EFFECT OF LOW-LOAD HAMSTRING STRENGTH TRAINING ON THE H/Q RATIO AND ELECTROMYOGRAPHIC ACTIVITY IN VARIOUS GYMNASTIC ACTIONS IN YOUNG AESTHETIC GROUP GYMNASTS

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ABSTRACT

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Muscle balance is an important factor for decreasing injury risks among sports, as weak agonist-antagonist strength ratio may predispose to injuries. Hamstring-to-quadriceps (H/Q) strength ratio has been studied in several sports in order to describe the muscular balance of thighs. During pubertal longitudinal growth, hamstrings may be weaker due to the mechanical stress of growth. As both hamstring flexibility and knee extension strength are important for aesthetic group gymnastics (AGG), the H/Q strength ratio might be expected to be low among this sport. Describing muscle activation patterns of hamstrings and quadriceps femoris in AGG actions is efficient for determining the H and Q activities and relations in different movements. Neural effects of low-load hamstring strength training on these muscle activities were studied to determine if strength training, in order to improve muscle balance, affects performance or muscle activities in performance.

Two age groups of AGG gymnasts (10–11 yrs old, n = 30; 13–14 yrs old, n = 30) were measured cross-sectionally for the H/Q strength ratio and hamstring flexibility as finger-ground distance (FGD). Subgroups (n = 8) were chosen from each group for the measurement of balance, jump mechanics and *biceps femoris*, *vastus lateralis* and *vastus medialis* activities in gymnastic actions. A 9-week intervention period with low-load hamstring strength training was carried out to determine effects of strength training on four AGG movements (body swing, split leap, balance with leg in front, balance with leg behind).

No changes were observed for the FGD, split leap or body swing during the strength training period, or between the age groups. For the split leap, the time for take-off and RFD correlated negatively ($p < 0.001$) with flight time indicating a relation of shorter contact time, explosive take-off and longer flight time. The activation of *biceps femoris* (BF) differed in the two balance movements; activation was higher ($p < 0.01$) in the balance with leg in front. Also, the activation of BF in this particular movement increased during the intervention period, but the increase was not statistically significant. However, the velocity moment decreased, especially for the right leg as supportive ($p = 0.02$), indicating improved balance and performance.

To conclude, the low-load hamstring strength training affected the balance with leg in front by improving the balance. As the intervention did not influence the FGD, strengthening of hamstrings may be suggested for gymnasts in order to improve the H/Q strength ratio. Because the strength training in the present study was synchronized into typical AGG training, it remains unknown whether the improvements on balance were directly related to the strength training.

Keywords: gymnastics, H/Q, hamstring, strength training, electromyography, balance

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LIST OF ABBREVIATIONS

AGG – Aesthetic group gymnastics
BF – *Biceps femoris*
COF – Center of forces
EMG – Electromyography
FGD – Finger-ground distance
H – Hamstrings
H/Q – Hamstrings-to-quadriceps
IAP – Intracellular action potential
MVC – Maximal voluntary contraction
MVIC – Maximal voluntary isometric contraction
Q – Quadriceps femoris
RFD – Rate of force development
S-EMG – Surface electromyography
VL – *Vastus lateralis*
VM – *Vastus medialis*

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1 INTRODUCTION

Aesthetic group gymnastics (AGG) is internationally practiced sport consisting of a gymnastic program performed in competitions (IFAGGa). The program includes movements from three main movement groups; jumps and leaps, balance movements, and body movements. Among other factors, also muscle balance and coordination are evaluated in AGG performance. (IFAGGb 2012.) Furthermore, adequate muscle balance and flexibility are considered important in preventing injuries (Alter 2004, p. 221–226). Weak unilateral muscle balance of hamstring (H) and quadriceps femoris (Q) and its relation to injuries in sport has been studied in adults with varied results (Makaruk *et al.* 2010; Holcomb *et al.* 2007; Worrell *et al.* 1991). The H/Q strength ratio has also been studied in children (Siatras *et al.* 2004; Holm and Vøllestad 2008), but research in this field lacks consistent results, especially among competitive sports. Usually hamstrings are weaker than quadriceps femoris (Alter 2004, p. 221–226), and therefore strengthening the hamstrings may increase the muscle balance of the thigh. Especially during pubertal fast bone growth, hamstrings may be weaker and more susceptible to injuries compared to its antagonist (Wild *et al.* 2013).

The aim of the present study was to describe the strength of hamstrings and quadriceps femoris and the activation of thigh muscles in different AGG actions in two groups of young gymnasts; 10–11 years old and 13–14 years old. Because international study of AGG is minimal, muscle activation patterns were also studied to describe the gymnastic actions. As adaptations in the nervous system attribute to the magnitude of muscle activity (Kraemer & Häkkinen 2002, p. 20–29), an intervention period of low-load hamstring strength training was conducted to improve the muscle balance of the thigh. Effects of hamstring strength training on muscle activation or performance in AGG actions were also studied. Furthermore, the effect of low-load hamstring strength training on flexibility was determined, as adequate flexibility is required in performing AGG program.

2 AESTHETIC GROUP GYMNASTICS

Aesthetic group gymnastics is an international sport for women and girls. It serves under the International Federation of Aesthetic Group Gymnastics (IFAGG). AGG requires sport-specific skills integrated in physical and technical high class performance. Also the composition and choreography of the AGG program is evaluated, and it affects the scoring in competitions. Internationally, the competing age categories start from girls 10 years of age. (IFAGGa; IFAGGb 2012.)

2.1 Description

AGG is gymnastics based on natural total body movement. It involves dynamic, rhythmic, and harmonious movements via a natural flow from one movement to another. All movements must be performed fluently, economically and with a natural use of strength. The amplitude and variety in dynamics and speed should be recognized in AGG performance. (IFAGGa.)

The composition of the AGG program must contain varied and versatile movements, such as body waves, swings, bendings, rotations, jumps and leaps, balances and pivots, steps, skips and hops, and different combinations. Movements evaluated in technical scores are divided into three movement categories: jumps and leaps, balance movements and body movements. Each of these categories includes several varied movements. (IFAGGb 2012.)

A good level of physical performance such as flexibility, strength, speed and coordination are required. A competitive group consists of 6 to 10 gymnasts. Choreography of an AGG program should create a story through the movements by using an expressive interpretation of music. AGG is a combination of art, expression, feelings and a high level competitive sport. (IFAGGa.)

2.2 Physical and technical performance

AGG performance must show a high level of physical performance in the form of adequate flexibility, good muscle control and strength, speed, coordination and endurance. The composition of the competition program must show bilateral muscle control. (IFAGGb 2012.) Alter (2004, p. 31) has defined muscular control as “adequate balance, coordination, or control of one’s body part(s) or sufficient muscular strength to perform a given skill”. The competition program includes jumps and leaps that require mainly strength and speed, and movements that require primarily great flexibility, as balance movements, for example. Coordination is required for performing fluent steps, lifts etc. (IFAGGb 2012.) The permitted competition program length is from 2 minutes 15 seconds to 2 minutes and 45 seconds, which points out that performance requires both aerobic and anaerobic endurance (IFAGGb 2012; Rönkkö 2006).

All movements and elements of the competition program are evaluated. The scoring is based on three sectors: technical value, artistic value and execution. Technical and artistic judges evaluate mainly the composition, while executive judges evaluate the performance and make the deductions. In execution, also healthy aspects of the performance are considered. Common healthy aspects appreciated in AGG are related to muscle balance: bilateral work, good alignment of the supporting leg, alignment of shoulders and hips, and good posture. (IFAGGb 2012.)

The technical content of a competition program consists of jumps and leaps, balance movements, and body movements. Required elements in body movements include two body waves (figure 1), two body swings, two A-series of body movements (each consisting of two body movements) and two B-series of body movements (each consisting of three body movements). Required balance movements and jumps/leaps are classified either as A or B difficulties. B-difficulties are more challenging and more valuable than A-difficulties, because they usually have either rotation or body movement included. (IFAGGb 2012.)

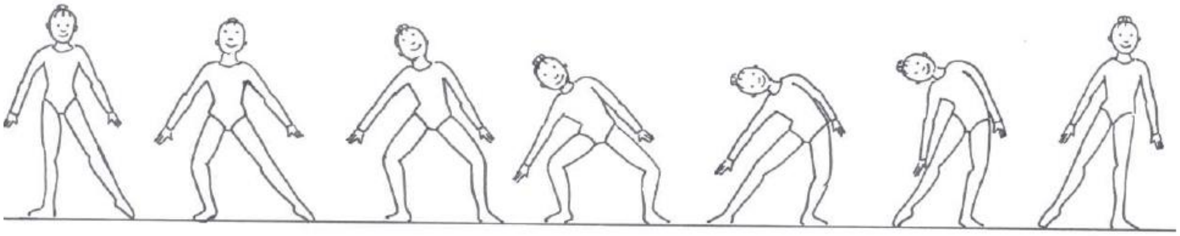


FIGURE 1. Body wave (The Finnish Gymnastics Federation 2010)

In some balance movements and leaps, also the amplitude of legs may determine whether the difficulty is considered as A or B. In other words, better flexibility can have contribution to more valuable difficulties. For example, a split leap is considered as a B-difficulty, if the amplitude of legs is minimum 180 °, otherwise it will be counted as an A-difficulty. In the competition program there must be two different balance movements and one balance movement series, and also, two different jumps/leaps and one jump series. In addition, there can be supplementary combinations of difficulties (consisting jump + balance, for example). (IFAGGb 2012.)

2.3 Thigh muscles in gymnastic movements: Anatomic point of view

The muscle groups of hamstrings and quadriceps femoris affect the muscle balance of the thigh. The hamstrings consist of three posterior thigh muscles: *biceps femoris*, *semitendinosus* and *semimembranosus*. *Biceps femoris* is a two-headed muscle located in the posterior and lateral part of the thigh, while *semitendinosus* and *semimembranosus* locate in the medial part of the posterior thigh. Hamstrings produce extension of the hip and flexion of the knee. Also, in semiflexed position of the knee with extension of the hip, *biceps femoris* acts as a lateral rotator and *semitendinosus* and *semimembranosus* as medial rotators of the lower leg/thigh. (Alter 2004, p. 221–227.)

The antagonist for hamstrings is the muscle group of quadriceps femoris. This muscle group consists of four muscles. These are *rectus femoris* (located in front of the femur), *vastus lateralis* (on the lateral side of the femur), *vastus medialis* (on the medial side of the thigh) and *vastus intermedius* (between the femur and rectus femoris). Quadriceps femoris muscles extend the knee. (Alter 2004, p. 221–227.)

In gymnastics, the action of extending the knee by quadriceps femoris provides aesthetic, straight legs. They are also involved in holding the extended leg. The extension provides a propulsive force for jumping and leaping, and for rising up from a plié movement. Strengthening the quadriceps femoris may prevent knee pain. (Calais-Germain & Lamotte 2008, p. 150–151, 193.) Knee and leg extensions are important for AGG performance (IFAGGb 2012).

Muscle coordination

Muscle coordination between all the muscles of foot, knee and hip is essential for healthy sport. Developing better coordination and alignment may prevent knee pain (Calais-Germain & Lamotte 2008, p. 150–151, 193). Coordination of these muscles is needed especially in jumping. Transition to vertical jumping is from “triple flexion”, in other words, from dorsiflexion of ankle, flexion of knee and flexion of hip. Vertical jump movement is produced via “triple extension”, in other words, plantar flexion of ankle, extension of knee and extension of hip. In leaps and other jumps directed forward, the propulsion factors of walking and vertical jumping are combined with adequate coordination. (Calais-Germain & Lamotte 2008, p. 274.)

Flexibility of hamstrings

Hamstrings are being stretched and put into tension in movements that require extreme flexibility. When the stretch or tension is high in relation to hamstring flexibility, it may take the pelvis into extension. This may provoke flexion of the lumbar spine and cause extra stress on posterior spinal ligaments. (Calais-Germain & Lamotte 2008, p. 150–151.) Therefore, in AGG it is important that hamstring flexibility is adequate for performing movements requiring high flexibility of the posterior part of the leg.

In several movements, the flexibility of the posterior part of the leg may be affected by the flexibility of other muscles or ligaments. This is evident, for example, in the test movement of bending forward and touching hands to the floor with straight legs. This movement produces tension to the hamstrings but also to the monoarticular muscles of the hip and the posterior ligaments of the spine. (Calais-Germain & Lamotte 2008, p. 152.)

Flexibility of quadriceps femoris

Besides hamstrings, also the flexibility of quadriceps femoris is important. For example, the tension of rectus femoris may take the pelvis into flexion. This kind of tension may be produced by continues stretch or gymnastic movements performed without adequate flexibility. Tension-caused pelvis flexion is more evident when the knee is flexed. Pelvis flexion may reinforce ligamentary stiffness and therefore provoke lumbar arching. (Calais-Germain & Lamotte 2008, p. 150–151, 193.)

For performing front split with correct alignment, it is important to have flexibility in hip flexors to avoid extreme turnout of the rear leg (Alter 2004, p. 221–227). In AGG, many required balances and leaps include alignment of the front split. The front split is an asymmetrical movement, while the right and left halves of the pelvis behave differently: the other half is anteverted and other half retroverted. These types of asymmetrical positions also affect the sacroiliac joints in an asymmetrical manner. (Calais-Germain & Lamotte 2008, p. 152.) Therefore, it is important to practice front splits on both legs, and this is appreciated in AGG in the terms of bilateral work.

3 MUSCLE BALANCE AND H/Q STRENGTH RATIO

In this context, muscle balance is defined as a balance in strength properties. Muscle balance may be considered as balance between limbs next to each other (defined here as bilateral muscle balance) or balance between agonist and antagonist muscles (defined here as unilateral muscle balance). The antagonist muscles locating at the opposite sides of a joint must give an equal pull force for creating optimal structural balance and achieving homeostasis. The possible imbalances of bilateral muscle strength, or agonist and antagonist strength, may be due to several different factors, for example, weak muscles or hypertonic muscles. In these situations, intervention can be done by strengthening the weak muscle, and in the case of agonist-antagonist imbalance, also by stretching the possibly shortened muscle. (Alter 2004, p. 30, 221–226.)

