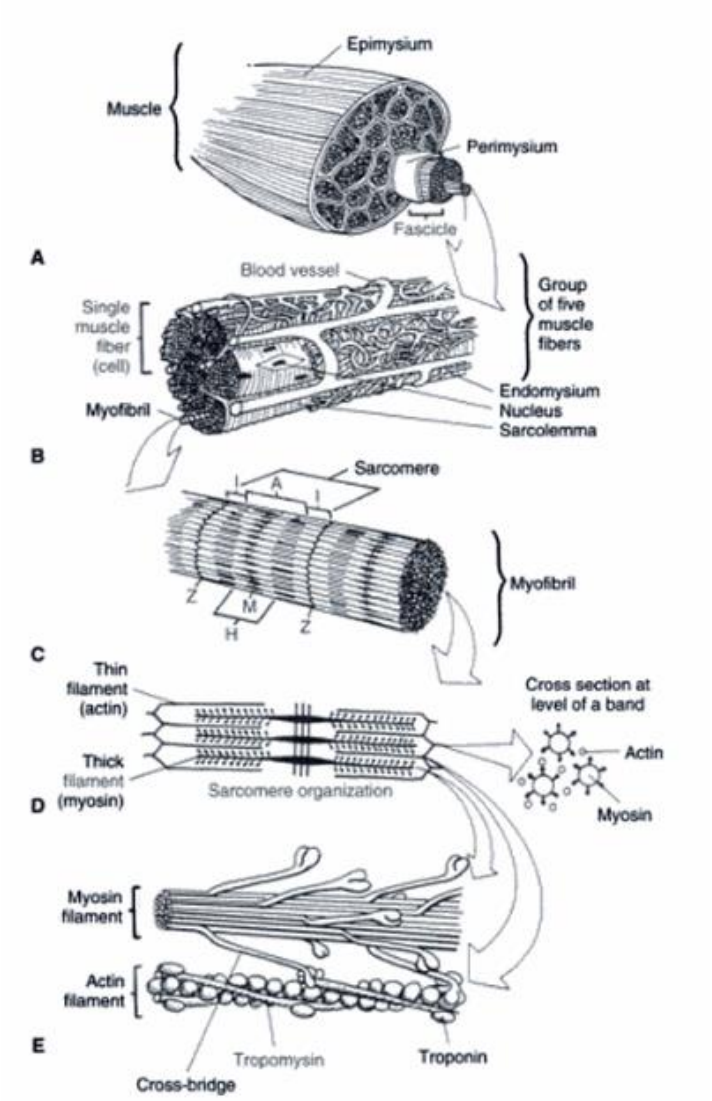



FIGURE 4. Organization of muscle and muscle fiber (A), myofibril (B), sarcomere (C & D) and myosin and actin filaments (E) (Lorenz & Campello 2001, 150).

The force evoked during tetanic twitch is relative to the extent which twitches overlap and summate. The force of the motor unit depends on the contraction time and the rate at which the action potentials are evoked. Fiber type effects on force and maximal force is often greater in fast- than slow-twitch units. The force of the whole muscle depends on the number of motor units activated and the discharge rate of motor neurons. Also such structural factors as the number of the cross bridges formed, the force produced by each cross bridge, the numbers of sarcomeres in parallel and hence cross sectional area of the muscle and the pennation angle of the muscle fibers are affecting the force produced during the contraction. (Kandel et al. 2013, 771–782.)

# 3 STRENGTH TRAINING

Muscular strength is needed in different sports. Besides its unconditional importance in strength based sports like powerlifting (IPF 2016) and weightlifting (IWF 2018) several studies have shown that improved strength performance is beneficial also in for example endurance based sports and team sports (e.g. Baker 2002; Hoff et al. 2002; Storen et al. 2008). Thus it is reasonable that strength training has become as a popular form of exercise among athletes of different sports (Fleck & Kraemer 2014, 1).

Strength training is often used to improve muscular strength and/or increase muscle size (Fleck & Kraemer 2014, 1). Different strategies are used to gain either strength improvements or muscle hypertrophy. Among the classic strength/power periodization model for strength gains lower amount of repetitions should be performed with higher intensity whereas for hypertrophic responses higher amount of repetitions with lower intensity should be used. Classic strength/power periodization model is presented in Table 1. (Fleck & Kraemer 2014, 57–59.)

Table 1 Classic strength/power periodization model (Modified from Kraemer & Häkkinen 2014, 72).

| | **Strength** | **Hypertrophy** |
|---|---|---|
| **Volume** | Moderate | High |
| **Intensity** | High | Moderate |
| **Sets** | 3–6 | 3–6 |
| **Repetitions** | 1–5 | 8–20 |
| **Rest between sets** | 2–5 min | 30–60 s |

## 3.1 Neural adaptations to strength training

Greater strength levels and muscle hypertrophy following strength training are results from training adaptations in muscle structure and nervous system. As can be seen from the Figure 5 early improvements in maximum strength during the first weeks of strength

training can be explained mainly by changes in neural factors. The role of the muscle hypertrophy in strength gain increases among the training. (Häkkinen 1994.)

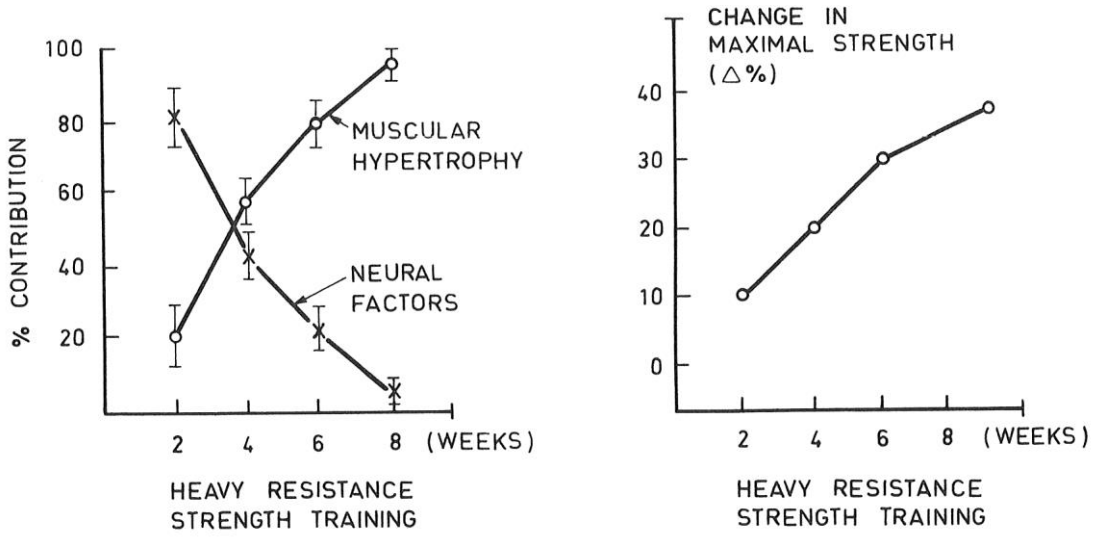



FIGURE 5. Percentage of contributions of muscular hypertrophy and neural factors in strength gain during a heavy resistance strength training in previously untrained subjects. (Häkkinen 1994.)

Possible structural changes following high-intensity resistance training are increments in muscle cross sectional area (e.g. Housh et al. 1992; Kawakami et al. 1995; Aagaard et al. 2001), muscle fiber cross sectional area (e.g. MacDougall et al. 1980; Aagaard et al. 2001; Campos et al. 2002), muscle thickness (e.g. Abe et al. 2000) and muscle fiber pennation angle (e.g. Kawakami et al. 1995; Aagaard et al. 2001). Possible neural changes following strength training is enhanced neural drive from the spinal motoneurons (Aagaard et al. 2002) resulting increments in agonist muscle integrated electromyography (iEMG) (e.g. Häkkinen & Komi 1983), maximal motor unit or motor neuron firing frequency (e.g. Van Cutsem et al. 1998; Aagaard et al. 2002), motor neuron recruitment (Aagaard et al. 2002) and motor unit synchronization (e.g. Milner-Brown & Lee 1975). It has been also reported that untrained subjects are not able to fully voluntarily activate all motor units of knee extensors (e.g. Jakobi & Cafarelli 1998; Roos et al. 1999) so resistance training can also result as increments in voluntary activation in at least some lower limb muscles as Knight and Kamen (2001) indicated.

Strength gains following strength training may also be explained by a learning effect because it seems that even in a simple single-joint movements the skill is required for optimal expression of strength (Nozaki et al. 2005). Task specific learning resulting from strength training have been demonstrated in several studies as an enhanced intermuscular coordination that is reduced antagonist activation and enhanced use of synergist muscles during the contraction (e.g. Rutherford & Jones 1986; Carolan & Cafarelli 1992). The role of the skill in performing complex multi-joint movements like squat is likely greater than in single-joint movements. Thus it is possible that also antagonist activation is greater in such complex movements and there is more opportunity for learning about optimal activation patterns during strength training (Folland & Williams 2007). Learning resulted by motor skill training has been detected to induce changes in motor cortex, for example increases in corticospinal excitability (e.g. Perez et al. 2004; Jensen et al. 2005), so there is a possibility for motor cortex changes also after strength training consisting of complex multi-joint or whole-body movements.

## 3.2 Overloading and overreaching

Strength gains following strength training require sufficient training stimulus and overloading which can be achieved by gradually increased, or progressive strength training (Zatsiorsky & Kraemer 2006, 10–12, 15; Fleck & Kraemer 2014, 10–11). Improvements in performance are based on supercompensation (Figure 6). As can be seen from the picture the performance is reduced immediately following training session. During the recovery phase performance shifts to increase due to training adaptations and finally reaches a new level of performance along the supercompensation. If new appropriate training stimulus occurs during supercompensation phase athlete's performance improves (Figure 7b). If recovery phases between training sessions are too short the performance decreases (7a) and if they are too long the performance remain constant (7c). (Zatsiorsky & Kraemer 2006, 10–12.)

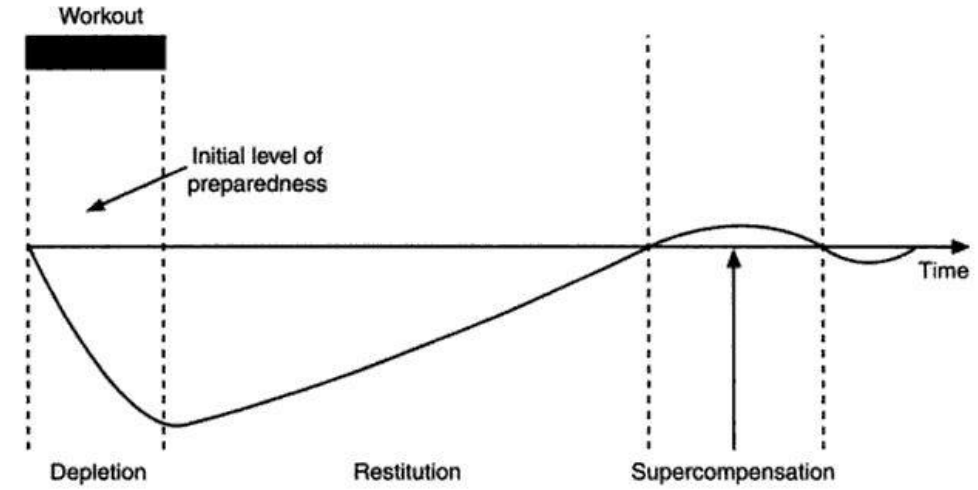



FIGURE 6. Changes in performance immediately after training session, during the recovery phase and during the supercompensation phase (Zatsiorsky & Kraemer 2006, 10.)

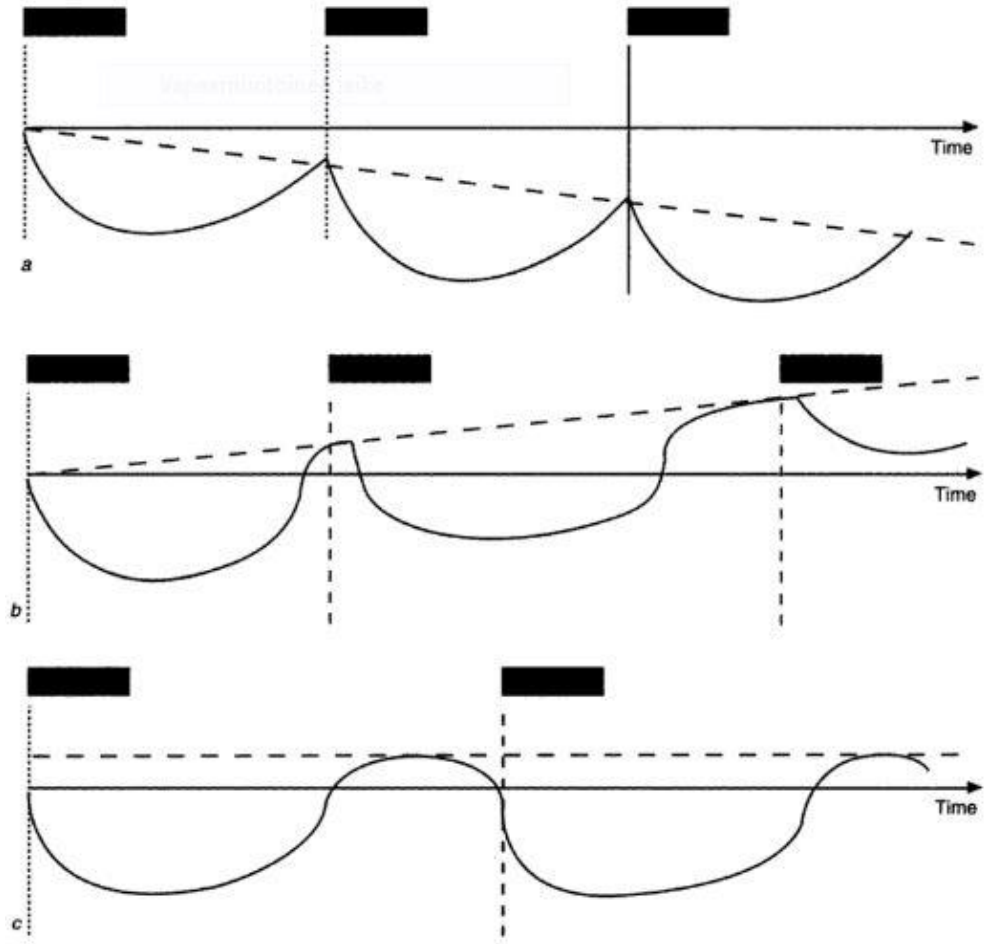



FIGURE 7. The effect of time intervals between training sessions: (a) too short time intervals lead to decrements in performance, (b) adequate time intervals lead to increments in performance and (c) too long time intervals lead to unchanged performance. (Zatsiorsky & Kraemer 2006, 11.)

One variation of supercompensation theory is overloading microcycle (Figure 8). During overloading microcycle several training sessions with high training load are performed with short time intervals between them to induce overreaching which results as a temporal decrease in performance. After that longer period of rest is executed and due to training adaptations and fatigue removal the performance reaches the new level. (Zatsiorsky & Kraemer 2006, 11–12.)

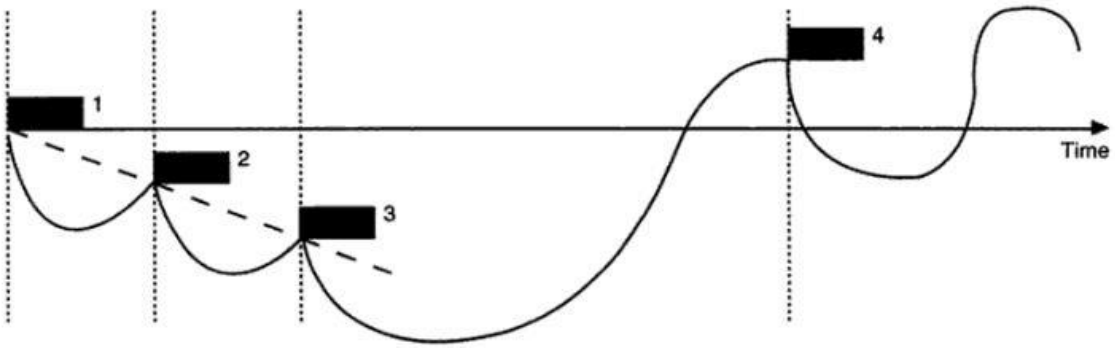



FIGURE 8. The overloading microcycle. Time intervals between the first three training sessions are too short but after them the longer period is included and improvement in performance is achieved. (Zatsiorsky & Kraemer 2006, 12.)

