The relationship between stretching and physical performance in middle-aged adults: a cross-sectional study

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Tiivistelmä

Tausta ja tarkoitus

Välitön venyttelyn jälkeinen voiman heikkeneminen ja nivelen liikelaajuuden kasvu sekä ohimenevät viskoelastiset muutokset ovat perusteellisesti tutkittuja välittömiä vaikutuksia. Pidempiaikaisen venyttelyharjoittelun mukautumisvaikutukset ovat epäselvempiä. Tämän tutkimuksen tarkoituksena oli tutkia venyttelyn yhteyttä fyysiseen suorituskykyyn.

Menetelmät

Tutkimus toteutettiin poikkileikkaustutkimuksena, jonka tutkittavat (n=455) valittiin satunnaisesti viidestä eri ikäryhmästä (37, 42, 47, 52 ja 57 vuotta). Fyysisesti täysin passiiviset henkilöt suljettiin tutkimuksesta pois. Tutkittavat jaettiin ryhmiin: 1) jossain määrin aktiiviset and 2) aktiiviset, sekä alaryhmiin: a) venyttely ja b) ei-venyttely, heidän fyysisen aktiivisuuden sekä venyttely tottumustensa mukaan. Fyysisistä suorituskykyä mitattiin seuraavilla testeillä: UKK-kävelytesti (2 km), askelkyykky, ponnistushyppy, muunneltu punnerrus, selän sivutaivutus sekä polven koukistajalihasten venyvyys aktiivisessa ojennusliikkeessä. Tulosten tilastolliset analyysit tehtiin ANCOVA- menetelmällä.

Tulokset

Venyttely alaryhmät erosivat toisistaan liikunnan useuden, keston ja intensiteetin osalta. Eroja löytyi myös lihaskuntoliikunnan ja pelien harrastamisessa sekä päivittäisen kävelyn määrässä. Tilastollisesti merkitsevä ero venyttelijöiden ja ei-venyttelijöiden välillä havaittiin aktiivisilla muunnellussa punnerrus testissä. Jossain määrin aktiivisilla tilastollisesti merkitsevä ero alaryhmien välillä havaittiin muunnellussa punnerrus testissä (MD 1.5 toistoa; 95% CI 0.1 to 2.8, p=0.023), ponnistushypyssä (MD 2.7 cm; 95% CI 0.5 to 4.9, p= 0.008) sekä 2-km kävelytestissä (MD -0.75 min; 95% CI -1.32 to -0.17, p=0.004). Liikkuvuus testeissä tai askelkyykyssä tilastollisesti merkitseviä eroja ei löydetty.

Johtopäätökset

Tulokset osoittivat, että venyttelyn muusta fyysisestä aktiivisuudesta riippumaton yhteys fyysiseen suorituskykyyn on pieni muutamaa poikkeusta lukuun ottamatta. Tutkimuksen heikkouksista johtuen tämän tutkimuksen tuloksia on tulkittava varoen. Lisäksi tulokset osoittivat, että säännöllisen venyttelyn yhteys fyysiseen suorituskykyyn ei näytä olevan haitallinen.

Asiasanat: venyttely, fyysinen suorituskyky, lihasvoima, hyppytesti, kävely nopeus, liikkuvuus

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Abstract

Background and purpose

Stretch-induced strength loss and increase in ROM and transient viscoelastic accommodations immediately after stretching have been well established. The effects of long-term stretching are more ambiguous. The purpose of the present study was to investigate the association between stretching and physical performance.

Methods

This study was conducted as a cross-sectional analysis. The participants (n=455) were randomly selected from five different age frames (37, 42, 47, 52 and 57 yrs). The participants were first divided into physical activity (PA) groups according to their overall level of PA: 1) somewhat active and 2) active, and then to sub-groups: a) stretching and b) non-stretching based on stretching habits. Physical performance tests included UKK 2-km walk, one-leg squat, jump-and-reach, modified push-up, side bending and hamstring extensibility tests. ANCOVA analysis was performed.

Results

Differences between the stretching sub-groups were found in exercise intensity, duration, frequency, daily walking distance and neuromuscular training. In the active subjects a significant (MD 1.3 reps; 95% CI 0.1 to 2.4, p=0.022) mean difference between the stretching and non-stretching sub-groups was observed only in modified push-up test performances. In the somewhat active subjects a significant mean difference between the stretching and non-stretching sub-groups was observed in modified push-up (MD 1.5 reps; 95% CI 0.1 to 2.8, p=0.023), jump-and-reach (MD 2.7 cm; 95% CI 0.5 to 4.9, p= 0.008) and UKK 2-km walk test performances (MD -0.75 min; 95% CI -1.32 to -0.17, p=0.004). In flexibility tests or in one-leg squat no significant mean differences were observed.

Conclusions

Results indicated that the independent relationship of stretching beyond overall physical activity level on physical performance is small with few exceptions. Due to the limitations of this study the results need to be interpreted with caution. Furthermore, the results indicated that regular stretching doesn’t seem to have a detrimental association with physical performance.

Keywords: muscle stretching exercises, physical fitness, muscle strength, jump performance, walking speed, flexibility

CONTENTS

1 INTRODUCTION

Stretching is typically considered as an essential part of comprehensive sports training program. Stretching is often recommended based on its proposed reducing effect on sports injuries and delayed onset muscle soreness (DOMS, post exercise muscle soreness), and enhancing effect on performance. These recommendations lack scientific base, because the available evidence is inconsistent (Herbert & Gabriel 2002, McHugh & Cosgrave 2010).

According to recent reviews pre-event stretching diminishes force and power production (i.e. stretch-induced strength loss) and may improve running economy (McHugh & Cosgrave 2010, Shrier 2004). Acute bout of stretching has been found to induce changes in viscoelastic properties (Kubo et al. 2001a). However these changes are transient in time and return even faster than the achieved increase in range of motion (Mizuno et al. 2011, McHugh & Cosgrave 2010).

A systematic literature search to study the long-term effects of stretching on physical performance was conducted in 2010 and an additional search in 2011-2012. The effects of long-term stretching are ambiguous and especially when looking at strength measures the results are conflicting (Handel et al. 1997, Hunter & Marshall 2002, Guissard & Duchateau 2004, Woolstenhulme et al. 2006, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007, Bazett-Jones et al. 2008, LaRoche et al. 2008, Stanziano et al. 2009, Ylinen et al. 2009, Yuktasir & Kaya 2009, Marshall et al. 2011, Nelson et al. 2012). Therefore the purpose of the present cross-sectional study was to investigate the plausible association between regular stretching and physical performance in middle-aged adults. To our knowledge, this cross-sectional study is first to investigate the association between physical performance and stretching in middle-age adults without any pre-descripted stretching intervention. Therefore it can give important knowledge on the role of realistic amount of stretching on physical performance in the non-athletic population.

2 PHYSICAL PERFORMANCE

In literature there are many terms to describe physical performance, such as physical fitness and physical capacity. Physical performance can be used as an umbrella term to factors that affect subjects' ability to perform a physical activity (Åstrand ym. 2003, 273, Powers & Howley 2009, 326). For example muscle strength, flexibility, coordination, endurance, nutrition, and source of energy have an effect on physical performance. Also conation, alertness and motivation, which are driven by central nervous system (CNS), affect physical performance as well as environmental factors (Åstrand 2003, 480, Powers & Howley 2009, 417, 431).

2.1 Aerobic performance

Aerobic capacity is the ability to use oxygen to produce energy. In aerobic energy production energy is produced from lipids and glucose with the help of oxygen (Cerny & Burton 2001, 25, 41). Maximal oxygen uptake (VO_{2max}) describes body's ability to transfer and use oxygen during physical exercise. Though for exercise VO_{2max} is the fundamental measure for physiologic functional capacity, it isn't the only variable of endurance performance. There are intrinsic qualities, such as capillary density, enzymes, mitochondrial size and number and muscle fiber type, which also have an influence on endurance performance (McArdle et al. 2007, 239, Powers & Howley 2009, 56, 158). Aerobic energy production takes place in mitochondria as co-operation between electron transport chain and Krebs cycle and with endurance training it is possible to develop oxygen capacity of the muscle by increasing the amount of mitochondria (Powers & Howley 2009, 37, 56, 158).

2.1.1 Aerobic performance testing

VO_{2max} is the most valid measurement for cardio and respiratory system function as keeping it high requires high levels of pulmonary, cardiovascular as well as neuromuscular function. VO_{2peak} is the highest achieved oxygen consumption during the test (McArdle et al. 2007, 239-240). In VO_{2max} test large muscle groups should be used and the rate of work should be reproducible (Åstrand et al. 2003, 280, Powers & Howley 2009, 433), as for example in cycle ergometer or with treadmill walking or running, where large muscle groups are used and speed is kept steady. Maximal oxygen consumption is influenced by mode of exercise, heredity, state of training, gender, body size and composition and age (McArdle et al. 2007, 242).

The most precise test for oxygen consumption can be conducted in laboratory environment with for example cycle ergometer and spirometer. When testing an athlete, the test should be conducted with method that reminds the most that sport of the study subject (Powers & Howley 2009, 433, 306-307). Always laboratory environment isn’t available or is inconvenient, for example when testing larger groups. For healthy adults a UKK 2 -km walking test, with fast walking and additional measurements such as walking time, age, BMI, heart rate added into the prediction equation, is a feasible and reasonably accurate alternative for determining the cardiorespiratory fitness. It is usually also free of systematic over- or underestimations (Laukkanen et al. 1991, Zakariás et al. 2003). The UKK 2 -km walking test can also be used as a reasonably accurate field test to predict changes in VO_{2max} in healthy non-athletic adults (Laukkanen et al. 2000). Though, it should be remembered, that all predictions do contain standard error of estimate (SEE) (McArdle et al. 2007, 247).

2.2 Muscle performance

Muscle performance or muscle fitness can be used as a unifying term to describe muscular strength and muscular endurance (ACSM 2000, 81). Muscular strength refers to maximal force of the muscle, which is the largest possible force that can be produced by the muscle on its whole range of motion (ROM) at a certain velocity. Muscular endurance describes muscles ability to do several muscle contractions or to be able to maintain a certain amount of the muscles maximum voluntary contraction (MVC) for extended period of time (ACSM 2000, 81, 84, Powers & Howley 2003, 280). Muscle power describes the rate at which muscles can produce work (i.e. power production) (Enoka 2002, 114-115).

Various factors have an effect on muscle strength. Two significant neural factors are frequency of stimulation and the amount of motor units recruited (Hamilton et al. 2008, 71, McArdle et al. 2007, 408). Muscle force is also proportional to its physiological cross-sectional area (Maughan et al. 1989). Other muscular factors are for example muscle fiber contractile structure and energy transfer capacity of muscle fibers. As for muscle power, the limiting factors are energy-producing capacity of muscle protein filaments (McArdle et al. 2007, 386, Hamilton et al. 2008, 48, Prilutsky 2000, 56).

Every muscle has also got its optimum length, where it can produce its maximal tension (i.e. force-length relationship). If the muscle is longer or shorter than this optimal length, its force production diminishes. Usually optimal length is little longer than its resting length. Also contraction velocity affects the amount of muscle force. As velocity increases, force decreases, which also means that when load increases, muscle contraction velocity decreases. This is because it takes time to form transversal bridges between actin and myosin filaments (Hamilton et al. 2008, 52-53).

2.2.1 Muscular performance testing

Knee extensors, flexors and ankle plantar flexors seem to be the most common targets of stretching and testing in research studying the effects of stretching on muscle performance (McHugh & Cosgrave 2010, Simic et al. 2012). The upcoming strength measurement methods are often used in studies investigating the chronic effect of stretching.

Maximal isometric strength, isometric power and isometric endurance can be assessed with isometric contraction. Muscle strength can be tested with dynamometer as muscle voluntary contraction (MVC) in a specific joint angle against resistance that doesn't move. Joint angle is noteworthy because rate of force production (i.e. power) and peak torque are joint specific (Humphries et al. 2006, 212). Testing is usually done with 2-3 maximal repetitions and the best result describes the maximal muscle contraction in certain joint angle (Powers & Howley 2009, 444). Since muscle force is related to muscles cross-sectional area (Maughan et al. 1989), it's not recommended to compare absolute values from subjects of different sizes (Ahtiainen & Häkkinen 2004, 139). The rate at which the strength declines can be used to assess the isometric muscle endurance, when the subject maintains a single contraction for a longer period of time (Humphries et al. 2006, 212).

Dynamic 1RM testing is used to test maximal dynamic muscular strength and it can be defined as the weight a subject can successfully lift in a good form through a specified ROM just one time. It has been considered as a golden standard of dynamic maximal isotonic muscle assessment, however there are several methods for predicting the 1RM. The predictions are usually based on the performance of submaximal loads, body mass, percentage loads, repetitions, or various combinations of the before mentioned (Humphries et al. 2006, 208, 210). As stated by Levinger et al. (2009) 1RM-testing protocols with familiarization and one testing session are sufficient for maximal strength assessment in inactive middle-aged adults as it was found to be a reliable method. Chest and leg press, lateral pull-down, triceps pushdown, knee extension, seated row and biceps curl were all tested by Levinger et al. (2009) and high ICC (ICC>0.99) and correlation (r>0.9) values were found for all exercises. In the testing protocol used, a light warm-up and one set of 10 repetitions at a relatively light load preceded the 1RM test. After 10 repetitions a gradual increase in load, depending on participants self-perceived capacity, followed until the 1RM was reached. One-minute rest period between attempts was used. More repetitions can be also used, since they are considered safer than 1RM testing (Powers & Howley 2009, 445-446). According to Taylor and Fletcher (2012) also 8 RM testing with familiarization is reliable in men and women (ICC > 0.9).

Endurance strength can be also determined by dynamic assessment with measures such as time to fatigue and repetitions. Free weights or machines can be used to test relative or absolute endurance strength. In relative strength measure the subject lifts a certain percentage of his or her 1RM for as many times as possible. In absolute measure the subject does as many repetitions as possible with a certain load (Humphries et al. 2006, 210).

With isokinetic dynamometry muscle force or moment is tested throughout the range of motion of the joint with a standardized angular velocity and controlled accommodating resistance so that the muscle force or moment production variations within joints ROM can be discovered (ACSM 2000, 83, Humphries et al. 2006, 212, Powers & Howley 2009, 445-446). Different angular velocities can be used, when using isokinetic devices ranging from 0 to 500 °/s. Measurements such as peak torque, angle specific torque, power and rate of force development can be analyzed using isokinetic method. Furthermore muscular endurance can be obtained using isokinetic testing by using multiple contractions and quantified as a contraction number, time or torque decline value that falls below 50% of the maximum value (Humphries et al. 2006, 213). Usually speed strength is tested with 240°/s, maximal strength with 60 °/s and endurance strength with 180 °/s angular velocities (Ahtiainen & Häkkinen 2004, 145). Isometric strength can be assessed with isokinetic dynamometer at angular velocity of 0 °/s (Humphries et al. 2006, 212).

Jumping and agility tests can be used as a field test to assess muscle power of lower extremities and throwing tests for upper extremities. Vertical jumps (e.g. counter movement (CMJ) and static jump) are used to measure leg extensor power production and drop jumps are used to assess reactive force of the muscle. Stretch-shorten cycle is used in these movements (Humphries et al. 2006, 209, 211), which means that eccentric stretching in muscle-tendon unit precedes concentric contraction. The muscle-tendon unit stores energy during the eccentric stretch. After the stretch the energy gets released and muscle relaxes back to its resting length. If concentric contraction follows the eccentric stretch, the stored energy can be used and muscle force production is greater than if the muscle contracted form it's resting length (Hamilton et al. 2008, 53-54). According to Markovic et al. (2004) CMJ and SJ are the most reliable and valid field tests for the estimation of explosive power of the lower limbs if measured with contact mat and digital timer. The results can be generalized to physically active men. The Cronbach's alpha in the jumps (squat jump, CMJ, Sargent jump (VJ) and standing long jump) varied between 0.95 and 0.98 and the within-subject variation (CV%) varied between 2.4% to 3.3%.