The muscle group of hamstrings (H) is the antagonist for the muscle group of quadriceps femoris (Q), and vice versa. The balance of muscle strength between hamstrings and quadriceps femoris (H/Q) is essential for injury prevention. It has been studied that the H/Q strength ratio depends on the type of sport. (Alter 2004, p. 221–226.) Also age and pubertal status (Armstrong *et al.* 1997, p. 313–318, Wild *et al*. 2013) and gender (Huston & Wojtys 1996; Holm & Vøllestad 2008) are factors contributing the H/Q strength ratio. It has been suggested that a decrease from the normal, 50 % to 70 %, hamstring-to-quadriceps femoris muscle strength ratio may predispose to injuries (Alter 2004, p. 221–226).

Besides the injury risk caused by imbalance in muscle strength, also imbalances in flexibility may be in association with injury risk (Worrell *et al.* 1991). Furthermore, imbalance in flexibility may also be related to imbalance in strength (Daneshjoo *et al.* 2013). Also, acute stretching for hamstrings-only, without stretching the antagonist muscles, may decrease strength ratio of these muscles (Costa *et al.* 2009). Therefore, flexibility training for leg muscles may be reasonable to be performed for both agonist and antagonist muscles to prevent muscle imbalance.

3.1 Importance of muscle balance in injury prevention for athletes

Bilateral muscle balance

Imbalance in strength of the hamstrings of the left and right leg may cause strains and other injuries (Alter 2004, p. 221–226). This kind of imbalance in muscle strength ratios may be due to asymmetric use of muscles. (Van Praagh 1998, p. 229.) In other words, possible asymmetric use of muscles in gymnastics, as in leaps performed with right leg only, for example, is a risk for muscle imbalance and injuries. Moreover, muscle balance between the legs should be controlled to reduce the risk of strains and other injuries. AGG rules inform that bilateral muscle balance, in addition to other factors in physical performance, must be showed in a gymnastic program to attain maximum scores (IFAGGb 2012). Muscle bilateral work is not evaluated or required in all sports.

Unilateral muscle balance

There are a plenty of research studies performed in the field of hamstring strength, H/Q strength ratios and their possible connection to injuries in athletes. The H/Q ratio contributes to muscle balance or imbalance in posterior versus anterior thigh muscles. In some exercises or actions, as in running, for example, both agonist and antagonist muscles of the thigh contract at the same time. If either of these forces is greater than the other, a risk for injury exists. Usually the hamstrings are weaker than the quadriceps femoris, and this can lead to strains in the hamstring muscle group. (Alter 2004, p. 221–226.)

Quadriceps femoris, hamstrings and *gastrocnemius* play a major role in stabilization of the knee. Also knee joint surface geometry, the menisci and secondary ligament stabilizers affect the functional stability of the knee. (Huston & Wojtys 1996.) Holcomb *et al.* (2007) discussed, that the anterior cross ligament (ACL) experiences higher shear forces when the H/Q ratio is low, and therefore a risk for ACL injury in the knee exists. The study of Yeung *et al.* (2009), performed with sprinters, reported that the weak H/Q ratio (less than 0.6) may be related to injuries in hamstrings. Also Alter (2004) suggested that the H/Q strength ratio less than 50–70 % may predispose to injuries.

For AGG gymnasts, the landings from jumps and leaps are, among others, one risk factor for injuries. Beutler *et al.* (2009) have reported that weak hamstrings may be an important predictor for poor jump landing. Poorness of the landing was determined by its biomechanics. In total, there are many research results showing that low levels of hamstring strength or low H/Q ratios are related with injuries in the knee or in hamstrings (Gabbe *et al.* 2006; Devan *et al.* 2004; Söderman *et al.* 2001). It has been suggested, that a muscle rebalancing, conditioning program for the lower extremity may be reasonable, especially for quadriceps femoris dominant female athletes, in order to prevent injuries (Huston & Wojtys 1996).

A few study results on the H/Q strength ratios are collected in table 1. Most of the reported H/Q strength ratios are measured isokinetically, either as a conventional strength ratio with concentric force of hamstrings/concentric force of quadriceps, or as a functional strength ratio with eccentric force of hamstrings/concentric force of quadriceps. Isometrically measured H/Q ratios are published more rarely. However, according to Lord *et al.* (1992), isometric strength has been found correlating highly with isokinetic strength for both quadriceps femoris and hamstrings.

It should be noted, that also other factors, not related to either unilateral or bilateral strength ratios, may be risk factors for strains or other injury in hamstrings (Van Praagh 1998, p. 229). Flexibility imbalances, for example, may be in association with injury risk in athletes (Worrell *et al.* 1991). Moreover, in gymnastics, the emphasis in repetitive training of certain exercises may also increase the risk of overuse injuries. This may lead to even higher rates of injury than in contact sports, for example. To reduce the risk of injury, it is crucial to practice under sufficient supervision. (Brown & Brant 1988, p. 279–283.)

TABLE 1. A collection of a few studies on the H/Q ratio. The velocities in isokinetic measures differ between 60° to 500° /s.

Authors	**Subjects**	**Type of measurement**	**H/Q ratio**
Daneshjoo *et al.*(2013)	male soccer players	isokinetic	0.5-0.75
Fousekis *et al.* (2010)	soccer players	isokinetic	H_{con}/Q_{conc} 0.59-0.71 H_{ecc}/Q_{conc} 0.76-1.19
Kong & Burns (2010)	recreationally active females & males	isometric, isokinetic	0.42-0.8
Makaruk *et al.* (2010)	male sprinters and jumpers	isokinetic	0.51-0.78
Beutler *et al.* (2009)	male and female cadets	isometric	females 0.51 males 0.49
Yeung *et al.* (2009)	female & male sprinters	isokinetic H_{ecc}/Q_{conc}	not injured 0.96 H-injured 0.71
Holm and Vøllestad (2008)	children 7-12 years old	isokinetic H_{con}/Q_{conc}	girls 0.51-0.59 boys 0.55-0.68
Holcomb *et al.* (2007)	female soccer players	isokinetic H_{ecc}/Q_{conc}	0.96
Devan *et al.* (2004)	female field hockey, soccer, basketball players	isokinetic	0.62- 0.75
Siatras *et al.* (2004)	male gymnasts and swimmers, 9-11 years old	isokinetic H_{con}/Q_{conc}	0.65-0.88
Söderman *et al.* (2001)	female soccer players		0.52-0.54
Faro *et al.* (in Armstrong *et al.* 1997, p. 313–318)	boys 8-10 years old and adult men	isokinetic H_{con}/Q_{conc}	boys 0.62-0.79 adult men 0.55-0.67
Worrell *et al.*(1991)	male athletes	isokinetic	0.51-0.71

3.2 Muscle balance in children

Positive correlations between chronological age from childhood to adolescence and strength exist, especially in males. In females, the onset of puberty is at about 12 years of age, although, individual variation is large. Correlations have been reported in the prepubertal period, but strength changes in the postpubertal period remain controversial. In the prepubertal period, females demonstrate consistently lower absolute composite strength than males, however, the rate of increase in strength is similar for both genders. In the pubertal period, the strength changes between genders become more significant. The acceleration in rate of strength increases is high in boys but only slight and plateau-leading in girls. (Van Praagh 1998, p. 193–238.)

Related factors affecting strength changes during the childhood via maturation and longitudinal growth, are, muscle size, neurological development, motor coordination and changes in biomechanics (Van Praagh 1998, p. 193–238). Studies have reported of lower neural capacity indicated as lower muscle activation scores in prepubertal children compared to adults (Grosset *et al.* 2008; O'brien *et al.* 2010). Also, higher agonist-antagonist muscle coactivation rates may explain some strength differences between children and adults (Lambertz *et al.* 2003; Grosset *et al.* 2008; Frost *et al.* 1997). At puberty, also maturational awakening and sexual differentiation of the neuroendocrine axis play a significant role in force production (Van Praagh 1998, p. 193–238).

It has been reported that the H/Q strength ratio might be higher in children compared to adults. In the study of Faro *et al.* (in Armstrong *et al.* 1997, p. 313–318), 8–10 year old prepubescent children had significantly higher H/Q results compared to adults; however, the reasons for the difference were not clear. The authors concluded that smaller body size and different anatomy of children might be related to the reported differences. Wild *et al.* (2013) reported that puberty-related growth may cause strength changes and a decrease in the H/Q ratio. Therefore, puberty-related growth may be considered as one factor for changes in the H/Q ratio from childhood to adult.

In children aged 8–12 years, significant differences have been reported in the H/Q strength ratio between genders, as boys seem to have better muscle balance in thigh muscles. According to Holm and Vøllestad (2008), boys may have approximately 10 % higher H/Q strength ratios than girls of the same age. They reported that gender differences exist even before biomechanical maturational effects alter the children's biomechanics and anatomy. However, they observed only small differences in the H/Q ratios for each age group within prepubescent children.

3.3 Effect of puberty-related growth on hamstring muscles

Muscles that cross multiple joints, as *biceps femoris*, are susceptible to strain injury. A typical strain injury in hamstrings involves one muscle, usually the *biceps femoris*. More severe injuries involve more than one muscle, typically at the common tendon of origin for all hamstring muscles. (Garrett 1996.)

Puberty-related, longitudinal growth spurt in bones is associated with the growth of muscle and tendon units and remodeling of tendon insertion points. These changes may influence the lever arm of a muscle, as well as to lead into reduction of flexibility and increase in the stress across the joint and musculotendinous units. If the muscle is flexible and conditioned already before the intense growth phase, it can absorb more stress. This leads to the conclusion that conditioning and flexibility training are effective tools for prevention of musculotendinous strains, if considered already before the fast growth phase. (Van Praagh 1998, p. 60, 284.)

In gymnastics, there is a sport-specific advantage for individuals experiencing the puberty-related growth later, or continuing longer, than average child (Georgopoulos *et al.* 2001; Georgopoulos *et al.* 2010; Brown & Branta 1988, p. 227). For these individuals, there is perhaps more time to develop the adequate flexibility level before the intense puberty-related growth phase.

Wild *et al.* (2013) reported of musculoskeletal changes among girls at the time of their growth spurt. The results of the study agreed with the general knowledge that the peak of growth velocity in lower limbs occurs before the peak of velocity of total height. The peak velocity of torso growth occurs, then, after the peak of velocity of total height. They discussed that because bones grow faster than developing musculature during growth spurt, an associated decrease in lower limb flexibility due to bone growth, may exist. In this study of Wild *et al.* (2013), only the flexibility of hamstring muscles decreased significantly, suggesting that compared to quadriceps femoris, hamstrings may be weaker and more susceptible to injury while rapid bone growth. The decrease in hamstring flexibility occurred around the time of peak lower limb growth.

In addition to flexibility changes in hamstrings, Wild *et al.* (2013) reported of strength changes during the growth spurt (figure 2). The quadriceps femoris strength increased significantly while the hamstring strength did not, leading to the weakened H/Q strength ratio. This lag in development of hamstring muscle strength, relative to quadriceps femoris strength, needs further research. A lower H/Q ratio during the growth spurt may have risk effects on pubescents, as, for example, a low H/Q ratio in landing performances of jumps is related with knee injury risk (Wild *et al.* 2013).

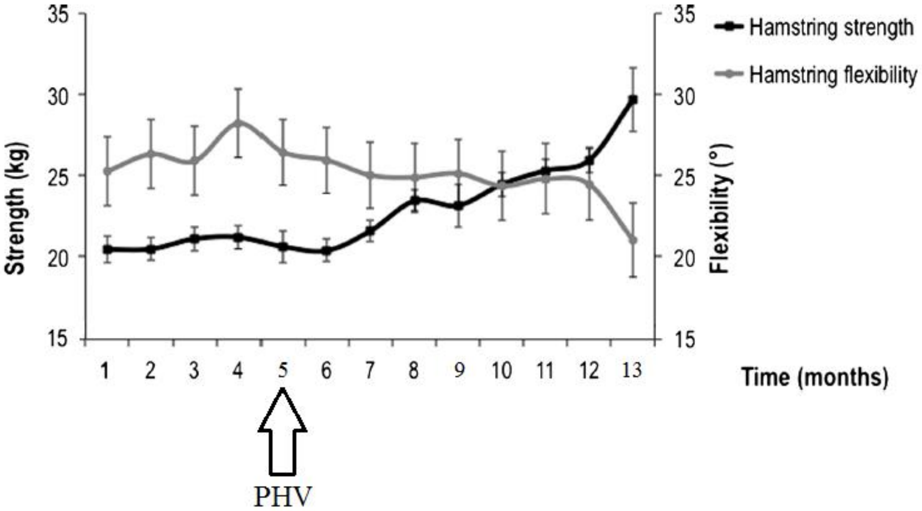


FIGURE 2. Changes in hamstring flexibility and strength around the peak height velocity (PHV). An increase in angle indicates a decrease in flexibility. Modified from Wild *et al.* (2013)

Besides anatomical differences caused by the longitudinal growth spurt, there are several other strength-related gender differences reported in adolescence. These are, laxity of ligaments around the knee (Dugan 2005; Huston & Wojtys 1996), age-related hormonal profile (Dugan 2005) and muscle activation patterns (Huston & Wojtys 1996), for example. For many of these variables, it is not clear whether they are caused at puberty or occur later on in adolescence.

Because of the possible effects of puberty and the longitudinal growth spurt on the H/Q ratio and flexibility, the empirical part of the present study included two age groups to determine possible differences in the younger group (before growth spurt) compared to older group (during or immediately after the peak growth spurt).

3.4 Flexibility training and muscle balance

In AGG, flexibility of leg muscles is evaluated in scores within the shapes of balances and jumps (IFAGGb 2012). Though, flexibility training is relevant for athletes in AGG. The flexibility training for hamstring and quadriceps femoris is also important as a preventive tool against injury risks (Calais-Germain & Lamotte 2008, p. 150–152, 193; Daneshjoo *et al.* 2013). Also, the length of the muscle affects the capacity to produce force (Komi *et al.* 2003, p. 119–120).