During overreaching it is possible to observe some changes in neural factors. Häkkinen and Komi (1983) noticed that during the first 12 weeks of heavy resistance strength training the iEMG of the vastus lateralis and vastus medialis muscles increased but from training week 12 to week 16 iEMG turned to decrease. Such decrease in iEMG during strength training period may indicate overreaching and training induced fatigue of nervous system (Häkkinen 1994). To our knowledge, the effects of overreaching or training induced fatigue on corticospinal excitability or inhibition have not been investigated previously.

## 3.2 Taper in strength training

The periodization of training is used to optimize training adaptations during both short and long periods of time. In linear periodization model the peaking phase is used just before major competition to peak physical performance. In peaking phase the training volume is reduced and intensity increased when compared to preceding training periods. (Fleck & Kraemer 2014, 258–263.) This period with short-term reduction in training load before competition is commonly called as a taper (Gibala et al. 1994). Previously taper

has been defined as “a progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance” (Mujika & Padilla 2000).

The main purpose of the taper is to reduce negative effects and fatigue accumulated during preceding training period, rather than gain further improvements in strength capacity and fitness (Mujika & Padilla 2003). However, at least if overloading exists before taper, can some gain been achieved also through a small improvements in positive effects, as Thomas et al. (2008) noticed in their swimming study. The effectiveness of taper can be illustrated through a fitness-fatigue model. Fitness-fatigue model represents the positive and negative effects of training on athlete’s performance. The relationship between these fitness and fatigue effects determines the performance of athlete at certain time point (Figure 9). Usually fatigue decays in a shorter time than fitness which makes performance improvements possible when training load is reduced during taper. (Banister 1991, 413–417.) However, it is important to balance between rest and training during taper as positive fitness effects may reduce after detraining (Mujika & Padilla 2000).

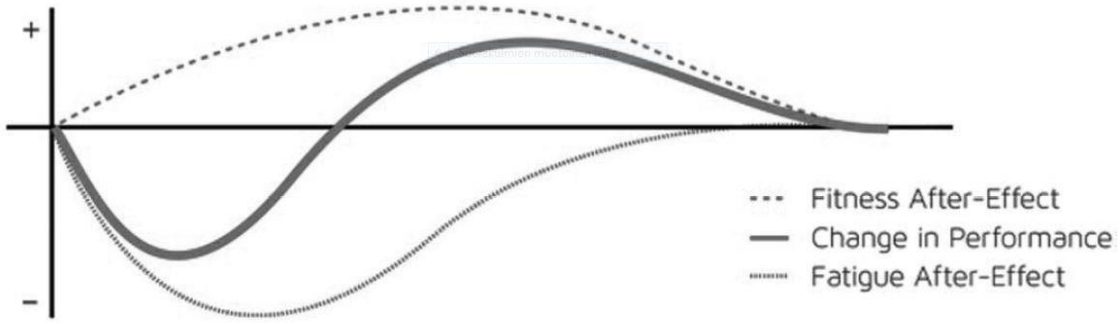



FIGURE 9. Fitness-fatigue model (Pritchard et al. 2015).

### 3.2.1 The length of the taper

The length of the taper period has varied between different strength training studies from 1 to 4 weeks (Häkkinen et al. 1991; Gibala et al. 1994; Coutts et al. 2007; Izquierdo et al. 2007; Chtourou et al. 2012; Zaras et al. 2014; Rhibi et al. 2016). Häkkinen et al. (1991) and Coutts et al. (2007) used taper duration of 1 week, Chtourou et al. (2012), Zaras et al. (2014) and Rhibi et al. (2016) used duration of 2 weeks and Izquierdo et al. (2007) used

duration of 4 weeks. All these studies reported improvements in strength performance after taper.

However, most of these studies measured strength performance only before and after the training period and after the taper period. Thus, it is unclear whether the performance is changing during the taper period and which is the most optimal duration of taper if achieving the peak performance. Only studies that measured the performance during the taper were Häkkinen et al.'s (1991) and Gibala et al.'s (1994) which included strength performance measurements on 3 days during 1 week taper and every second day of 10 day taper, respectively. Gibala et al. (1994) noticed that strength remained at increased level at least 8 days during the taper. However, it is still unclear whether, for example, one week taper especially after training period to induce overloading is long enough to fully overcome the effects of accumulated fatigue, as Pritchard et al. (2015) discussed about the results of Coutts et al.'s (2007) study.

### 3.2.2 Type of the taper

Mujika and Padilla (2003) presented four different type of tapers that are most commonly used: linear taper, exponential taper with slow or fast decay and step taper (Figure 10). During linear and exponential tapers the training load is reduced progressively in linear or exponential fashion, respectively. In exponential taper the reducing of the training load can be executed even with slow or fast decay, hence the total training load is higher in the slow decay taper. In step taper or so called reduced training period the training load is reduced nonprogressively with a standardized reduction. (Mujika & Padilla 2003.) As mentioned earlier, during the taper the training volume and thus load is reduced but intensity is kept high or increased (Fleck & Kraemer 2014, 260–262). Several studies have reported that lowering volume but keeping intensity at high level during taper leads to improvements in strength performance (Häkkinen et al. 1991; Gibala et al. 1994; Izquierdo 2007; Chtourou et al. 2012; Rhibi et al. 2016). Zaras et al. (2014) found out that improvements in maximum strength are greater if training intensity is high during taper when compared to low training intensity during taper.

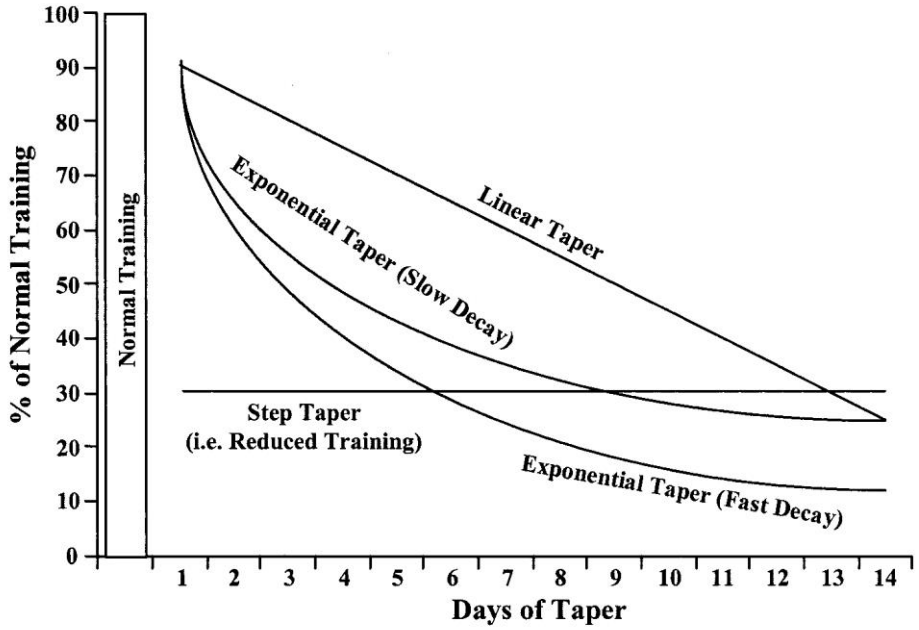



FIGURE 10. Different types of tapers: linear taper, exponential taper with slow or fast decay, and step taper. (Mujika & Padilla 2003.)

Both progressive (Gibala et al. 1994; Izquierdo et al. 2007; Rhibi et al. 2016) and step taper (Häkkinen et al. 1991; Coutts et al. 2007; Chtourou et al. 2012; Zaras et al. 2014) have been reported to have improving effect on strength performance. In Gibala's et al. (1994) study well trained strength athletes improved their low velocity strength performance of elbow flexors during 8 day progressive taper following 3 weeks of elbow flexors strength training. Izquierdo et al. (2007) noticed that after 4 weeks of progressive taper following 16 weeks of resistance training strength trained athletes could improve both upper and lower body maximal strength. Rhibi et al. (2016) reported that volleyball players were able to improve their lower limb maximal strength after two weeks of linear taper following five weeks of resistance training.

Häkkinen et al. (1991) in turn showed that highly trained strength athletes could improve their maximum strength of leg extensor muscles after only one week of step taper following two weeks of regular training. Also Coutts et al. (2007) noticed that after 1 week step taper following 6 week of strength training maximal low-velocity isokinetic torque of knee extensors and flexors improved in rugby league players. Chtourou et al. (2012) as well showed that recreationally active participants could improve their knee extensors maximum strength after two week step taper following 12 weeks of strength training.

Zaras et al. (2014) reported that throwing athletes improved their maximal isometric and dynamic leg press results during two week step taper after 12 and 15 weeks of strength training.

Even if the different type of tapers have been used in strength training and studies, it seems that there is no comparison available about effects of different type of tapers on strength performance. Consequently there is a need for study that is comparing the effects of different type of tapers on strength performance.

### 3.3.3 The effect of taper on neural mechanisms

There is not much information available about neural mechanisms behind force increments following reduced strength training. Häkkinen et al. (1991) detected increase in elite athletes' maximal force and averaged maximum iEMG of knee extensor muscles after one week of reduced training period following two weeks of heavy resistance strength training. However, for lower level strength athletes they did not detect any changes in maximal force and maximal iEMG. As they discussed, a three week experimental period might have been too short to reveal increase in maximal iEMG and/or force for strength trained athletes who have limited potential for further strength developement. However, they concluded that especially in advanced strength athletes the nervous system may be in an important role when peaking maximal strength during taper. (Häkkinen et al. 1991.)

Gibala et al. (1994) in turn investigated effects of 10-day taper following three weeks of elbow flexor strength training on motor unit activation. Motor unit activation was assessed with interpolated twitch technique. However, even if the low velocity concentric strength improved they did not detect significant changes in motor unit activation during the taper. Researchers discussed that there is a possibility that neural changes occurred during the taper but the interpolated twitch technique was not necessarily sensitive enough to detect those. (Gibala et al. 1994.)

As Pritchard et al. (2015) mention in their review, it seems that there is a need for further research to investigate whether neural changes play a role in strength improvements after a taper. It is also necessary to know what are those neural mechanisms that possible are

affecting on strength performance after taper to better understand the effects of the training.

# 4 CORTICOSPINAL EXCITABILILTY AND INHIBITION

As discussed earlier (see Chapter 3.1), corticospinal excitability may change as the result of training. The corticospinal excitability can be investigated using transcranial magnetic stimulation where the motor cortex is stimulated with magnetic stimulator and artificial action potentials, called motor evoked potentials (MEP), are evoked in a target muscle (Figure 11). By analyzing motor responses, changes in corticospinal excitability can be assessed. (Barker et al. 1985; Avela & Gruber 2011, 115.) TMS as a method is more closely described in Chapter 4.2. Here, the assessment of some most general variables of corticospinal excitability and the effects of strength training and motor skill training on them, are presented.

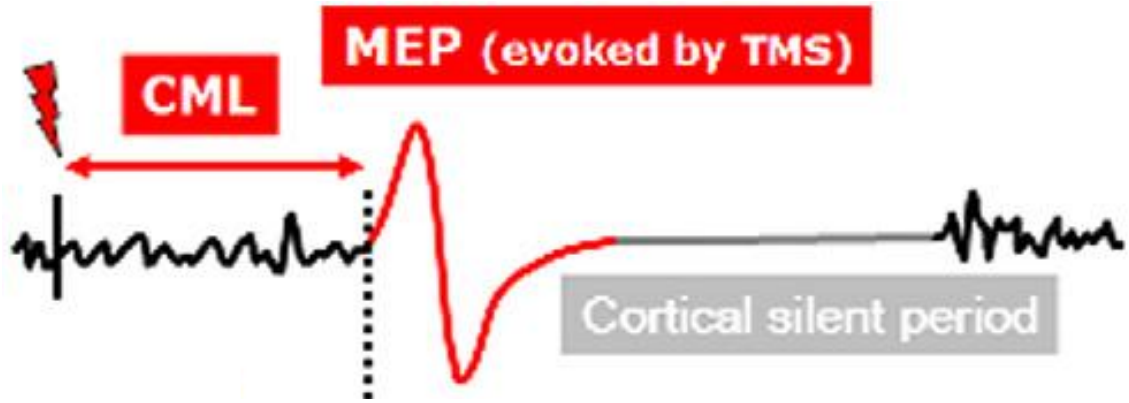



FIGURE 11. Motor evoked potential (MEP) evoked by TMS, cortical motor latency (CML) preceding MEP and cortical silent period (SP) following MEP (Modified from Grobba et al. 2012.)

## 4.1 Assessment variables

### 4.1.1 Motor thresholds

Rossini et al. (2015) defines the cortical motor threshold (MT) "as the minimal intensity of motor cortex stimulation required to elicit a reliable MEP of minimal amplitude in the target muscle". There are some differences in thresholds between different muscles. For hand and forearm muscles thresholds are the lowest (about 40–50 % of maximal stimulating output, MSO) whereas for trunk, lower limb and pelvic muscles thresholds are

higher (about 55–65 %, 60–90 % and 75–100 % of MSO, respectively). (Rossini et al. 2015.)

*Resting motor threshold* (rMT) is determined from passive muscle (Rossini et al. 2015) and it indicates the global excitability of the corticospinal pathway (Avela & Gruber 2011, 120). rMT is often defined as the stimulating intensity, which evokes MEPs with amplitude at least 50 µV in 5 out of 10 trials. However, to get reproducible results, more trials are needed. Getting the desirable MEP value in 10 out of 20 trials is more reliable way to determine rMT. (Rossini et al. 2015.)

*Active motor threshold* (aMT) is usually determined from slightly active muscle (approximately 20 % contraction of maximal voluntary contraction). In determination of aMT the limit for the MEP amplitude is often 100 µV. (Rossini et al. 2015.) Groppa et al. (2012) introduces some guidelines for determining cortical motor threshold. Stimulating should be started with subthreshold intensity and the coil placed over the optimal site of stimulation. In the beginning, the stimulating intensity is increased in steps of 5 % of maximal stimulator output until stimulating consistently evokes MEPs with amplitude over 50 µV in each trial. Then, the stimulating intensity is decreased in steps of 1 % of maximal stimulator output until positive responses are evoked in less than 5 out of 10 trials. The cortical motor threshold is then defined as the latest stimulating intensity plus 1 % of maximal stimulator output. (Groppa et al. 2012.) Malcolm et al. (2006) detected that determining the motor threshold has a high test-retest reliability at least in some hand muscles.

### 4.1.2 The size of the MEP

MEP-size as a response to TMS can be used to evaluate the global excitability of the corticospinal pathway (Avela & Gruber 2011, 121). MEP is usually recorded from the target muscle with bipolar surface EMG-electrodes. The size of the MEP can be determined either measuring the peak-to-peak amplitude, or amplitude from pre-MEP baseline to peak, or by measuring the area under the curve. Basically, the higher the stimulation intensity is the greater is the MEP-response up to the certain level (see input-output rela-

tionship later) (Groppa et al. 2014). Because there is some variability in MEP sizes between single trials, several MEPs are needed to get a reliable assessment of the MEP size (Rossini et al. 2015).

MEPs can be measured during tonic activity or relaxation (Rossini et al. 2015). During slight activity (contraction level 5-10 % of maximal voluntary isometric contraction, MVIC) the relative variability of MEPs evoked by constant stimulation intensity and during particular pre-EMG level is lower than during relaxation. Therefore, the slight voluntary activation during stimulation stabilizes cortical and spinal excitability. (Darling et al. 2006.) Voluntary contraction during stimulus also increases cortical excitability and decreases the threshold for indirect activation of neurons. In other words, during voluntary activity lower stimulation intensity is needed to evoke appropriate MEP and motor threshold is decreased. (Avela & Gruber 2011, 120–122; Mazzocchio et al. 1994.) However, there may be differences between muscles in effects of activity on MEP-amplitudes (Avela & Gruber 2011, 122). Also, the strength of the voluntary contraction effects on the increase of cortical excitability (Martin et al. 2006). Martin et al. (2006) noticed that MEP-amplitudes were greatest during voluntary contractions at around 50–75 % of MVC in biceps brachii and brachioradialis muscles. At higher contraction levels MEP-amplitudes decreased and during MVC they decreased about 25 % of maximal M-wave (Martin et al. 2006).

### 4.1.3 The input-output relationship

The input-output relationship (I/O-curve or stimulus-response curve) can be created from several stimuli in different intensities. Input refers the intensity of the stimulus and output refers the magnitude of the muscle response (MEP). (Avela & Gruber 2011, 120–121.) Input-output relationship has a sigmoidal shape (Figure 12). Sigmoidal shape is partly due to progressive motor unit recruitment. When the maximal MEP amplitude is achieved, input-output relationship reaches the plateau and MEP amplitude does not increase even if the stimulus intensity increases. (Devanne et al. 1997; Groppa et al. 2014.) However, the plateau is not always reached when stimulating muscles with high rMT (for example lower leg muscles) (Avela & Gruber 2011, 121). In rest the higher stimulation

intensity is needed to reach the plateau when compared to preactivated situation (Groppa et al. 2014).