3 FLEXIBILITY

The definition of flexibility and related terms differ tremendously depending on source. According to ACSM (2000) flexibility can be defined as “ability to move a joint through its complete range of motion”. Siff (2000, 133-134) defines flexibility of a joint by structural (or architectural) limitations, mechanical properties of the muscles and soft tissues, neuromuscular processes that control muscle and its length and the pain threshold of the subject when approaching the end of the ROM. However, in this study flexibility is defined as joint ROM as American college of sports medicine (2000) has suggested unless otherwise stated.

Flexibility is an important factor in various sports as well as in activities of daily life. It is joint specific and the determinants of musculoskeletal flexibility are for example surrounding tissues compliance (e.g. muscle fiber type and architecture and muscles’ viscoelastic properties, joint capsule), muscle cross-sectional area and subjective stretch tolerance (ACSM 2000, Alter 2004, 27-29, Magnusson et al. 1997). Magnusson et al. (1997) noticed that in elite level male orienteers those who had restricted ROM (poorer performance in toe touch test) were also stiffer and had lower stretch tolerance compared to the subjects, with better ROM. Stretch tolerance can be defined as subjects ability to tolerate higher torques, without the elevation of pain level (Magnusson et al. 1997).

3.1 Muscle-tendon unit properties associated with flexibility

Viscoelasticity is a quality of skeletal muscle and due to its elasticity muscle returns to its original shape after tensile force is removed (Magnusson 1998, Hamilton et al. 2008, 45). Viscosity refers to the fact that muscle elasticity is dependent on how long tensile force affects it (Magnusson 1998). Skeletal muscle is able to generate force by contracting but tendons are mostly responsible for the force transmitting to the skeleton and storing elastic energy (Enoka 2002, 227, Hamilton et al. 2008, 45-46).

Tendons differ in dimensions, for example length, cross-sectional area and attachments. These differences have an influence on tendons mechanical properties that determine muscle performance (Herzog 2000, 21, Enoka 2002, 227).

When load-deformation relation is normalized by cross-sectional area and length, the biomechanical properties of tendons can be compared as stress-strain relations and described by stress-strain curve. The linear region of stress-strain curve, i.e. slope, represents the elastic region of tendon (i.e. stiffness, elasticity, the change in force per unit change in length) and beyond this region (>10% strain) plastic changes take place in tissue and its resting length changes (Enoka 2002, 228). According to Kubo et al. (2001b) there is no significant association between passive muscle stiffness and extensibility of the tendon structures, but passive stiffness is significantly correlated to body mass, muscle thickness and MVC.

The material properties of muscle-tendon unit are viscoelastic stress-relaxation response, creep and hysteresis. In a static phase of stretch the tension (resistance offered by tendon) gradually declines over time (i.e. force/stress-relaxation) (Taylor et al. 1990, Magnusson et al. 1997, Weppler & Magnusson 2010). As the force declines, the length of the tendon increases (i.e. creep) (Taylor et al.1990, Ryan et al. 2010) and while the stretch tension is removed some of the energy is dissipated during the unloading phase (i.e. hysteresis) (Taylor et al. 1990). Thus, tendons have both viscous and elastic properties.

3.1.1 Flexibility testing

When flexibility is tested on a human subject, the tests usually measure joint angles, not muscle length. Muscle length however is just one dimension of muscle length and according to Weppler and Magnusson (2010) one-dimensional muscle length can be referred as *extensibility*. Extensibility is defined further as “muscles ability to extend to a predetermined endpoint”, which according to several recent human studies is often subjects' sensation (i.e. stretch tolerance) (Magnusson et al. 1996a, Chan et al. 2001, LaRoche & Connolly 2006, Ylinen et al. 2009, Ben & Harvey 2010, Weppler & Magnusson 2010).

Magnusson et al. (1996a) investigated the effect of 3 weeks stretching intervention on the tissue properties and concluded that increased range of motion is likely to be a consequence of increased stretch tolerance as ROM and passive torque increased but no change in tissue properties (e.g. stiffness, energy) were observed. Multi-dimensional muscle length includes extensibility, tension (i.e. passive resistance of the muscle being stretched), cross-sectional area and time. When one of these dimensions is added, on top of extensibility measure, various biomechanical properties can also be obtained (Weppler & Magnusson 2010). It should be noted that term extensibility is defined differently depending on author but in this study extensibility is used to describe one-dimensional muscle length like proposed by Weppler and Magnusson (2010).

Hamstring flexibility seems to be the most common measurement of extensibility in research studying the effects of long-term stretching on flexibility (Halbertsma & Göeken 1994, Bandy 1997, Chan et al. 2001, Nelson et al 2001, Ben & Harvey 2010, Reid & McNair 2011). Straight leg raise (SLR) is often used to test hamstring flexibility (Halbertsma & Göeken 1994, LaRoche & Connoly 2006, Ylinen et al. 2009, Ayala & Sainz de Baranda 2010, Ben & Harvey 2010, Marshall et al. 2011). SLR can be conducted with passive manual (PSLR) (Ayala & Sainz de Baranda 2010) or active leg raise (ASLR) (Ylinen et al. 2010) or with the help of a specific instrument (ISLR) (LaRoche & Connoly 2006, Ylinen et al. 2009, Ben & Harvey 2010, Marshall et al. 2011). As stated by Ylinen and colleagues (2010) ASLR and PSLR have poor ability to detect changes, but ISLR has good reproducibility (ICC 0.94) and ability to detect changes.

According to Ylinen et al. (2010) during SLR the subject lays supine lower limbs extended. Ankle position varies between protocols (Halbertsma & Göeken 1994, LaRoche & Connoly 2006, Ylinen et al. 2009, Ayala & Sainz de Baranda 2010, Ben & Harvey 2010, Marshall et al. 2011) and in some cases support is used for lumbar lordosis (Ayala & Sainz de Baranda 2010, Marshall et al. 2011). In ASLR the subject lifts the leg as high as possible keeping the leg straight (Ylinen et al. 2010). Ylinen et al. (2010) used 3 lifts attempting to enhance the lifting force, as it affects the final ROM measurement, and used the best performance as the result.

In PSLR the examiner manually lifts the leg keeping the knee joint straight (Ayala & Sainz de Baranda 2010, Ylinen et al. 2010). In PSLR the end point varies form examiners perception of firm resistance and beginning of pelvic rotation to subjects' maximal tolerance (Ayala, Ylinen et al. 2010). In ISLR the apparatus is attached to the participant usually at the ankle level and straps are used to secure a good form, though these technical details vary little between different devices. The angular velocity is often set between 3-5°/sec (Halbertsma & Göeken 1994, LaRoche & Connoly 2006, Ylinen et al. 2009, Ben & Harvey 2010, Ylinen et al. 2010, Marshall et al. 2011). The end point usually is subjects' discomfort (Ylinen et al. 2010).

Sit-and-reach is also often used to test hamstring extensibility, hip joint and low back flexibility (ACSM 2000, 86, Nelson et al. 2001, Woolstenhulme et al. 2006, Kokkonen et al .2007, Stanziano et al. 2009). Baltaci et al. (2003) investigated the relations between three sit- and-reach tests (chair sit-and-reach, back saver sit-and-reach and traditional sit-and-reach) to hamstring extensibility tested with SLR and their results indicated that traditional sit-and-reach ($r=0.63$ left and $r=0.53$ right, $p<.01$) and back saver sit-and-reach tests ($r=0.37$ left and $r=0.25$ right, $p<.05$) were highly related to hamstring extensibility.

In the sit-and-reach test the subjects sits with straight legs and feet flat against the sit-and-reach testing box. Then the subjects reaches forward as far as possible keeping knees extended, hands on top of each other and elbows extended. The score is recorded as the distance from the tip of the middle finger to the feet (Woolstenhulme et al. 2003). The sit-and-reach test can also be conducted on left and right leg separately, as stated by Baltaci et al. (2003). According to ACSM (2000) this enables the examiner to evaluate symmetry.

Knee extension test is also used to test hamstring flexibility. For example Gajdosik and Lusin (1983) conducted the active knee extension test (AKET) as follows: the subject is in supine and the lower extremity not being measured and pelvis are secured to a table. The hip is flexed to 90°, quadriceps touching the bar of the testing device and the subject actively extends the knee while maintaining the hip joint position. The degree of knee flexion is recorded with a goniometry and the maximal angle of knee flexion represents the point of hamstring tightness. It should be noted that when trembling of the limb started the subjects were instructed to flex their knee until the trembling stopped and the first point of no shaking was considered as the end point. In a study by Ross (2007) a similar measurement was used, however the end point of the test was the maximal extension of the knee without losing the contact with the center bar of the testing device. The Pearson reliability coefficient of this method was shown by Gajdosik and Lusin (1983) to be 0.99, when using strict body stabilization, a well-defined and easily observed end point of motion, as well as precise instrument placement.

Covert et al. (2010) used passive knee extension test, where the starting position is similar to AKET, but the investigator, who also performed the knee extension, maintained the position of the hip. The end point of passive knee extension test can be determined by the subject (i.e. maximal tolerable stretch)(Covert et al. 2010) or by the investigator (e.g. firm feel) (Fasen et al. 2009). Handel et al. (1997) and Reid and McNair (2011) have also used passive knee extension to test hamstring flexibility, but the knee extension was conducted in sitting position with the hip in 90 degrees. Also dynamometer can be used to test the passive knee extension (Reid & McNair 2011).

Ankle range of motion is also fairly common target of interest in research studying the effects of long-term stretching on flexibility (Nelson et al. 2001, Guissard & Duchateau 2004, Mahieu et al 2007, Johansson et al. 2009, Rees et al. 2007, Christiansen

2008, Cristopolski et al. 2009). The ankle dorsiflexion ROM can be measured knee flexed or extended, as active ROM or passive ROM. The measurements can be conducted in weight bearing position or in non-weight bearing position. A simple goniometer or instrument such as dynamometer can be used (Guissard & Duchateau 2004, Mahieu et al. 2007, Christiansen 2008, Krause et al. 2011). The study by Krause et al. (2011) demonstrated best reliability (ICC 0.82) in modified lunge test, where maximal ankle dorsiflexion is achieved in weight bearing position. The most deficient reliability was observed in active ROM tests with knee extended and flexed (ICC 0.62 and 0.55). The reliability of passive dorsiflexion measurements with knee extended and flexed were moderate (ICC 0.67 and 0.79) (Krause et al. 2011).

4 STRETCHING

The American college of sports medicine (2000) suggests that properly conducted muscle stretching exercises can help in improving as well as maintaining joint range of motion and so recommends static or PNF stretching for the major muscle-tendon groups at least 2-3 times 3 to 4 repetitions a week for 10 to 30 second static stretch, until mild discomfort (or when doing PNF stretching 6-sec contraction and 10-30 second stretch). According to a definition by Hamilton et al. (2008, 408-409) in active stretching the subject produces the stretch independently by antagonist muscle contraction. In passive stretching gravity or assistant is used to produce the stretching or the subject actively intensifies the stretch for example in sit-and-reach by pulling from the toes.

Pre-event stretching in this study refers to stretching done right before athletic performance, performance testing, training or any other physical activity. Acute effects refer to effects caused by stretching and they are observed immediately after stretching has stopped or during. Long-term stretching refers to stretching that is done regularly for a longer period of time, e.g. 2-8 weeks or more, and the effects of long-term stretching are referred as chronic effects (wash-out period between testing and stretching).

4.1 Stretching techniques

In ballistic stretching a rhythmic bouncing motion is used to stretch the muscle (Alter 2004, 157, Mahieu et al. 2007). Ballistic stretching can also be called as dynamic or isotonic stretching (Alter 2004, 157). For example in the study by Mahieu et al. (2007) a classic standing wall push stretch was preformed as ballistic stretching to stretch the plantar flexors. The subjects bent the front knee and moved up and down at a pace of one movement per second without stopping to the stretching position.

In static stretching a relaxed muscle is stretched slowly until held still for a certain period of time (Alter 2004, 159). The intensity of stretch varies from slight feeling of stretch to a maximal tolerable stretch (Rees et al. 2007, Bazett-Jones et al. 2008, Reid & McNair 2011, Nelson et al. 2012). As stated by Morton et al. (2011) a large proportion of the muscle tendon unit elongation during passive stretch is due to tendon elongation. For example the change in length during passive dorsiflexion to end range ROM the displacement of muscle tendon junction accounted for 47% and tendon elongation accounted for 53% of the overall change in MTU length.

Proprioceptive neuromuscular facilitation (PNF) is a combination of static stretching and active contraction of the stretched muscle (Enoka 2002, 368). Several different variations and combinations of PNF stretching exist, for example contract-relax, hold relax and contract relax-antagonist contract (Sharman et al. 2006).

According to Rees et al. (2007) contract-relax agonist-contraction PNF stretching (CRAC) is the same as contract-relax PNF (CR), except in CRAC PNF stretching a contraction of the antagonist muscle is performed during the stretching phase. As stated by Rees et al. (2007) the CRAC-PNF protocol for ankle joint can be performed as follows. The ankle is passively moved into maximal pain-free dorsiflexion, which is followed by a maximal isometric contraction of plantar flexors for 6 to 10 seconds. The ankle is returned to neutral position for 2-second rest period. Next the ankle is moved into maximal pain-free dorsiflexion accompanied by maximal 6 to 10 seconds contraction of the dorsiflexors. The previous phases are repeated 4 to 6 times.

The purpose of the contraction preceding the stretch in hold-relax stretching is to inhibit the stretch-evoked activity of the muscle by decreasing the excitability of alpha motoneurons. In the antagonist-contract PNF stretching the aim of the antagonist contraction is to decrease the excitability of motorneurons that innervate muscle to be stretched (reciprocal inhibition reflex) (Enoka 2002, 398-369). In opinion by Chalmers (2004) these before mentioned methods that are supposed to produce muscle relaxation during stretching might not actually work during stretching like it is usually claimed in literature.

4.2 Acute effects of pre-event stretching on viscoelastic properties and performance

Taylor at al. (1990) has studied the biomechanical effects of stretching using rabbit muscle-tendon units (MTU). According to Taylor at al. (1990) cyclic stretching of MTU to 10 % beyond resting length for 10 times, with a technique resembling ballistic stretching, leads to progressive decrease in passive peak tension. The tension offered by the stretched muscle decreases 16.6% in total, the most pronounced decrease occurring in the first cycles. Taylor et al. (1990) were able to demonstrate stress-relaxation and creep of the MTU during procedures resembling static stretching (10 times 30 second static stretch slowly from 1.96N to 78.4N torque) as the tension declined gradually during the static phase and the length of the MTU increased. The greatest relaxation and length increase of the MTU occurred in the first few static stretches. Taylor et al. (1990) observed also that tensile force and energy absorption depend on the rate of applied stretch so that with faster stretch the MTU absorbs more energy. Kubo et al. (2001a) have been able to demonstrate the decrease in hysteresis and stiffness after acute bout of stretching in human tissues in vivo. Magnusson et al. (1996b) were also able to demonstrate repeated stretch induced changes in biomechanical variables, however they also noticed that the changes in the variables returned to baseline within 1 hour.

According to meta-analytical review by Simic et al. (2012) there is clear evidence that statistically and practically significant detrimental acute effects are induced on maximal strength and explosive muscle strength (e.g. jump performances) by pre-exercise static stretching. The acute effects of static stretching on muscle power when tested, as peak power and mean power, are still ambiguous. Also in a critical review by Shrier (2004) reductions in strength performance (torque, force, jump) were found immediately after different kind of stretching exercises (static, ballistic and PNF) in subjects of both sexes with various training backgrounds.