It has been studied that in soccer, the non-dominant leg has lower flexibility, which may lead to injury (Daneshjoo *et al.* 2013). From the results of the study of Daneshjoo *et al.* *(*2013), it can be interpreted that differences in bilateral muscle strength balance may, in some cases, be in relation to muscle flexibility imbalance. Also Worrell *et al.* (1991) reported that flexibility imbalances may be in association with injury risk in athletes. In AGG, flexibility is the most valuable physical component. Bilateral balance in flexibility is required to achieve more balanced movements with healthy aspects considered. However, the unilateral muscle balance is not evaluated at the same magnitude, unless it is related to weak performance. (IFAGGb 2012.)

A lack of flexibility may be related to strain injuries. A strain may be due to an excessive stretch, or a combination of stretch and muscle contraction. The more energy the muscle can absorb, the more resistant it is to strain. The ability of a muscle to absorb energy includes both passive and active elements. The passive elements include muscle fibers and connective tissue and their properties; their resting length and elasticity, for example. The active elements are involved because muscle activation increases the ability to absorb energy. (Garrett, 1996.)

The clinical study of Garrett (1996) suggested that cyclic stretching appears to be beneficial in injury prevention, if it is performed with a reasonable amount of force. Therefore, it might be reasonable for gymnasts to gain the required flexibility by cyclic stretching, without high external force. In AGG, there are several different stretching methods used.

As mentioned earlier, Wild *et al.* (2013) reported of a decrease in hamstring flexibility due to bone growth. Also, Van Praagh (1998, p. 284) suggested that flexibility gains might be reasonable to acquire already before the fast growth phase for preventing injuries. Based on these results, it may be concluded that especially hamstring flexibility should be trained before puberty. This may be the common conception in AGG.

However, there has been some speculation whether the stretching of agonist only is reasonable or not. Costa *et al*. (2009) reported that stretching hamstrings-only resulted in a decrease in the H/Q strength ratio, measured before and after stretching. This could indicate that the injury risk with the lower H/Q ratio increases while stretching hamstrings prior performance events. It remains unclear, whether this risk of stretching hamstrings-only is even more relevant in women, who in general are reported to have lower H/Q strength ratios. Because hamstring stretching is relevant for AGG athletes to achieve adequate flexibility (IFAGGb 2012), further research is essential to clarify the chronic effects of hamstring stretching on the H/Q strength ratio.

4 H/Q MUSCLE ACTIVITY

There are two main factors for strength development; adaptations in the nervous system, and adaptations in contractile elements (Komi 2003, p. 3–22). Adaptations in the nervous system attribute to the magnitude of muscle activity (Kraemer & Häkkinen 2002, p. 20–29), and muscle activity can be estimated by electromyography (EMG). Electromyographic signals represent electric potential originally produced by motor unit activation. (Merletti & Parker 2004, p. 2–7.) Surface electromyography is a common method to study sport-related issues on muscle activity. (Merletti & Parker 2004.)

Compared to adults, children have overall lower neural capacity, which is observed in lower magnitude of muscle activation (Grosset *et al.* 2008; O'brien *et al.* 2010). As the magnitude of muscle activation has been found age-related, also differences in antagonist coactivation between children and adults exist (Lambertz *et al.* 2003; Falk *et al.* 2009; O'Brien *et al.* 2009). Besides child-adult differences in neural capacity, also differences between genders have been reported considering muscle activation and activation patterns (Huston & Wojtys 1996).

Muscle activity of H/Q has been studied in several sports including football (Wright *et al.* 2009), but research on AGG is extremely narrow. Single studies on leg muscle activation patterns have, however, been performed. In jumps and leaps, as well as in some balance movements, activation of leg muscles have been reported (Dyhre-Poulsen 1987; George 1980, Takala 2010) but, for example, the body movements of AGG remain to need further study.

4.1 Motor unit activation

A motor unit is the functional unit of a skeletal muscle, consisting of an alpha (α)-motoneuron and the specific muscle fibers it innervates. The cell body of α-motoneuron locates in the spinal cord and is the final point of summation for descending and reflex inputs. (Merletti & Parker 2004, p. 2-3.) Alpha motoneuron consists of dendrites, a cell body and an axon, which together act as a transmitter of an electrochemical impulse from the spinal cord to the muscle. Dendrites conduct the nerve impuls to the cell body, from which the impulse continues along the axon to the muscle fibers. (McArdle 2007, p. 402–403.) Some motor units have only a few muscle fibers to innervate (muscles associated with fine motor control) while others can innervate even thousands of muscle fibers (muscles associated with forceful movements, as quadriceps femoris) (Watkins 2010).

Muscle fibers innervated by the same motoneuron manifest nearly identical histochemical, biochemical and contractile characteristics. The motor units can be classified as type I, type IIa and type IIb according to their physiological properties. Type I muscle (slow twitch) fibers have high levels of ATPase activity and low levels of succinic dehydrogenase and their metabolism is mainly oxidative. The enzyme activities of the types IIa and IIb are considered as reversed compared to type I, and they both have fast twitch properties. Type IIa act by oxidative glycolytic metabolism and is more fatigue resistant than type IIb, which uses only glycolytic pathways for metabolism. Motor unit types appear to be randomly distributed across the muscle cross section and depending on the function of the muscle, the percentage of the fiber types may vary. (Merletti & Parker 2004, p. 3–6.)

The greater amount of motor units is recruited and/or the higher their firing frequency is, the greater is the force produced. Motor unit recruitment seems to be the major mechanism for generating extra force above 50 % of maximal voluntary contraction (MVC). Furthermore, a strong relationship between EMG signal and the exerted force might be expected. (Merletti & Parker 2004, p. 6–7.) The widely accepted size principle, originally presented by Henneman *et al.* (1965), proposes that motor units are recruited in order of increasing size of the α-motoneuron. According to this principle, type I motor units (low-threshold) are recruited first and type II motor units (higher threshold) secondly, by increasing motoneuron firing frequency.

The EMG signal represents the electric potential field generated by the depolarization of the sarcolemma. Either intramuscular or surface electrodes are used in detection of EMG signals. EMG signal is derived from the potential change in sarcolemma. This change is due to an electrical impulse from the cell body of α-motoneuron, which causes an emission of acetylcholine in the neuromuscular junction that excites the sarcolemma to depolarize. Intracellular action potential (IAP) propagates along the sarcolemma (depolarizing zone), and after the excitation has stopped, the repolarizing zone will follow. The IAP, originally generated by a motor unit, can be detected also in locations relatively far from the signal source. This can be achieved because IAP determines an electrical field to the surrounding space. (Merletti & Parker 2004, p. 81–91.)

Comparison of H/Q strength ratio between females and males has been performed. Huston and Wojtys (1996) suggested that different initial muscle recruitment patterns may contribute largely for differences in hamstring and quadriceps femoris muscle strength between genders. They observed that muscle recruitment patterns were different for females and males, and for female athletes and non-athletes. Muscle activities in response to anterior tibial translation, in other words, in response for knee stabilization, were different among genders, and among elite athletes compared to the control groups. In overall, it was observed that female athletes were quadriceps femoris dominant, as they relied more on the quadriceps femoris and *gastrocnemius* muscles compared to hamstrings. In males, hamstring dominance was found. However, non-athletic females did not demonstrate significant amplitude of quadriceps femoris dominance, and therefore, the training background of the athletes could be one factor for the development of quadriceps femoris dominant activation pattern. As quadriceps femoris dominance brings more risk factors for muscle imbalance (Alter 2004, p. 221–226), female athletes may be more susceptible to develop injuries among sports.

4.2 Development of the neuromuscular system from child to adult

There has been controversy in studies regarding neural activation in children compared to adults. Some studies report lower muscle activation scores in prepubertal children compared to adults (Grosset *et al.* 2008; O'brien *et al.* 2010), which indicates lower overall motor unit activation: lower neural capacity. Grosset *et al.* (2008) demonstrated that adults had higher motor unit activation compared to 7–11 year old children, while measured as maximum EMG amplitude during maximum voluntary contraction of *triceps surae*. In the same study, motor unit activation also increased progressively with age when measuring 7–11 year old children. However, their study indicated that muscular changes were even greater than the changes in neural activation.

O'brien *et al.* (2009) discussed that the lower muscle activation among children would be due to activation of fewer motor units than adults. Furthermore, in a review article of Dotan *et al.* (2012) a hypothesis was presented, that children recruit fast type II motor units to a lesser extent than adults. This is based on the size principle (Henneman *et al.* 1965), which indicates that the lower overall motor unit activation would be a result of a lesser activation of high-threshold motor units (type II), since they are typically activated as the last ones. Still, not all studies agree with significant changes in muscle activity rates through age (Seger & Thorstensson 2000).

Agonist-antagonist muscle coactivation may explain some strength differences between children and adults. Simultaneous activation of antagonist muscles detracts from the externally measured force output and attributes to the examined agonist muscles. Antagonist coactivation rates are considered generally higher in children compared to adults, which can be observed from figures 3 and 4. (Frost *et al.* 1997; Grosset *et al.* 2008; Hassani *et al.* 2009; Lambertz *et al.* 2003.) The reduction in antagonist coactivation may lead to increased neural capacity and increased force production (Häkkinen, 2002).

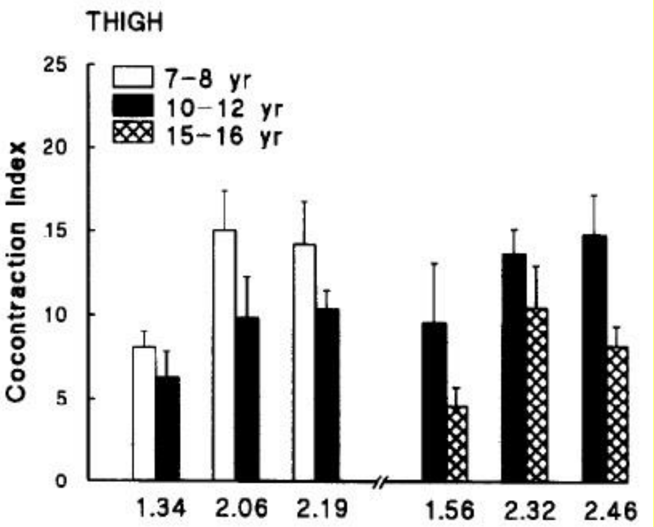


FIGURE 3. Agonist-antagonist coactivation index values for identical speeds of walking or running performed by two age groups for thigh muscles (quadriceps femoris and hamstrings, $p < 0.05$). Co-activation index is calculated from the overlapping area of agonist and antagonist muscle activation. (Frost *et al.* 1997)

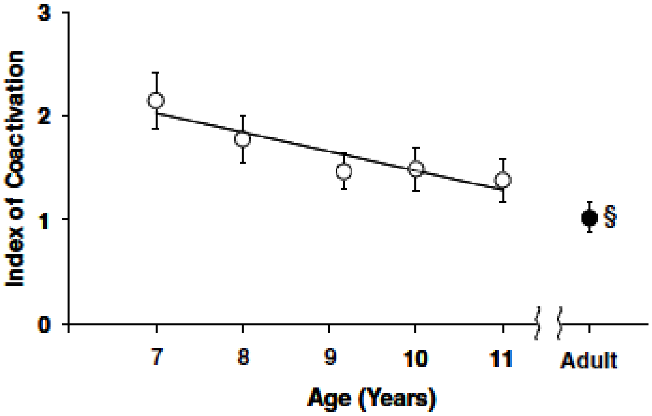


FIGURE 4. Decreasing agonist-antagonist coactivation of tibialis anterior in different age points ($p < 0.05$). (Grosset *et al.* 2008)

While agonist-antagonist coactivation has great effects on the muscle activation levels, also other factors may contribute to muscle activation changes through age. It is suggested, that both gender (Holm & Vøllestad 2008; O'Brien *et al.* 2010), and force level (Grosset *et al.* 2008) may contribute to the effects of development on muscle activation levels. The exact factors for different activation patterns between genders and the timing of their occurrence remain uncertain. One explanation for greater antagonist coactivation in children may be the protective aspect of cocontraction, which may inhibit, for example, joint damage. Skeletal and muscular systems undergo changes during growth, and Frost *et al.* (1997) suggested that with maturation of the skeletal system, the need for dynamic protection via antagonist coactivation is lower. This may explain both the greater amount of antagonist coactivation in children versus adults, and older children versus younger children. (Frost *et al.* 1997.) Because of greater tendon compliance among children (Lambertz *et al*. 2003), the muscle length dependent effects, as force production in eccentric movements, are also important for consideration when testing young children.

4.3 Antagonist-coactivation of hamstrings and quadriceps femoris

Hassani *et al.* (2009) studied the antagonist activity of thigh muscles (*biceps femoris, vastus lateralis, vastus medialis*) in children and adults in different knee joint angles. They reported that coactivation was higher in extreme angles, and concluded that the higher joint angles may have caused a deficit in neuromuscular performance in children, that could be attributed to higher antagonist activity. Also, antagonist coactivation present under submaximal conditions (Lambertz *et al.* 2003) may be greater than in maximal isometric contractions (Falk *et al.* 2009; O'Brien *et al.* 2009). Coactivation in submaximal AGG movements has not been reported at the publication time of the present study.

Also De Vito *et al.* (2003) have studied antagonist coactivation. They reported that neither the level of force nor the duration of the contraction affected the amplitude of antagonist coactivation, when measured from the *biceps femoris* in young adults. They also reported a gender independent effect: level of adiposity did not correlate with the level of antagonist coactivation.

As antagonist coactivation in children may inhibit joint damage (Frost *et al.* 1997), the antagonist activation of hamstrings and quadriceps femoris is important for protecting knee joint from injuries. Antagonist coactivation of *vastus lateralis* and *biceps femoris* in landing of a jump has been studied by da Fonseca *et al.* (2006). They reported that athletic women had lower coactivation rates than non-athletic women, and discussed of subsequent knee injury risk in women with lower coactivation rates.