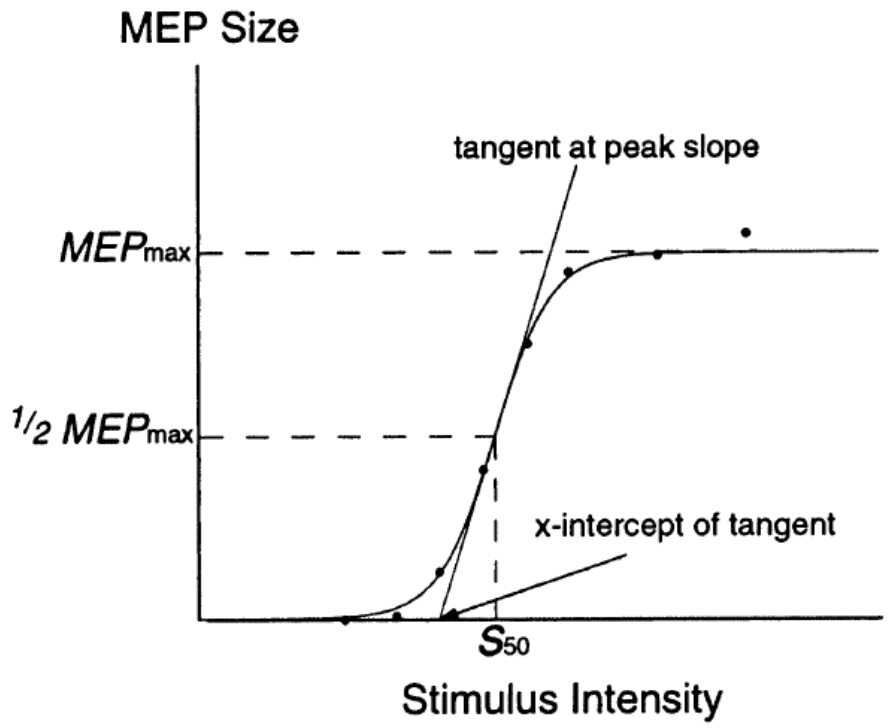



FIGURE 12. Input-output relationship (I/O-curve). (Carrol et al. 2001.)

The slope of the I/O-curve and the size of the MEP-amplitude in plateau can be used to estimate the increase in EMG-activity in particular stimulating intensity. Thus, they describe the excitability of the corticospinal pathway. (Carroll et al. 2001.) Changes in corticospinal excitability can shift the I/O-curve to the left or to the right, and also change the slope of the curve. When neural excitability increases also MEP-amplitudes are greater. (Rossini et al. 2015.) Among to Malcolm et al. (2006) the slope of the I/O-curve has a high test-retest reliability in several hand muscles.

### 4.1.4 Silent period

Silent period (SP) refers a pause in the ongoing EMG-activity after MEP during voluntary contraction (Figure 11) (Avela & Gruber 2011, 122). SP can be measured only during voluntary activation. It is usually defined to begin from the onset of the MEP and end to the point where EMG-activity is beginning again. (Groppa et al. 2014.) The duration of

the SP can be around 200–300 ms (Ingehilleri et al. 1993) and it increases when stimulating intensity increases (Ingehilleri et al. 1993; Groppa et al. 2014). Ingehilleri et al. (1993) noticed that background activity does not have an effect on SP duration.

The SP is created by both spinal and cortical mechanisms. (Avela & Gruber 2011, 122). Spinal mechanisms generates the early part (<50 ms) of SP whereas the rest of the SP (>50 ms) is produced by inhibitory mechanisms within primary motor cortex (Ingehilleri et al. 1993). However, there is also a possibility that the spinal portion of the SP can last even 150 ms, as Yacyshyn et al. (2016) noticed. Total duration of the SP is usually changed only by cortical mechanisms (Rossini et al. 2015). It seems that some inhibitory cortical neurons within motor cortex can be stimulated by TMS so the duration of SP can indicate the cortical excitability (Avela & Gruber 2011, 122.) Whereas the duration of the SP increases when intracortical inhibition increases, it can be used to assess intracortical inhibition (Rossini et al. 2015). A rough estimation of the properties of silent period can be achieved with 5–6 trials, but for more precise estimation more, for example 20–30, trials are needed. SP duration can be measured by calculating an average from single trials or by calculating an average from MEP/SP rectified traces. (Groppa et al. 2014.)

## 4.2 Strength training and corticospinal excitability and inhibition

The effects of short-term (4 wk) strength training on corticospinal excitability has been examined in various studies. Studies has been done considering both upper (Carroll et al. 2002; Jensen et al. 2005; Kidgell & Pearce 2010; Kidgell et al. 2010) and lower limb muscles (Beck et al 2007; Griffin & Carafelli 2007; Lee et al 2009). Results from different studies are partly in contrast to each other when some studies report increase in cotricospinal excitability (Beck et al. 2007; Griffin & Carafelli 2007; Kidgell et al. 2010) while others report no changes or even decrease in corticospinal excitability after 4 week strength training (Carroll et al. 2002; Jensen et al. 2005; Lee etal 2009; Kidgell & Pearce 2010). It has to be considered that between these studies there are differences in muscles studied, type of strength training performed (isometric vs. dynamic, explosive vs. non-explosive) and conditions and details used in TMS that may partly explain conflicts between results. The findings from different studies are presented in Table 2.

TABLE 2. The effects of strength training on the MEP-size, the slope of the input-output -curve (I/O-curve) and the duration of the silent period (SP). 1RM = one repetition maximum.

| Study | Training | Maximum strength | MEP-size | Slope of the I/O-curve | SP duration |
|---|---|---|---|---|---|
| **Griffing & Cafarelli 2007** | 4 wk isometric, tibialis anterior | MVIC +18 % | + | | |
| **Kidgell et al. 2010** | 4 wk, dynamic, bicebs brachii | 1RM +28 % | + | 0 | |
| **Beck et al. 2007** | 4 wk ballistic, ankle plantar and dorsal flexors | | | + | |
| **Kidgell & Pearce 2010** | 4 wk, isometric, first dorsal interosseus | MVIC +34 % | 0 | | - |
| **Lee et al. 2009** | 4 wk, dynamic, wrist abductors | MVIC +11 % | 0 | | |
| **Carroll et al. 2002** | 4 wk, dynamic, first dorsal interosseus | MVIC +33 % | - | | |

*Effects of strength training on MEP-size and I/O -curve.* The increase in MEP-size or the slope of the I/O-curve suggesting the increase of corticospinal excitability following strength training period has been reported in several studies. Griffin and Cafarelli (2007) found out that the size of the MEP during slight tonic activity increased after 4 week maximal isometric strength training of tibialis anterior muscle. Kidgell et al. (2010) in turn studied the effects of heavy-load dynamic strength training period of biceps brachii muscle and noticed as well the increase of MEP-size during slight background activity. However, they did not detected any changes in the slope of the I/O-curve (Kidgell et al. 2010). Beck et al. (2007) found out the task- and training-spesific increase of the slope of the I/O-curve after 4 week ballistic ankle strength training. However, also studies with no significance changes in MEP-size or the slope of the I/O-curve exist. Kidgell and Pearce (2010) and Lee et al. (2009) did not detect any changes in MEP-size during background activity after 4 week isometric strength training of first dorsal interosseus and 4 week dynamic strength training of wrist abductors respectively, even if the maximal voluntary

isometric force increased 34 % and 11 % respectively. Carroll et al. (2002) noticed that MEP-size during various different background activity decreased after 4 week dynamic strength training for first dorsal interosseus muscle.

*Effects of strength training on silent period.* Kidgell and Pearce (2010) noticed that the duration of silent period decreased after 4 week isometric strength training of first dorsal interosseus muscle. Reduction in the duration of the silent period after strength training may indicate reduced inhibition both in spinal and cortical level (Kidgell & Pearce 2010).

*Meaning of changes in corticospinal excitability.* Enhancement of MEP-size after strength training may suggest adaptations in cortical level and changes in recruitment gain (Beck et al. 2007). Increase in MEP-size may be explained by an increase in the number and size of the descending volleys generated by TMS or by an increase in the number of corticospinal cells activated (Kidgell et al. 2010). Changes in synaptic input, synchronization and enhanced short-term and long-term potentiation may be the factors leading to the increased excitability of the central nervous system. As the effect of these increases in excitability initial motor unit firing rates may increase and thresholds for motor unit recruitment decrease. That results as a faster force production and a greater muscle force ouput. (Griffin & Cafarelli 2007.) The decrease in MEP-size after strength training in turn can be explained either by the smaller amount of motoneurones activated by the descending volleys or by the greater degree of cancellation of motor unit action potentials at the muscle membrane (Carroll et al. 2002).

## 4.3 Motor skill training and corticospinal excitability

Motor skill training have been noticed to increase corticospinal excitability (Perez et al. 2004; Jensen et al. 2005). Jensen et al. (2005) assessed the effects of 4 week motor skill training of elbow flexors on corticospinal excitability. They found that following training maximal MEP ($MEP_{max}$) increased and the minimal stimulation intensity required to elicit MEPs decreased significantly at rest and during contraction suggesting increase in corticospinal excitability. Perez et al. (2004) in turn noticed increase in corticospinal excitability after only 32 minutes of motor skill training of tibialis anterior muscle. They found

that I/O-curve was significantly greater after than before training. Results from these studies indicate that such changes in corticospinal excitability may be of importance for task acquisition (Jensen et al. 2005).

However, Christiansen et al. (2017) noticed that the progression of the motor skill training has an effect on changes in corticospinal excitability. In their study two groups did motor skill training for 4 days: the first group trained with task difficulty progressively increasing and for the second group task difficulty remained the same through a whole training period. Corticospinal excitability assessed with the area under the I/O-curve increased in both groups after the first day of training, but continued increasing through the rest of the period only for progressive training group. Thus, it seems that in motor skill training the task difficulty has to be high enough in relation to motor skill level to induce changes in corticospinal excitability. (Christiansen et al. 2017.)

## 4.4 Transcranial magnetic stimulation

Transcranial magnetic stimulation (TMS) can be used to study corticospinal excitability. It is a noninvasive method that has been used since 1985. In TMS corticospinal pathway is activated by stimulating motor cortex with magnetic stimulation which evokes action potentials in target muscles. (Barker et al. 1985.)

### 4.4.1 Equipment and stimulation

Stimulation is performed by magnetic stimulator which consists of a flat coil and a high-voltage capacitor. Discharging of capasitor induces electrical current flow through the coil. (Barker et al. 1985.) Current produces a magnetic field which is oriented perpendicular to the coil (Figure 13) (Hallet 2007). Rapidly changing, pulsed magnetic field induces electrical eddy currents to surrounding conductive tissue. (Rothwell 1997.) When the coil is held on the scalp and motor cortex is stimulated, evoked electrical eddy currents cause changes in motor neuron membrane potentials and result an action potential or excitatory or inhibitory postsynaptic potential (Terao & Ugawa 2002). Thus, stimulation can temporarily excite or inhibit motor cortex areas (Hallet 2000). Evoked action potentials are

called motor evoked potentials (Avela & Gruber 2011, 115) and they can be detected with surface electrodes from the target muscle (Barker et al. 1985) (Figure 10).

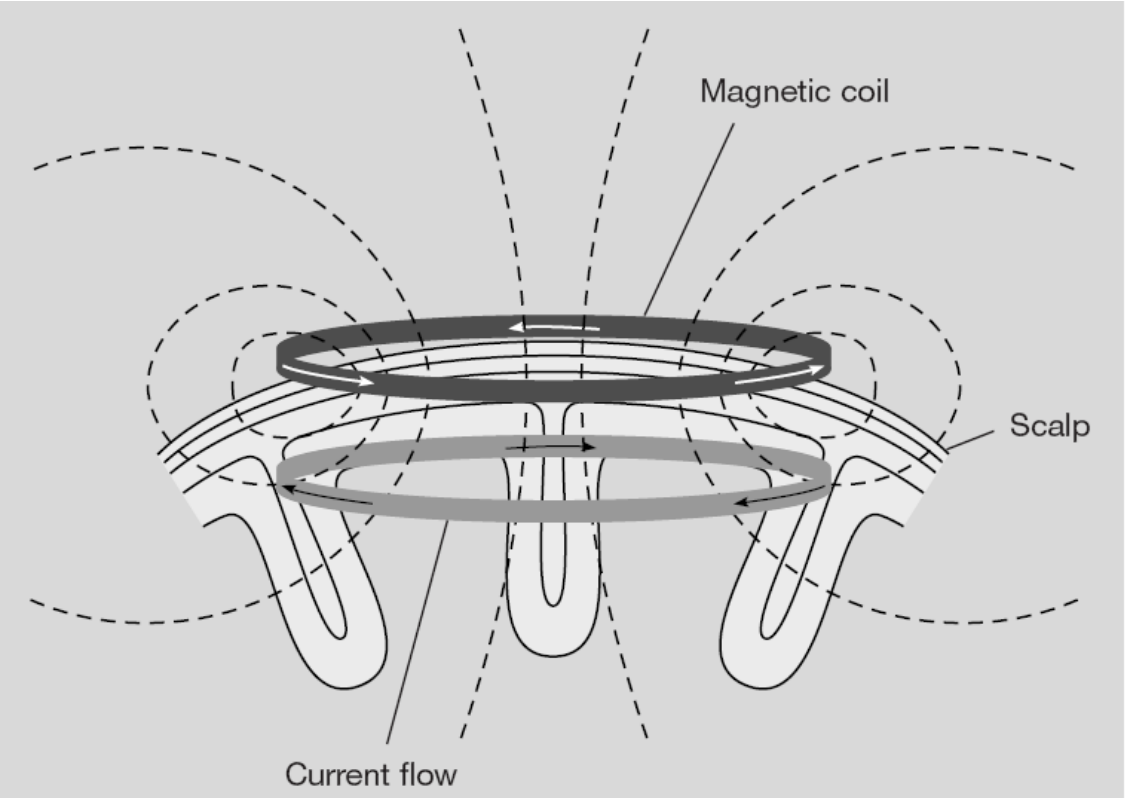
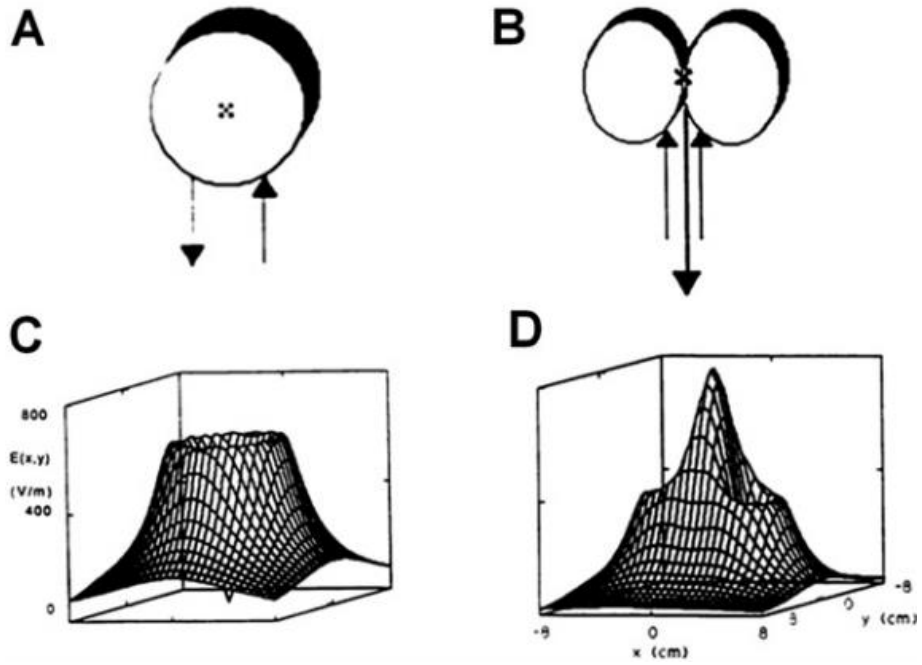



FIGURE 13. Electrical current in the coil induces a magnetic field oriented perpendicular to the coil. (Hallett 2000.)

*The waveform of the stimulus.* The waveform of the magnetic stimulus can be either monophasic or biphasic (Avela & Gruber 2011, 116). Along to Arai et al. (2005) biphasic magnetic stimulation is more effective way to activate motor cortex than monophasic stimulation. They noticed that threshold to evoke particular muscle response in relaxed muscle, and thus stimulating intensity needed, is significantly lower when stimulating motor cortex with biphasic than with monophasic magnetic stimulation. Additionally, single stimuli given by biphasic magnetic stimulation evokes greater muscle response compared to stimuli given by monophasic stimulation. (Arai et al. 2005.)