Furthermore, the effects on maximal muscle performance vary depending on type of muscle contraction and tend to decrease with reduction of stretching duration (Simic et al. 2012). It may even be that no detrimental effects even occur with shorter durations (less than 30 sec) of stretching within a warm-up especially if the participants are highly trained (Behm & Chaouachi 2011). According to Simic et al. (2012) isometric contraction seems to be more greatly affected compared to dynamic contraction, with no difference between eccentric and concentric contractions in maximal strength tests. However as stated by Behm and Chaouachi (2011) dynamic stretching probably has no effect or may even increase performance.

Both Shrier (2004) and Simic et al. (2012) speculated that the stretch-induced transient reduction in stiffness of the muscle-tendon unit could be the reason behind the decrements on maximal strength seen acutely after stretching. However stretch induced strength loss is at least partly due to neural effects, e.g. decrease in stretch reflex sensitivity and decrease in EMG amplitude (Avela et al. 1999, Shrier 2004, Rossi et al. 2010).

4.3 Long-term stretching

To gain knowledge on the effect of log-term stretching on physical performance a systematic literature search was conducted in 2010 from Medline (1950-2010), Pubmed, Cochrane and CINAHL databases. Search terms used were: performance, physical performance, muscle performance, aerobic performance, aerobic capacity, stretch*, stretching, flexibility, flexibility training, pliability, pliability training. Limits were set at 13–65 years of age, randomized controlled trial, controlled trial or at least clinical trial. Studies were accepted if they were at least controlled trials, intervention lasted at least 4 weeks, subjects were healthy 13-65 years and at least one of the outcomes measured the effect of stretching on physical performance but not flexibility or coordination. Studies were excluded if subjects had an illness or orthopedic problem or for example study inclusion criteria had been tight muscles. Additionally hand search was used.

At that time 9 studies were accepted (Handel et al. 1997, Nelson et al. 2001, Hunter & Marshall 2002, Woolstenhulme et al. 2006, Kokkonen et al. 2007, Rees et al. 2007, Bazett-Jones et al. 2008, LaRoche et al. 2008, Yuktasir & Kaya 2009), and a systematic error and validity analysis was conducted on the 9 original studies using the guidelines in Cochrane Handbook for systematic reviews for interventions (Higgins & Green 2009). A fairly substantial risk of systematic error was found mainly because of vague reporting or failure to report certain matters, such as blinding, randomization, and allocation to groups as well as reasons for dropouts and selective reporting.

In 2011-2012 a new search from Medline was conducted (1994 to present) with more compliant limitations. No age frame was used and studies that had tight muscle or orthopedic problems, i.e. osteoarthritis were included. Also shorter interventions were accepted as long as the intervention lasted at least two weeks. However the study design had to be at least randomized controlled trial. Flexibility as a target of interest, was added to the search and previously used terms were used with addition of the following terms: physical fitness, range of motion, muscle performance, energy metabolism or oxygen consumption, muscle, skeletal or muscle strength or muscle contraction, biomechanics or elasticity, extensibility and muscle stretching exercises. Hand search was used in addition and studies investigating acute effects were excluded. A systematic error and validity analysis wasn’t conducted for all the 21 new studies. However very similar problems emerged as in the original 9 studies.

The mean intervention duration was approximately 6.5 weeks varying from 15 days to 12 weeks. The participants’ physical activity status varied from inactive to highly active and most of the participants were under 30 years old. Few studies, looking into the effect of stretching on walking performance, had participants older than 60 years. Lower limb muscles were the most common targets of stretching exercises and static stretching the outmost common stretching method even though ballistic and PNF stretching and its variations were used also. The interventions and outcomes are described in more detail in *appendix 2.*

4.3.1 Chronic effects of stretching on viscoelastic properties and flexibility

Several studies trying to determine the effect of stretching on flexibility have found that extensibility (e.g. flexibility, ROM) can be increased by long-term stretching when no significant changes occur in control groups (Halbertsma & Göeken 1994, Bandy et al. 1997, Handel et al. 1997, Chan et al. 2001, Nelson et al. 2001, Guissard & Duchateau 2004, Reid & McNair 2004, LaRoche & Connolly 2006, Woolstenhulme et al. 2006, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007, Christiansen 2008, Cristopoliski et al. 2009, Fasen et al. 2009, Stanziano et al. 2009, Ylinen et al. 2009, Yuktasir & Kaya 2009, Ayala & Sainz de Baranda 2010, Ben & Harvey 2010, Covert et al. 2010, Marshall et al. 2011, Reid & McNair 2011, Watt et al. 2011, Nelson et al. 2012). In addition to increased ROM, several studies have observed significant increases in passive torques after stretching, without significant changes in controls (Chan et al. 2001, Reid & McNair 2004, LaRoche & Connolly 2006, Ylinen et al. 2009, Reid & McNair 2011).

For example in the study by Reid and McNair (2011) an increase in maximal passive resistive force up to +49% was observed the change being statistically significant when compared to pre-score and to the control group (-5.8%, $p>.05$). Nevertheless, the stress-strain curve of human muscle is non-linear (Wright & Johns 1961) and a change in the material properties of the muscle can only be concluded if a decrease in passive resistance can be demonstrated at the same joint angle, or if a greater joint angle can be achieved with the same resistance (Magnusson 1998). Thus, the increase in peak passive torque observed with increases in ROM might reflect increases in stretch tolerance (Reid & McNair 2012).

Mahieu et al. (2007) found also significant increases in ankle ROM with knee extended and flexed after 6 weeks static (+8%, +9%, p>.05) and ballistic (+9%, +11%, p>.05) stretching. However the ROM increased significantly (+8%, +5%, p>.05) in the control group as well. Mahieu and colleagues (2007) speculated that the change in control group might be as a consequence of learning effect. Interestingly Mahieu at al. (2007) didn't find the increase in passive resistive torque like the before mentioned studies did but they found a small but significant decrease (-8%, p<.05) in passive resistance to stretch in plantar flexors after 6 weeks static stretching with no significant changes observed in the control group. In the study by Mahieu and colleagues (2007) the passive resistance to stretch was measured during standardized ROM from 20° of plantar flexion to 10° dorsiflexion and thereby the results indicate that structural changes could have taken place.

Furthermore, one study didn't find significant changes in ROM in stretching group or in control group (Bazett-Jones et al. 2008). The participants in the study by Bazett-Jones et al. (2008) were young (18.57±0.73 yrs) female track and field athletes who had been stretching regularly before intervention. It could be speculated that by their previous stretching they had already reached their optimal extensibility, as speculated by Bazett-Jones et al. (2008). Also their background in running sports could be at least partly the reason why no increase in the extensibility of the hamstrings was observed. Woolstenhulme and colleagues (2006) found in their study that sprint training increased hamstring ROM to the same extent as stretching when compared to controls. In addition, the stretching methods (static) and flexibility measurements (AKET) used in the study, might explain the results because static stretching exercises may have inadequate effect on dynamic range of movement. This might be because static stretching doesn't pay any deliberate attention to neuromuscular processes, e.g. the reflexes that control the functional range of movement, as stated by Siff (2000, 134).

The chronic effect of long-term stretching on muscle stiffness is ambiguous. Guissard & Duchateau (2004) observed a significant decrease in stiffness (-33%) during 15-25° of dorsiflexion, after 6 weeks intervention. Also no significant changes in passive torque were found, regardless of the significant increases in ankle dorsiflexion ROM (+30.8%). In addition after one month stiffness was still different from control and 74% of the gain in ankle dorsiflexion was still present. In the study by Marshall et al. (2011) in addition to significant increase in ROM (+20.9%, $p < 0.001$; $d = 0.86$, $1 - \beta = 0.62$) a significant decrease in stiffness was observed during 20–50° of flexion (-31%, $p<0.05$; $d= -0.89$, $1 - \beta = 0.64$), but no change in maximal stiffness when compared to baseline and to control group where no significant changes were observed. Not to mention Mahieu at al. (2007), who found a significant decrease (-27%, p<.05) in Achilles tendon stiffness after 6 weeks ballistic stretching and small and non-significant decrease (-10%, p=.231) after static stretching with no significant changes in the control group (-2%, p=.100). These results by Guissard and Duchateau (2004), Mahieu et al. (2007) and Marshall et al. (2011) indicate again that long-term stretching might induce chronic structural adaptations.

An increase in stiffness is often seen after resistance training and has been hypothesized to be due to hypertrophy (Klinge et al. 1997, Kubo et al. 2010). However significant increases in stiffness have been observed after stretching intervention (Reid & McNair 2004, Rees et al. 2007, Reid & McNair 2011). In the study by Rees et al. (2007) muscle activation during measurement wasn't monitored, which could have affected the results. In addition the stretching method used during intervention included muscle contraction, which could have led to increases in stiffness.

In the studies of Reid and McNair (2004, 2011) muscle activity was monitored and static stretching was used and still significant increases in stiffness in the final 10% of the ROM (mean change 0.22 Nm/deg, 95% CI 0.06 to 0.35) were observed. Due to changes in stiffness Reid and McNair (2011) expressed some speculations of possible architectural changes being behind the increase in the knee extension ROM (mean change (95% CI) 7.7° (2.6 to 12.7°). However, Reid and McNair (2012) measured stiffness in the final 10% of the ROM, which means that the stiffness was measured during different joint angles in the pre- and post-intervention measurements. Thus, the increase in stiffness in the studies of Reid and McNair (2004, 2011) might merely demonstrate that the muscle stiffness was higher at the new end range of the motion, which was achieved most likely because of increased stretch tolerance. In the studies where stiffness was measured using constant joint angles, for example in the study by LaRoche & Connolly (2006) 50-85° hip flexion was used, no significant changes were found in stiffness (Halbertsma & Göeken 1994, LaRoche & Connolly 2006).

In a quite recent study by Ben and Harvey (2010) ROM was tested with and without standardized torque after six weeks of static hamstring stretching by comparing experimental leg to control leg. They found that ROM increased when standardized torque wasn't used (mean treatment effect -10º; 95% CI 6 to 14º) without difference in pain intensity between legs, but didn't when standardized torque was applied (mean treatment effect -1º; 95% CI -3 to 2º). Reid and McNair (2011) found also significant increases in ROM without standard torque and with a standard torque (50% of pretest maximal torque) significant decreases were found. However these changes didn't differ from the control group. In the opinion of Ben & Harvey (2010) these results support the hypotheses that stretching improves stretch tolerance.

Guissard & Duchateau (2004) also found significant decreases in H reflex, which may be used as an approximate measure of motor neuron pool excitability (Enoka 2002, 300). They also found significant decreases in tendon tap reflex, which illustrates muscle spindle responsiveness (Enoka 2002, 299-300). No significant changes were found in control leg. The results by Guissard & Duchateau (2004) suggest that neural changes also might contribute to chronic changes in ROM after stretching intervention.

Ben and Harvey (2010) compared the control leg also to a control group and found no significant difference between the control leg and control group in passive hip flexion angle with or without standardized torque which can be interpreted as no cross training effect was induced by stretching. However according to Nelson and colleagues (2012) stretching might have a cross training effect. They observed no significant changes in control group and significant increases in flexibility in experimental leg (+8%) and in control leg. Notwithstanding, this result presented by Nelson and colleagues (2012) should be interpreted with caution as they only found 1% (62.3° ± 7.3 to 61.8° ± 8.1) increase in the control leg. In addition, several other studies used contralateral leg as control (Handel et al. 1997, Guissard & Duchateau 2004, Ross 2007, Ylinen et al. 2009) and found no significant changes in control leg between pre- and post-tests, though the results were not compared to any control groups.

4.3.2 Chronic effects on strength, power and walking ability

The effect of long-term muscle stretching exercises on muscle strength or power hasn't been quite as thoroughly studied as the effect on muscle flexibility (appendix 2). The results are inconsistent, still none of the studies found stretching to have detrimental effects on tested strength performance variables (Handel et al. 1997, Hunter & Marshall 2002, Guissard & Duchateau 2004, Woolstenhulme et al. 2006, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007, Bazett-Jones et al. 2008, LaRoche et al. 2008, Stanziano et al. 2009, Ylinen et al. 2009, Yuktasir & Kaya 2009, Marshall et al. 2011, Nelson et al. 2012).

Several studies investigating the effect of long-term stretching on muscle strength were not able to find significant effects (Guissard & Duchateau 2004, LaRoche et al. 2008, Ylinen et al. 2009, Marshall et al. 2011). Even so several studies found statistically significant increases in strength in plantar flexors, knee extensors and flexors after stretching intervention, without significant changes in control groups (Handel et al. 1997, Rees et al. 2007, Kokkonen et al. 2007, Nelson et al. 2012). Rees et al. (2007) observed up to 26% ($p<.001$) increase in maximal isometric force of plantar flexors after CRAC-PNF stretching, compared to pre intervention and to control group (+2%, $p>0.05$). However these increases in strength might not be because of the stretching itself but due to isometric contraction of the stretched muscles during the CRAC-PNF stretching. This hypothesis is supported by the fact that Rees et al.

(2007) observed a significant increase in MTU stiffness. Also Handel et al. (1997), who used CR-PNF method, observed significant increases (+0.8cm) over pre-score in tight circumference after intervention, with no changes in controls. In addition, the studies, in which no significant changes were found, used static stretching method (Guissard & Duchateau 2004, LaRoche 2008, Ylinen et al. 2009, Marshall et al. 2011).

Nevertheless, Kokkonen et al. (2007) and Nelson et al. (2012) used passive static stretching and still significant increases in strength were observed in stretching groups when compared to pre-score. No significant changes in control groups were found. The total stretching time per muscle group varied from 2.25 minutes a week for 10 weeks (Kokkonen et al. 2007) to 6 minutes a week for 10 weeks (Nelson et al. 2012). Nelson and colleagues (2012) for example observed a significant (+29%, approx. 100N) increase in maximal ankle plantar flexion strength in leg that was stretched. The total stretching time per muscle group, the intensity of stretching exercises or the target of stretching doesn’t seem to explain the difference between the studies that found significant strength increases and those that didn’t. Neither does the age nor activity status of the participants, as they are fairly similar.

Interestingly Nelson and colleagues (2012) they found also a significant increase over pre-score (+11%, p<05) in strength in the control leg and no significant changes in the actual control group. According to Nelson et al. (2012) this indicates a cross-training effect, but it should be noted that the stretching of the experimental leg was conducted in standing position control leg as supportive leg. This could have led to the strength gains observed, without actual cross-training effect.

The results on explosive muscle power are also conflicting some studies finding significant changes (Handel et al. 1997, Hunter & Marshall 2002, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007) whereas some studies not (Guissard & Duchateau 2004, Woolstenhulme et al. 2006, Bazett-Jones et al. 2008, LaRoche et al. 2008, Yuktasir & Kaya 2009). Rees et al. (2007) found significant increases in rate of torque development (RTD) in plantar flexors after 4 weeks intervention of CRAC-PNF stretching when compared to controls and to pre-test. LaRoche et al. (2008) and Guissard & Duchateau (2004) however didn't find significant changes in the RTD of the hip extensors or plantar flexors in any of the groups after 4 and 6 weeks interventions with passive and ballistic stretching. Even though the total stretching time a week per muscle group was higher in the studies by LaRoche et al. (2008) and Guissard & Duchateau (2004) (15 min and 12.5 min) with no relevant differences in exercise numbers or target muscles. Thus, it seems that the muscle contraction in the CRAC-PNF stretching might be behind the performance enhancements in this case.

None of the studies testing drop jump, didn't find significant changes in jump performance (Hunter & Marshall 2002, Yuktasir & Kaya 2009), yet changes were found in other jumping tests after stretching. Significant increases were found in counter movement jump (Hunter & Marshall 2002), single leg jump (Kokkonen et al. 2007, Ross 2007) and in vertical jump (Kokkonen et al. 2007). Bazett-Jones et al. (2008) and Woolstenhulme et al. (2006) used also vertical jump test but no significant changes were found. The total stretching time per week differed between studies that found significant changes (17.5 to 72 minutes a week) (Hunter & Marshall 2002, Kokkonen et al. 2007, Ross 2007) and those who didn't (8 to 12 minutes a week)(Woolstenhulme et al. 2006, Bazett-Jones et al. 2008). Also in the studies by Hunter and Marshall (2002) and Kokkonen et al. (2007) all the major lower limb muscles were stretched, when in the interventions of Bazett-Jones et al. (2008) and Woolstenhulme et al. (2006) only 3 muscles or less were stretched.