4.4 Muscle activation in gymnastics

Dyhre-Poulsen (1987) and Takala (2010) have reported of reaction forces and leg muscle activities during gymnastic jumps and leaps. George (1980) describes the muscle activity patterns during balance movements. However, research on muscle activities in body movements of AGG has not been reported at the publication time of the present study.

Jumps and leaps

Leaps consist of take-off, flight time and landing. Figure 5. shows an example of a leap. During the flight time, there may be variations in the body position and movement, but general mechanisms for most of the leaps are the same. Usually they consist of single-leg take-off and single-leg landing. The take-off phase of a leap is a fast, accelerating approach and is followed with the contact of the pushing leg to the ground while leaning the body backward. A brief flexion of ankle, knee and hip of the push leg and forceful extension of these joints (kickback action), following immediately to the flexion, is essential for leaps. (George 1980, p. 125-126.) To perform this kind of powerful extension, hamstrings (extension of the hip), quadriceps femoris (extension of the knee) and calf muscles (plantar flexion of the ankle) must be activated to produce force (Alter 2004, p. 215–226).

In the beginning of flight phase, the leading leg extends forward and the hip of the push leg hyperextends backward. To achieve the required amplitude between the legs, the position must undergo specifically timed changes from a partial split of the take-off, to fully split legs of the flight, and back to the partial split prior to the landing. In the landing phase, only the ankle, knee and hip joints of the leading leg flex to absorb the force of the impact to the ground. (George 1980, p. 125–126.) For reducing the impact of landing, for example, eccentric force production of *vastus lateralis* is relevant (Takala 2010).

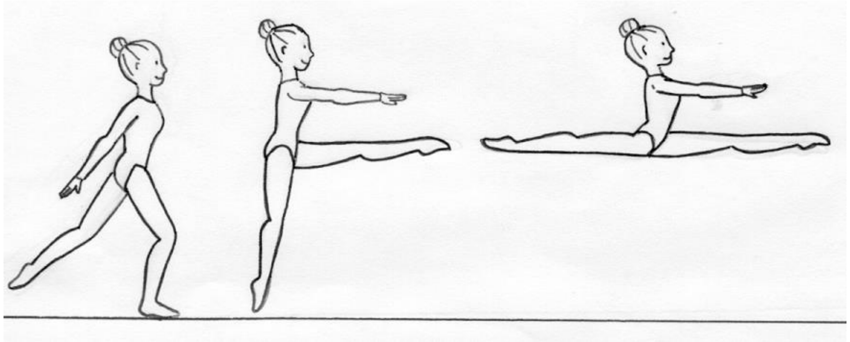


FIGURE 5. Take-off and flight of a split leap (IFAGGb 2012)

Dyhre-Poulsen (1987) described that height of a split leap does not correlate with the skill of leaping, whereas the ability to strongly extend the pushing leg does. Takala (2010) reported also a negative correlation between the contact time and flight time of a split leap. The reported contact times of the take-off were 0.20 s in the study of Dyhre-Poulsen (1987), as in the study of Takala (2010). Dyhre-Poulsen (1987) discussed, that the best gymnasts may reach and keep the split position faster and longer to create an illusion of a high split leap. The flight times in these studies were 0.46 s (Takala 2010) and 0.49 s (Dyhre-Poulsen 1987) for gymnasts with mean age between 17-18 years. Takala (2010) also reported that force of landing was 6.4 ± 1.3 times the body weight.

Takala (2010) reported of muscle activities in the take-off, flight and landing parts of split leap. As presented in figure 6, two quadriceps femoris muscles, *rectus femoris* and *vastus lateralis*, were activated relatively more than *biceps femoris* (hamstrings) in the pushing leg in both the take-off and flight. Takala (2010) discussed that if the activation of the quadriceps femoris in the pushing leg would be lower during flight, the pushing leg might rise higher, showing more flexibility. This could happen if the gluteus and hamstring muscles, antagonists to quadriceps femoris, have the opportunity to activate relatively more.

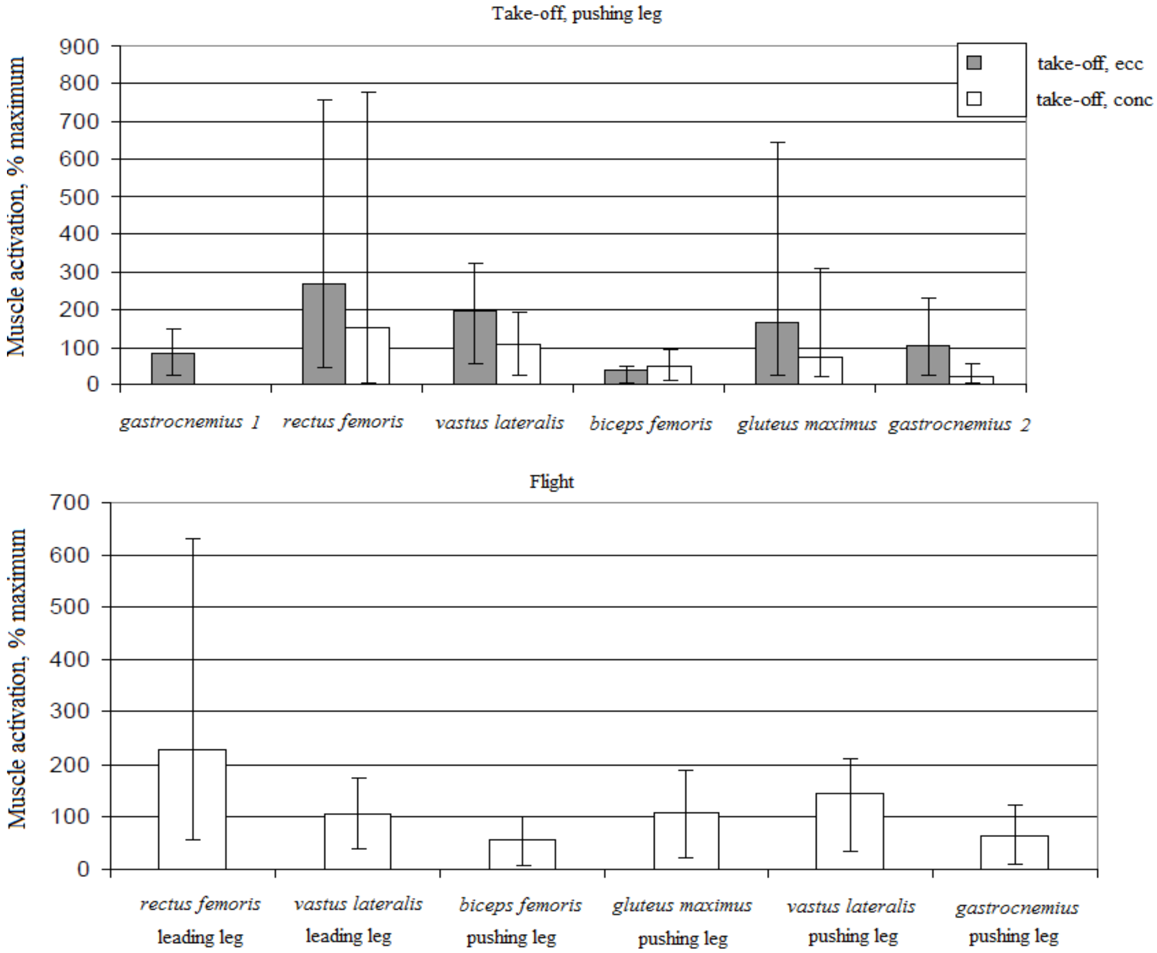


FIGURE 6. Muscle activities of take-off (upper figure) and flight (lower figure) in split leap. Modified from Takala (2010)

Balance movements

In AGG performances, there are both static and dynamic balance movements. Pirouttes (pivots) are one form of the dynamic balances (IFAGGb 2012), and they consist of turning around the longitudinal axis of the body. This axis is formed by the extending supportive leg, trunk and head. (George 1980, p. 129–130.) In AGG, variety of body positions during balance movements can be applied (IFAGGb 2012). The first phase in pirouttes is the push-off from lunge position, where the extension of supportive leg (hip, knee, ankle) is important (George 1980, p. 129–130). Sufficient quadriceps femoris and hamstrings activation is crucial to produce enough force in extending the knee or hip (Alter 2004, p. 215–226). Body mass is then balanced upward and pirouette is initiated. During the rotational phase, the longitudinal axis from the ball of the supportive foot to the head is maintained. The speed of the pirouette lowers progressively, when ankle, knee and hip joints of the supportive leg are flexed and knee joint of the swinging leg extended. (George 1980, p. 129–130.) In static balances, the shape must be fixed via the supportive leg (IFAGGb 2012). Therefore, isometric muscle activation of the supportive leg must be coordinated to produce force and good performance. Figure 7. shows an example of a static balance movement.

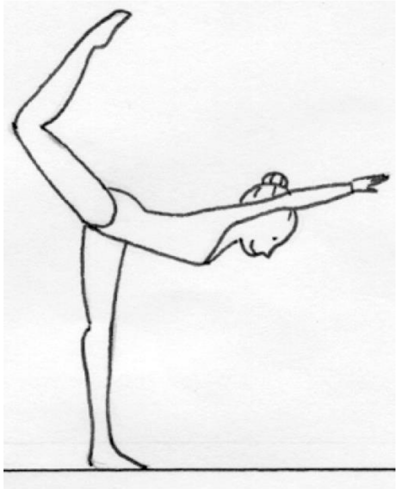


FIGURE 7. Static balance, leg behind. (IFAGGb 2012)

Balance can be measured as the amount of velocity moment in postural sway, which can be calculated as the mean area covered by the movement of center of forces (COF) per each second. This informs of the velocity and the amplitude of the postural sway. (Era *et al.* 1996.) The less postural sway – the more balanced the position is.

Body movements

Until present, there has probably not been international research information published concerning body movements in AGG. The minimum required body elements in the program are body swings and body waves, which can be performed in different levels, such as standing or on the floor (IFAGGb 2012). As in figure 8, the supportive legs produce flexion-extension movement of the knee joint during the movement. Because there is a lack of studies on this specific body movement, the movement may be analyzed first for the legs only. There are study results available concerning muscle activities of legs during a squat movement, which resembles the movement of body swing for the legs.

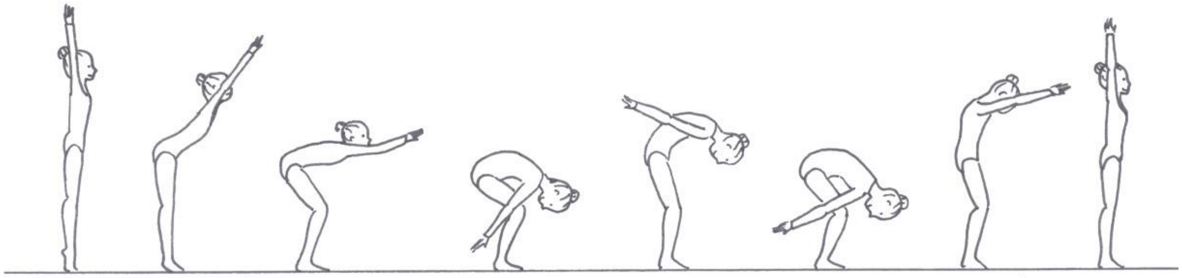


FIGURE 8. Body swing (The Finnish Gymnastics Federation 2010)

Youdas *et al.* (2007) studied, for example, a single-limb squat performed on a stable surface. They reported of women displaying significantly more (normalized) muscle activity in quadriceps femoris compared to men during the movement, and men generating significantly more (normalized) muscle activity in hamstrings. The conclusion of this study was that women are more quadriceps femoris dominant compared to men in a single-limb squat. Whether this implies also to body swings or not, would need further research.

4.5 Surface EMG

With surface electromyography, it is possible to study clinical aspects of muscle-related diseases as well as some sport-related issues, for example. A clinical neurophysiologist is mainly interested in the recruitment and firing behavior of single motor units (MUs) (Stegeman *et al*. 2000). A sport-related issue, on the other hand, may concern muscle activation patterns, coordination of muscles, and strength-training induced adaptations, for example (Merletti & Parker 2004). As effects of strength training in children are mainly mediated via neurological mechanisms (Granacher *et al.* 2011; Kraemer & Häkkinen 2002, p. 155–157; Lambertz *et al.* 2003), surface EMG studies for investigating effects of strength training are reasonable, especially in children. An example of EMG activation measured with electromyography is presented in figure 9.

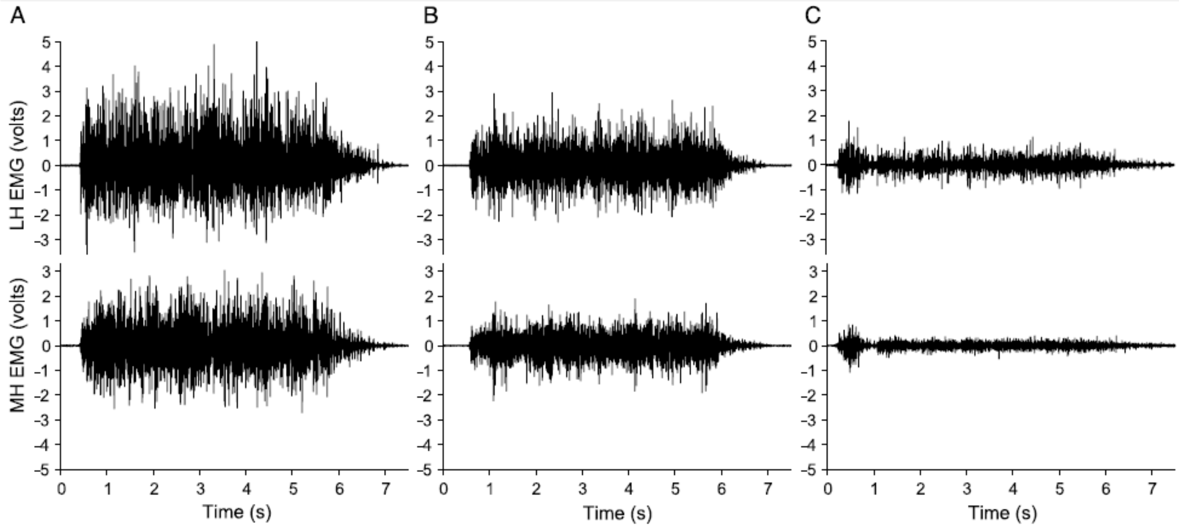


FIGURE 9. An example of EMG activation. EMG measured from MVIC (A), 50 % effort of MVIC (B) and 10 % effort of MVIC (C) of medial hamstring (MH) and lateral hamstring (LH) muscles. (Campy *et al.* 2009)

EMG/force ratio

Force production depends on the recruitment of additional motor units and on the increase of firing rate of the active motor units. The same pattern is observed with surface EMG: The amplitude of activation depends on the recruitment and the firing rate of the already active motor units. Since both the force and EMG activation are increasing with the same mechanisms, it is possible to estimate muscle force from surface EMG amplitude. (Merletti & Parker 2004, p. 97–99.)