*The shape of the coil.* The site of the stimulation in TMS is not very focal because magnetic fields diverge after they leave the coil. The shape of the coil and structural aspects of motor cortex determine the site of stimulation. (Avela & Gruber 2011, 117.) A round

coil (diameter about 8–12 cm) induces the strongest electrical current under the circumference of the coil whereas the current in the middle of the circle is zero (Figure 14 A & C). Thus, a round coil stimulates neurons from quite a large area. In figure-of-8 coil the strongest current is in the intersection of two circle parts (Figure 14 B & D). Stimulating with figure-of-8 coil is thus more focal and selective than stimulating with round one. (Rothwell 1997; Hallet 2000.) With round and figure-of-8 coil the maximal stimulation depth without undesirable side effects and pain is around 20 millimeters (Rudiak & Marg 1994; Roth et al. 2002). With double-cone coil and Hesed coil it is possible to stimulate areas in depth of 3-4 centimeters and 5-7 centimeters, respectively (Roth et al. 2002; Terao & Ugawa 2002).




FFIGURE 14. A round coil (A) and electric field it induces (C), and figure-of-8 coil (B) and electric field it induces (D). (Hallet 2007.)

*The coil orientation.* The coil orientation and current direction have an effect on stimulus effectiveness (Brasil-Neto et al. 1992). Brasil-Neto et al. (1992) reported, that the greatest muscle responses to magnetic stimulation are induced when the stimulating current in the brain flows from posterior to anterior and is directed approximately perpendicular to central sulcus.

*The stimulating site.* It is unclear where the exact site of the magnetic stimulation in motor neurons is (Hallett 2000). DiLazzaro et al. (1998a) measured latencies and sizes of volleys evoked by TMS. Based on their results they concluded that volleys evoked by TMS consist of I-waves, so it seems that corticospinal cells are activated indirectly with TMS. That means, that TMS does not stimulate the axon of the neuron directly but rather indirectly by presynaptic stimulation of neurons. However, it seems that TMS can also stimulate axons directly, evoking D-waves, with very high stimulating intensities. (DiLazzaro et al. 1998a.)

### 4.4.2 Intersession reliability and reproducibility of TMS measurements

Several methodological and physiological aspects have an effect on reliability and reproducibility of TMS measurements (e.g. Kiers et al. 1993; Ellaway et al. 1998; Darling et al. 2006; Luc et al. 2014; O'Leary et al. 2015). For example differences between electrode placements, coil location (O'Leary et al. 2015) and coil orientation (Mills et al. 1992) between measurement sessions may affect the reliability and reproducibility of TMS measurements. In between-day measurements it is necessary to re-establish the optimal stimulation site, i.e. hot spot, to ensure appropriate location of the coil. Even if the between-day measurements have showed less reliability than within-day measurements, are they still supported as a reliable tool to study corticospinal excitability. (O'Lerary et al. 2015.)

Also stimulus intensity, background activity, the recruitment of motoneurons and the size of the field generated by the magnetic coil are related to the variability of MEP response (Kiers et al. 1993). In the study of Luc et al. (2014) MEPs elicited by various stimulus intensities between 95–140 % of AMT showed moderate to strong intersession reliability in vastus medialis oblique muscle. Darling et al. (2006) found out that relative variability of prestimulus EMG amplitude and MEPs is lower if stimulation is performed during slight voluntary contraction (5 and 10 % of MVIC) when compared to relaxed state. Also AMT has shown strong day-today reliability in vastus medialis oblique muscle (Luc et al. 2014) and soleus (Lewis et al. 2014) as well as the slope of the I/O-curve in some hand muscles (Malcolm et al. 2006).

# 5 PURPOSE OF THE STUDY

Taper may have a critical role determining ranking between top level athletes in competitions (Mujika & Padilla 2003). To our knowledge the effects of different type of tapers on strength performance has not been compared previously. To our knowledge, either the effects of taper on corticospinal excitability has not been investigated previously. In this study two groups of recreationally active men performed 8 weeks of strength training followed either by 2 weeks of step taper or 2 weeks of linear taper. The aim of this study was to investigate the effects of step taper and linear taper on strength performance and corticospinal excitability and inhibition, and compare those effects of different type of tapers to each other.

Research questions and hypotheses are:

1. Is there a difference between the effects of 2 weeks of step taper and 2 weeks of linear taper after 8 weeks of strength training period on strength performance?

*Hypothesis.* Both step taper (Häkkinen et al. 1991; Coutts et al. 2007; Chtourou et al. 2012; Zaras et al. 2014) and progressive taper (Gibala et al. 1994; Izquierdo et al. 2007; Rhibi et al. 2016) have been reported to have improving effect on strength performance. To our knowledge, the comparison between the effects of different type of tapers on strength performance has not been done previously. Thus, the hypothesis cannot be rationalized.

2. What are the effects of 8-week strength training period on corticospinal excitability and inhibition?

*Hypothesis.* Results from different studies considering the effects of strength training on corticospinal excitability are partly in contrast to each other because some studies report increase in cotricospinal excitability (Beck et al. 2007; Griffin & Carafelli 2007; Kidgell et al. 2010) while others report no changes or even decrease in corticospinal excitability

after 4 week strength training (Carroll et al. 2002; Jensen et al. 2005; Lee etal 2009; Kidgell & Pearce 2010). Motor skill training instead has been reported to enhance the corticospinal excitability (Perez et al. 2004; Jensen et al. 2005). In this study recreationally active men will perform strength training including complex multi-joint and whole-body movements, so motor learning and thus increments in corticospinal excitability during strength training period can be hypothesized.

3. What are the effects of 2-week step and linear taper periods on corticospinal excitability and inhibition?

To our knowledge the effects of taper or reduced training on corticospinal excitability have not been investigated previously. It is possible that fatigue will accumulate during strength training period and induce changes in neural factors, and that during taper fatigue will decrease (Häkkinen & Komi 1983; Mujika & Padilla 2003). However the effects of accumulated fatigue on corticospinal excitability has not been investigated previously. Due to the lack of information about the effects of taper period and accumulated fatigue on corticospinal excitability hypotheses cannot be rationalized.

# 6 METHODS

## 6.1 Participants

21 healthy, recreationally active men with at least one year of experience in strength training volunteered this study. Eleven of them participated in every measurement sessions and finished the study. Two participants dropped out because of injuries, 5 because of healthy reasons and 3 because of other reasons. Participants were divided in two groups. In group 1 six participant and in group 2 five participant finished the study (n = 6 + 5). Mean age, height and weight of finished participants of the first group was 26 ± 3 years, 182,7 ± 6,3 cm and 81,3 ± 10,1 kg, respectively and of the second group 26 ± 3 years, 178,4 ± 3,2 cm and 84,0 ± 11,3 kg, respectively.

Participants were informed about the procedures, and risks and discomforts associated with them. Procedures were approved by the ethical committee of the University of Jyväskylä. All participants gave their written consent before participating. Participants were instructed to restrain from exhaustive exercise for 48 hours, from alcohol for 24 hours (O'Leary et al. 2015) and from caffeine 3–4 hours before each measurement session. Participants were informed to follow their regular diet during the study.

## 6.2 Experimental procedure

This study was a part of the larger strength training project. Only part of the performed measurements were taken into account and are presented in this study. The study consisted of 1-week control period followed by 8 weeks of strength training and 2 weeks of taper. Six measurement sessions were performed: before the control period (Control measurements), after the control period (Pre-measurements), after 5 weeks of strength training (Mid-measurements), after 8 weeks of strength training (Post-measurements), after 1 week of taper (Taper 1 -measurements) and after two weeks of taper (Taper 2 -measurements). Participants were asked to continue their normal daily activities and training schedule during control period. Strength training period started after Pre-measurements and both groups performed the same training protocol (see 6.3.1 Strength training

-period) for the whole 8 week period. During two-week taper period the reduction in training volume followed different manners in each group: the first group followed step-taper and the second group followed linear taper (see 6.3.2 Taper-period). During the 8-week strength training period participants performed 3 training sessions per week and during the 2-week taper 2 training sessions per week.

Measurements were divided into 2 parts and performed in 2 consecutive days (Measurement day 1 & 2 or M1 & M2, respectively). On measurement weeks during the 8-week strength training period the first training session of the week was replaced by the first measurement day. The composition of measurement days is explained further in chapter 6.4. The schedule of the measurement and training sessions is presented in Table 3.

Table 3. Schedule for measurement sessions (M1 and M2) and training sessions. During week 0 (control) participants were asked to continue their normal daily activities and training (Control).

| | **Day 1** | **Day 2** | **Day 3** | **Day 4** | **Day 5** | **Day 6** | **Day 7** |
|---|---|---|---|---|---|---|---|
| **Wk 0** | M1 (Control) | M2 (Control) | Control | Control | Control | Control | Control |
| **Wk 1** | M1 (Pre) | M2 (Pre) | *Training* | | *Training* | | |
| **Wk 2** | *Training* | | *Training* | | *Training* | | |
| **Wk 3** | *Training* | | *Training* | | *Training* | | |
| **Wk 4** | *Training* | | *Training* | | *Training* | | |
| **Wk 5** | *Training* | | *Training* | | *Training* | | |
| **Wk 6** | M1 (Mid) | M2 (Mid) | *Training* | | *Training* | | |
| **Wk 7** | *Training* | | *Training* | | *Training* | | |
| **Wk 8** | *Training* | | *Training* | | *Training* | | |
| **Wk 9** | M1 (Post) | M2 (Post) | *Training/ taper* | | *Training/ taper* | | |
| **Wk 10** | M1 (Taper 1) | M2 (Taper 1) | *Training/ taper* | | *Training/ taper* | | |
| **Wk 11** | M1 (Taper 2) | M2 (Taper 2) | | | | | |

## 6.3 Strength training

During the 8-week hypertrophic and maximum strength training period the program was same for both groups and 3 supervised training sessions per week were performed. Strength training period was divided into two phases: the first phase was training weeks from 1 to 5 and the second phase weeks from 6 to 8. Exercises used in different training phases are presented in Table 4.

TABLE 4. Exercises used during the first (weeks 1–5) and the second (weeks 6–8) strength training phases.

| **WEEKS 1–5** | **Day 1** | **Day 3** | **Day 5** |
|---|---|---|---|
| | squat | leg press | squat |
| | bench press | overhead press | bench press |
| | row | knee extension | row |
| | side plank | leg curl | back extension |
| | | lat pull-down | plank |
| **WEEKS 6–8** | **Day 1** | **Day 3** | **Day 5** |
| | squat | squat | squat |
| | bench press | bench press | bench press |
| | row | knee extension | leg press |
| | back extension | leg curl | row |
| | plank | overhead press | side-plank |
| | | lat pull-down | |

During the first training phase 5 sets of 5 repetitions were performed in squat and bench press. The load was increased from week to week. In the first training session 5RMs were determined for squat and bench press, and results were used to determine the loads for following sessions. In other exercises the load was determined with rated perceived exertion (RPE) and repetitions in reserve (RIR) -scales (Appendix 1). Repetitions, sets and intensity of the main exercises (squat, leg press, knee extension, bench press and overhead press) during the first training phase are presented in Table 5. Between the first and the second training phase Mid-measurements were performed (on week 6) and after that the second training phase started. Training program for the second training phase (weeks 6–8) is presented in Table 6.

TABLE 5. Training program for the first phase of the training period (weeks 1–5). Repetitions, sets and intensity of the main exercises are presented. M = measurements, Avg int. = average intensity of the week.

| **WK 1** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
|---|---|---|---|
| **Squat** | 1RM & power | 5RM | |
| **Bench press** | 1RM & power | 5RM | |
| **Leg press** | MVIC | | 3x10, RPE 8 |
| **Knee extension** | MVIC | | 3x10, RPE 8 |
| **Overhead press** | | | 3x10, RPE 8 |
| **WK 2 avg int. 69–70%** | **Day 1** | **Day 3** | **Day 5** |
| **Squat** | 5x5, constant load | | 5x5, progressive load |
| **Bench press** | 5x5, constant load | | 5x5, progressive load |
| **Leg press** | | 3x10, RPE 8 | |
| **Knee extension** | | 3x10, RPE 8 | |
| **Overhead press** | | 3x10, RPE 8 | |
| **WK 3 avg int. 75–76 %** | **Day 1** | **Day 3** | **Day 5** |
| **Squat** | 5x5, constant load | | 5x5, progressive load |
| **Bench press** | 5x5, constant load | | 5x5, progressive load |
| **Leg press** | | 3x10, RPE 9 | |
| **Knee extension** | | 3x10, RPE 8 | |
| **Overhead press** | | 3x10, RPE 9 | |
| **WK 4 avg int. 80–82 %** | **Day 1** | **Day 3** | **Day 5** |
| **Squat** | 5x5, constant load | | 5x5, progressive load |
| **Bench press** | 5x5, constant load | | 5x5, progressive load |
| **Leg press** | | 2x10+2x8, RPE 9 | |
| **Knee extension** | | 10/8/10, RPE 8 | |
| **Overhead press** | | 4x8, RPE 8 | |
| **WK 5** | **Day 1 appr. 86 %** | **Day 3** | **Day 5 avg int. 60 %** |
| **Squat** | 5x5, constant load | | 3x5, prog. load, light |
| **Bench press** | 5x5, constant load | | 3x5, prog. load, light |
| **Leg press** | | 2x10+2x8, RPE 9 | |
| **Knee extension** | | 10/8/10, RPE 8 | |
| **Overhead press** | | 4x8, RPE 8 | |

TABLE 6. Training program for the second phase of the training period (weeks 6–8). Repetitions, sets and intensity of the main exercises are presented. M = measurements.

| **WK 6** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
|---|---|---|---|
| **Squat** | 1RM & power | 5RM | 4x3: 75/80/82.5/87.5 % |
| **Bench press** | 1RM & power | 5RM | 4x3: 75/80/82.5/87.5 % |
| **Leg press** | MVIC | | |
| **Knee extension** | MVIC | | 4x3: 75/80/82.5/87.5 % |
| **Overhead press** | | | 4x3: 75/80/82.5/87.5 % |
| **WK 7** | **Day 1** | **Day 3** | **Day 5** |
| **Squat** | 5x3, RPE 9≤, 1 set 3RM | 3x5: 70/75/80 % | 5x2, RPE 9≤, 1 set 2RM |
| **Bench press** | 5x3, RPE 9≤, 1 set 3RM | 3x5: 70/75/80 % | 5x2, RPE 9≤, 1 set 2RM |
| **Leg press** | | | 5x2, RPE 9≤, 1 set 2RM |
| **Knee extension** | | 3x5: 70/75/80 % | |
| **Overhead press** | | 3x5: 70/75/80 % | |
| **WK 8** | **Day 1** | **Day 3** | **Day 5** |
| **Squat** | 6x3, RPE 9≤ , 1 set 3RM | 3x5: 70/75/80 % | 6x2, RPE 9≤, 1 set 3RM |
| **Bench press** | 6x3, RPE 9≤ , 1 set 3RM | 3x5: 70/75/80 % | 6x2, RPE 9≤, 1 set 3RM |
| **Leg press** | | | 6x2, RPE 9≤, 1 set 3RM |
| **Knee extension** | | 3x5: 70/75/80 % | |
| **Overhead press** | | 3x5: 70/75/80 % | |

After training week 8 Post-measurements were performed. Then 2-week taper was included: step-taper for the group 1 and linear taper for the group 2. Taper performed with reduced volume by the reduction in repetitions and sets from those performed on the last training week (week 8). Group 1 trained both taper weeks with 46 % volume of the pre-taper value. Group 2 trained the first taper week with 58 % and the second taper week with 34 % volume of the pre-taper value, so the total volume during both weeks was 46 % of the pre-taper value.

Loads used in squat and bench press during taper were 85 %, 87.5 % and 90 % of 1RM. Mean intensity for both groups in both weeks was 87 %. 90 % of 1RM was determined to be a load that was 2.5 kg lower than the highest load used in set of three repetitions in squat and bench press in the last training session of the training week 8. Load used in leg

press through the whole taper was the average load of the last two sets performed in week 8. Training program for taper-period for group 1 and 2 are presented in Table 7.