Two studies also studied the effect of stretching exercises on sprint time. Kokkonen et al. (2007) found a significant decrease in 20-m sprint time between pre- and post-tests when stretching group decreased their time by 1.4% (approx. -0.05 sec, p<.05) and control group increased their time by non-significant 1.4% (approx. 0.05 sec, p>.05). Bazett-Jones et al. (2008) found a non-significant 0.09 second mean difference (-1%) between pre- and post-tests in stretching group and -0.06 second (-0.7%) in control group in 55-m sprint test. Thus, no conclusions can be drawn from these results, as the changes in control groups were nearly the same as in the stretching groups. Nevertheless, it seems that long-term stretching induces no deleterious effects on sprint performance.

The participants in most of the studies reviewing the effects of stretching on muscle performance are around 30 years or younger with the exception of Stanziano et al. (2009). They studied the effects of 8 weeks stretching intervention on muscle strength, muscle endurance, power and flexibility in elderly participants (88.7 ± 5.4 yrs) with relatively functional tests. Stanziano et al. (2009) found statistically significant improvements in nearly all of the measures. Significant changes were found also in the control group in the strength measures, but not in flexibility tests. Thus, the effect of stretching on muscle performance in the elderly population stays open to debate, but flexibility seems to increase. The age-induced changes e.g. decrease in passive resistive torque and muscle stiffness during the last half of the available ROM (Gajdosik et al. 1999), doesn't seem to affect the mechanism behind the flexibility enhancements.

Only few RCT studies that measured cardiorespiratory fitness were found in the systematic literature search. Nelson et al. (2001) measured VO_{2max} and Kokkonen et al. (2007) measured VO_{2peak} mainly to check that the physical activity levels had stayed constant during the intervention. Even though, neither of the studies found any significant changes. Gleim et al. (1990) investigated the association of clinical measures of flexibility to the economy of walking and jogging. The flexibility of the subjects was tested and tree groups were formed: “tight”, “normal” and “loose”. Gleim et al. (1990) concluded that subjects who were tight consumed oxygen the least, during steady-state walking and running on a treadmill.

Walking performance was studied in few studies investigating the effect of stretching on gait speed and other gait variables in elderly. A significant increase in comfortable/self-chosen gait speed (Christiansen 2008, Stanziano et al. 2009, Watt et al. 2011) or at least improvements in gait variables (e.g. step length, double support duration) resulting in faster walking speed (Cristopolski 2009) were found, without significant changes in controls. No significant changes were found, when tested with fast speed (Watt et al. 2011).

4.4 Summary

In summary, pre-event static stretching causes stretch-induced strength loss, increases in flexibility and has also been found to induce changes in viscoelastic properties of the muscle. However, these changes, induced by pre-event stretching, are transient in time.

The effects of long-term stretching on physical performance are more ambiguous. According to randomized controlled studies long-term stretching can improve flexibility, but there is no consensus concerning the mechanism behind the increases. According to some studies long-term stretching increases subjective stretch tolerance, but some studies have been able to demonstrate viscoelastic changes.

Several randomized controlled studies have found improvements in muscular performance after stretching interventions, without significant changes in controls. However, also several studies were not able to find significant effects on strength performance. Long-term stretching doesn’t seem to have detrimental effects on strength, at least according to existing scientific evidence. There is also some evidence that long-term stretching might have some effect on walking ability, however more randomized controlled trials are needed.

5 PURPOSE OF THE STUDY

The purpose of the present study was to investigate the association between regular stretching and physical performance.

Research question:

- *Is there an association between stretching and physical performance?*

6 METHODS

6.1 Study protocol

This study was conducted as a cross-sectional analysis, which used data collected already in 1992-1993 for a larger study at the UKK institute. The original study subjects were randomly selected from middle-aged adults who had previously attended preventive health examinations for all Tampere city residents. The study consisted of five different age frames (37, 42, 47, 52 and 57 yrs old at the time of the study) (Suni et al. 1998).

The study subjects answered questionnaire on self-rated health, leisure time physical activity (LTPA) and other living habits. Also standard pretest health screening was conducted (Suni et al. 1999).

6.2 Subjects

From the 499 subjects who participated in the fitness tests in 1993, eventually 455 subjects (91%) (225 men and 230 women) were included in this study. Those subjects who according to leisure time physical activity (LPTA) questionnaire did not report weekly physical activity were excluded as well as those who didn’t answer the questionnaire.

The participants were divided into somewhat active and active groups according to their overall physical activity (PA) level. Subjects fell into the active group if they performed with brisk intensity daily cycling 20 minutes or more or daily walking distance was at least 6 km. Subjects fell into the active group also if they reported to do brisk or strenuous activity at least 2 times a week and at least one of the following: a) performed at least 75 minutes a week of some kind of neuromuscular training (gym, games or downhill skiing) or b) at least 75 minutes/week of aerobic training, or c) daily walking distance at least 3km or d) daily cycling time at least 20 min. Rest of the subjects fell into “somewhat active” -group, which means that they were physically active at least once a week, but didn’t meet the criterion, i.e. the amount or the intensity requirements, of the active group.

In addition, the participants were designed into stretching or non-stretching sub-groups. The stretching sub-group included subjects who reported regular stretching before, during or after exercise (n=203). Those who answered negatively fell into the non-stretching sub-group (n=252) as well as those who had left the answer blank (n=4). It should be noted that regular stretching isn’t a synonym for long-term stretching in this study, as it is not known how long the participants in the stretching group have been stretching. The stretching sub-groups are exclusive of each other as well as physical activity level groups. The background characteristics are presented in table 1 as a percent value out of the stretching and non-stretching sub-groups.

6.3 Leisure time physical activity questionnaire

LTPA questionnaire was self-administered and consisted of questions referring to leisure-time exercise and active transportation. Questions on physical activity included the intensity, frequency, duration and mode. Questions on active transportation, in terms of daily walking and cycling, regarded mainly duration and distance (Suni et al. 1999). The physical activity habits of the subjects are presented in table 2.

6.4 Physical performance tests

The test battery was originally developed to be a tool for health enhancing physical activity (PA) promotion. The battery includes motor, musculoskeletal, cardiorespiratory fitness and body composition aspects (Suni et al. 1996). As described previously in more detail by Suni et al. (1996) the measurements took place in two occasions. In the first session standard pretest health screening (incl. sociodemographic background factors, BMI and blood pressure measurement) took place. The second session included the health related fitness (HRF) assessment, where tests were conducted to each subject individually in a standard order.

Cardiorespiratory fitness

Cardiorespiratory fitness and walking ability (min) was tested with UKK 2-km walk test. Subject walks as fast as possible for 2 km on flat surface using normal walking style. The outcome of the test is time (min). Physical activity related validity was demonstrated by 2-km walk in both men and women (Suni et al. 1999).

Hamstring extensibility

The hamstring extensibility was tested with active knee extension range of motion (AKET). The subject lays supine, the hip and the knee are flexed to 90° degrees as the opposite leg rests extended. The inclinometer was attached to the medial side of the ankle of the limb to be measured and the tester supported the position of the knee. The subjects actively extended their knee, keeping their buttock in touch with a bench. The test outcome is the end point ROM angle in degrees at maximal active extension (Suni et al. 1996). When using strict body stabilization, a well-defined and easily observed end point of motion, as well as precise instrument placement the Pearson reliability coefficient of AKET is 0.99, according to Gajdosik and Lusin (1983).

Trunk lateral flexion

Trunk side bending test was used to test trunk flexibility by measuring the total range of movement of lateral flexion of the thoracic and lumbar spine and pelvis. Position for each foot was marked on the floor 15 cm apart. Subjects stood on the marks, with their back and their buttocks, scapula and head touching the wall. Arms were straight beside the body and the site of the middle finger was marked on the lateral tight in the upright position for both sides as well as at the end of the test movement (lateral flexion). Rotation of trunk or movement from pelvis or heels wasn't permitted and the back, scapulae, head and buttocks needed to stay in contact with the wall during the test movement. The subjects were supposed to bend as far as possible sliding the middle finger along their lateral tight.

The lateral flexion was first done to right and then to left. The test score was the distance the fingertip moved down the leg during maximum lateral bending. A cloth tape was used to measure the distance between the fingertip mark of the starting position and the fingertip in the maximal lateral flexion position. The results were recorded for both sides, added together and averaged for the mean side-bending score in millimeters (Suni et al. 1996). The inter-rater reliability of trunk lateral flexion was high (ICC 0.92, standard error of measurement (SEM) 1.4cm and the CV of reproducibility 4.7%) as reported by Suni and colleagues (1996).

Lower extremity extensor strength

The one-leg squat test was used to test lower extremity extensor strength and the test started without external weight. External load with a weight belt was added at each successive step, first 10% of body weight increasing up to 40%. The test ended when the subjects felt they could not step with any more weight. The subjects were instructed to take a short step forward on the mat, squat down with a straight back until their left knee lightly touched the mat and then raise up immediately to the starting position. The squat was performed first with right leg and then repeated with the left leg. Results for the right and left sides were added together.

The load limits for a successful one-leg squat were: 1 = able to perform squat with two legs; 2 = able to perform one-leg squat with body weight; 3 = able to perform one-leg squat with an extra load of 10% of body weight; 4 = able to perform one-leg squat with an extra load of 20% of body weight; 5 = able to perform one-leg squat with an extra load of 30% of body weight; 6 = able to perform one-leg squat with an extra load of 40% of body weight (Suni et al. 1996). The inter-rater reliability (ICC) of one-leg squat was 0.86, SEM 0.9 points and CV for reproducibility 12.1%, as reported by Suni et al. (1996).

Leg extensor power

Jump-and-reach test was used to test musculoskeletal fitness, lower extremity function and leg extensor power. Subjects stood next to the jump-and-reach board facing forward. Before jumping, the standing height was marked with magnesium-powdered middle finger of the dominant arm by raising it straight up as high as possible. One practice jump was allowed and the subjects were instructed to jump as high as possible and to swing their arms to enhance the performance. The subjects were advised to touch the board with their middle finger while at the highest position. In preparation for the jump flexion in the knees was allowed, but feet had to stay in place. The difference between the standing reach height and the jump reach height was measured in centimeters with a tape measure. Two test jumps were performed and the best result was recorded (Suni et al. 1996). Jump-and-reach test can also be called vertical jump test (McArdle et al. 2007, 384). The inter-rater reliability (ICC) of jump-and-reach was 0.98, SEM 3.0 cm and CV for reproducibility was 2.4%, as reported by Suni et al. (1996).

Upper limb musculoskeletal fitness

Modified push-up test was used to test dynamic upper-body endurance strength of extensor muscles and ability to stabilize the trunk. The subjects lay prone on a mat. First they clapped their hands behind their back, then performed a normal straight-leg push-up by extending the elbows straight. In the up position they touched with one hand the top of the supporting hand. The push-up cycle ended in the prone lying position. One push-up cycle was practiced before actual test. The subjects were instructed to do as many push-ups as possible in 40 seconds. The number of push-ups completed in 40 seconds was counted (Suni et al. 1996). The inter-rater reliability (ICC) of modified push-up test is 0.88 SEM 2.6 repetitions, and test-retest reproducibility (CV) 0.6%, as reported by Suni et al. (1996).

6.5 Statistical analysis

Statistical analyses were performed using PASW Statistics 18.0 (IBM Corp., Somers, NY). Statistical significance of differences in background and PA characteristics between non-stretching and stretching sub-groups was analyzed with Chi^2 test and t-test. Also descriptive tables and crosstabs were used to illustrate differences between groups.

The differences in selected fitness tests results between different PA and stretching groups were compared with ANCOVA. The data didn't cover all the baseline assumptions for ANCOVA use, but because the sample size was big enough, this was considered acceptable. The level of significance was set at $p<.05$ (95% CI) and Sidak was used in confidence interval adjustment. Sex, age, civil status, education, smoking, physical effort in occupation, waist circumference and frequency were used as covariates to manage their influence on results. Interactions of sex and age were considered in the analysis, but only in one-leg squat interaction was found ($p<.02$).

7 RESULTS

Regarding background characteristics no significant differences were found between the non-stretching and stretching sub-groups within somewhat active or active subjects (Table 1). However, significant differences were found between the non-stretching and stretching sub-groups in their physical activity habits. In general the subjects in the stretching sub-groups did exercise more often, with longer exercise duration and with higher intensity than the subjects in the non-stretching sub-groups. The description of physical activity of the study subjects can be seen in table 2.

Table 1. Background characteristics of the study subjects (n=455) in stretching sub-groups and PA groups. Values are presented in % within sub-group (n).

	Stretching - Physical activity groups											
Background characteristics	**Non-stretching - Somewhat active[2]**			**Stretching - Somewhat active[2]**			**Non- stretching – Active[1]**			**Stretching – Active[1]**		
	Men	Women	**Total**	Men	Women	**Total**	Men	Women	**Total**	Men	Women	**Total**
Sex	52 % (71)	48 % (65)	**100 % (136)**	39 % (29)	61 % (46)	**100 % (75)**	47 % (54)	53 % (62)	**100 % (116)**	55 % (71)	45 % (57)	**100% (128)**
Age group												
37 yrs	13 % (18)	10 % (14)	**24 % (32)**	1 % (1)	20 % (15)	**21 % (16)**	9 % (10)	6 % (7)	**15 % (17)**	14 % (18)	11 % (14)	**25 % (32)**
42 yrs	8 % (11)	7 % (10)	**15 % (21)**	11 % (8)	11 % (8)	**21 % (16)**	7 % (8)	10 % (12)	**17 % (20)**	10 % (13)	11 % (14)	**21 % (27)**
47 yrs	11 % (15)	9 % (12)	**20 % (27)**	9 % (7)	9 % (7)	**19 % (14)**	10 % (12)	17 % (20)	**28 % (32)**	10 % (13)	6 % (8)	**16 % (21)**
52 yrs	8 % (11)	13 % (18)	**21 % (29)**	8 % (6)	5 % (4)	**13 % (10)**	10 % (12)	10 % (12)	**21 % (24)**	11 % (14)	5 % (7)	**16 % (21)**
57 yrs	12 % (16)	8 % (11)	**20 % (27)**	9 % (7)	16 % (12)	**25 % (19)**	10 % (12)	9 % (11)	**20 % (23)**	10 % (13)	11 % (14)	**21 % (27)**
BMI[4]												
<18.5	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**
18.5–24.9	18 % (25)	20 % (27)	**38 % (52)**	15 % (11)	32 % (24)	**47 % (35)**	23 % (27)	28 % (33)	**52 % (60)**	29 % (37)	29 % (37)	**58 % (74)**
25.0–29.9	24 % (33)	18 % (24)	**42 % (57)**	23 % (17)	19 % (14)	**41 % (31)**	16 % (18)	21 % (24)	**36 % (42)**	21 % (27)	13 % (16)	**34 % (43)**
30.0–34.9	7 % (9)	9 % (12)	**15 % (21)**	1 % (1)	7 % (5)	**8 % (6)**	5 % (6)	3 % (3)	**8 % (9)**	4 % (5)	2 % (3)	**6 % (8)**
35.0–39.9	1 % (2)	1 % (1)	**2 % (3)**	0 % (0)	3 % (2)	**3 % (2)**	3 % (3)	1 % (1)	**3 % (4)**	2 % (2)	0 % (0)	**2 % (2)**
> 40.0	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**	0 % (0)	0 % (0)	**0 % (0)**
Marital status												
Single[3a]	7 % (9)	9 % (12)	**15 % (21)**	4 % (3)	20 % (15)	**24 % (18)**	10 % (12)	11 % (13)	**22 % (25)**	10 % (13)	9 % (12)	**20 % (25)**
In relationship[3b]	46 % (62)	39 % (53)	**85 % (115)**	35 % (26)	41 % (31)	**76 % (57)**	36 % (42)	42 % (49)	**78 % (91)**	45 % (58)	35 % (45)	**80 % (103)**
Educational level[5]												
Low	46 % (63)	36 % (49)	**82 % (112)**	28 % (21)	44 % (33)	**72 % (54)**	39 % (45)	45 % (52)	**84 % (97)**	43 % (55)	32 % (41)	**75 % (96)**
High	6 % (8)	12 % (16)	**18 % (24)**	11 % (8)	17 % (13)	**28 % (21)**	8 % (9)	9 % (10)	**16 % (19)**	12 % (15)	13 % (16)	**24 % (31)**
Smoking status												
Non-Smoker	35 % (47)	43 % (58)	**77 % (105)**	25 % (19)	49 % (37)	**75 % (56)**	31 % (36)	45 % (52)	**76 % (88)**	40 % (51)	38 % (49)	**78 % (100)**
Smoker	18 % (24)	5 % (7)	**23 % (31)**	13 % (10)	12 % (9)	**25 % (19)**	16 % (18)	8 % (9)	**23 % (27)**	16 % (20)	6 % (8)	**22 % (28)**
Occupational physical activity[6]												
Light	15 % (21)	14 % (19)	**29 % (40)**	20 % (15)	20 % (15)	**40 % (30)**	11 % (13)	20 % (23)	**31 % (36)**	22 % (28)	17 % (22)	**39 % (50)**
Moderate	32 % (44)	34 % (46)	**66 % (90)**	15 % (11)	40 % (30)	**55 % (41)**	27 % (31)	32 % (37)	**59 % (68)**	25 % (32)	26 % (33)	**51 % (65)**
Heavy	4 % (6)	0 % (0)	**4 % (6)**	4 % (3)	1 % (1)	**5 % (4)**	9 % (10)	2 % (2)	**10 % (12)**	9 % (11)	2 % (2)	**10 % (13)**

1) Active: daily cycling 20 minutes or more or daily walking distance was at least 6 km with brisk/strenuous intensity OR brisk/strenuous activity at least 2 times a week and at least one of the following: a) performed at least 75 minutes a week of some kind of neuromuscular training (gym, games or downhill skiing) or b) at least 75 minutes/week of aerobic training, or c) daily walking distance at least 3km or d) daily cycling time at least 20 min.