However, there are contributing factors, as the location of the electrode or the thickness of the subcutaneous fat layer, which may have a great influence to the relation between the EMG activation and force (table 2). In addition, muscle conditions including muscle length, temperature and fatigue affect this relation, and considering the large variability of the behavior of EMG amplitude depending on these factors, an adaptive EMG-force relation is not reasonable. (Merletti & Parker 2004, p. 97–99.)

TABLE 2. Some factors contributing the relation of EMG activation and force. Collected from Merletti & Parker (2004, p. 97–103).

Factor	**Influence on EMG**
recruitment of additional MUs	contributes to the amplitude of EMG
firing rate of already active MUs	contributes to the amplitude of EMG
location of electrode	defines the place where to detect the amplitude
thickness of subcutaneous fat layer	defines the amount of volume conductor
muscle length	joint angle influences the activity of the muscle
muscle temperature	influences the rate of chemical reactions
muscle fatigue	fatigued muscle generates higher EMG signals compared to non-fatigued muscles

EMG activity in MVIC vs. dynamic actions

In dynamic actions, it is possible to analyze the function and coordination of muscles in different movements and postures via muscle activation patterns (Merletti & Parker 2004, p. 367). However, while recording muscle activities of certain muscles, it may be more accurate to use static, isometric actions for minimizing movement of the electrode in relation to the muscle (Merletti & Parker 2004, p. 89–95). In dynamic movements, the coactivation of antagonist muscles may also differ depending on the position of the body. For example, in the study of Draganich *et al.* (1989), the coactivation of hamstrings in knee extension performed at sitting position was reported significantly different compared to the activation performed with the knee extension at prone position. This should be taken into consideration when studying coactivation patterns in different movements.

In maximal voluntary isometric contractions (MVIC), the antagonist coactivation might be different compared to dynamic movements. In MVIC, there might be minimal or no age-related changes in antagonist coactivation. Under submaximal conditions, these changes may be greater. (Falk *et al.* 2009; O’Brien *et al.* 2009; Lambertz *et al.* 2003.) Furthermore, the possible strength gains in isometric MVIC during biological development would not be, for main part, due to coactivation changes. However, in submaximal or dynamic movements, this could be one factor affecting increases in strength.

Absolute surface-EMG comparison between subjects is not reasonable because of large variability of EMG-affecting factors. However, it may be more reasonable to normalize and compare the ratio of absolute EMG value measured from dynamic movement to the absolute EMG value of MVC, as have been done in previous studies (Frost *et al.* 1997; da Fonseca *et al.* 2006). This ratio informs how high the activation is compared to the individual maximum of voluntary muscle activation.

Volume conductor properties

The tissue separating the signal source muscle and the detecting electrode is called volume conductor. It consists of the skin and the subcutaneous adipose tissue, and its characteristics affect to the nature and amplitude of the detected EMG signal. As body fluids conduct, and fat attenuates the electrical signal, the electrical properties of subcutaneous tissue have effects on the EMG signal. One of the most important sources of error in recording EMG signals with surface EMG is the existence of crosstalk, which is mostly due to the volume conductor properties. Crosstalk is false signals, detected by the surface electrodes, that originally propagate from another muscle near to the one studied. Crosstalk can lead to false conclusions especially when studying movement analysis, where it is crucial to detect which muscles are active in each time point. While using surface EMG electrodes, the effect of volume conductor is greater than while using intramuscular electrodes that are inserted closer to the muscle fiber. To remove some technical interference, the signals from surface EMG are usually detected as a combination of the signals recorded at different electrodes. The “classical” bipolar technique is an example of this kind of method. (Merletti & Parker 2004, p. 87–91; Nordander *et al.* 2003.)

The thickness of subcutaneous adipose tissue varies between genders and individuals (Daneshjoo *et al.* 2013; Nordander *et al.* 2003) and therefore individual variations affect the filtering effect of the volume conductor. The amount and properties of the subcutaneous tissue, or its fat content, can be measured easily by BMI, or more reliably by skinfold calipers. (Nordander *et al.* 2003.) In adults, women have higher fat content and higher levels of subcutaneous adipose tissue than men (Camhi *et al.* 2011). In children and young adults, Tafeit *et al.* (2007) observed gender differences in seven different age groups from 7 to 21 years and found that girls had significantly more subcutaneous fat in the age groups of 11–21 years, compared to boys of same age. From this study, the levels of subcutaneous fat in three different measuring points in the thigh are presented in figure 10.

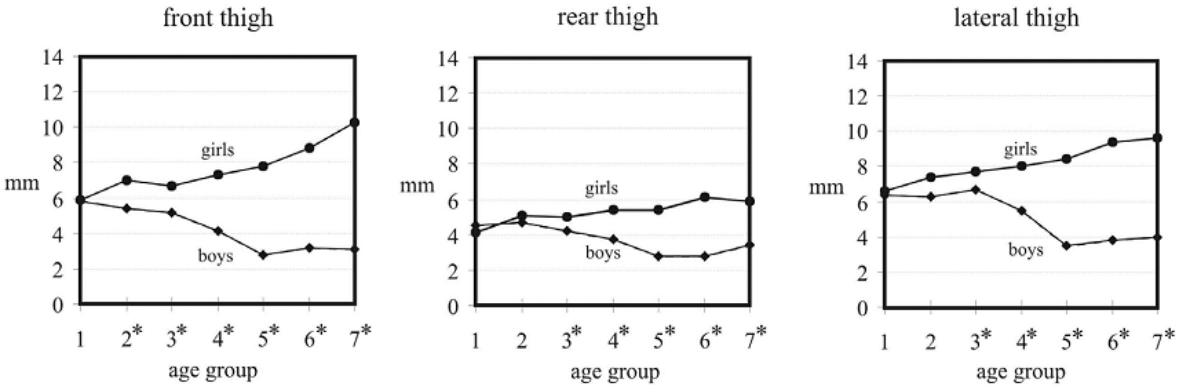


FIGURE 10. Subcutaneous fat in girls and boys (age groups 1: 7–9 yrs, 2: 9–11 yrs, 3: 11–13 yrs, 4: 13–15 yrs, 5: 15–17 yrs, 6: 17–19 yrs, 7: 19–21 yrs). * = significant difference between genders. (modified from Tafeit *et al.* 2007)

As Tafeit *et al.* (2007) did not find significant gender differences in the amount of subcutaneous fat in children under 11 years old, Kainbacher *et al.* (2011) reported contrary results. They suggested that also girls aged 5–7 years would have thicker subcutaneous adipose tissue in comparison with boys. This difference between genders was due to the greater decrease of fat in abdomen and legs in boys. To conclude, thicker subcutaneous adipose tissue among girls may lead to attenuated surface EMG signals detected.

5 STRENGTH TRAINING

Strength of a muscle is defined as the maximal force generated at a determined velocity. Therefore, effects of strength training are usually controlled by testing maximal force production. Strength training may be divided into resistance training and muscular endurance training depending on the repetitions and loads used. (Komi 2003, p. 3–7.) Furthermore, resistance training is divided into maximal strength training, hypertrophic strength training and explosive strength training. Explosive strength training develops power. Both maximal and explosive strength training bring adaptations mainly to the nervous system, while hypertrophic strength training affects also largely to the peripheral fatigue in contractile elements. In gymnastics, power and local muscle endurance are required for optimal performance. (Kraemer & Häkkinen 2002, p. 20–29, 115–122.)

Gymnastics includes mostly skill training. However, skill training alone may not yield the desired results, and supplementary strength training may be important for improving physical performance, especially in jumps. Furthermore, needs analysis must be taken into consideration while forming skill-specific strength training. (Kraemer & Häkkinen 2002, p. 115–122.) The goal of strength training in aesthetic sports, as the name says, may be to avoid hypertrophic training and increases in size of muscles, and furthermore, to improve strength by increasing EMG activity.

Strength training exercises are divided into static and dynamic movements. In static exercises the muscle performs isometric action: producing force without movement. Dynamic exercises are either concentric actions, with shortening movement of muscle fibers, or eccentric actions, with lengthening movement of muscle fibers. The combination of eccentric and concentric actions is usually called the stretch-shortening cycle. (Komi 2003, p. 3–7.)

Factors affecting force production on neural level, are, motor unit recruitment, firing frequency, modification by muscle and tendon receptors, coordination and skill. Also characteristics of muscle tissue, such as muscle cross-sectional area and fibre type, affect strength. When planning strength training programs, several factors must be taken into consideration, as training specificity, training overload, intensity, frequency, volume, repetitions, sets, rest, reversal and interference. (Kraemer & Häkkinen 2002, p. 9–18.)

Strength increases naturally from birth to adulthood and is influenced mostly by biological maturation and sexual differentiation. Already in childhood, strength training may improve performances and reduce the rate of sport injury. (Van Praagh 1998, p. 214–218.) Strength training may help to maintain the muscle balance to prevent muscle strains in hamstrings (Alter 2004, p. 223). To improve the H/Q ratio and muscle balance of thigh muscles, a training period that emphasizes hamstring strength is needed (Holcomb *et al.* 2007).

5.1 Strength training adaptations in children

There is a positive correlation between age and maximal voluntary contraction within prepubertal girls. Strength training at this age may lead to significant increases in strength. The strength gain is rapid during the prepubertal phase until 12 years of age, and after this, in the late puberty, the increases in strength are only slight. (Van Praagh 1998, p. 194–211.) This may indicate that for improving muscle imbalance, the strength training for weak antagonist muscles would be beneficial to be practiced already in prepuberty, when the strength gains are possibly greater.

Mechanisms for strength gains in children are slightly different compared to adults; morphological adaptation is small compared to the strength gains. One mechanism for training-induced strength gains is the increase in neuromuscular activation. In children, also the improvement of motor coordination plays a role when studying the increases in strength; however, in simple single-joint exercises this attribution is small. In addition, qualitative adaptations in the muscles, such as changes in contractile properties, may have some contribution. (Granacher *et al.* 2011; Van Praagh 1998, p. 214–216.) The effects of strength training depend also on the age of subjects and type of strength training. Maximal muscle strength might be lower in children than in adults, even when normalized to body mass (Lambertz *et al.* 2003). Several studies have suggested that training-induced strength gains in children are mediated mainly via neurological mechanisms, while hypertrophy playing a minor role (Granacher *et al.* 2011; Kraemer & Häkkinen 2002, p.155–157; Lambertz *et al.* 2003).

According to data from Pfeiffer and Francis (1986), hamstring (knee flexion) trainability in prepuberty may be higher compared to quadriceps femoris (knee extension) in boys (figure 11). In this study, hamstring trainability was reported higher in prepuberty compared to puberty or post-puberty, indicating that prepuberty is a sensitive period for hamstring strength training. Therefore, for optimal strength development and sport performance, it may be appropriate to seek for hamstring strength gains already in childhood. (Van Praagh 1998, p. 194–211; Pfeiffer & Francis 1986.)

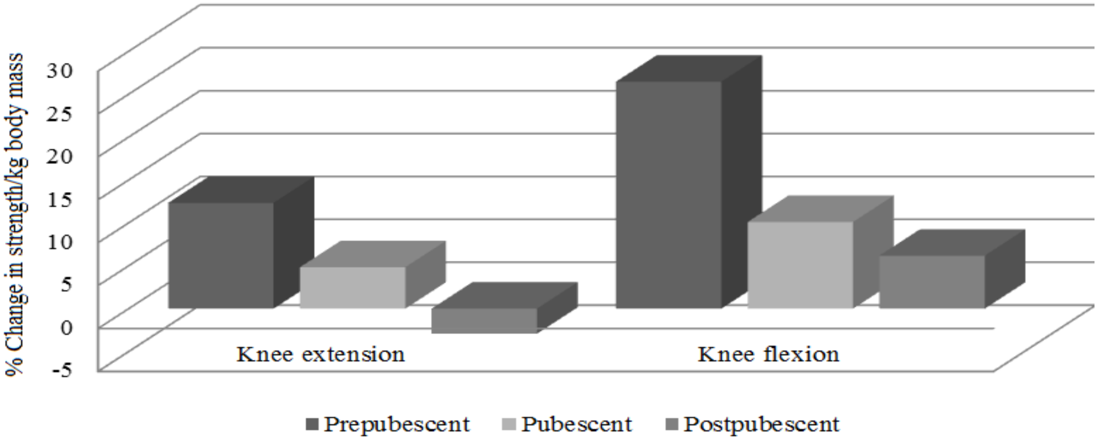


FIGURE 11. Strength changes in males after a training period. Data from Pfeiffer & Francis (1986)

As research on strength training in children is limited, some neurological adaptations, as mechanisms of learning, for example, may be partly applied from studies performed with untrained adults. Strength training performed with untrained adults, as in children, may induce strength gains for large part by neurological mechanisms. The improvement of ability to recruit high-threshold motor units is high within the first four weeks of training (Merletti & Parker 2004, p. 373). Also enhanced motor unit synchronization and simultaneous fluctuations in motor unit firing rate have been proposed as contributors for strength gains due to strength training (Merletti & Parker 2004, p. 373; Semmler *et al.* 1998). Strength athletes should keep their training intensity very high, or maximal, in order to produce increases in the maximal voluntary neural activation of muscles (Kraemer & Häkkinen 2002, p. 27–28).