TABLE 7. Training program for 2-week step-taper for group 1. M = measurements.

| **TAPER-WEEK 1** | | | |
|---|---|---|---|
| **GROUP 1** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
| **Squat** | 1RM & power | 4x3: 85/87.5/90/87.5 % | 4x2: 85/87.5/90/87.5 % |
| **Bench press** | 1RM & power | 4x3: 85/87.5/90/87.5 % | 4x2: 85/87.5/90/87.5 % |
| **Leg press** | MVIC | 2x6 | |
| **Plank** | | 2x3x20/10 s | |
| **Back ext.** | | | 2x10 |
| **GROUP 2** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
| **Squat** | 1RM & power | 5x3: 85/87.5/90/87.5/85 % | 5x2: 85/87.5/90/87.5/85 % |
| **Bench press** | 1RM & power | 5x3: 85/87.5/90/87.5/85 % | 5x2: 85/87.5/90/87.5/85 % |
| **Leg press** | MVIC | 3x6 | |
| **Plank** | | 2x3x20/10 s | |
| **Back ext.** | | | 2x10 |
| **TAPER-WEEK 2** | | | |
| **GROUP 1** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
| **Squat** | Power | 4x3: 85/87.5/90/87.5 % | 4x2: 85/87.5/90/87.5 % |
| **Bench press** | Power | 4x3: 85/87.5/90/87.5 % | 4x2: 85/87.5/90/87.5 % |
| **Leg press** | MVIC | 2x6 | |
| **Plank** | | 2x3x20/10 s | |
| **Back ext.** | | | 2x10 |
| **GROUP 2** | **Day 1 & 2 (M)** | **Day 3** | **Day 5** |
| **Squat** | Power | 3x3: 85/90/85 % | 3x2: 85/90/85 % |
| **Bench press** | Power | 3x3: 85/90/85 % | 3x2: 85/90/85 % |
| **Leg press** | MVIC | 1x6 | |
| **Plank** | | 2x3x20/10 s | |
| **Back ext.** | | | 2x10 |

Relative training volume, reduction in training volume and repetitions performed during taper-period for both group are presented in Table 8. Volumes are calculated from training volume of training week 8.

TABLE 8. Training volume manipulation during taper period.

| TAPER-WEEK 1 | | Squat | Bench press | Leg press | Lower body | Upper body |
|---|---|---|---|---|---|---|
| **Training volume %** | *Group 1* | 46 % | 46 % | 51 % | 45 % | 38 % |
| | *Group 2* | 58 % | 56 % | 77 % | 61 % | 48 % |
| **Reduction %** | *Group 1* | 54 % | 54 % | 49 % | 55 % | 62 % |
| | *Group 2* | 42 % | 44 % | 23 % | 38 % | 52 % |
| **Repetitions** | *Group 1* | 20 | 20 | 12 | 32 | 20 |
| | *Group 2* | 25 | 25 | 18 | 43 | 25 |
| **TAPER-WEEK 2** | | | | | | |
| **Training volume %** | *Group 1* | 46 % | 46 % | 51 % | 45 % | 38 % |
| | *Group 2* | 34 % | 34 % | 26 % | 28 % | 29 % |
| **Reduction %** | *Group 1* | 54 % | 54 % | 49 % | 55 % | 62 % |
| | *Group 2* | 66 % | 66 % | 74 % | 72 % | 71 % |
| **Repetitions** | *Group 1* | 20 | 20 | 12 | 32 | 20 |
| | *Group 2* | 15 | 15 | 6 | 21 | 15 |
| **OVERALL** | | | | | | |
| **Training volume %** | *Group 1* | 46 % | 46 % | 51 % | 45 % | 38 % |
| | *Group 2* | 46 % | 45 % | 52 % | 45 % | 38 % |
| **Reduction %** | *Group 1* | 54 % | 54 % | 49 % | 55 % | 62 % |
| | *Group 2* | 54 % | 55 % | 48 % | 55 % | 62 % |
| **Repetitions** | *Group 1* | 40 | 40 | 24 | 64 | 40 |
| | *Group 2* | 40 | 40 | 24 | 64 | 40 |

## 6.4 Data collection

As explained earlier, measurements were divided into two consecutive days and were performed six times: Control, Pre, Mid, Post, Taper 1 and Taper 2. Measurements were tried to perform at the same time of the day for each subject on different measurement weeks. In the morning (6:30–10 a.m.) of the first measurement day blood samples and body composition (InBody 720 body composition analyser, Biospace Co. Ltd, South Korea) were measured following 12-hour fast. In the afternoon or evening (12:00–9:00 p.m.) of the first measurement day following measurements were performed: cross sectional

area (CSA) of m. vastus lateralis (VL) with ultrasound (Alpha 10, Aloka Co Ltd, Japan), warm up, MVIC in leg press, 1RM in squat, 1RM in bench press, power in squat and power in bench press. However, few exceptions in the measurements of the first day existed: body composition and CSA of VL were not measured in Mid- and Taper 1 -measurements, and 1RM in squat and bench press were not measured in Taper 1 -measurements. On the second measurement day between 11:00 a.m. and 9:00 p.m. electrical stimulation of femoral nerve (ESN), TMS of the VL and electrical stimulation of the knee extensors muscle belly (interpolated twitch technique, ITT) were performed. The division and order of the measurements on two measurement days are presented in Table 9.

TABLE 9. The division and order of the measurements on two measurement days.

| **Measurement day 1**<br>**6:30–10:00 a.m.** | **Measurement day 1**<br>**12:00–9:00 p.m.** | **Measurement day 2**<br>**11:00 a.m.–9:00 p.m.** |
|---|---|---|
| Blood samples | Ultrasound: CSA of VL | ESN: femoral nerve |
| Body composition | Warm up | TMS: VL |
| | Leg press, MVIC | ITT: knee extensors |
| | Squat, 1RM | |
| | Bench press, 1 RM | |
| | Squat, power | |
| | Bench press, power | |

### 6.4.1 Strength measurements

Strength measurements were performed at the first measurement day as can be seen from the Table 4. In the beginning of each strength measurement session about 10 minute warm up was performed. Warm up consisted of aerobic exercise cycling (5 min) followed by light strength exercises (e.g. squat with bodyweight) and dynamic stretching exercises for lower limbs (e.g. short interval stretching of m. iliopsoas) and upper limbs (e.g. arm circles). Here, only those strength measurement that were used in this study (MVIC legpress and 1 RM squat) are described.

*Maximal voluntary isometric leg press.* After warm up -protocol MVIC in leg press electromechanical dynamometer (Department of Biology of Physical Activity, University of Jyväskylä Finland) with 107° knee angle was performed bilaterally (Figure 15). EMG-recordings were done during the contractions. At least 3 maximal 3-5 second contractions were performed with 1 minute of rest between contractions. If the maximum force of the latest contraction was 5 % or more higher than the second best, the new contraction was performed, but still no more than 5 contractions were performed. Participants were instructed to voluntary produce as high force as fast as possible and maintain the contraction until the permission to relax was given. Participants were encouraged loudly. The performance was accepted if lower back touched the back rest and backside touched the seat. Participants were allowed to pull from the handles themselves towards the seat. The background force (induced by the legs resting on the force plate) before the contraction was not allowed to be over 300 N. Force of each attempt was sampled at 2000 Hz and filtered by a 10 Hz low-pass filter (4th order Butterworth). Force data was analyzed with a customized script (Signal 4.08, Cambridge Electronic Design, Cambridge, UK).

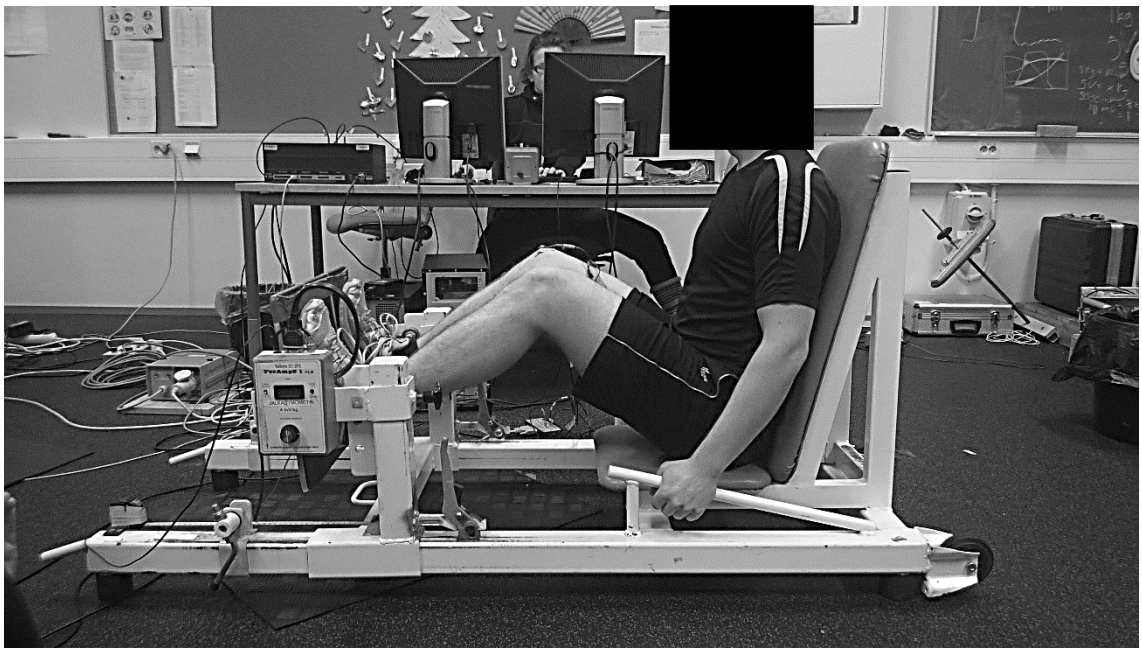


FIGURE 15. Maximal isometric voluntary contraction in leg press dynamometer with knee angle of 107°.

*Squat 1 RM.* After MVIC in leg press the maximum strength in back squat was assessed with 1RM test. Squat was performed in the smith apparatus (Figure 16). First, warm up -sets were performed in a following way (repetitions x load %/1RM): 10 x bar (26 kg), 5

x 50 %, 2–4 x 70 % and 1 x 90 % with 2 minute rest between sets (modified from Pazin et al. 2011). In the first measurement session 1RM was estimated based on participant's recommendation and in the rest of the sessions the previous 1RM was used to calculate warm up loads. After that the 1RM aimed to be accomplished within 3–5 trial with 2,5–5 kg increments in load and 3 minute rest between trials (Pescatello et al. 2014, 95–96). In the first measurement session participants were allowed to choose the grip width and standing width and those same values were used in the following measurements. The high bar -placement was used. In starting and ending position hip and knees were fully extended (Figure 16 a) and in a down position thighs were parallel to the floor (Figure 16 b). An elastic band was used to control the depth of the squat and the up-command was given when a backside touched the band.

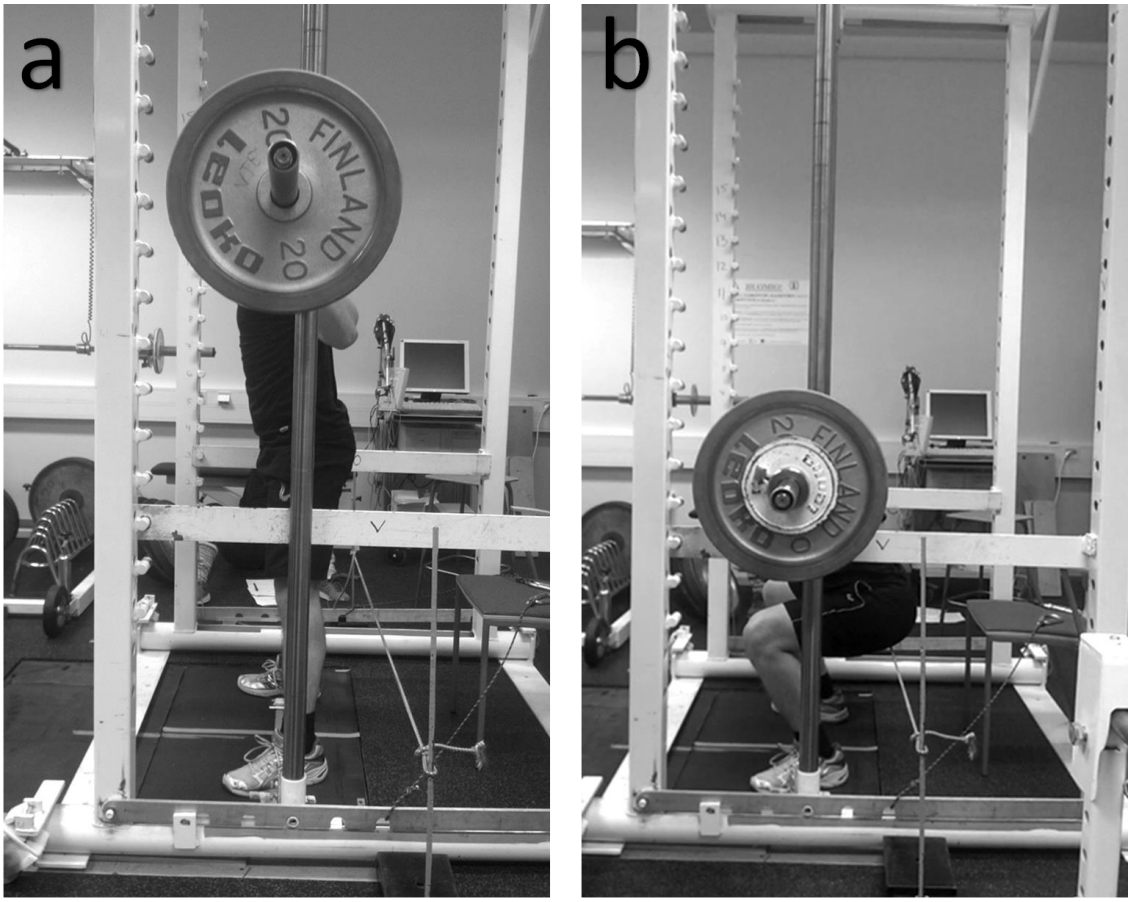



FIGURE 16. Back squat performed in smith apparatus. In starting and ending position hip and knees are extended (a) and in a down position thighs are parallel to the floor (b). An elastic band is controlling the depth of the squat.

### 6.4.2 EMG-recordings

During electrical femoral nerve stimulation and transcranial magnetic stimulation the surface EMG-recordings were performed from VL and m. biceps femoris (BF) of the right leg. Bipolar Ag/AgCl electrodes (Ambu BlueSensor N, Denmark, 10 mm diameter 20 mm inter-electrode distance) were placed on the skin after shaving, abrasion and cleaning. The recording sites were determined according to the SENIAM guidelines (Hermens et al. 1999, 45–46) and were marked with a tattoo spot before control measurements. TeleMyo 2400R (Noraxon, Scottsdale, USA) and EISA (Freiburg, Germany) were used as signal receivers. Sampling frequency was 2000 Hz and Signal 4.04 software (Cambridge Electronic Design, UK) was used for recording.

### 6.4.3 Electrical nerve stimulation

Supramaximal electrical stimulation applied to the femoral nerve of the right leg was used to determine the maximal amplitude of the M-wave (Mmax) of the VL. Self-adhesive stimulation electrodes (6,98 cm V-trodes, Mettler Electronics Corp, USA) were placed on the skin at the femoral triangle (cathode) and at the halfway between the trochanter major and iliac crest (anode). During the stimulation participant sat in rest in the knee extensor apparatus with 107° knee angle, knee joint just over the side of the seat, ankle bound to the lever and arms crossed (Figure 17). Single pulses were delivered by a constant-current stimulator (Model DS7AH, Digitimer Ltd, UK) and the stimulation intensity was increased in 5–10 mA stages (1 ms single-pulse, 400 V) until the amplitude of the M-wave reached a plateau. Thereafter the stimulation intensity of 125 % of the intensity that was enough to reach the plateau was used to give 3 more stimuli, and those responses were used to measure the amplitude of the maximum M-wave. (Modified from Walker et al. 2013.)