2) Somewhat active: Physically active at least 1x week, but less than active[1]

3) a: Single, separated, divorced or widowed. 3)b: married or cohabiting.

4)<18.5 underweight, 18.5–24.9 normal weight, 25.0–29.9 overweight, 30.0–34.9 obesity, 35.0–39.9 difficult obesity, >40 morbid obesity.

5) Low= secondary school, High=high school graduate or vocational training, university/university of applied sciences.

6) Light=sitting job, Moderate=standing job, light moving job or not working, heavy=heavy physical job.

More specifically, within somewhat active subjects statistically significant differences between the non-stretching and stretching sub-groups were found in frequency (p<.001), duration (p<.001), and intensity (p<.001) of exercise and in neuromuscular training (0<.02). Within active subjects significant differences between the non-stretching and stretching sub-groups were found in exercise intensity (p<.001), frequency (p<.001), daily walking distance (p<.05) and in neuromuscular training (p<.001).

Table 2. Physical activity (PA) in the stretching sub-groups and physical activity groups. Values are presented in % within sub-group (n)[4].

		Stretching - Physical activity groups				**Chi2[4]**
Type of physical activity		Non-stretching – Somewhat active[2]	Stretching – Somewhat active[2]	Non- stretching – Active[1]	Stretching – Active[1]	Pearson sig.
Exercise for health and fitness						
Frequency	< 1/wk	46 % (62)	16 % (12)	19 % (22)	3 % (4)	.000
	approx. 1/wk	25 % (34)	40 % (30)	13 % (15)	10 % (13)	
	approx. 2/wk	23 % (31)	28 % (21)	26 % (30)	36 % (46)	
	approx. 3/wk or more	7 % (9)	16 % (12)	42 % (48)	51 % (65)	
Duration	<20min	29 % (40)	5 % (4)	7 % (8)	2 % (2)	.000
	20-40 min	51 % (69)	57 % (43)	46 % (53)	40 % (51)	
	> 40 min	20 % (27)	37 % (28)	47 % (55)	59 % (75)	
Intensity	Light	68 % (92)	31 % (23)	16 % (18)	5 % (6)	.000
	Brisk	31 % (42)	57 % (43)	78 % (90)	72 % (92)	
	Strenuous	2 % (2)	12 % (9)	7 % (8)	23 % (30)	
Type of exercise						
Aerobic	Somewhat active[3b]	62 % (84)	48 % (36)	14 % (16)	11 % (14)	.000
	Active[3a]	38 % (52)	52 % (39)	86 % (100)	89 % (114)	
Neuromuscular	Somewhat active	95 % (129)	83 % (62)	85 % (98)	51 % (65)	.000
	Active	5 % (7)	17 % (13)	16 % (18)	49 % (63)	
Commuting						
Daily walking distance (km)	<1 km	14 % (19)	15 % (11)	6 % (7)	7 % (9)	.000
	1-2 km	40 % (54)	48 % (36)	11 % (13)	21 % (27)	
	3-5 km	41 % (55)	33 % (25)	45 % (52)	40 % (51)	
	>=6 km	5 % (7)	4 % (3)	37 % (43)	32 % (41)	
Daily cycling time (min)	<20 min	94 % (128)	100 % (75)	69 % (80)	74 % (95)	.000
	> 20 min	6 % (8)	0 % (0)	31 % (36)	26 % (33)	

1) Daily cycling 20 minutes or more or daily walking distance was at least 6 km with brisk/strenuous intensity OR brisk/strenuous activity at least 2 times a week and at least one of the following: a) performed at least 75 minutes a week of some kind of neuromuscular training (gym, games or downhill skiing) or b) at least 75 minutes/week of aerobic training, or c) daily walking distance at least 3km or d) daily cycling time at least 20 min.

2) Physically active at least 1x week, but less than active[1]

3a) min 75min/week,

3b) less than 75 min/week

4) Between. **all** groups

Flexibility

In *average trunk side bending*, the mean difference between the non-stretching and stretching subgroups was not statistically significant in the somewhat active group or in the active group. The mean lateral flexion (cm) of the sub-groups is shown in figure 1 (A).

In hamstring extensibility, the mean difference between the non-stretching and stretching sub groups was not statistically significant in the somewhat active nor in the active group. The mean hamstring flexibility (°) of the sub-groups is shown in figure 1 (B). Table 3 shows the mean difference and statistical significance between the non-stretching and stretching sub-groups in the somewhat active and active groups. The mean differences between active and somewhat active subjects are presented in appendix 3.

Table 3. The mean difference (95%CI) between the non-stretching and stretching sub-groups.

Physical activity	**Somewhat active**[2]			**Active**[1]		
	Stretching - Non-stretching			**Stretching - Non-stretching**		
	MD	(95% CI)	p	MD	(95% CI)	p
Performance tests						
Flexibility						
Avg. lateral flexion (cm)	0.3	-1.1 to 1.6	.997	0.7	-0.5 to 1.9	.545
Hamstring (°)	3.0	-0.8 to 6.9	.202	2.9	-0.5 to 6.2	.145
Muscular performance						
One-leg squat (points)	0.4	-0.3 to 1.1	.482	0.6	0.0 to 1.2	.083
Modified push-up (reps)	1.5	0.1 to 2.8	**.023**	1.3	0.1 to 2.4	**.022**
Jump-and-reach (cm)	2.7	0.5 to 4.9	**.008**	1.5	-0.5 to 3.5	.244
Walking performance						
UKK 2-km walk (min)	-0.75	-1.32 to -0.17	**.004**	-0.37	-0.87 to 0.13	.281

1) Active: daily cycling 20 minutes or more or daily walking distance was at least 6 km with brisk/strenuous intensity OR brisk/strenuous activity at least 2 times a week and at least one of the following: a) performed at least 75 minutes a week of some kind of neuromuscular training (gym, games or downhill skiing) or b) at least 75 minutes/week of aerobic training, or c) daily walking distance at least 3km or d) daily cycling time at least 20 min.

2) Physically active at least 1x week, but less than active[1]

Muscle performance

In the *modified push-up*, within the active and somewhat active groups the stretching sub-groups had significantly better performance (more repetitions) than the non-stretching groups. The mean push-up repetitions of the sub-groups are shown in figure 1 (C).

In the *one-leg squat*, the mean difference between the non-stretching and stretching sub groups was not statistically significant in the somewhat active nor in the active group. The mean squat repetitions of the sub-groups are shown in figure 1 (D).

In the *jump-and-reach test*, the mean difference between the non-stretching and stretching sub-groups was not statistically significant in the active group. Within the somewhat active group the stretching sub-group jumped significantly higher, than the non-stretching sub-group. The mean jump heights (cm) of the sub-groups are shown in figure 1 (E).

Cardiorespiratory fitness

In the *UKK 2-km walk test*, the mean difference between the non-stretching and stretching sub-groups was not statistically significant in the active group. Within the somewhat active group the stretching sub-group had significantly faster walking time (better performance) than the non-stretching sub-group. The mean walk time (min) of the sub-groups is shown in figure 1 (F).

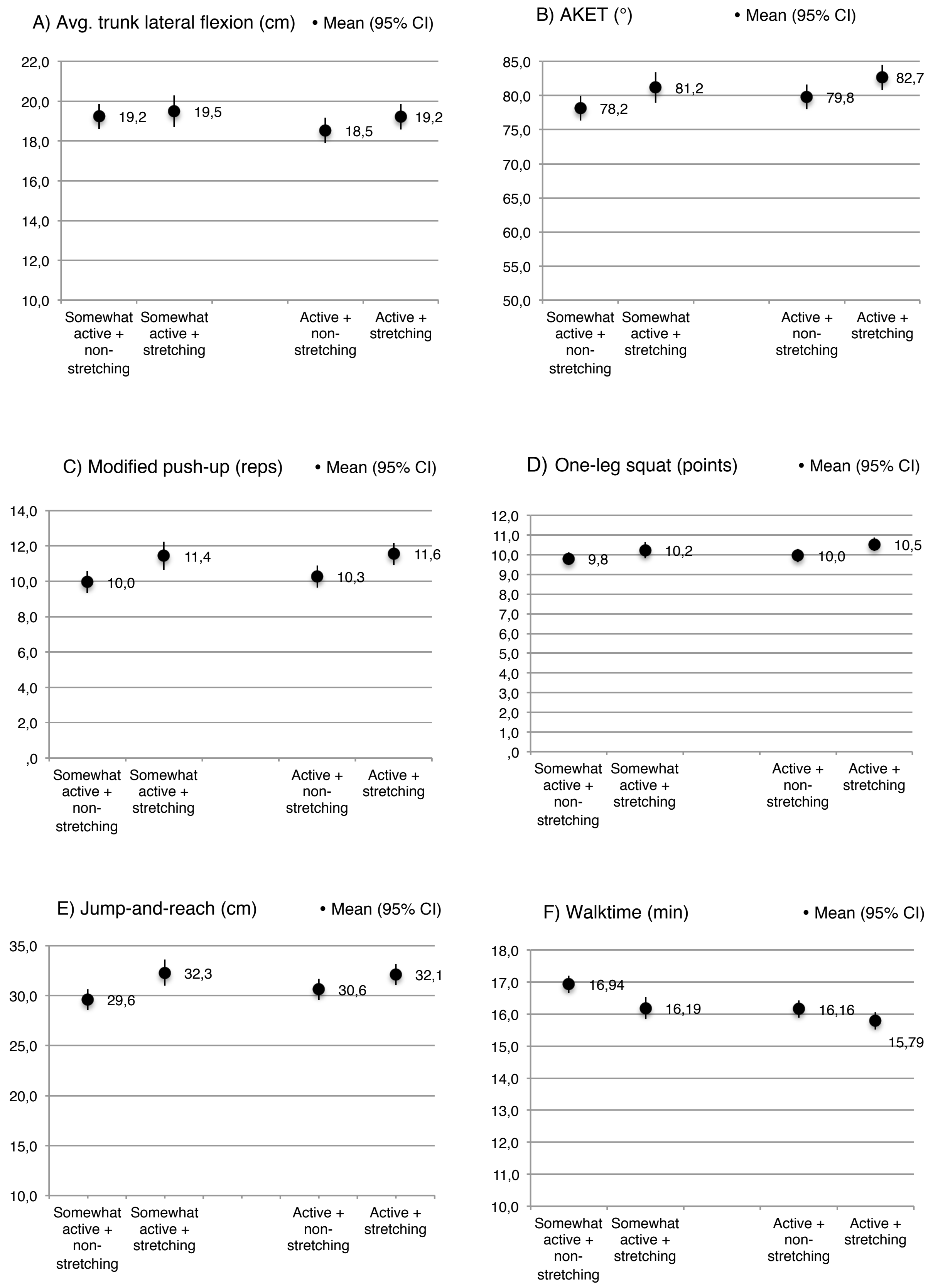

Figure 1. Results of the physical performance tests (mean with 95% CI) presented in the stretching and non-stretching sub-groups in the active and somewhat active groups. A) Average trunk lateral flexion, B) Active knee extension, C) Modified push-up, D) One-leg squat, E) Jump-and-reach, F) Walktime

8 DISCUSSION

The most important target of interest of this cross-sectional study was to determine whether somewhat active or active middle-aged adults who stretch regularly have better physical performance when comparing to subjects that do not stretch. In general the present cross-sectional results showed a trend favoring stretching as a part of physical activity regimen. Nevertheless, significant associations between stretching and physical performance were found only in few performance measures. Stretching didn't seem to have a detrimental association with any of the physical performance tests.

8.1 Flexibility

In this cross-sectional study the results from two flexibility tests were in unity and no association between muscle stretching exercises and flexibility was found. This is controversial with previous RCTs that have shown that by long-term stretching flexibility (e.g. extensibility, ROM) can be increased, without significant changes in controls (Halbertsma & Göeken 1994, Bandy et al. 1997, Handel et al. 1997, Chan et al. 2001, Nelson et al. 2001, Guissard & Duchateau 2004, Reid & McNair 2004, LaRoche & Connolly 2006, Woolstenhulme et al. 2006, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007, Christiansen 2008, Cristopoliski et al. 2009, Fasen et al. 2009, Ylinen et al. 2009, Yuktasir & Kaya 2009, Ayala & Sainz de Baranda 2010, Ben & Harvey 2010, Covert et al. 2010, Marshall et al. 2011, Reid & McNair 2011, Watt et al. 2011, Nelson et al. 2012).

There are several reasons that could be the explanation why stretching didn't have additional benefit on top of physical activity in flexibility measures in this study. It is possible that the participants of this study do not do stretching frequently enough. The result might also be due to improper stretching technique or different targets of stretching, than what was measured. None of these factors could be standardized, as they were not asked in the LTPA questionnaire.

It could also be speculated that the difference in mean age of participants in this current study and in the before mentioned studies could at least partly explain the discrepancy between the results. However, in the study by Christiansen (2008), Watt et al. (2011) and Cristopoliski et al. (2009) the participants were 65 years or older and still had significant changes in ROM, so the age difference explanation is unlikely.

After an acute bout of stretching, transient changes in material properties of muscle in human tissues has been demonstrated (Magnusson et al. 1996b, Kubo et al. 2001, Mizuno et al. 2011) and some indications of changes have been observed also after long-term stretching (Guissard & Duchateau 2004, Mahieu et al. 2007, Marshall et al. 2011). That being said, several studies also support the hypothesis of increased subjective stretch tolerance as the reason behind the increases in ROM (Magnusson et al. 1996a, Chan et al. 2001, LaRoche & Connolly 2006, Ylinen et al. 2009, Ben & Harvey 2010, Weppler & Magnusson 2010, Reid & McNair 2011). Therefore it could be speculated that the stretching interventions have increased the ROM, because the participants have expected it to happen after stretching. However, in this cross-sectional study this plausible effect of stretch tolerance didn’t exist due to the design of the study and perhaps that’s why no differences were observed between the stretching and non-stretching sub-groups.