In untrained adults, learning of the motor task may have a great contribution to the muscle activation. It has been suggested that in the beginning of learning process, the magnitude of muscle activity changes, and when continuing the training, the alterations in the duration of the muscle activation will come more important. (Gabriel & Boucher 2000.) Increases in the maximum EMG in the beginning of the strength training program are large, but will lower after long background of training (Kraemer & Häkkinen 2002, p. 20–29). Training does not, however, necessarily lead to increased neuromuscular activity. For example, Gabriel *et al.* (2001) did not find any changes in muscle activation of *biceps bracchii* after an isometric training period. As we can interpret from the variety of results, the gains in force and muscle activation are dependent on the methods and intervention type used.

It has been suggested, on the contrary to usual stereotypes, that strength training performed with full range of motion (ROM) and correct techniques does not limit flexibility. However, it is possible that strength training performed with partial ROM involves chronic shortening of the muscle, leading to decreased flexibility. (Alter 2004, p. 128–130.) Therefore, also young gymnasts should consider performing their strength training with full ROM to prevent decreases in flexibility.

5.2 Strength training protocols

Maximal strength training

Maximal strength training consists of neural loading, which refers to using very high training loads combined with a low number of repetitions. This type of resistance training leads to acute fatigue in the contractile characteristics of the muscles, and even more importantly, in the nervous system. Fatigue in maximal strength training leads to lower maximal force produced. (Kraemer & Häkkinen 2002, p. 20–29.)

Hypertrophic strength training

Hypertrophic strength training consists of high volume training with medium or high loads. This type of training leads to acute fatigue in neuromuscular performance combined with a great accumulation of blood lactate and acute hormonal responses. In hypertrophic resistance training, as in maximal strength training, fatigue leads to lower maximal force produced. It may also take place in the nervous system. Women typically exhibit less fatigue than men. (Kraemer & Häkkinen 2002, p. 20–29.) However, during prepuberty, there are no differences between girls and boys in trainability for strength characteristics (Van Praagh 1998, p. 241–263).

Explosive strength training

In gymnastics, power is required for optimal performance, especially in jumps. Explosive, power-type strength training includes low loads and high or maximal velocity. This type of strength training also leads to acute fatigue in neuromuscular performance. Fatigue in explosive strength training leads to lower maximal force produced and decreased explosive strength. (Kraemer & Häkkinen 2002, p. 20–29, 115–122.) In jumps, also the stretch-shortening cycle and elasticity affect performance and power (Van Praagh 1998, p. 241–263).

Muscle endurance training

Muscular endurance training consists of a large amount of repetitions of low-load strength exercises. This type of training develops local muscular endurance but may not be effective for producing strength increases. However, physiological adaptations, due to muscular endurance training, results in enhanced aerobic performance that can be counterproductive to the development of strength and power. (Komi 2003.) Muscle endurance may sometimes correlate with muscle mass, but not in all cases (Swallow *et al.* 2007).

In gymnastics, local muscle endurance is required for optimal performance. Because AGG program lasts over 2 minutes, muscular endurance is needed for fluent performance of the final parts of the program. Especially static positions, as balance movements, require local isometric strength. (Kraemer & Häkkinen 2002, p. 115–122.) As strength training with high loads may have risks (Kraemer & Häkkinen 2002, p. 155–157, 167-175), it is safer to use low-load strength training among children.

5.3 Hamstring strength training to improve the H/Q ratio

Yeung *et al.* (2008) suggested that athletes with strength imbalance could undergo muscle strength training to decrease the risk of hamstring injury. Especially resistance training may help to maintain the muscle balance to prevent muscle strains in hamstrings (Alter 2004, p. 223). To improve the H/Q ratio, a training period that emphasizes hamstring strength is needed (Holcomb *et al.* 2007).

Study results suggest that the H/Q ratio can be improved by hamstring strength training. In the study of Holcomb *et al*. (2007), isokinetically measured H/Q strength ratio improved significantly already due to six weeks of training for female adult soccer players. Furthermore, Mjølsnes *et al.* (2004) reported that eccentric hamstring strength training incresed H/Q ratio significantly with male soccer players due to a 10-week training period, but concentric strength training did not result in significant strength gains. Also, the results from Kaminski *et al.* (1998) indicate that eccentric strength training is correlated with strength gains in hamstrings.

Eccentric hamstring strength training has been studied also in the matter of hamstring injury prevention. Gabbe *et al.* (2006) suggested that eccentric training may have a negative correlation with the incidence of hamstring injuries. Also Arnason *et al.* (2008) reported results of effectiveness of eccentric hamstring training in preventing hamstring strains.

Holm and Vøllestad (2008) suggested that for handball players, hamstring strength training prescription should be done already in childhood, for injury prevention. Progressive strength training can be performed safely and successfully also in children, with free weights or/and with body weight, for example. (Brown & Branta 1988, p. 99).

6 RESEARCH PROBLEMS

The purpose of the present study was to examine muscle activation patterns in AGG movements, as well as to find possible effects of low-load hamstring strength training on muscle activation, balance, leap mechanics and hamstring flexibility. Also, differences between prepubertal and pubertal girls were studied to determine possible age differences. Research problems are listed below.

Muscle activation patterns

1. Does muscle activation for thigh muscles differ between different phases of gymnastic movements?
2. Does muscle activation between hamstrings and quadriceps femoris differ in gymnastic movements?
3. Does activation of muscles, balance or leap mechanics differ between prepubertal and pubertal girls?
4. Does the activation of muscles correlate with balance or leap mechanics?

Effects of low-load strength training intervention

5. Are there any training-induced changes for the muscle activation in gymnastic movements?
6. Are there any training-induced changes for the balance or leap mechanics?
7. Does the flexibility of hamstrings change during the training intervention?

7 METHODS

The empirical part of the study was carried out in 2011, mainly at the University of Jyväskylä. Part of the measurements was done at Kisakallio Sports Institute within a training camp for national AGG gymnasts. The measurements were carried out in co-operation with Henni Takala, and half of the results will be reported in her Master's thesis. The study consisted of cross-sectional and longitudinal parts. It included two age groups: a younger group, which consisted of gymnasts of 10 or 11 years old at the year of measurement, and an older group, which consisted of gymnasts of 13 or 14 years old at the year of measurement.

7.1 Experimental design

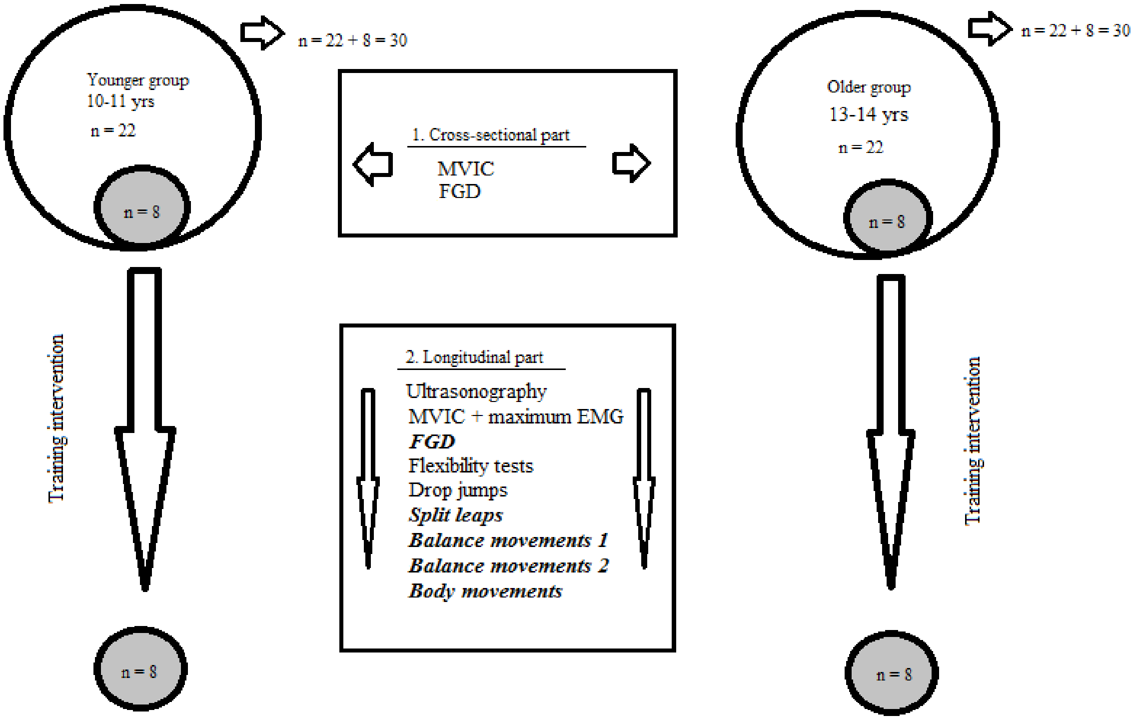


FIGURE 12. Experimental design. Tests in bold are reported in the present study and all the others will be reported in the Master's thesis of Takala.

The study was carried out in two sections (figure 12). In the *cross-sectional part* of the study two age groups of gymnasts were compared with the MVIC test for hamstrings and quadriceps femoris and with finger-ground distance (FGD) test. The H/Q strength ratio was calculated from the MVIC results by dividing the hamstring MVIC by quadriceps femoris MVIC. In the *longitudinal part* of the study we took subgroups from the subject groups used in the first section, and compared them longitudinally. These subgroups performed PRE and POST measurements with an intervention period in between. The intervention period consisted of low-load strength training for hamstrings in addition to normal AGG training.

The performed tests in the longitudinal study, besides the MVIC and FGD, were EMG measurements in AGG actions for studying muscle activity patterns of thigh muscles. For normalizing the EMG values of AGG actions to maximum values, EMG was also measured during the MVIC tests. To investigate the changes in performance, also balance and leap mechanics were recorded. In addition to FGD, also other flexibility measurements for leg muscles were measured, as well as muscle thickness (ultrasonography) and EMG from drop jumps; these variables will be reported in more detail in the Master's thesis of Takala.

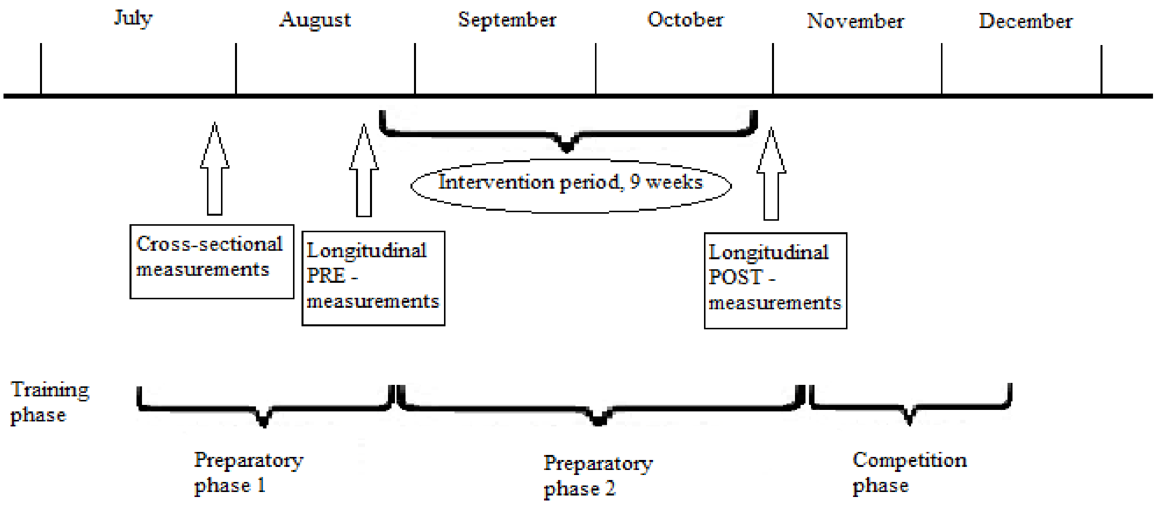


FIGURE 13. Timing of the study

The cross-sectional part of the study was carried out at the end of Summer, when gymnasts had started their first preparatory phase of AGG training after a training break. The longitudinal PRE measurements were placed at the end of preparatory phase 1, while the intervention period was timed for the preparatory phase 2 of AGG training. The POST tests were measured just before the competition phase. The timing of the study is presented in figure 13.

Most of the measurements for the cross-sectional study were done at a national AGG training camp to ensure that the subjects were skilled in AGG. The training camp did not include maximal or hypertrophic strength training but may still have had effects on the results. The measuring protocol of the cross-sectional study consisted of anthropometric measurements (height, weight), general warm-up, FGD test and the MVIC, in this order. The MVIC measurements were performed on the David –force chair for knee flexion and knee extension. The preceding warm-up was individual and included also stretching exercises (20 seconds) for hamstrings and quadriceps femoris. The usual duration of warm-up was about 20 minutes, but some of the subjects were measured after an AGG training session, so they had been warming up longer.

In the longitudinal study, the protocol of the measurements was more complex (figure 14). For anthropometric measurements, besides height and weight, also the amount of body fat was estimated with skin-fold calipers. The warm-up consisted of 10 minutes of cycling with bicycle ergometer, individual routines, and stretching exercises (20 seconds). In each measurement, the subjects had time to try the test movements before the actual measurement. The total time for measurements was from 2 to 3 hours, which is the normal duration for an AGG training session.