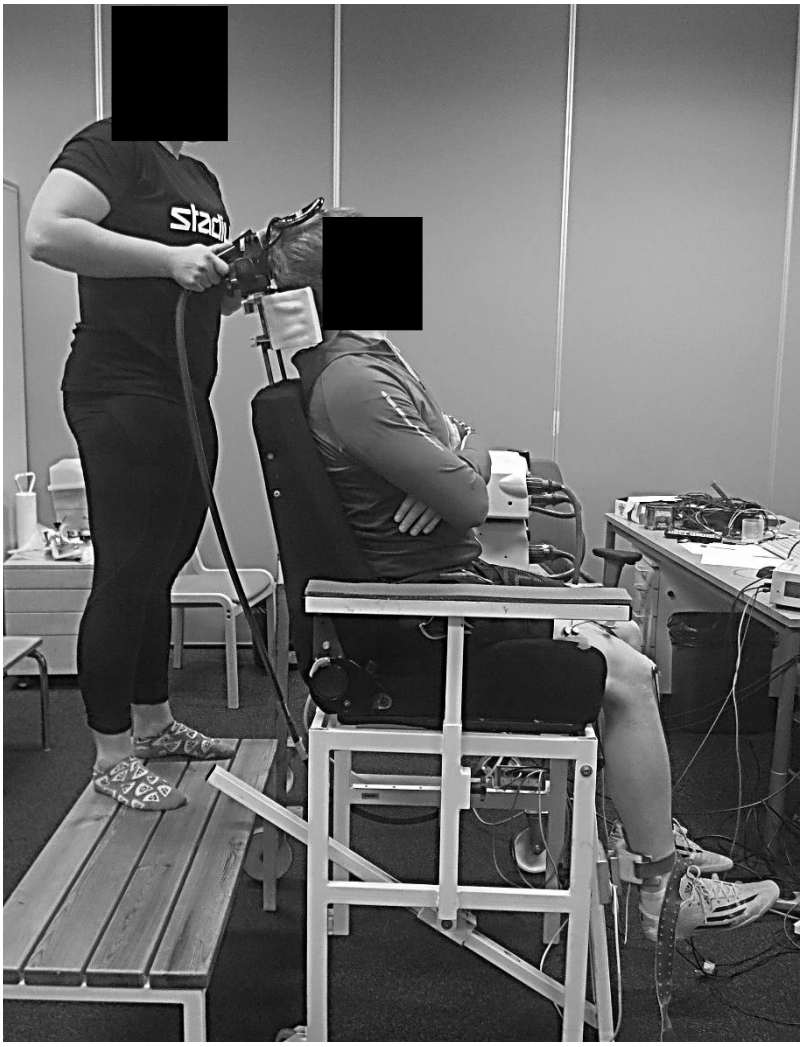


FIGURE 17. During the electrical stimulation of the fermoral nerve and the transcranial magnetic stimulation participant sat in the knee extensor apparatus with knee joint angle of 107°, knee joint just over the side of the seat, ankle bound to the lever and arms crossed. The coil support was used to control the position of the coil during the transcranial magnetic stimulation.

### 6.4.4 Transcranial magnetic stimulation

Transcranial magnetic stimulation was used to assess the corticospinal excitability and inhibition of the VL. Magstim $200^2$ -magnetic stimulator (Magstim Co., Witland, Dyfed, UK) with curved figure-of-8 coil (diameter 90 mm) was used to perform stimulation. Single pulse stimulation was applied over the motor cortex of the left hemisphere to induce MEPs on VL of the right side. The coil was held in posterior-to-anterior direction and the coil support was used to control the position of the coil during the stimulation

(Figure 17). Position and orientation of the coil were held manually. Participant was seated as previously described concerning to electrical nerve stimulation (Figure 17).

*MVIC and the hotspot.* First, the maximum force of the knee extensors was determined with 2–3 trials (3–5 s contractions, 30–60 s rest between trials) after submaximal warm up contractions. Thereafter the hotspot for the stimulation was searched by moving the coil with 0,5–1 cm steps and finally the optimal stimulating site was marked on a sculp. Stimulating was performed during the background force of 5 % of the MVIC to decrease the relative variability of MEPs (Darling et al. 2006). The activity was performed in 30 s cycles with 30 s rest between trials to prevent fatigue. Stimuli were given with 5–8 randomized interstimulus intervals, as was done through the whole TMS procedure. The hotspot was searched individually on every measurement session.

*Active motor threshold.* AMT was determined as well during 30 s cycles of 5 % background activity. AMT was defined as the lowest intensity needed to evoke 3 out of 5 (e.g. Carroll et al. 2002) MEPs over background activity (Temesi et al. 2014).

*Input-output curve.* I/O-curve was defined by giving 5 stimuli (Carroll et al. 2009) at each of the following stimulating intensities: 100 %, 110 %, 120 %, 130 % and 140 % of AMT. The order of intensities was pseudorandomized between participants but remained the same for each participant in all measurement sessions. Stimulating was performed during 5 % activity in 30 s cycles as described previously (Figure 18).

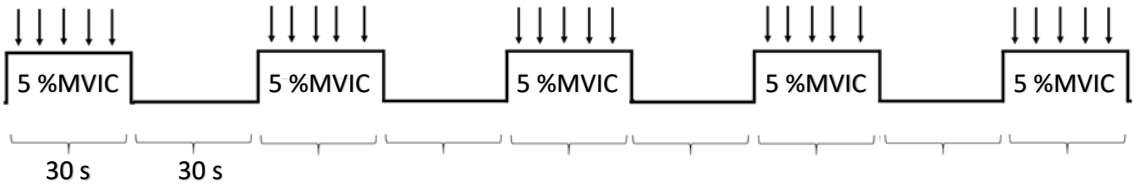



FIGURE 18. Illustration of the protocol of the input-output -curve. Background activity of 5 % of the MVIC was maintained in 30 s periods separated with 30 s of rest. 5 stimuli (arrows) at each stimulating intensity (100 %, 110 %, 120 %, 130 % and 140 % of AMT) were given with 5–8 s interstimulus intervals. Intensity used on each block was pseudorandomized but remained the same for each subject through all measurement sessions.

*Silent period.* For eliciting silent periods two sets of 3 contractions (3–5 s) were performed: the first set with the force level of 50 % of MVIC and the second with maximum contraction. 30 s rest was applied between 50 %MVIC contractions and 60 s rest between maximum contractions. During each contraction stimulus was given at intensity of 130 % of AMT. Stimulating protocol for SP is illustrated in Figure 19.

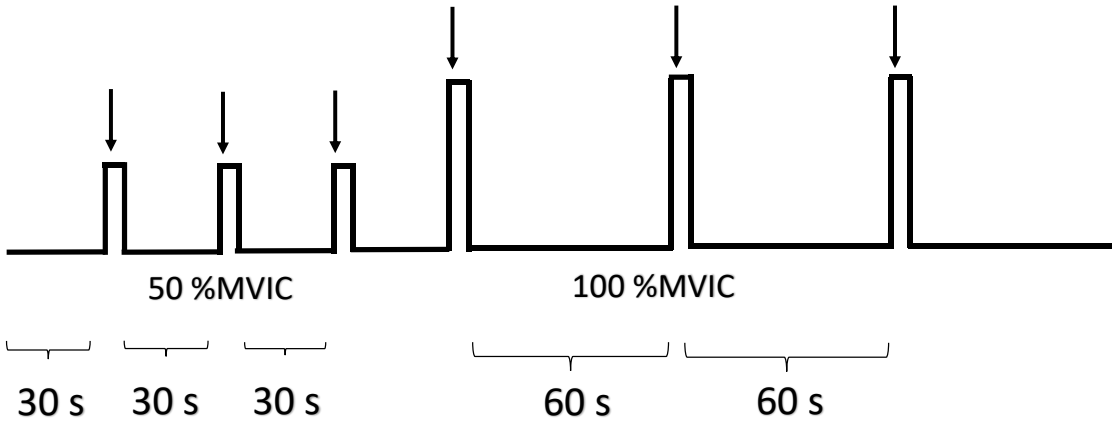



FIGURE 19. Illustration of the protocol for silent period measurements. First, 3 contractions (3–5 s) with force level of 50 % of MVIC separated by 30 s resting intervals were performed. After that 3 maximum contractions (3–5 s) separated by 60 s resting intervals were performed. One stimulus at intensity of 130 % of AMT was given during each contraction.

## 6.5 Data analysis

*Leg press MVIC.* The peak force of MVIC in leg press was analyzed with automated analysis in Signal 4.08 -software (Cambridge Electronic Design, Cambridge UK). The best value from all 3–5 trials was used.

*Knee extension MVIC.* The peak force of MVIC in knee extension was analyzed manually from force curve with Spike 2 -software (version 6.17, Cambridge Electronic Design Limited, Cambridge, UK). The best value from 3 trials was used.

*Pre-stimulus EMG-level.* Pre-stimulus EMG-level was determined as an average EMG-activity (aEMG) from rectified signal (Devanne et al. 2002) during 500 ms time window preceding each TMS-stimulus (Ruotsalainen et al. 2014). The average of aEMG-level preceding 5 stimuli at each stimulation intensity was used. Data from ES and TMS was

analyzed with Spike 2 -software (version 6.17, Cambridge Electronic Design Limited, Cambridge, UK).

*Mmax- and MEP-area.* Areas of maximal M-waves and MEPs were analyzed manually from rectified signal by placing the first cursor at the onset of M-wave/MEP and the second cursor at the beginning of the silence (i.e. absence of EMG-activity). MEP-areas were normalized to the Mmax-areas by dividing them by the average of 3 Mmax-areas.

*I/O-curve.* For I/O-curve the average of all 5 MEP-areas at each stimulation intensity was taken and plotted against the stimulation intensity. The sum of MEPareas achieved with different stimulation intensities was taken. The slope of the I/O-curve was determined by linear regression analysis from the steepest point of the curve (i.e. the greatest increase in MEParea between two consecutive stimulation intensities) (Rosenkranz et al. 2007).

*Silent period.* Duration of relative SPs were defined manually from rectified signal by placing cursors at the onset of MEP and at the return of the continuous EMG. Average duration from all 3 stimuli at each background force level was taken.

## 6.6 Statistical analysis

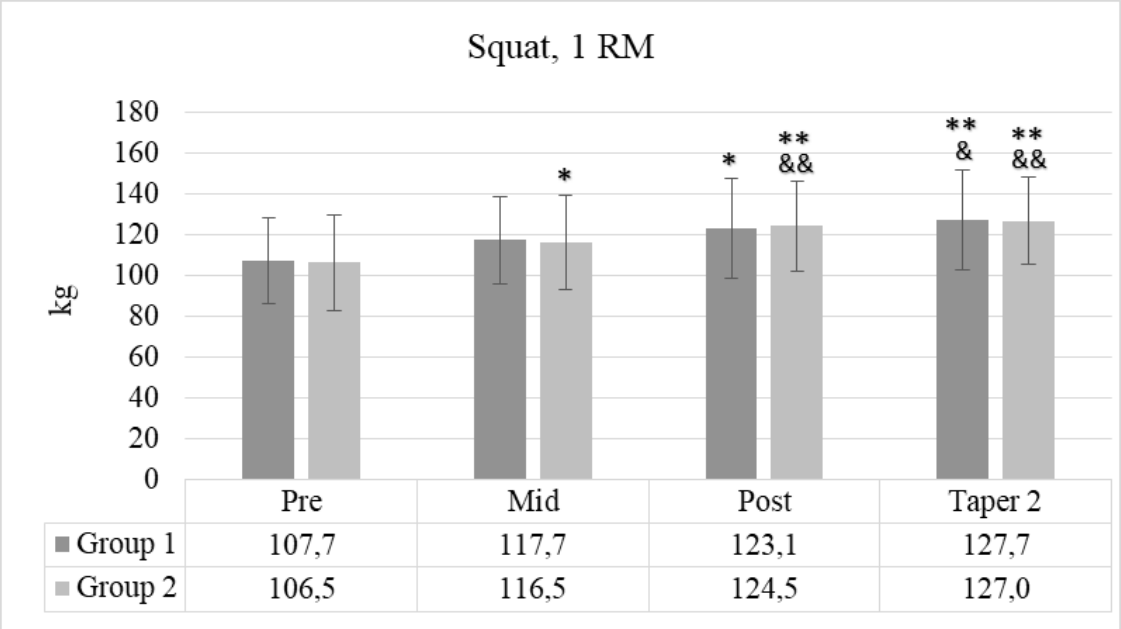
Results are presented as means ± standard deviations. The normality of the data was examined using Shapiro-Wilk -test. Within group changes between measurement sessions were analyzed using repeated measures ANOVA for normally distributed data. Greenhouse-Geisser correction was used with repeated measures ANOVA if the sphericity could not be assumed. If the data was not normally distributed the related-samples Friedsman's two-way analysis of variance by ranks was used to examine within group changes. Between group differences were analyzed using one-way ANOVA for normally distributed data. If data was not normally distributed or if the homogeneity of variances could not be assumed the independent-samples Mann-Whitney U -test was used.

Level of statistical significance was set at $p \leq 0.05$* and other threshold values for statistical significancies were $p < 0.01$** (very significant) and $p < 0.001$*** (extremely significant). Further statistical analysis was performed using IBM SPSS Statistics -software (v. 24, SPSS Inc, Chicago, IL, USA).

# 7 RESULTS

## 7.1 Strength performance

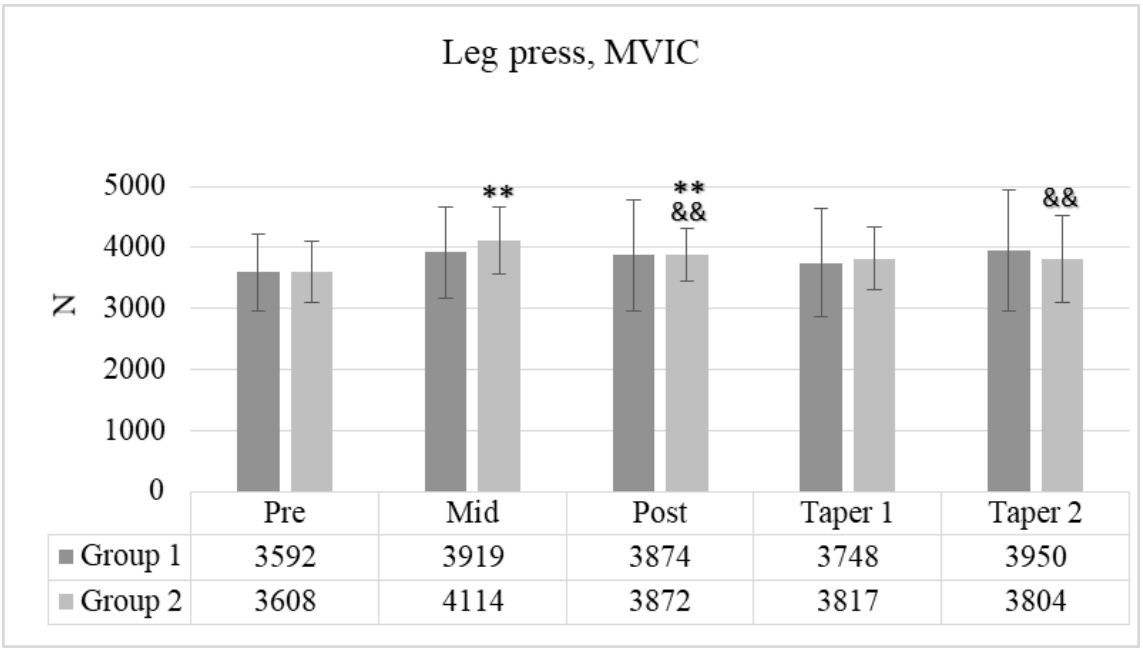
*Squat.* There were no significant differences in squat 1 RM between Control- and Pre-measurement sessions in either group. For group 1 squat 1 RM improved significantly from Pre (107,7 ± 21,3 kg) to Post- (123,1 ± 24,4 kg, p = 0,028) and Taper 2 -measurements (127,7 ± 25,6 kg, p = 0,009), and from Mid- (117,7 ± 24,5 kg) to Taper 2 -measurements (p = 0,011). For group 2 squat 1 RM improved significantly from Pre (106,5 ± 23,2 kg) to Mid- (116,5 ± 24,5 kg, p = 0,014), Post- (124,5 ± 21,3 kg, p = 0,002) and Taper 2 -measurements (127,0 ± 21,3 kg, p = 0,001). For group 2 squat result improved significantly also from Mid- to Post- (p = 0,008) and Taper 2 -measurements (p = 0,003). Results between groups did not differ significantly from each other at any measurement session. Squat results for both group can be seen from Figure 20.




| | Pre | Mid | Post | Taper 2 |
|---|---|---|---|---|
| Group 1 | 107,7 | 117,7 | 123,1 | 127,7 |
| Group 2 | 106,5 | 116,5 | 124,5 | 127,0 |

FIGURE 20. Results of squat 1 RM (kg). *Significant difference compared to Pre-value, p ≤ 0,05, **Very significant difference compared to Pre-value, p < 0,01, &Significant difference compared to Mid-value, p ≤ 0,05, &&Very significant difference compared to Mid-value, p < 0,01.

*Leg press.* There were no significant differences in leg press MVIC between Control- and Pre-measurement sessions in either group. Group 1's results did not change significantly during the study. Group 2's results improved significantly from Pre- (3608 ± 544 N) to Mid (4114 ± 433 N, p = 0,001) and Post-measurements (3872 ± 509 N, p = 0,004). Group 2's results also decreased significantly from Mid to Post- (p = 0,008) and Taper 2 -measurements (3804 ± 581 N, p = 0,029). Results between groups did not differ significantly from each other at any measurement. session. Leg press MVIC results for both group can be seen from Figure 21.




| | Pre | Mid | Post | Taper 1 | Taper 2 |
|---|---|---|---|---|---|
| Group 1 | 3592 | 3919 | 3874 | 3748 | 3950 |
| Group 2 | 3608 | 4114 | 3872 | 3817 | 3804 |

FIGURE 21. Results of leg press MVIC (N). **Very significant difference compared to Pre-value, p < 0,01, &&Very significant difference compared to Mid-value, p < 0,01.