It has also been hypothesized that static stretching may have inadequate effect on dynamic range of motion (Siff 2000, 134). In this study the hamstring extensibility was tested with AKET, so if it´s assumed that static stretching is the most common stretching technique in the non-athletic middle-aged population, the hypothesis presented by Siff (2000, 134) might explain at least partly the results of this study. With that being said, Ross (2007) was able to find significantly greater increase in AKET in experimental leg than in control leg after intervention of passive static hamstring stretching. It should be noted that in the study by Ross (2007) the subjects had tight hamstrings and the effect of stretching might be greater in tight muscles. In addition, lateral flexion test might also strain other tissue more than the MTU complex itself and therefore the association of stretching and physical activity is small.

The results of this study indicate that stretching most likely doesn’t offer any additional benefit in flexibility measures on top of regular physical activity. This result is supported by several studies investigating and comparing the effect of stretching and other physical activities on flexibility. For instance, Woolstenhulme et al. (2008) demonstrated that by sprint training the flexibility could be increased to the same extent as with stretching exercises. It has also been observed that with resistance training independently or combined with stretching or with cardiovascular training (jogging or walking), the flexibility can be increased to the same extent as with stretching independently (Fatouros et al. 2002, Morton et al. 2011, Simaõ et al. 2011).

8.2 Muscular performance

The results of this study indicate that there might be an association between stretching and upper limb endurance strength in active and somewhat active subjects and in lower-limb power in somewhat active subjects. These observations are supported by few RCT studies that investigated the effects of long-term stretching on *strength* (Handel et al. 1997, Rees et al. 2007, Kokkonen et al. 2007, Stanziano et al. 2009, Nelson et al. 2012), *power* (Handel et al. 1997, Hunter & Marshall 2002, Kokkonen et al. 2007, Rees et al. 2007, Ross 2007, Stanziano et al. 2009) and *muscular endurance* (Handel et al. 1997, Kokkonen et al. 2007, Rees et al. 2007, Stanziano et al. 2009, Hunter & Marshall 2002, Ross et al. 2007). It should also be noted that there are also several studies were no such effect was found (Guissard & Duchateau 2004, Woolstenhulme et al. 2006, Bazett-Jones et al. 2008, LaRoche et al. 2008, Ylinen et al. 2009, Yuktasir & Kaya 2009, Marshall et al. 2011)

Stretch of the muscle tissue has been shown to be a strong boost to protein synthesis, at least in animal studies (Goldspink 1999). In this current study no significant differences were found between the stretching and non-stretching sub-groups in lower extremity extensor strength test in neither of the activity groups and in lower extremity power test only in the somewhat active subjects. These inconsistent results make it unconvincing, that the association between stretching and modified push-up as well as jump-and-reach tests could be attributed to hypertrophy, achieved by the stretching groups with regular stretching exercises.

The type of muscle strength differs between one-leg squat and jump-and-reach tests, which could explain at least partly why significant relationship was found only in one of the two lower limb strength tests. Ross et al. (2007) speculated that by increasing flexibility, increased compliance might have resulted in a greater ability to store and release potential energy, and so allow subjects to generate higher propulsive forces. This could also explain the association between stretching and jump-and-reach test in the current study as jump test relies more on explosive force. This speculation is conflicting with the results from the studies investigating the acute effects of stretching. Increases in compliance have been observed not to offer any benefit in muscle power production or even decrease the muscle power (Magnusson et al. 1998, Kubo et al. 2001, Mizuno et al. 2011, Simic et al. 2012). Also according to Kubo et al. (2001b) passive muscle stiffness has no favorable effect on muscle performance during stretch shortening cycle exercises, e.g. jump.

When interpreting the results of this study it should be taken into account that in general the stretching sub-groups exercised more, when compared to the non-stretching subjects. Even though the differences exist, the possible association between of stretching and strength performance can’t be ruled out completely. The results from the study by Kokkonen and colleagues (2010) suggest that for resistance training novices, adding stretching into the training program might promote strength gains.

8.3 Walking performance

In this study a relationship between stretching and walking performance was found in somewhat active subjects. It is unlikely that the slightly better performance in stretching group could be explained with association between stretching and VO_{2max} even though there is a relationship between gait speed and VO_{2max} (Fiser et al. 2010). Nelson et al. (2007) investigated the effect of long-term stretching on VO_{2peak} and running economy and didn't find significant changes in economy or VO_{2peak}, despite the significant increases in ROM.

Hip extensibility wasn't measured in this study, but greater stride length in the stretching sub-group could be the reason behind the association of stretching and walking performance. Christiansen (2008) and Watt et al. (2011) found significant increases in comfortable/self-chosen gait speed. Stanziano et al. (2009) speculated that the increase in gait speed could be due to increase in stride length. For example Watt et al. (2011) found a 2.7 cm increase in stride length and increase in step length, without significant changes in controls, was found also by Cristopolski et al. (2009).

It should be noted again, that there was significant differences between the stretching and non-stretching sub-groups within the same PA level (Table 2). Thus, this significant difference is also distinctly possible explanation behind the association between cardiorespiratory fitness and walking ability test and stretching in this study.

Furthermore, the observed association might also be due to the association between gait speed and muscle strength (Fiser et al. 2010). Similar association between stretching and lower extremity power (jump-and-reach performance) was also seen in somewhat active subjects and it could be associated with walking ability. This hypothesis is supported by the fact that even though the differences between subjects' within the sub-groups were quite similar in both activity levels, significant associations between stretching and muscle power as well as walking performance measures were found in somewhat active subjects.

8.4 Limitations

The limitation of this study is linked to the cross-sectional design. The data used in this study was not originally intended to serve as a data for research question in this study, that is, this more or less secondary analysis of the original data. Due to this there were some information lacking, for example on stretching methods, intensities, frequencies and durations.

Results may be affected by significant differences observed within the non-stretching and stretching sub-groups. Therefore, further fine-tuning of the physical activity group criteria could have reduced the source of error in this study.

9 CONCLUSIONS

The present cross-sectional results indicated that the independent relationship of stretching beyond overall physical activity level on physical performance is small with few exceptions. However, due to the limitations of this study the results need to be interpreted with caution. Furthermore, the results of this current study indicated that regular stretching doesn’t seem to have a detrimental association with physical performance.

More studies on long-term stretching are needed. Especially more studies investigating the effects of realistic amounts of stretching on physical performance in middle-age adults and older are in demand. Similar cross-sectional study on a population with more homogenous physical activity habits would give a better insight on this matter.

REFERENCES

ACSM (American college of sports medicine). ACSM's guidelines for exercise testing and prescription. 6th edition. Lippincott Williams& Wilkins, 2000:85-86.

Ahtiainen J, Häkkinen K. Hermo-lihasjärjestelmän toiminnan mittaaminen. In Keskinen KL, Häkkinen K, Kallinen M. (ed.) Kuntotestauksen käsikirja. Tampere: Tammer-Paino oy, 2004:139, 145.

Alter MJ. Science of flexibility. 3rd ed. Stanningley: Human Kinetics, 2004.

Avela J, Kyröläinen H, Komi PV. Altered reflex sensitivity after repeated and prolonged passive muscle stretching. J Appl Physiol 1999;86:1283–1291.

Ayala F, Sainz de Baranda P. Effect of 3 different active stretch durations on hip flexion range of motion. J Strength Cond Res 2010;24:430–436.

Bandy WD, Iron JM, Briggler M. The Effect of Time and Frequency of Static Stretching on Flexibility of the Hamstring Muscles. Phys *Ther* 1997;77:1090-1096.

Baltaci G, Tunay, Besler A, Gerçeker S. Comparison of three different sit and reach tests for measurement of hamstring flexibility in female university students. Br J Sports Med 2003;37:59–61. doi: 10.1136/bjsm.37.1.59

Bazett-Jones DM, Gibson MH, McBride JM. Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching. J Strength Cond Res 2008;22:25-31. doi: 10.1111/j.1600-0838.2009.00926.x

Behm DG, Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. Eur J Appl Physiol 2011: 2633–2651. DOI 10.1007/s00421-011-1879-2

Ben M, Harvey LA. Regular stretching does not increase muscle extensibility: a randomized controlled trial. Scand J Med Sci Sports 2010;20:136-144.

Cerny F, Burton H. Exercise physiology for health care professionals. Champaign: Human Kinetics, 2001.

Chalmers, G. Reexamination of the Possible Role of Golgi Tendon Organ and Muscle Spindle Reflexes in Proprioceptive Neuromuscular Facilitation Muscle Stretching. Sports Biomechanics 2004;3:159-183.

Chan SP, Hong Y, Robinson PD. Flexibility and passive resistance of the hamstrings of young adults using two different static stretching protocols. Scand J Med Sci Sports 2001;11:81-86.

Christiansen CL. The effects of hip and ankle stretching on gait function of older people. Arch Phys Med Rehabil 2008;89:1421-1428.

Covert CA, Alexander MP, Petronis JJ, Davis DS. Comparison of ballistic and static stretching on hamstring muscle length using an equal stretching dose. J Strength Cond Res 2010;24:3008–3014.

Cristopoliski F, Barela JA, Leite N, Fowler NE, Felix Rodacki AL. Stretching Exercise Program Improves Gait in the Elderly. Gerontology 2009;55:614–620. DOI: 10.1159/000235863

Enoka RM. Neuromechanics of human movement. 3th ed. Leeds: Human kinetics, 2002.

Fasen JM, O'Connor AM, Schwartz SL, Watson JO, Plastaras CT, Garvan CW, Bulcao C, Johnson SC, Akuthota V. A randomized controlled trial of hamstring stretching: comparison of four techniques. J Strength Cond Res 2009;23: 660–667.

Fatouros IG, Taxildaris K, Tokmakidis SP, Kalapotharakos V, Aggelousis N, Athanasopoulos S, Zeeris I, Katrabasas I. The Effects of Strength training, Cardiovascular Training and Their Combination on Flexibility. Int J Sports Med 2002; 23: 112–119.

Fiser VM, Hays NP, Rogers SC, Kajkenova O, Williams AE, Evans CM, Evans WJ. Energetics of Walking in Elderly People: Factors Related to Gait Speed. J Gerontol A Biol Sci Med Sci 2010; 65:1332-7. doi:10.1093/gerona/glq137

Gleim GW, Stachenfeld NS, Nicholas JA. The Influence of Flexibility on the Economy of Walking and Jogging. J Orthop Res 1990:8;814-823.

Gajdosik R, Lusin G. Hamstring Muscle Tightness: Reliability of an Active-Knee-Extension Test. Phys Ther 1983;63:1085-1088.

Gajdosik R, Vander Linden D, Williams A. Influence of Age on Length and Passive Elastic Stiffness Characteristics of the Calf Muscle-Tendon Unit of Women. Phys Ther 1999; 79:827-838.

Goldspink G. Review Changes in muscle mass and phenotype and the expression of autocrine and systemic growth factors by muscle in response to stretch and overload. J Anat 1999;194:323-334.

Guissard N, Duchateau J. Effect of static stretch training on neural and mechanical properties of the human plantar-flexor muscles. Muscle Nerve 2004; 29: 248–255.

Halbertsma JPK, Göeken LN. Stretching exercises: Effect of passive extensibility and stiffness in short hamstrings of healthy subjects. Arch Phys Med Rehabil 1994;75:976–981.

Hamilton N, Weimar W, Luttgens K. Kinesiology. Scientific basis of human motion. 11.ed. New York: McGraw-Hill, 2008.

Handel M, Horstmann T, Dickhuth HH, Glüch RW. Effects of contract-relax stretching training on muscle performance in athletes. Eur J Appl Physiol 1997;76:400-408.

Herbert RD, Gabriel M. Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review. BMJ 2002;325:468.

Herzog W. Mechanical Properties and Performance in Skeletal Muscles. In Zatsiorsky VM (ed.) Biomechanics in sport. Performance enhancement and injury prevention. Commerce place: Blackwell science, 2000.

Higgins JPT, Green S (ed.). The Cochrane Collaboration, *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.0.2 [www-document] 2009 [retrieved 9.5.2010] www.cochrane-handbook.org

Humphries B, Dugan EL, Doyle TLA. Muscular fitness. In Kaminsky LA (senior editor) ACSM's Resource manual for guidelines for exercise testing and prescription. 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2006: 208-213.

Hunter JP, Marshall RN. Effects of power and flexibility training on vertical jump technique. Med sci sport exer 2002:478-486.

Johanson MA, Cuda BJ, Koontz JE, Stell JC, Abelew TA. Effect of Stretching on Ankle and Knee Angles and Gastrocnemius Activity During the Stance Phase of Gait. J Sport Rehabil 2009;18:521-534.

Klinge K, Magnusson SP, Simonsen EB, Aagaard P, Klausen K, Kjaer M. The effect of strength and flexibility training on skeletal muscle electromyographic activity, stiffness, and viscoelastic stress relaxation response. Am J Sports Med 1997;25: 710-6.

Kokkonen J, Nelson AG, Eldredge C, Winchester JB. Chronic static stretching improves exercise performance. Med sci sport exer 2007;39:1825-1831.

Kokkonen J, Nelson AG, Tarawhiti T, Buckingham P, Winchester J. Early-phase resistance training strength gains in novice lifters are enhanced by doing static stretching. J Strength Cond Res 2010;24:502–506.

Krause DA, Cloud BA, Forster LA, Schrank JA, Hollman JH. Measurement of Ankle Dorsiflexion: A Comparison of Active and Passive Techniques in Multiple Positions. J Sport Rehabil 2011;20:333-344.

Kubo K, Kanehisa H, Kawakami Y, Fukunaga T. Influence of static stretching on viscoelastic properties of human tendon structures in vivo. J Appl Physiol 2001a;90:520–527.

Kubo K, Kanehisa H, Tsunoda N. Is passive stiffness in human muscles related to the elasticity of tendon structures? Eur J Appl Physiol 2001b; 85: 226-232. DOI 10.1007/s004210100463

Kubo K, Ikebukuro T, Yata H, Tsunoda N, Kanehisa H. Time course of changes in muscle and tendon properties during strength training and detraining. J Strength Cond Res 2010;24: 322–331.

LaRoche DP, Connolly DAJ. Effects of Stretching on Passive Muscle Tension and Response to Eccentric Exercise. Am J Sports Med 2006;34:1000-1007. DOI: 10.1177/0363546505284238

LaRoche DP, Lussier MV, Roy SJ. Chronic stretching and voluntary muscle force. J strength cond res 2008;22:589-596.

Laukkanen R, Pasanen M, Tyry T, Vuori I. A 2-km walking test for assessing the cardiorespiratory fitness of healthy adults. Int J Sports Med 1991;12:356-362.

Laukkanen R, Kukkonen-Harjula T, Oja P, Pasanen M, Vuori M. Prediction of Change in Maximal Aerobic Power by the 2-km Walk Test after Walking Training in Middle-Aged Adults. Int J Sports Med 2000;21:113-116. DOI: 10.1055/s-2000-8872

Levinger I, Goodman G, Hare LD, Jerums G, Toia D, Selig S. The reliability of the 1RM strength test for untrained middle-aged individuals. J Sci Med Sport 2009;12:310-316. doi:10.1016/j.jsams.2007.10.007

Magnusson SP, Simonsen EB, Aagaard P, Sorensen H, Kjaer M. A mechanism for altered flexibility in human skeletal muscle. J Physiol 1996a; 497:291-298.

Magnusson SP, Simonsen EB, Aagaard P, Kjaer M. Biomechanical Responses to Repeated Stretches in Human Hamstring Muscle In Vivo. Am J Sports Med 1996b;24:622-628.