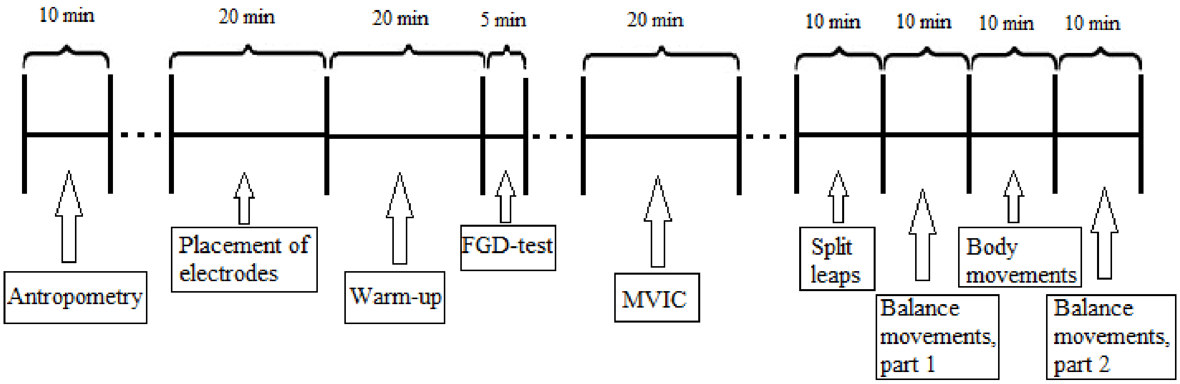


FIGURE 14. The protocol of the measurements in the longitudinal the study. The parts with broken dott line represent measurements for the Takala's study. The durations marked are approximate.

Independent t-tests and ANOVA were used as statistical tests to determine differences between groups and results. Also, Pearson correlation was used to determine relations between results. Non-parametric statistical tests were used for some non-normally distributed data. The significance level was set to α = 0.05.

7.2 Subjects

Subjects were healthy volunteers from high national level female gymnasts. They did not have injuries at the time of measurements. Inform consents from both parents were required and approval from the ethical committee of University of Jyväskylä was also obtained. After analyzing the results, the subjects got feedback from their performance in the strength tests compared to other gymnasts.

In the younger group (10–11 yrs), the mean age at the year of measurement was 10.3 years for the cross-sectional (n = 30) and 10.4 years for the longitudinal (n = 8) study. In the older group (13–14 yrs), mean ages were 13.5 years for the cross-sectional (n = 30) and 13.4 years for the longitudinal (n = 8) study. Subjects estimated the age when they started gymnastic training, and in the cross-sectional study both groups had been training since 6–7 years of age. The AGG training volume of the older group was higher compared to the younger group. In the longitudinal study, the groups had been training since 7–8 years of age. The descriptive data is collected in table 3.

TABLE 3. Descriptive data: subjects. CS = Cross-sectional study, LS = Longitudinal study. Mean ± SD

	Age (yrs)	**Height** (m)	**Weight** (kg)	**BMI**	**Body fat** (%)	**Age, when started training**
CS 10–11 yrs (n = 30)	10.3	1.4± 0.07	34.0±6.3	17.2±1.9		6.4 ± 1.6
LS 10–11 yrs (n = 8)	10.4	1.38±0.10	34.8±7.7	18.1±2.2	24.5±3.1	7.3 ± 1.5
CS 13–14 yrs (n = 30)	13.5	1.58±0.05	47.0±5.8	18.9±2.1		6.6 ± 2.1
LS 13–14 yrs (n = 8)	13.4	1.54±0.04	44.9±7.1	18.8±2.4	24.1±3.5	7.9 ± 1.6

The age groups were significantly different in height, weight and BMI, both in the cross-sectional and in the longitudinal study. The older group had higher mean height, weight and BMI suggesting that they were further with puberty, while the younger group was more prepubertal. The subgroups used in the longitudinal study were equal to the groups in the cross-sectional study in BMI, FGD-test and H/Q strength ratios. Furthermore, they were representative enough for the larger population. However, the older subgroup did have slightly lower mean height than the older cross-sectional group.

7.3 Finger-ground distance

AGG training includes constant flexibility training. During the intervention period, the flexibility training of subjects did not differ from the normal training outside of the intervention period. Finger-ground distance (FGD) test was used to determine possible differences in hamstring flexibility among the two age groups, as well as determining possible changes before and after the intervention period. FGD test was chosen because it is often used by AGG coaches to test hamstring flexibility in the field measurements. Previous results have also been published for the FGD test in estimating flexibility changes in hamstrings (Meroni *et al.* 2010).

In addition to hamstring flexibility and range of motion, also relative lengths of torso and legs, as well as flexibility of hip and posterior ligaments of the spine, affect the results in FGD test. These effects may be significant especially during the growth spurt, when length of the body segments change rapidly. (Alter 2004, p. 121–122; Calais-Germain & Lamotte 2008, p. 152; Wild *et al.* 2013.) This growth effect may contribute to results between different age groups, but for the longitudinal study, the growth effect may be considered minimal, as the intervention period lasted only 9 weeks. Furthermore, possible changes in FGD results during a short intervention period may be considered to be due either to normal AGG training, which includes hamstring flexibility training, or, chronic shortening of the muscle during the strength training intervention. The chronic shortening might be possible, if the strength training is performed using partial range of motion only (Alter 2004, p. 128–130).

For all the subjects, the FGD test was familiar from previous field measurements. The test was conducted after warm-up. Short (20 s) stretches for hamstrings were performed before, to avoid test-related injuries. At the starting position, the subject stood on the edge of a bench or a table, with legs and feet together. The subject was asked to bend and reach forward towards the floor with straight knees and fingers. When the subject reached her voluntary maximum and kept it for minimum of 3 seconds, the distance between the upper surface of the bench/table and the maximum point reached by middle fingers was measured. If the middle finger of the other hand was further than the other, the distance was measured from the hand closer to the bench/table.

7.4 S-EMG and mechanics in gymnastic actions

Surface EMG was measured in gymnastic actions to determine thigh muscle activation patterns, differences in activation between two age groups, and possible changes due to the intervention period. EMG was recorded from movements of each of the three movement groups in AGG: jumps and leaps, balance movements, and body movements. As representing jumps and leaps, s-EMG in split leap was recorded. For recording s-EMG in balance movements, there were two variations of actions: balance movement with leg in front and balance movement with leg behind. For representing the group of body movements, s-EMG was measured from forward body swing. The s-EMG values for different movements and different parts of a single movement were compared. Also, differences between the two age groups, and PRE and POST results of the intervention period were compared.

The PRE and POST measurements took place at the same environment and at the same time of day (± 4 hours) for each subject. Also, the order of the tests was the same. After general warm-up with bicycle ergometer, the subjects had time to do their own individual warm-up routines and to try the test movements, before the actual measurements. All of the measured gymnastic actions were familiar and easy for the subjects, as they all had been practicing them for years. Because of the gained training-related skill in these movements, it was assumed that the changes in EMG patterns due to normal AGG training were small, although, possible. Furthermore, changes between PRE and POST measurements were assumed to be related to the strength training done during the intervention period.

Surface EMG was recorded from *biceps femoris,* as representing hamstrings, and *vastus lateralis* and *vastus medialis,* as representing quadriceps femoris. The bipolar electrodes were placed to smooth and shaved skin, and impedance was measured to be less than 10 k℧. The placement of the electrode for *biceps femoris* was at half point on the line between the ischial tuberosity and the lateral epicondyle of the tibia. For *vastus lateralis*, the placement was at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella, and for *vastus medialis*, at 4/5 on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament. Electrodes were attached to a wireless transmitter (Noraxon) at the waist of the subject.

All the s-EMG values were normalized to values recorded in the MVIC test and presented as percentages of maximum (% max). Values for *biceps femoris* were normalized to the values recorded in MVIC of knee flexion and values for *vastus lateralis* and *vastus medialis* to the values recorded in MVIC of knee extension, respectively. For both knee flexion and knee extension MVIC, the knee angle was 107 º. All the EMG results were analyzed with the Signal 2.16 – program.

When determining statistical differences, the data was analyzed with different aspects: for determining differences between PRE and POST tests, for determining differences between the age groups, and for describing muscle activation. Furthermore, muscle activation was examined first as differences in muscle activation between actions: differences between the leading leg and pushing leg in split leap, as well as differences between two balance movements. Secondly, differences in muscle activation between agonist and antagonist muscles were determined. Third, for describing muscle activation patterns, differences in muscle activation between phases of the movement were determined. For describing the movements, the PRE and POST results or the two age groups were considered as one group to gain a more representative picture for the activation pattern of the movement.

7.4.1 Split leap measurements

The split leaps were performed on a force plate for measuring ground reaction forces in addition to s-EMG. For acquiring optimal speed for the leap, the subjects took six determined steps/hops, resembling the typical AGG prepare for leap. EMG was recorded separately first from the pushing leg and then from the leading leg. The subject performed at least two rehearsal leaps before the actual measurement.

Muscle activity (*biceps femoris, vastus lateralis* and *vastus medialis*) was recorded during the split leap. When analyzed, the leap was divided into seven phases. These consisted of two phases of take-off, three phases of flight, and two phases of landing. Both the take-off and landing were divided further into eccentric and concentric parts, describing the EMG of deceleration and the EMG of forward-directed force. The flight time was divided into three parts to describe roughly the phases of opening legs into the split, the actual split position, and closing the legs as preparing for landing.

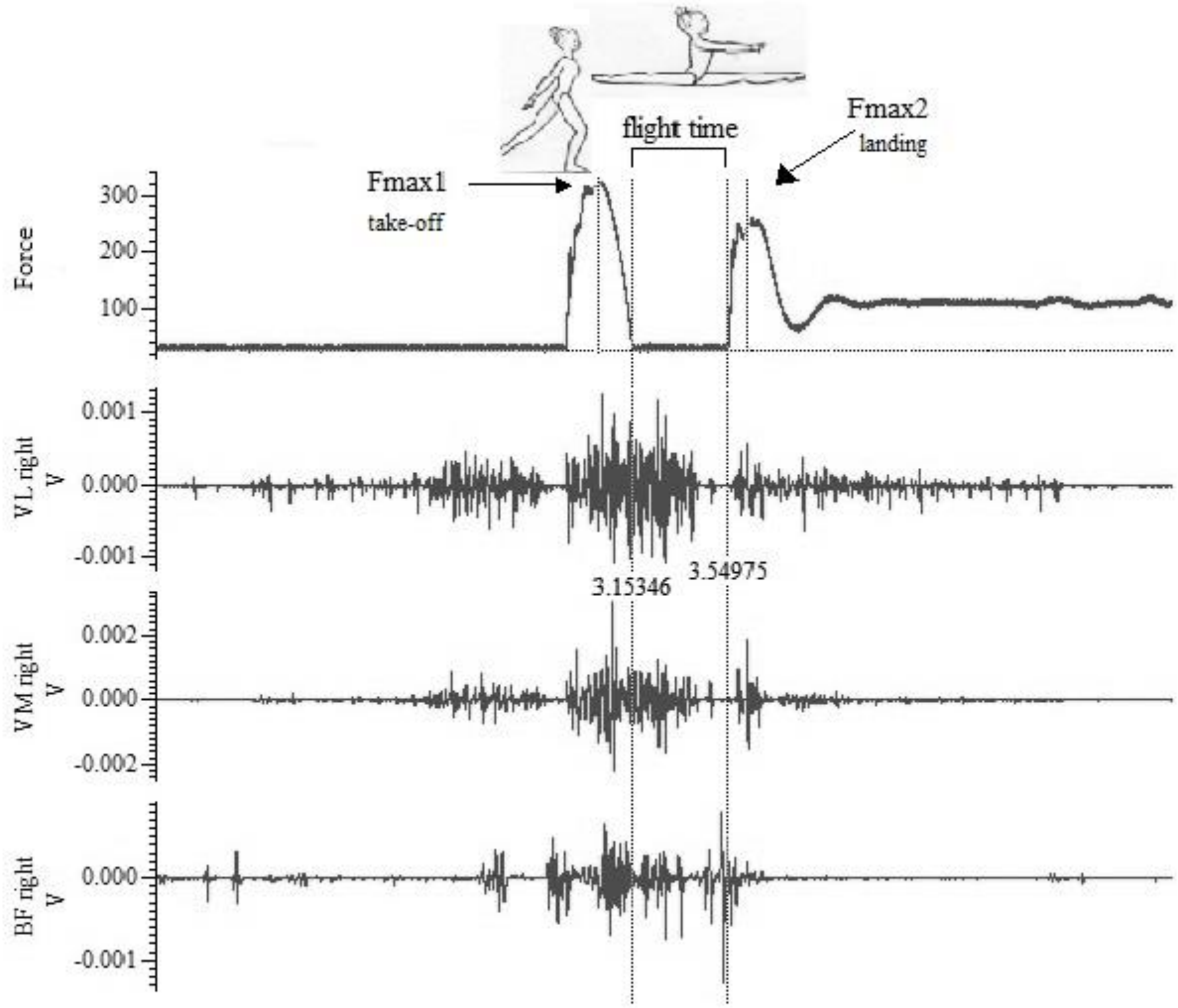


FIGURE 15. Performance of a split leap. EMG recorded from *vastus lateralis* (VL), *vastus medialis* (VM) and *biceps femoris* (BF). Ground reaction forces of take-off (Fmax1) and landing (Fmax2) are marked. Figure of split leap modified from IFAGGb (2012)

Besides the values of s-EMG, also mechanical properties, as the flight time and the time for take-off, were measured (figure 15). The time for take-off was divided into eccentric and concentric parts. Also, the rate of force development (RFD) was measured from the take-off to estimate the speed and production of explosive force. Furthermore, maximal vertical ground reaction force was measured from both the take-off (Fmax1) and landing (Fmax2). The reaction forces were normalized to body weight.

7.4.2 Balance movement measurements

The balance movements were measured in two parts with s-EMG measurements in the first part, and balance measurements on a Metitur plate in the second one. For receiving a larger picture for the muscle activity patterns, two different balance movements were performed. In the first one, the free leg was raised in front, with the help of the opposite arm and with upper body held vertically. In the second one, the leg was raised behind without help of hands and with upper body positioned horizontally.

s-EMG measurements

In the first part of the measurements, the EMG (*biceps femoris*, *vastus lateralis* and *vastus medialis*) was recorded from the straight supportive leg in both of the balance movements. The subjects kept a good static balance position for at least 4 seconds. Performances with any visible tottering were rejected. The EMG was analyzed from 500 ms in the middle of the performance. The balance movements were different for their center of the mass, as in the first movement, the upper body was more upright in position compared to the second one. The movements are presented in figure 16. The results were analyzed in order to determine possible differences between the PRE and POST tests, between the age groups, and between the two balance movements.