*Knee extension.* There were no significant within group differences in knee extension MVIC during the study in either group. Results between groups did not differ significantly from each other at any measurement session. Knee extension MVIC results for both group can be seen from Figure 22.

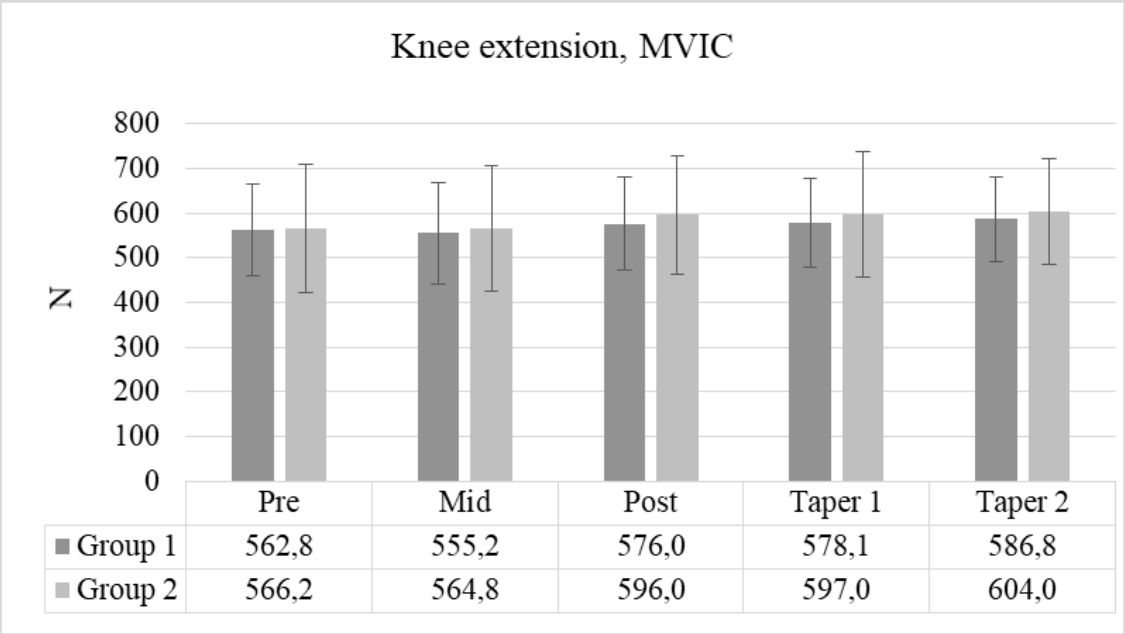



FIGURE 22. Results of knee extension MVIC.

## 7.2 Corticospinal excitability and inhibition

*Pre-stimulus EMG.* There were no significant within group differences between measurement sessions in pre-stimulus EMG during 5 % of MVIC background activity at any stimulation intensity of the I/O-curve. The only significant within group difference in pre-stimulus EMG-level was between group 2's MVIC-activities in SP-measurements at Pre- and Taper 1 -measurements (Pre: 0,106 ± 0,022 vs. Taper 1: 0,144 ± 0,025, $p = 0,005$). Excluding that, for either group there were no significant within group differences in pre-stimulus EMG-level either at 50 % of MVIC or during MVIC at SP-measurements. There were no significant between group differences in pre-stimulus EMG-level in any measurement session.

*AMT.* There were no significant within group differences in AMT during the study in either group. Results between groups did not differ significantly from each other at any measurement session. AMTs for both group can be seen from Figure 23.

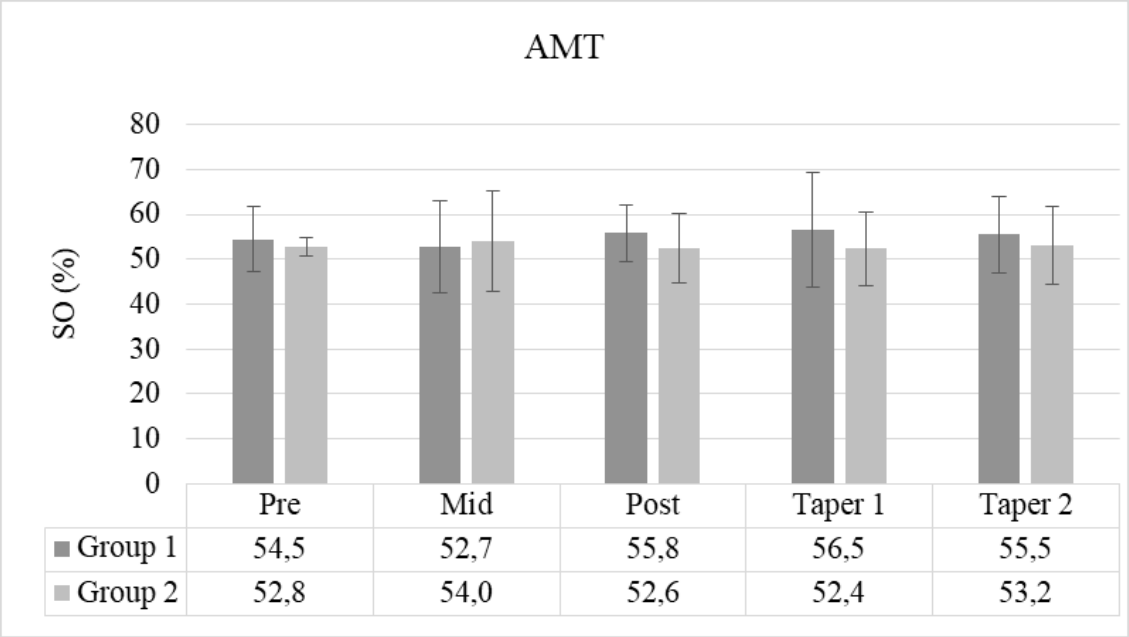



FIGURE 23. Active motor threshold (AMT) in each measurement session. Thresholds are presented as a percent of maximum stimulation output (SO).

*MEParea.* MEPareas are presented as a quotient of MEParea and Mmax area. The only significant difference in MEParea between Control- and Pre-measurement sessions were in group 2's areas with stimulation intensity (SI) of 110 % of AMT (Control 1,35 ± 1,05 vs. Pre 0,76 ± 0,64, p = 0,043). For group 1 there were no significant within group differences between measurements in MEParea with any SI. For group 2 there was a significant decrease in MEParea with SI of 100 % of AMT from Pre (0,32 ± 0,10) to Taper 1 (0,15 ± 0,48, p = 0,035) and Taper 2 (0,16 ± 0,47, p = 0,045), from Mid (0,30 ± 0,25) to Taper 1 (p = 0,001), and from Post (0,26 ± 0,41) to Taper 1 (p = 0,046) and Taper 2 (p= 0,048). With SI of 110 % of AMT MEParea decreased significantly from Pre (0,51 ± 0,17) to Taper 2 (0,30 ± 0,31, p = 0,036.) With SI of 120 % of AMT MEParea decreased significantly from Pre (0,75 ± 0,07) to Taper 1 (0,35 ± 0,12, p = 0,025), and from Mid (0,74 ± 0,23) to Taper 1 (p = 0,012), and increased significantly from Taper 1 to Taper 2 (0,64 ± 0,25, p = 0,017). With SIs of 130 % and 140 % of AMT MEParea decreased significantly from Mid (0,87 ± 0,08 and 1,01 ± 0,23, respectively) to Taper 1 (0,57 ± 0,38, p = 0,006 and 0,75 ± 0,32, p = 0,011, respectively). There were also significant differences in MEParea between groups since group 2's areas were significantly lower than group 1's with SI of 100 % of AMT in Taper 1 and Taper 2 -measurements, and with SIs of 110 % and 120 % of AMT in Taper 1 -measurements. MEPareas with different stimulation intensities for group 2 are presented in Figure 24.

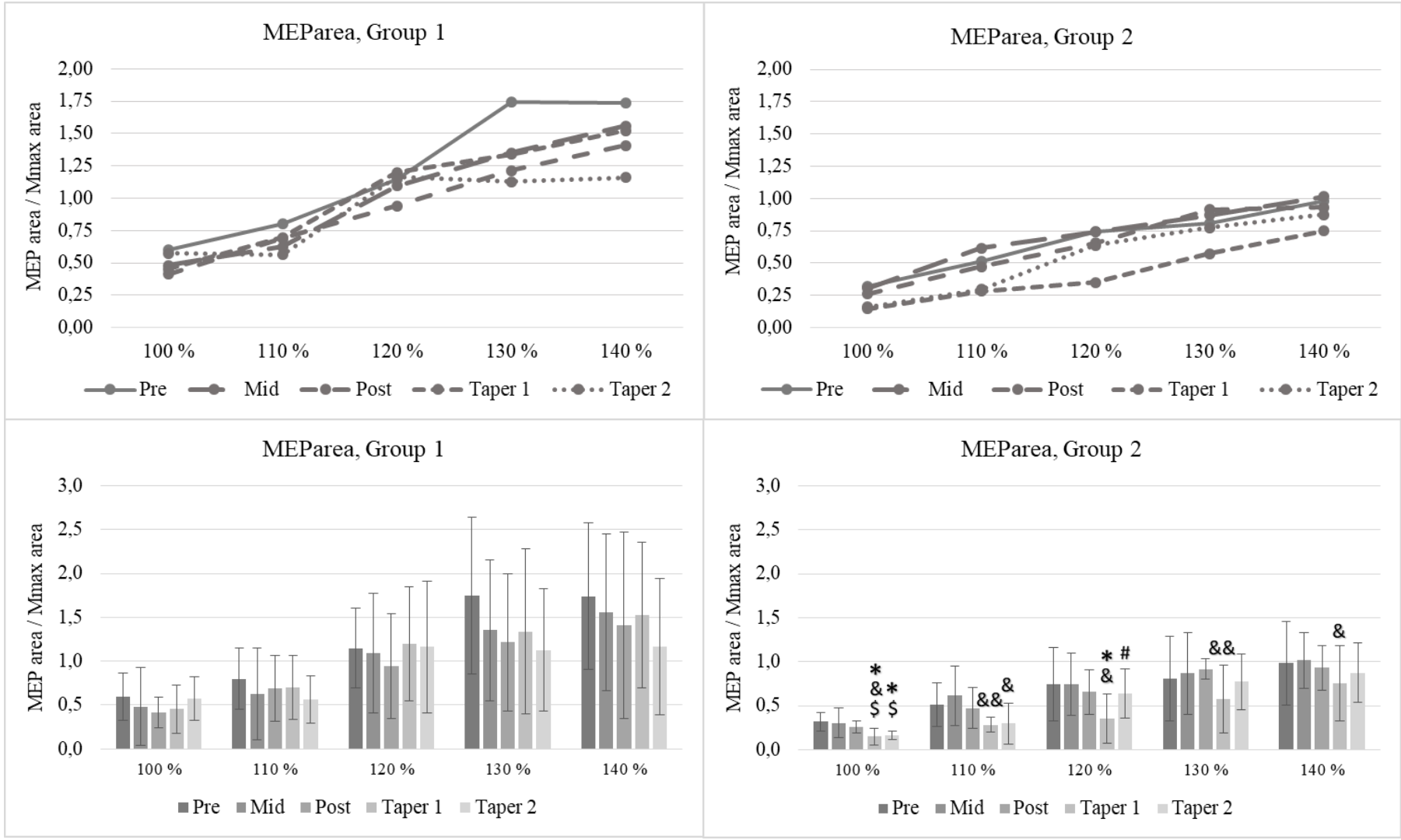
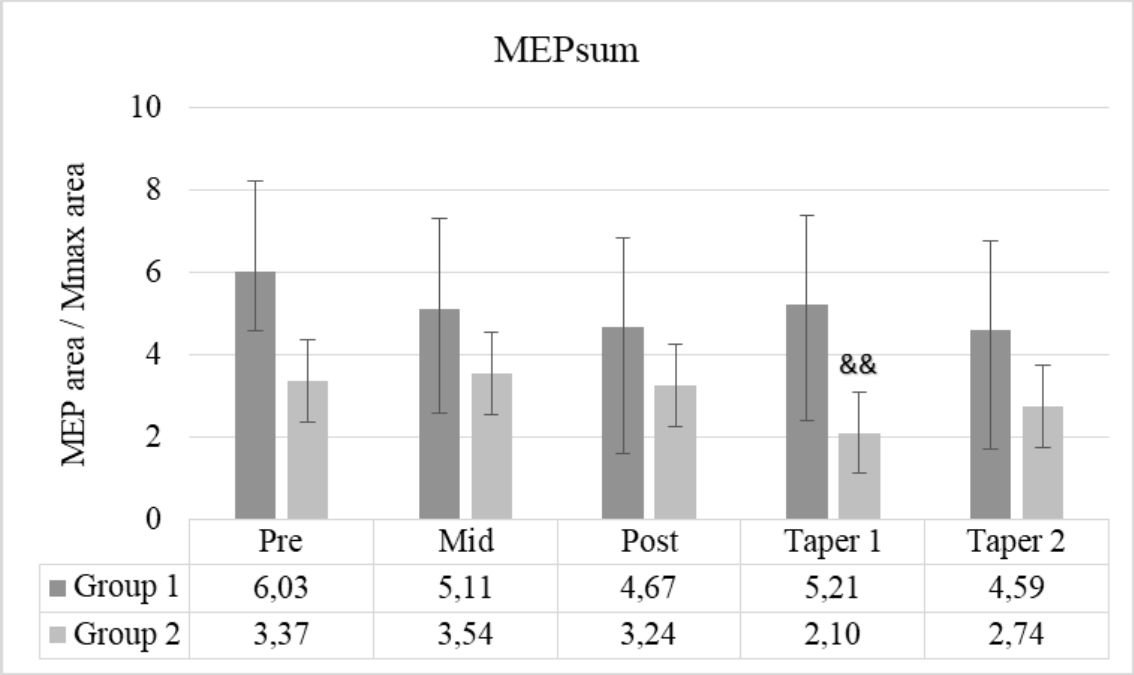



FIGURE 24. MEPareas for group 1 and 2 with stimulation intensities of 100 %, 110 %, 120 %, 130 % and 140 % of AMT. *Significant difference compared to Pre-value, $p \leq 0,05$, &Significant difference compared to Mid-value, $p \leq 0,05$, &&Very significant difference compared to Mid-value, $p < 0,01$, $Significant difference compared to Post-value, $p < 0,01$, #Significant difference between Taper 1- and Taper 2 -values, $p < 0,01$.

*MEPsum.* There were no significant differences in MEPsum between Control- and Pre-measurement sessions in either group. For group 1 there were no significant within group changes in MEPsum between measurement sessions. For group 2 there was a significant decrease in MEPsum from Mid (3,54 ± 1,44) to Taper 1 (2,10 ± 1,18, p = 0,001). There were no significant differences in MEPsum between groups in any measurement session. MEPsum-values for both group are presented in Figure 25.




| | Pre | Mid | Post | Taper 1 | Taper 2 |
|---|---|---|---|---|---|
| Group 1 | 6,03 | 5,11 | 4,67 | 5,21 | 4,59 |
| Group 2 | 3,37 | 3,54 | 3,24 | 2,10 | 2,74 |

FIGURE 25. MEPsum for group 1 and group 2. &&Very significant difference compared to Mid-value, p < 0,01.

*Slope of the I/O-curve.* There were no significant differences in slope of the I/O-curve between Control- and Pre-measurement sessions in either group. For group 1 there was a significant decrease in the slope of the I/O-curve from Pre- (0,061 ± 0,045) to Post- (0,039 ± 0,026, p = 0,006) and Taper 2 -measurements (0,042 ± 0,029, p = 0,011). For group 2 there were no significant within group changes in the slope of the I/O-curve between measurement sessions. In Taper 1 -measurements group 2's slope (0,027 ± 0,014) was significantly lower than group 1's (0,044 ± 0,032). Slopes of the I/O-curve for both group are presented in Figure 26.