Magnusson SP, Simonsen EB, Aagaard P, Boesen J, Johannsen F, Kjaer M. Determinants of musculoskeletal flexibility: viscoelastic properties, cross-sectional area, EMG and stretch tolerance. Scand J Med Sci Sports 1997;7:195-202.

Magnusson SP. Passive properties of human skeletal muscle during stretch maneuvers. A review. Scand J Med Sci Sports 1998;8:65-77.

Maughan Rj, Watson Js, Weir J. Strength And Cross-Sectional Area Of Human Skeletal Muscle. J Physiol 1983;338: 37-49.

Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. J Strengh Cond Res 2004;18:551-5.

Marshall P, Cashman A, Cheema B. A randomized controlled trial for the effect of passive stretching on measures of hamstring extensibility, passive stiffness, strength, and stretch tolerance. J Sci Med Sport 2011;14:535–540.

McArdle WD, Katch FI, Katch VL. Exercise physiology: energy, nutrition & human performance. 6th ed. Philadelphia: Lippincott Williams & Wilkins, 2007.

McHugh MP, Cosgrave CH. Review. To stretch or not to stretch: the role of stretching in injury prevention and performance. Scand J Med Sci Sports 2010;20:169-181. doi:10.1111/j.1600-0838.2009.01058.x

Mizuno T, Matsumoto M, Uemura Y. Viscoelasticity of the muscle–tendon unit is returned more rapidly than range of motion after stretching. Scand J Med Sci Sports 2011 (online early view) doi: 10.1111/j.1600-0838.2011.01329.x

Morton SK, Whitehead JR, Brinkert RH, Caine DJ. Resistance training vs. static stretching: Effects on flexibility and strength. J Strength Cond Res 2011;25:3391–3398.

Nelson AG, Kokkonen J, Eldredge C, Cornwell A, Glickman-Weiss E. Chronic stretching and running economy. Scand J med Sci Sports 2001;11:260-265.

Nelson AG, Kokkonen J, Winchester JB, Kalani W, Peterson K, Kenly MS, Arnall DA. A 10-week stretching program increases strength in the contralateral muscle. J Strength Cond Res 2012;26:832-836.

Powers S, Howley E. Exercise physiology. Theory and application to fitness and performance. 7.ed. New york: McGraw-Hill, 2009.

Prilutsky BI. Eccentric Muscle Action in Sport and Exercise. In Zatsiorsky VM (ed.) Biomechanics in sport. Performance enhancement and injury prevention. Commerce place: Blackwell science, 2000.

Rees SS, Murphy AJ, Watsford ML, McLachlan KA, Coutts AJ. Effects of proprioceptive neuromuscular facilitation stretching on stiffness and force-producing characteristics of the ankle in active women. J Strength Cond Res 2007;21:572-577.

Reid DA, McNair PJ. Effects of a six week lower limb stretching programme on range of motion, peak passive torque and stiffness in people with and without osteoarthritis of the knee. N Z J Physiother 2011;39:05-12.

Ross MD. Effect of a 15-day pragmatic hamstring stretching program on hamstring flexibility and single hop for distance test performance. Res Sports Med 2007;15: 271–281.

Rossi LP, Pereira R, Sim R. Influence of static stretching duration on quadriceps force development and eletromyographic activity. Human movement 2010; 11:137–143. Doi:10.2478/v10038-010-0020-4

Sharman JM, Cresswell AG, Riek S. Proprioceptive Neuromuscular Facilitation. Stretching Mechanisms and Clinical Implications. Sports Med 2006; 36: 929-939.

Shrier I. Does stretching improve performance? A systematic and critical review of the literature. Clin J Sport Med 2004;14:5:267-273.

Siff MC. Biomechanical Foundations of Strength and Power Training. In Zatsiorsky VM (ed.) Biomechanics in sport. Performance enhancement and injury prevention. Commerce place: Blackwell science, 2000.

Simaõ R, Lemos A, Salles B, Leite T, Oliveira E, Rhea M, Reis VM. The influence of strength, flexibility, and simultaneous training on flexibility and strength gains. J Strength Cond Res 2011;25:1333-1338.

Simic L, Sarabon N, Markovic G. Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. Scand J Med Sci Sports 2012: x;1-18. doi: 10.1111/j.1600-0838.2012.01444.x

Stanziano DC, Roos BA, Perry AC, Lai S, Signorile JF. The effects of an active-assisted stretching program on functional performance in elderly persons: A pilot study. Clinical interventions in aging 2009;4:115-120.

Suni JH, Oja P, Laukkanen R, Miilunpalo S, Pasanen M, Vuori I, Vartiainen T-M, Bös K. Helath-related fitness test battety for adults:Aspects of reliability. Arch Phys Med Rehabil 1996;77:399-405.

Suni JH, Oja P, Miilunpalo S, Pasanen M, Vuori I, Vuori I, Bös K. Health-related fitness test battery for adults: Associations with perceived health, mobility and back function and symptoms. Arch Phys Med Rehabil 1998;79:559-569.

Suni JH, Oja P, Miilunpalo S, Pasanen M, Vuori I, Vuori I, Bös K.Health-related fitness test battery for adults:Associations with physical activity patterns. Int J Sports Med 1999;20:189-191.

Taylor DC. Viscoelastic properties of muscle-tendon units. The biomechanical effects of stretching. Am J Sports Med June 1990;18:300-309. doi:10.1177/036354659001800314

Taylor JD, Fletcher JP. Reliability of the 8-repetition maximum test in men and women. J Sci Med Sport 2012;15:69–73.

Watt JR, Jackson K, Franz JR, Dicharry J, Evans J, Kerrigan C. Effect of a Supervised Hip Flexor Stretching Program on Gait in Frail Elderly Patients. PM&R 2011;3:330-335. DOI: 10.1016/j.pmrj.2011.01.006

Weppler CH, Magnusson SP. Increasing muscle extensibility: A Matter of increasing length or modifying sensation? Phys ther 2010;90:438-449.

Woolstenhulme MT, Griffiths CM, Woolstenhulme EM, Parcell AC: Ballistic stretching increases flexibility and acute vertical jump height when combined with basketball activity. J Strength Cond Res 2006;20:799-803.

Wright V, Johns RJ. Quantitative and Qualitative Analysis of Joint Stiffness in Normal Subjects and in Patients with Connective Tissue Diseases. Ann Rheum Dis 1961;20:36-46. doi: 10.1136/ard.20.1.36

Ylinen J, Kankainen T, Kautiainen H, Rezasoltani A, Kuukkanen T, Häkkinen A. Effect of stretching on hamstring muscle compliance. J Rehabil Med 2009; 41: 80-84.

Ylinen J, Kautiainen H, Häkkinen A. Comparison of active, manual, and instrumental straight leg raise in measuring hamstring extensibility. J Strength Cond Res 2010;24: 972–977.

Yuktasir B, Kaya F. Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance. J Bodywork Mov Ther 2009;13:11-21.

Zakariás C, Petrekanits M, Laukkanen R. Validity of a 2-km Walk Test in Predicting the Maximal Oxygen Uptake in Moderately Active Hungarian Men. Eur J Sport Sci 2003; 3: 1-8.

Åstrand P-O, Rodahl K, Dahl H, Stromme S. Textbook of work physiology. Physiological bases of exercise. 4. ed. Champaign: Human Kinetics, 2003.

Table 5. RCT studies: The effect of non pre-event stretching on physical performance

			STRETCHING			OUTCOMES (results)	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and method[6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Halbertsma & Göeken 1994 **n=14**	Students (mean 26.5 yrs) Tight hamstrings	4	Hamstring Passive static (janda) (1)	2xday 10 min (total of 20min/day)	Not reported		**Hip flexion ROM** (ISLR) Stretching (+5.3°*) Control **Angle between pelvis and leg)** Stretching (-5.2°*) Control (0.2°) **Passive elastic muscle moment** (at 75% extensibility) Stretching (-0.2Nm) Control (-0.3Nm) **Max. passive muscle moment** Stretching (-13.6Nm*) Control (-0.3Nm) **Stiffness** Stretching (no change) Control (no change)
Bandy et al. 1997 **n=93**	(mean age 26.24 yrs) Tight hamstrings	6	Hamstring Passive static (1)	5xwk Group 1: 3x60 sec, Group 2: 3x 30 sec, Group 3: 1x 60 sec, Group 4: 1 x 30 sec, Group 5: control	Gentle stretching sensation		**Knee extension ROM** (hip at 90°) G1 (+24%#‡*) G2 (+24%#‡*) G3 (+24%#‡*) G4 (+27%#‡*) (no sig difference btw groups) Control (+1%#)
Handel et al. 1997 **n= 16**	Male athletes (mean 26.6 yrs) Control leg.	8	Knee extensors and flexors Contract-relax (2?)	3xwk 8 x 10 sec contraction - 10-15 sec passive stretch	Not reported	**Isokinetic torque:** **Eccentric** condition (60 & 120 N×s^{-1}) Flexor (+18.2%*‡ and +16.5%*‡) Extensor (+18.9%*‡ and +23%‡*) Control (no sig change) **Concentric c.** (60, 120, 180, 240 N×s^{-1}) Flex. (+9.4%*, +4%, +8%* & +10.4%*) Ext. (+6.9%‡, +0.5%, +3.7% & +1.4%) Control (no sig change) **Max. isometric force** Flex. (+11.3%*) Ext. (+8.8%) Control (no sig change) Control (no sig change)	**Active knee ROM** (Extension & flexion) Stretching (+1.1° & +2.6°*) Control (no sig change) **Passive knee ROM** (Extension & flexion) Stretching (+5.6°* & +6.3°*) Control (no sig change) In addition: **Tight circumference** Stretching (+0.8cm*) Control (no sig. change)

			STRETCHING			OUTCOMES (results)	
Study	**Subjects**	**Intervention (wk)**	**Target muscle groups and method [6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Chan et al. 2001 **n=40**	Healthy university students (20±3 yrs)	Group 1: 8wk, Group 2: 4wk	Hamstrings Static (1)	3xwk G1 1x 5x30 sec G2: 2x 5x30 sec (30sec rest)	Maximum stretch without pain		**Knee extension ROM** (hip at 90°) G1: (+7%$^{\#}$, +11.2°$^{\ddagger *}$) G2: (+5%$^{\#}$, +8.9°$^{\ddagger *}$) (no sig. differences btw groups) Control (0%$^{\#}$) **Passive resist. to stretch (**max ROM) G2 (+21%$^{\#}$, + 4.7 Nm$^{\ddagger *}$) G1 (-4%$^{\#}$, -1Nm) Control (0-2%$^{\#}$)
Nelson et al. 2001 **n=32**	Active trained gollege students	10	"All main muscle groups of lower limbs" Passive assisted (12) & passive static (15)	3xwk 3 x 15sec +15 sec rest	Noticeable tension		**Sit-and-reach ROM** Stretching (+9%*) Control (+0%$^{\# *}$) In addition: **Running economy**/VO_{2peak} Stretching (0) Control (0)
Hunter & Marshall 2002 **n=50 (24)**	Men from a variety of sporting backgrounds. (24 ± 4 yrs)	10	Hamstrings, quadriceps, hip ext., adductors & abductors, & plantar flx Static (+PNF) (?)	4xwk (PNF: 1xwk) Static: 3 x 20–60sec PNF:10sec contract. -Stretch	Point of only mild discomfort	**CMJ** Stretching (+3.7%$^{\#\ddagger}$) Control (-0.8%$^{\#}$) (0) **Drop jumps** (30-, 60- and 90-cm) Stretching (-0.2-3.4%$^{\#}$) Control (0.8-2.2%$^{\#}$)	
Guissard & Duchateau 2004 **n=12**	Healthy men and women. (21 to 35 yrs) Control leg.	6	Plantarflexors Passive static (4)	5xwk 5x 30 sec +30 sec rest	Maximum dorsiflexion tolerated	**Muscle Voluntary Contraction** Stretching (+5%$^{\#}$) Control (0%$^{\#}$) **Rate of force development** Stretching (+0.6%$^{\#}$) Control (+4.2%$^{\#}$)	**Ankle dorsiflexion ROM** Stretching (+30.8%$^{\ddagger *}$) Control (+2.5%$^{\#}$) **Passive stiffness** (trough 15-25°) Stretching (-33%$^{\ddagger *}$) Control (+0.9%$^{\#}$) **Passive torque** Stretching (-2.5%$^{\#}$) Control (+2.6%$^{\#}$)
Reid & McNair 2004[1] **n=43**	Male subjects (mean age, 15.8± 1.0 yrs)	6	Hamstring Passive static (1)	1xday for 5days a week 3x 30 sec	Stretching sensation		**Max. knee ext. ROM** (hams. flexibility) Stretching (+63%$^{\#\ddagger *}$) Control (?%) **Max. passive resistive force** Stretching (+57%$^{\#\ddagger *}$) Control (?%) **Stiffness** (final 10%) Stretching (+26%$^{\#\ddagger *}$) Control (?%)

			STRETCHING			OUTCOMES (results)	
Study	**Subjects**	**Intervention (wk)**	**Target muscle groups and method ^{6} (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
LaRoche & Connoly 2006 **n=29**	Recreationally active men (31.6 ± 15.2 yrs)	4	Hamstring G1: Active/passive static G2: Ballistic (1)	3xwk 10 x 30 sec + 30 sec rest	Mild discomfort	**Work absorption** G1 (-8%) G2 (0%) Control (-14%)	**Hip peak ROM** (ISLR) G1 (+9.5%‡) G2 (+9.3%‡) Control (+1.2%) **Stiffness** (50°-85° hip flx) G1 (-10.3%) G2 (-10%) Control (-2%) **Peak passive torque** G1 (+30.1%‡) G2 (+25.4%*) Control (0%)
Woolstenhulme et al. 2006 **n=34**	Recreationally active healthy university students	6	Knee flx, ext & ankle dorsiflx G1: Pas. static (4) G2: Ballistic (4)	2xwk 2 x 30 sec + 15 sec rest	Feeling of tightness but not pain	**Vertical jump** G1 (0%) G2 (+1%$^{\#}$) Control (-1%$^{\#}$)	**Sit-and-reach** G1: +2.2 ± 1.0 cm‡ G2: +3.3 ± 0.9 cm‡ Control (from a fig. +1.0±1cm)
Mahieu et al. 2007 **n=81**	Recreationally active men and women (around 20 to 24 yrs old)	6	Plantar flexors G1: Pas. static G2: Ballistic	7xwk 5x 20 sec +20 sec rest	The point just before discomfort		**Ankle ROM knee extended** G1 (+8%$^{\#*}$) G2 (+9%$^{\#*}$) Control (+8%$^{\#*}$) **Ankle ROM knee flexed** G1 (+9%$^{\#*}$) G2 (+11%$^{\#*}$) Control (+5%$^{\#*}$) **Resist.Torque (**20° plant.flx-10°dorsflx) G1 (-8%$^{\#*}$) G2 (-1%$^{\#}$) Control (-5%$^{\#}$) **Achilles tendon stiffness** G1 (-10%$^{\#}$) G2 (-27%$^{\#*}$) Control (-2%$^{\#}$)

		STRETCHING				OUTCOMES (results)	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and method ^{6} (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Kokkonen et al. 2007 **n= 38**	Physically inactive or recreationally active students	10	Hamstrings, quadriceps, adductors, abductors external- & internal rotatores, plant.flexors & dors.flexors Passive assisted static (12) + Passive static (15)	3xwk 3 x 15 sec + 15 sec rest	Not reported	**Standing long jump** Stretching (+2.3%*) Control (-2%$^{\#}$) **Vertical jump** Stretching (+6.7%*) Control (0%$^{\#}$) **1RM knee flx.** Stretching (+15.3%*) Control (+2%$^{\#}$) **1RM Knee ext.** Stretching (+32.4%*) Control (+2%$^{\#}$) **Knee flx. endurance** Stretching (+30.4%*) Control (-1%$^{\#}$) **Knee ext. endurance** Stretching (+28.5%*) Control (0%$^{\#}$) **20-m sprint time** Stretching (-1.4%*) Control (1%$^{\#}$)	**ROM (Sit and reach)** Stretching (+18.1%*) Control (-2%$^{\#}$) In addition: **VO_{2peak}** No changes in stretching or control groups
Rees et al. 2007 **n=20**	Healthy, active women (19.7 ± 1.6 yrs)	4	Plantarflexors CRAC-PNF (1)	3xwk 4-6 x 6-10sec plantarflx.contract - 6-10 sec stretch	Pain free	**Max. isometric force** Stretching (+26%‡*) Control (+2%$^{\#}$) **Rate of torque development** Stretching (+25%‡*) Control (-1%$^{\#}$)	**Ankle dorsi flx ROM** Stretching (approx.+ 7.8%‡*) Control (-1-1.5%$^{\#}$) **Ankle MTU stiffness** Stretching (+8.5%‡*) Control (-1%$^{\#}$)
Ross 2007 **n=13**	Highly active US Air force academy cadets (20.3 ± 1.5 yrs). Tight hamstrings. Control leg	15days (approx. 2 weeks)	Hamstring Passive static (1)	1xday 5x30 sec+ 10 sec rest	Perceived tightness	**Single leg hop** Stretching (+5%$^{\#\ddagger}$*) Control (0%$^{\#}$)	**AKET ROM** Stretching (+15%$^{\#\ddagger}$*) Control (-3%$^{\#}$)
Bazett-Jones et al. 2008 **n=21**	Division III women's track and field athletes (18.57±0.73)	6	Hamstring Passive static (1)	4xwk 4x45sec (45-60s rest	Mild discomfort	**55-m sprint** Stretching (-1.0%$^{\#}$) Control (-0.7%$^{\#}$) **Vertical jump** Stretching (-3.8%$^{\#}$) Control (-2.5%$^{\#}$)	**AKET** Stretching (+2.1 to 1.7°) Control (-5.0 to -4.6°)

			STRETCHING			OUTCOMES (results)	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and method[6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Christiansen 2008 **n=37**	n=37 (72.1±4.7 yrs)	8	Hip flexors, ankle plantar flexors Pas. static (2)	2xday 3x45 sec	Maximal tolerable stretch	**Freely chosen gait speed** Stretching (+6%$^{\#\ddagger}$) Control (+2%$^{\#}$)	**Passive ankle dorsiflx ROM** Stretching (+45%$^{\#\ddagger}$) Control (+1%$^{\#}$) **Hip extension-knee flx ROM** Stretching (+12%$^{\#\ddagger}$) Control (0%$^{\#}$)
LaRoche et al. 2008 **n= 29**	Healthy and recreationally active men (31.6±15.2 yrs)	4	Hip extensors G1: Pas. static (1) G2: Ballistic (1)	3xwk 10 x 30 sec + 30 sec rest	Until a point of mild discomfort	**Hip ext. peak torque (60°’s^{-1})** G1 (+6%$^{\#}$) G2 (+5%$^{\#}$) Control (+4%$^{\#}$) **Rate of torque development** G1 (+6%$^{\#}$) G2 (+6%$^{\#}$) Control (+6%$^{\#}$)	**Hip peak torque angle** G1 (-2%$^{\#}$) G2 (+1%$^{\#}$) Control (0%$^{\#}$) **Work (0)** G1 (+4%$^{\#}$) G2 (+6%$^{\#}$) Control (+5%$^{\#}$)
Cristopoliski et al. 2009 **n=20**	Healthy elderly women (stretch 65.9 ± 4.2 yrs, control 65.4 ± 2.9 yrs)	4	Hip flexors, extensors, ankle plantar-flexors Passive assisted static (3)	3xwk 4x 60 sec	Discomfort		**Hip flexion** Stretching (approx. -66%‡) Control (-5.6% to -2%) **Hip extension** Stretching (+25%‡) Control (+0.3%) **Ankle plantar flx.** Stretching (+17.5%‡) Control (+0.8%)
Fasen et al. 2009 **n=82**	(mean 33 yrs with a mode of 30)	8	Hamstrings G1:90/90 pas. G2:90/90 act. G3:SLR act. assisted+neuromob. G4:SLR pas. (1)	5xvko 3x30sek	Not reported		**Knee extension ROM** (Hamstring flexibility[2]) G1 (+?%) G2 (+?%‡) G3 (+?%‡) G4 (+?%‡) Control (?%)
Johanson et al. 2009 **n=16**	Men and women, (27.4 ± 8.2 yrs). Restricted ankle ROM.	3	Gastrocnemius Pas. static (1)	2xday/ daily 5x 30 sec. +10	Stretching sensation		**Ankle dorsiflx ROM** with straight knee Stretching (+469% to 540%$^{\#\ddagger}$) Control (50% to 400%$^{\#}$) **Knee flexed** Stretching (+469% to 540%$^{\#\ddagger}$) Control (0.8% to 823%$^{\#}$)

APPENDIX 1/ (8 pages)

				STRETCHING		**OUTCOMES (results)**	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and method [6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Stanziano et al. 2009 **n=17**	Elderly residents of a residential retirement community (88.7 ± 5.4 yrs)	8	Shoulder, hip, trunk and calf areas Passive static with antagonist contraction (10)	2xwk 10 x 4-5 sec	Not reported	**30-sec chair stand, modif. ramp power, 8-ft up-&-go, 50-ft gait speed** Stretching (+17%$^{\#\ddagger *}$, +26$^{\#\ddagger *}$, -13%$^{\#\ddagger *}$, -12%$^{\#\ddagger *}$) Control (-22%$^{\# *}$, -8%$^{\# *}$, +21%$^{\# *}$, +15%$^{\# *}$) **30-sec arm curl, gallon jug shelf test** Stretching (+46%$^{\#\ddagger *}$, -14%$^{\#\ddagger *}$) Control (-11%$^{\#,}$ +2%$^{\#}$)	**Back-scratch, modified chair, sit-and-reach, supine knee-extension, modified total body rotation** Stretching (+?%$^{\ddagger *}$) (With the exception of the left back scratch and right sit-and-reach) Control (no sig. Change) (Except Significant decrease in right-side knee extension)
Ylinen & al. 2009 **n=12**	Healthy recreationally active men. Tight hamstrings Control leg.	4	Hamstrings Passive static (1)	1x day 6 x 30 sec	Not reported	**Max. isometric knee flx** Stretching (+2.9%$^{\#}$) Control (-2.9%$^{\#}$)	**Peak hip flx ROM** (iSLR) Stretching leg (+25%$^{\#\ddagger *}$) Control (+3%$^{\#}$) **Angle were stretching was felt** Stretching (+37%$^{\#\ddagger *}$) Control (+5%$^{\#}$) **Mean resisting force (peak ROM)** Stretching (+22%$^{\# *}$) Control (+8%$^{\#}$) **Mean resisting force (stretch felt)** Stretching (+3%$^{\#}$) Control (+1%$^{\#}$)
Yuktasir & Kaya 2009 **n=28**	Healthy male students (Physical Education and Sports) (21.82 ± 1.90 yrs)	6	Hamstring, triceps surae G1: Passive assisted static G2: CR-PNF (1)	4xwk G1:4x 30sec G2:4x 10sec str.+ contract+ 15sec str.	maximum range tolerated by the subjects.	**Drop jump** 60 cm G1 (+8%$^{\#}$) G2 (+1%$^{\#}$) Control (+1%$^{\#}$)	**Hip flexion ROM** (pSLR) G1 (+15.4°$^{\#\ddagger *}$) G2 (+19.2°$^{\#\ddagger *}$) (no sig. diff. btw G1 and G2) Control (+3.2°$^{\#}$)
Ayala & Sainz de Baranda 2010 **n=150**	Recreationally active uni. students (21.3± 2.5 yrs) Subjects with short hamstrings excl.	12	Hamstrings Passive static (4)	3xwk G:1 12x15sec G2: 6x 30sec G3: 4x45 sec	Not reported		**Hip flexion ROM** [4] (SLR) G1 (+23%$^{\#\ddagger *}$) G2 (+23%$^{\#\ddagger *}$) G3 (+24%$^{\#\ddagger *}$) (no sig. diff. btw groups) Control (+2%$^{\#}$)

APPENDIX 1/ (8 pages)

			STRETCHING			OUTCOMES (results)	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and method [6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Ben & Harvey 2010 **n=60**	Most were recreationally active. 18 year or older. Control leg (CL) and control group (CG)	6	Hamstring Passive static (1)	5xwk 30min/day continuously	Largest stretch they were willing to tolerate		**Hip flx ROM with standard stretch torque** Treatment effect btw stretching and CL: -1° 95% CI -3 to 2° Treatment effect btw CL and CG: -1° 95% CI -5 to 3° **Hip flx ROM (ISLR) non-standard.** Treatment effect btw stretching and CL: 10° 95% CI 6 to 14° Treatment effect btw CL and CG: -4° 95% CI -8 to 0°
Covert et al. 2010 **n=32**	Healthy men and women (21.97±2.6yrs) Subjects had tight hamstrings	4	Hamstrings G1: Active ballistic G2: Passive assisted static (1)	3xwk 1x30 sec	A strong but tolerable stretch		**Knee extension** (hip at 90°) ROM [3] G1 (+13%$^{\#\ddagger}$) Effect size d=1.21 G2 (+38%$^{\#\ddagger}$) Effect size d=2.35 (G2 increased sig more than G1) Control (-12%$^{\#}$) (sig?)
Marshall et al. 2011 **n=22**	Health recreationally active men and women (22.7 ± 3.8 yrs)	4	Hamstrings, glutes Passive static (4)	5xwk 3x 30 sec	Not reported	**Hamstring concentric strength** (30 and 120◦ s^{-1}) Stretching (+2.2% and 6%$^{\#}$) Control (+8.2% and 1.2%$^{\#}$)	**Hip flexion ROM** (iSLR) Stretching (+20.9%*) Control (+3.3%$^{\#}$) **Max. passive stiffness** Stretching (+43.5%$^{\#}$) Control (+8.5%$^{\#}$) **Passive stiffness during 20–50◦ flx** Stretching (-31%$^{\ddagger *}$) Control (+4.3%$^{\#}$)
Reid & McNair 2011 **n=39**	20 with OA of the knee joint and 19 without OA [8] (68.7±4.8 yrs)	6	Hip flexors, quadriceps, hamstrings, and upper and lower calf Static	5xwk 3x 60 sec	Until stretching sensation		**Knee extension ROM** Stretching (+11%$^{\ddagger *}$) Control (-2.5%$^{\#}$) **Knee ext.** (° at 50% of the max torque) Stretching (-9.1%$^{\#}$* (-5.1°)) Control (-7.3%$^{\#}$(-4.3°)) **Knee ext ROM** (at max. Torque) Stretching (-8.3%$^{\#}$*(-5.8°)) Control (-2.4%$^{\#}$(-2.1°)) **Passive resistive peak troque** Stretching (+49.5%$^{\ddagger *}$) Control (-5.8%$^{\#}$) **Stiffness** (final 10% of ROM) Stretching (+35.5%$^{\ddagger *}$) Control (-8.3%$^{\#}$)

		STRETCHING				OUTCOMES (results)	
Study	**Subjects**	**Inter-vention (wk)**	**Target muscle groups and meth-od [6] (number of exercises)**	**Frequency & Duration**	**Intensity**	**Muscle performance, walking performance**	**Flexibility, stiffness, passive torque**
Watt et al. 2011 **n=74**	Frail and older than 65 years and living either independently or in assisted- living facilities.	10	Hip flexor Passive static (1)	2xday/ daily 2 x 60 sec.	Not reported	**Comfortable walking speed** Stretching (+4.34%$^{\#\ddagger}$) Control (0%$^{\#}$) **Fast walking speed** Stretching (-1.29%$^{\#}$) Control (0%$^{\#}$)	**Hip extension ROM** (thomas) Stretching (> +5°‡) Control (<2°)
Nelson et al. 2012 [5] **n=25**	Physically inactive or recreationally active students (24±3 to 22±2 yrs) Control group and leg	10	Calf Passive static (1)	3xwk 4 x 30 sec.	Maximally tolerable level.	**Ankle plant.fx strength** (1RM standing toe raise) Stretching (+29%*) Control leg (+11%*) Control g.(-0.66%$^{\#}$ to -0.33%$^{\#}$)	**Ankle joint dorsifx ROM** Stretching (+8%* (approx.3.6°)) Control leg (+1%* (approx.0.5°)) Control g.(-0.27%$^{\#}$ to 0.28%$^{\#}$)

[1] The schools were randomly assigned to either the control group or the intervention group to avoid the possible interaction between subjects during the intervention period.

Intervention duration

[5] Cross-training effect was investigated: stretching performed with right leg, left leg and control group didn't do stretching.

[6] *Active:* the subject produces the stretch independently by antagonist muscle contraction. *Passive:* gravity is used to produce the stretching or the subject actively intensifies the stretch for example by pulling from the toes. *Assisted passive:* stretching performed by another person.

[8] Across all dependent variables no significant interaction with OA and non OA→ the data was combined to form a stretch and control group

(‡) Sig. diff between stretching and control group

(*) Significant change from pretest

($^{\#}$) Calculated %change (pre-post)

Table 6. The mean difference (95%CI) between the somewhat active and active subjects in the non-stretching and stretching sub-groups.

Performance test	PA groups and stretching sub-groups		MD	95% CI	Sig.
Trunk lateral flexion					
	Non-stretching - somewhat active	Non- stretching - active	-0.9	-2.3 to 0.5	0.443
	Non-stretching - somewhat active	Stretching - active	-1.1	-2.4 to 0.2	0.118
	Stretching - somewhat active	Non- stretching - active	-0.4	-1.9 to 1.1	0.983
	Stretching - somewhat active	Stretching - active	-0.6	-2.0 to 0.8	0.806
Hamstring extensibility					
	Non-stretching - somewhat active	Non- stretching - active	-1.3	-5.2 to 2.7	0.954
	Non-stretching - somewhat active	Stretching - active	-4.2	-7.9 to -0.6	0.013
	Stretching - somewhat active	Non- stretching - active	1.4	-3.0 to 5.7	0.958
	Stretching - somewhat active	Stretching - active	-1.6	-5.7 to 2.4	0.864
Modified push-up					
	Non-stretching - somewhat active	Non- stretching - active	-0.7	-2.1 to 0.6	0.664
	Non-stretching - somewhat active	Stretching - active	-2.1	-3.4 to -0.8	0.000
	Stretching - somewhat active	Non- stretching - active	0.5	-1.0 to 2.0	0.945
	Stretching - somewhat active	Stretching - active	-0.9	-2.3 to 0.5	0.459
One-leg squat					
	Non-stretching - somewhat active	Non- stretching - active	-0.5	-1.2 to 0.2	0.389
	Non-stretching - somewhat active	Stretching - active	-0.8	-1.5 to -0.2	0.005
	Stretching - somewhat active	Non- stretching - active	0.1	-0.7 to 0.9	1.000
	Stretching - somewhat active	Stretching - active	-0.3	-1.0 to 0.4	0.889
Jump-and-reach					
	Non-stretching - somewhat active	Non- stretching - active	-2.9	-5.2 to -0.7	0.004
	Non-stretching - somewhat active	Stretching - active	-4.0	-6.1 to -1.9	0.000
	Stretching - somewhat active	Non- stretching - active	-0.6	-3.0 to 1.9	0.991
	Stretching - somewhat active	Stretching - active	-1.6	-3.9 to 0.7	0.343
UKK 2-km walk test					
	Non-stretching - somewhat active	Non- stretching - active	0.92	0.33 to 1.51	0.000
	Non-stretching - somewhat active	Stretching - active	1.10	0.56 to 1.65	0.000
	Stretching - somewhat active	Non- stretching - active	0.17	-0.48 to 0.81	0.984
	Stretching - somewhat active	Stretching - active	0.35	-0.26 to 0.95	0.568