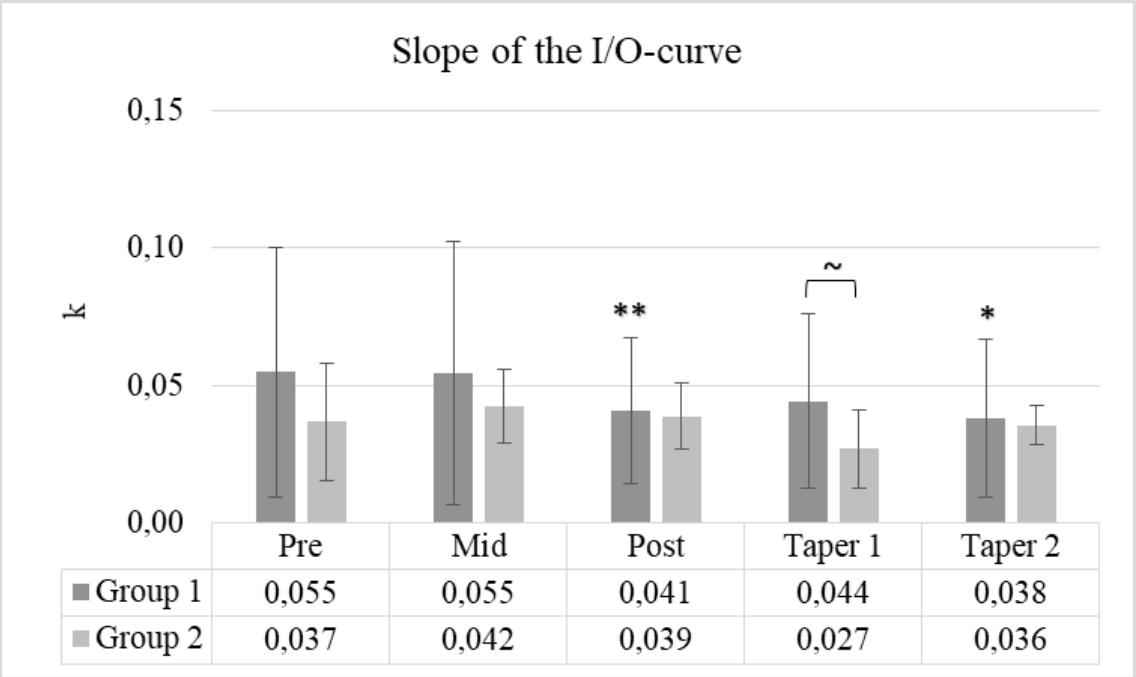
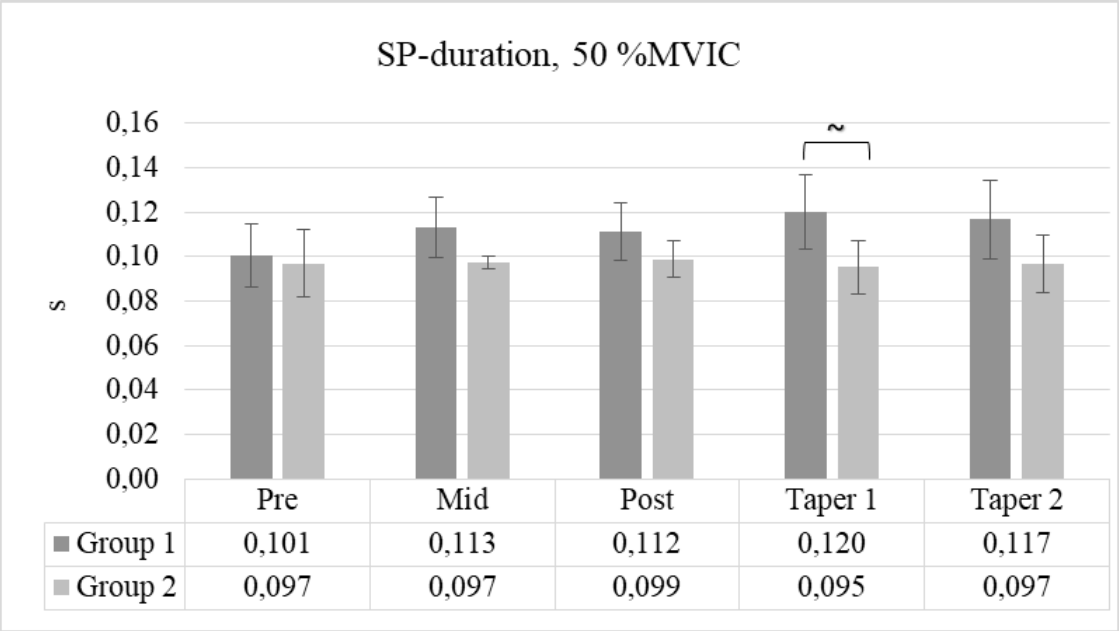


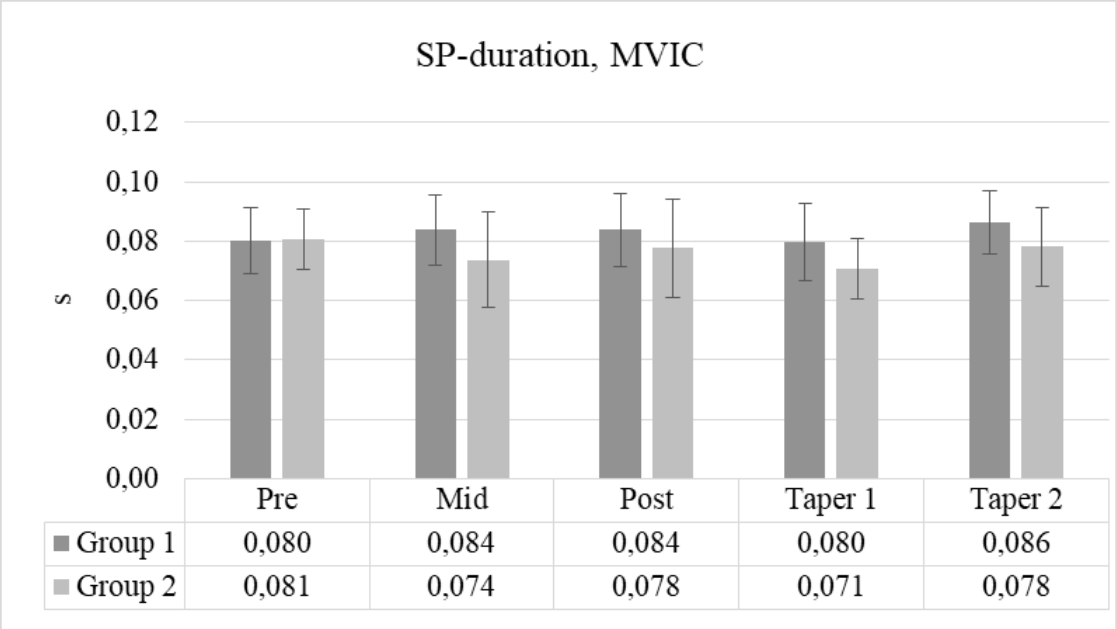

FIGURE 26. The slope of the I/O-curve during the study. *Significant difference compared to Pre-value, $p \leq 0,05$, **Very significant difference compared to Pre-value, $p < 0,01$, ~Significant difference between group 1 and 2, $p \leq 0,05$.

*SP-duration.* There were no statistical within group differences in SP-duration either with 50 % of MVIC background activity or during MVIC in either group. In Taper 1 -measurements group 2's SP during 50 % of MVIC was significantly lower than group 1's. There were no significant differences in SP-duration between groups either with 50 % of MVIC background activity or during MVIC in other measurement session. The durations of SPs during 50 of MVIC background activity and during MVIC are presented in Figure 27 and 28, respectively.




| | Pre | Mid | Post | Taper 1 | Taper 2 |
|---|---|---|---|---|---|
| Group 1 | 0,101 | 0,113 | 0,112 | 0,120 | 0,117 |
| Group 2 | 0,097 | 0,097 | 0,099 | 0,095 | 0,097 |

FIGURE 27. SP-durations during 50 % of MVIC background activity. ~Significant difference between group 1 and 2, $p \leq 0,05$.




| | Pre | Mid | Post | Taper 1 | Taper 2 |
|---|---|---|---|---|---|
| Group 1 | 0,080 | 0,084 | 0,084 | 0,080 | 0,086 |
| Group 2 | 0,081 | 0,074 | 0,078 | 0,071 | 0,078 |

FIGURE 28. SP-durations during MVIC.

# 8 DISCUSSION

The aim of this study was to investigate whether there are (1) differences between the effects of two taper models on strength performance, (2) changes in corticospinal excitability and inhibition as the effect of 8 week of strength training, and (3) changes in corticospinal excitability and inhibition following two different taper models. The main findings of this study were that (1) both groups improved their squat 1 RM through the study without differences between groups and that (2) group 2's corticospinal excitability showed some decrement following the first week of taper while group 1's did not. Here, the research questions and results are discussed.

*Research question 1:* Is there a difference between the effects of 2 weeks of step taper and 2 weeks of linear taper following 8 weeks of strength training period on strength performance?

Results of this study did not reveal a clear difference between the effects of step taper and linear taper on strength performance. As it can be seen from the results, squat 1 RM behaved in a similar manner in both groups during the 8-week strength training period and during two weeks of taper. Both groups improved their squat 1 RM significantly during the first 8-week strength training period (Pre–Post) and slightly during 2-week step taper (group 1) or linear taper (group 2). MVIC in leg press did not change greatly during the study in either group. For both group there is some improvement in MVIC from Pre- to Mid-measurements but after that only slight changes occur. Even there are some statistically significant within group changes in leg press MVIC for group 2 but not for group 1 there are not significant differences in results between groups in any phase of the study. Also knee extension MVIC results behaved in a similar manner for both group and a slight improvement in results following the strength training period and taper period can be detected for both group. Training program during the study did not include any isometric strength training which may explain minor changes in leg press and knee extension MVIC results.

In line with results of this study also previous studies have reported improvements in strength performance following both step taper (Häkkinen et al. 1991; Coutts et al. 2007; Chtourou et al. 2012; Zaras et al. 2014) and progressive taper (Gibala et al. 1994; Izquierdo et al. 2007; Rhibi et al. 2016). However, to our knowledge, the comparison between different taper models has not been done previously. This study showed, that step taper and linear taper following 8-week strength training had mainly similar effect on strength performance in recreationally active men.

*Research question 2:* What are the effects of 8-week strength training period on cortico-spinal excitability and inhibition?

Results from TMS-measurements of this study suggest that there were not remarkable changes in corticospinal excitability during 8-week strength training period. The only significant change in TMS-variables measured was a decrement of group 1's slope of the I/O-curve from Pre- to Post-measurements. However, even if there in MEP-area are not significant changes between Pre- and Post-measurements, for both group there can be seen a slight decreasing trend from Pre to Post in areas evoked with different stimulation intensities. The same decreasing trend can be detected also in MEPsum, especially for group 1. AMT and duration of silent periods remained practically constant during the study. Since AMT, MEP-area and the slope of the I/O-curve are indicating the global excitability of the corticospinal pathway (Carroll et al. 2001; Avela & Gruber 2011, 121; Rossini et al. 2015), it seems that during 8-week strength training period corticospinal excitability remained constant or slightly decreased.

Acute fatigue has been found to decrease corticospinal excitability (e.g. Brasil-Neto et al. 1993; Ruotsalainen et al. 2014). During fatigue, decrements in MEP-size may be caused by increment in inhibitory mechanisms (Ruotsalainen et al. 2014). To our knowledge there is not information available about the effects of long term fatigue or overreaching on corticospinal excitability and because of that those effects can only be speculated. One possibility is that acute and long term fatigue or overreaching have similar effects on corticospinal excitability. It is not clear if 8-week strength training period in this study was sufficient to induce overreaching because strength performance did not drop during 8-week period. Still, there is a possibility that 8-week strength training period caused some long term fatigue resulting in increments of inhibitory factors which could explain

the slight decrement of the measures describing corticospinal excitability. Intracortical inhibition can be assessed by the duration of the silent period (Rossini et al. 2015). However, the duration of the silent period remained constant during the strength training period and thus increments in inhibitory cortical mechanisms cannot be assumed.

It is also possible, that especially during the first weeks of strength training some technique improvements and motor learning have occurred. Motor skill training has found to increase corticospinal excitability (Perez et al. 2004; Jensen et al. 2005). If motor learning and fatigue has occurred at the same time, there is a possibility that their (possible) opposite effects on corticospinal excitability have canceled each other. Chistiansen et al. (2017) found that motor skill training must be progressive to induce increases in corticospinal excitability not only following first training session but also following next ones. Because main training exercises did not change during the study, possible motor learning may have affected corticospinal excitability only during the early phases of the strength training period.

*Research question 3:* What are the effects of 2-week step and linear taper periods on corticospinal excitability and inhibition?

It seems that in this study 2-week step and linear taper following 8-week strength training period had different effects on corticospinal excitability. During step taper (group 1) there were not significant changes in AMT, MEParea, MEPsum, slope of the I/O-curve or duration of silent periods. However, with the highest stimulation intensities of the I/O-curve (120 %, 130 % and 140 % of AMT) a slight increment in MEParea from Post- to Taper 1 -measurements, and following that a slight decrement from Taper 1- to Taper 2 -measurements, can be detected. Same, first slightly increasing and then slightly decreasing, trend can be detected also from MEPsum and the slope of the I/O-curve.

As discussed earlier, it is possible that before taper period some accumulated fatigue occurred, which decreased corticospinal excitability during the 8-week strength training period. During step taper participants trained both weeks with 46 % volume of the pre-taper value. Thus it is reasonable, that during taper with reduced training volume recovery from possible accumulated fatigue occurred and corticospinal excitability slightly increased. A slight decrement in corticospinal excitability during the second week of the taper may

indicate, that fatigue before taper was not very high and recovery took place during the first week of the taper, when the load during the second week was insufficient to maintain the corticospinal excitability.

Whereas corticospinal excitability seemed to slightly increase during the first week and decrease during the second week of the step taper, linear taper seemed to have opposite effects on corticospinal excitability. During linear taper the first week was performed with 58 % volume and the second week with 34 % volume of the pre-taper value. After the first week of linear taper MEParea was significantly lower than Pre- or Mid-values with every stimulation intensity. Also MEPsum and the slope of the I/O-curve reached their lowest point after the first week of the taper. These results may indicate that the training volume during the first week was too high to recover from possible fatigue following 8 week of strength training, but instead resulted in more fatigue, causing decrements in corticospinal excitability. During the second week of the linear taper MEParea increased even significantly from Taper 1, and also MEPsum and the slope of the I/O-curve showed some increments. Training volume during the second week was only 34 % of pre taper value which allowed the recovery from fatigue, and that may explain the increment in corticospinal excitability. Because taper was only two weeks, it is unclear if corticospinal excitability had continued increasing, remained constant or decreased during longer taper.

For both groups the greatest changes in MEParea during taper period occurred with the highest stimulation intensities (120 %, 130 % and 140 % of AMT). During TMS motor units are recruited with same size principle than in voluntary contraction, that is, with higher intensities faster units are recruited (Henneman et al. 1965; Hess et al. 1987). Changes in MEParea with higher but not with lower stimulation intensities may indicate that reduced training during taper affected more on fast motor units. That is reasonable, because training was performed mainly with high intensity when fast motor units are used.

*Limitations and future directions.* This study was a part of a larger project which composed of a master's thesis of two students and a bachelor thesis of one student. Study was planned in collaboration with professors and measurements were executed by students. Students did not have much experience from research which may have affected the accuracy of the measurements. However, between Control- and Pre-measurement sessions

there were not significant differences in results, excluding group 2's MEParea with stimulation intensity of 110 % of AMT, suggesting that methods have been reliable. During the study various drop-outs occurred so the number of finished participants was little (n = 6 + 5) which may affect the reliability of the results. Because of the time pressure, the duration of the strength training period was able to be only 8 weeks and taper period only 2 weeks. For the future research neural changes during (1) overreaching could be studied during longer strength training period which is sufficient to induce overreaching and during (2) longer taper following overreaching so that the duration of the different taper strategies' improving effect can be examined.

*Conclusion.* The results of this study suggest that there are not differences between the effects of step taper and linear taper on strength performance. Both strategies improved 1 RM in squat, which was the main exercise in this study. During the 8-week hypertrophic and maximum strength training period corticospinal excitability remained constant or slightly decreased. During the first week of step taper corticospinal excitability slightly increased and during second week slightly decreased, whereas during the first week of linear taper corticospinal excitability slightly decreased and during the second week slightly increased. Step taper could be applied after training period which had induced overreaching and/or if taper is going to be performed in a short period of time (e.g. one week), whereas linear taper could be applied in situation with less overreaching and among longer period of time (e.g. two or more weeks).

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# APPENDICES

## Appendix 1 – Resistance exercise specific rating of perceived exertion (RPE)

Modified from Zourdos et al. 2015.

| Rating (RPE) | Description of Percived Exertion |
|---|---|
| **10** | Maximum effort |
| **9.5** | No further repetitions but could increase load |
| **9** | 1 repetition remaining |
| **8.5** | 1–2 repetitions remaining |
| **8** | 2 repetitions remaining |
| **7.5** | 2–3 repetitions remaining |
| **7** | 3 repetitions remaining |
| **5–6** | 4–6 repetitions remaining |
| **3–4** | Light effort |
| **1–2** | Little to no effort |