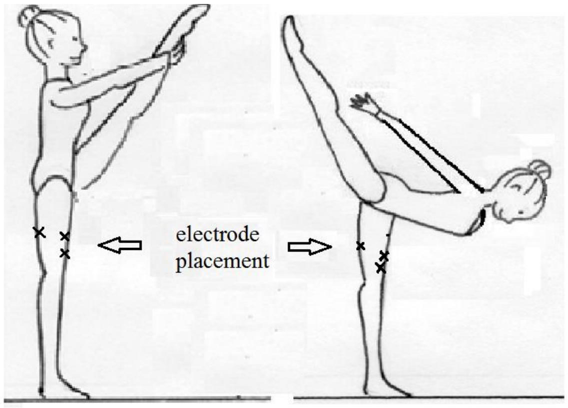


FIGURE 16. Static balance movements: leg in front and leg behind. Notice the difference in the position of the pelvis and the upper body in relation to the supportive leg. Modified from IFAGGb (2012)

Balance measurements on Metitur – balance plate

Both of the balance movements were performed also on a balance plate Metitur. The static position for 5 seconds was performed, and both of the balance positions mentioned above were performed with first right, and then left as supportive leg. The velocity moment of the postural sway, as well as travelled distances in directions of anterioposterior and mediolateral, were measured. The velocity moment was calculated as the mean area covered by the movement of center of forces (COF) during each second of the test, and it was considered to describe the velocity and amplitude of the sway (Era *et al.* 1996). The less there was postural sway detected – the more balanced the position was. The same was interpreted for the distances travelled in anterioposterior and mediolateral directions: if the movement was small, the static balance was better. In addition to absolute distances travelled, also the maximum length of side of the square was measured, by drawing a square around the distance travelled to describe the total distance of the COF movement. The results were analyzed with the Good Balance –program in order to determine possible differences between the two balance movements, between the two legs, and between the PRE and POST tests.

7.4.3 Body swing measurements

Muscle activation (*biceps femoris, vastus lateralis* and *vastus medialis*) in a body swing was recorded on a force plate. Four phases of a body swing were estimated on the basis of knee flexion-extension movement. The phases are roughly presented in figure 17. Differences in muscle activities between PRE and POST tests, between the age groups, between agonist and antagonist muscles, and between different phases of the movement were analyzed.

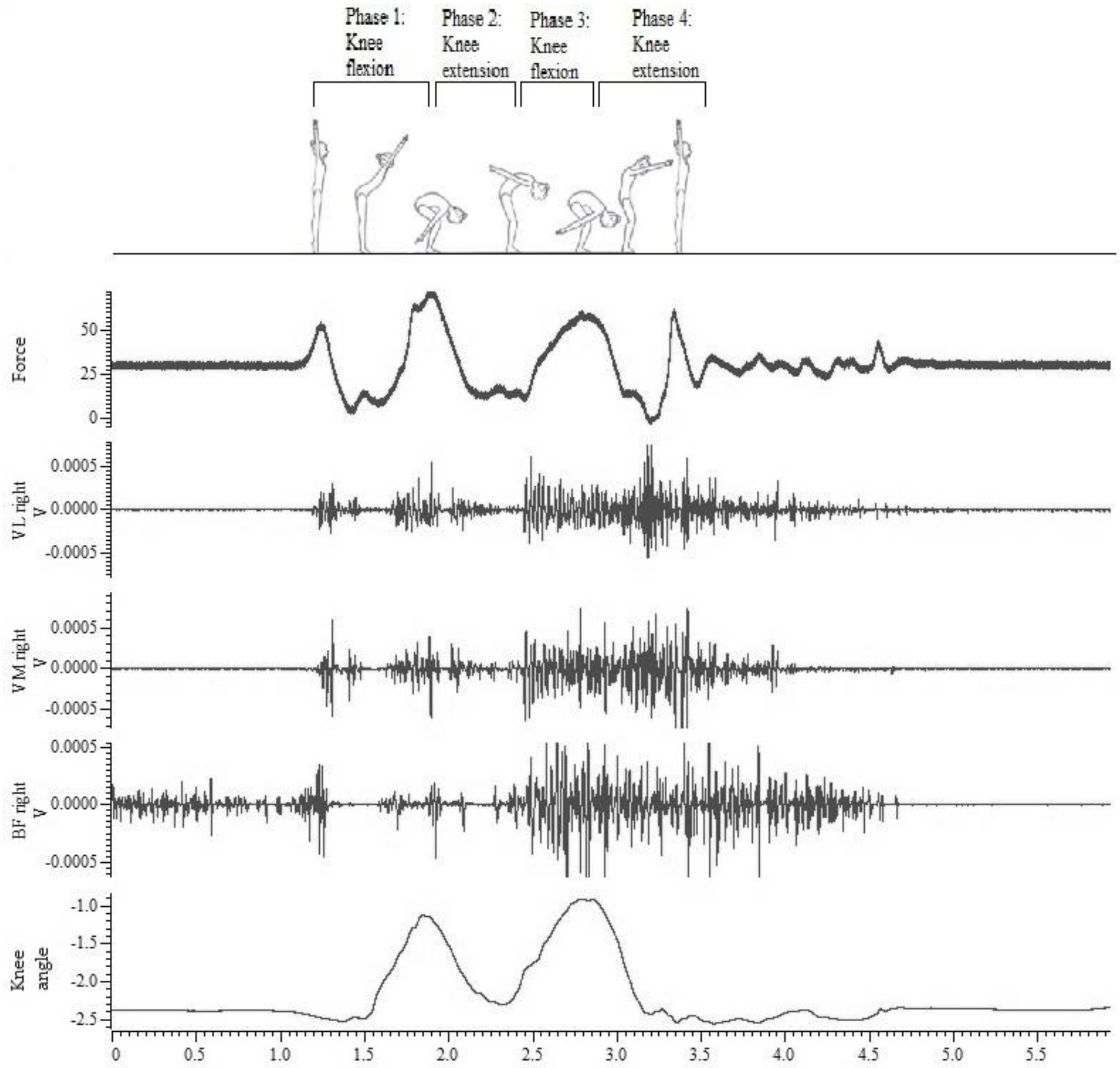


FIGURE 17. Performance of a body swing. Force, EMG from *vastus lateralis* (VL), *vastus medialis* (VM) and *biceps femoris* (BF), and knee angle recorded. Four phases of a body swing are marked according to knee flexion-extension –movement. Figure of body swing modified from the Finnish Gymnastics Federation (2010)

7.5 Low-load strength training intervention

Between the PRE and POST measurements, the subjects performed a 9-week low-load strength training intervention program for hamstrings. The aim of the training was to strengthen and increase the activation of the hamstrings and to increase muscular endurance. The training was integrated to AGG training sessions and it was performed in addition to normal AGG training. The timing of the intervention period was set to the preparatory phase 2 of normal training for minimazing disturbance for the upcoming competitive season. As the gymnasts had their summer-break reaching until the end of July, the strength training was considered safer to be started after a few weeks of normal training. None of the subjects were injured during the intervention period.

The training period was divided into three parts, each part lasting for three weeks. The younger group of subjects had gymnastic trainings 3–4 times in a week, and they performed hamstring strength training 3 times/week. The older group had gymnastic trainings 4–5 times in a week, and they also performed hamstring strength training 3 times/week. Both groups performed the same strength exercises, but the older group performed some of the movements with higher external loads compared to the younger group. The external loads were provided by ankle weights. All movements were not performed with full range of motion, and therefore chronic shortening of the muscle might have been produced, leading to decreased flexibility (Alter 2004, p. 128–130).

The exercises of the strength training program were designed to have some gymnastics-related specificity; there were also flexibility exercises and ankle plantar and dorsiflexion exercises synchronized. Both concentric, eccentric and isometric actions were involved. In the first part of the training program, on weeks 1-3, exercises 1, 2 and 3 were performed. Repetitions used were 2 x 12, and there was a minimum of 1 minute rest between every set. In the second part of the program, on weeks 4-6, the volume of the training was increased by increasing the load in two of the exercises. Other variables maintained the same. In the third part of the program, on weeks 7-9, the volume was increased further by adding a fourth exercise (exercise 4), which was performed as 1 x 12 repetitions. Again, other variables maintained the same. All strength exercises are presented in figures 18, 19, 20 and 21, and training loads used are collected in tables 4a and 4b.

FIGURE 18. Exercise 1. Standing against wall bars: Unilateral shin lift.

1) Lift of the shin (concentric for hamstrings)
2) Plantar flexion of the ankle (isometric for hamstrings)
3) Dorsiflexion of the ankle (isometric for hamstrings)
4) Lowering the shin (eccentric for hamstrings)

FIGURE 19. Exercise 2. Hanging on wall bars: Bilateral shin lift.

1) Lift of the shins (concentric for hamstrings)
2) Dorsiflexion of the ankle (isometric for hamstrings)
3) Plantar flexion of the ankle (isometric for hamstrings)
4) Lowering the shin (eccentric for hamstrings)

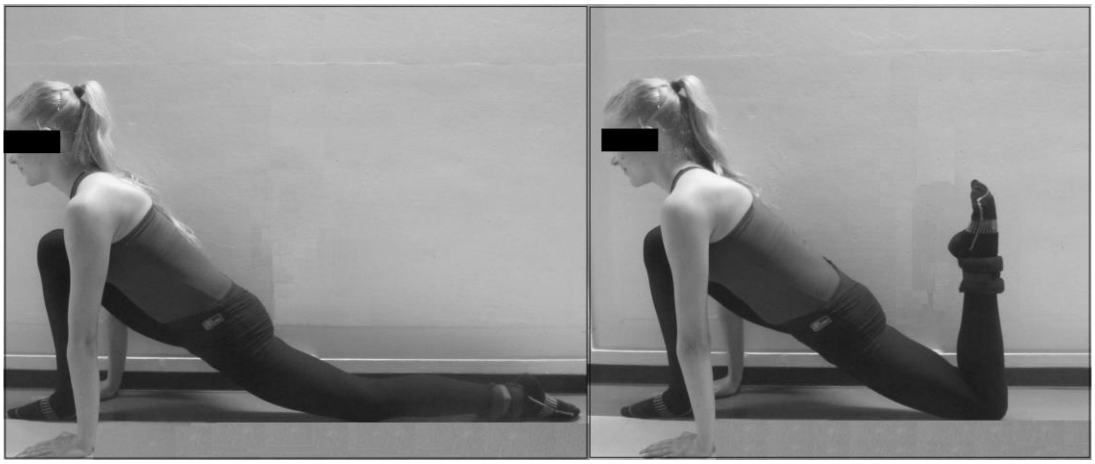


FIGURE 20. Exercise 3. Stretching position of *Iliopsoas*: Unilateral shin lift, performed until knee angle of 90 º, approximately (concentric and eccentric for hamstrings).

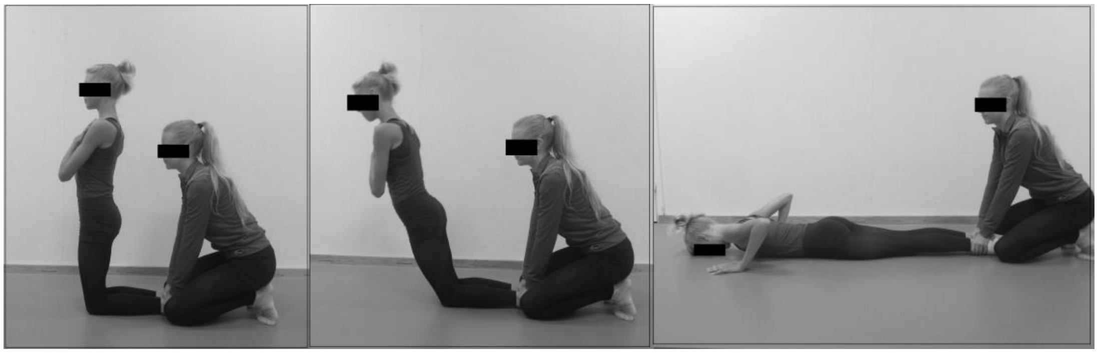


FIGURE 21. Exercise 4. Nordic hamstrings: Standing on knees, partner helping to keep the legs to the floor. Slow lowering of the body to the ground (eccentric for hamstrings).

TABLE 4a. Training intervention, 10–11 years old: training loads

	Load at weeks 1-3	**Load at weeks 4-6**	**Load at weeks 7-9**
Exercise 1.	no external load	ankle weight: 500 g	ankle weight: 500 g
Exercise 2.	ankle weight: 500 g	ankle weight: 500 g	ankle weight: 500 g
Exercise 3.	no external load	ankle weight: 500 g	ankle weight: 500 g
Exercise 4.	-	-	no external load

TABLE 4b. Training intervention, 13–14 years old: training loads

	Load at weeks 1-3	**Load at weeks 4-6**	**Load at weeks 7-9**
Exercise 1.	ankle weight: 500 g	ankle weight: 1000 g	ankle weight: 1000 g
Exercise 2.	ankle weight: 500 g	ankle weight: 500 g	ankle weight: 500 g
Exercise 3.	ankle weight: 500 g	ankle weight: 1000 g	ankle weight: 1000 g
Exercise 4.	-	-	no external load

8 RESULTS

The average H/Q strength ratios of gymnasts varied from 0.38 to 0.46. The ratios were not significantly different between the two age groups, and no significant changes in the H/Q ratios were observed during the training period. The H/Q strength ratios are collected in table 5, and will be reported more specifically in the work of Takala. Between the PRE and POST tests, there was no change in the finger-ground distance in either of the age groups. Also, there were no statistical differences between the two subgroups, although the older group did have 13 % higher FGD results.

TABLE 5. Isometric H/Q strength ratios in the cross-sectional (CS) and longitudinal (LS) study. Mean ± SD.

	CS study, n = 30	**PRE LS study, n = 8**	**POST LS study, n = 8**
10–11 yrs right leg	0.41 ± 0.07	0.43 ± 0.07	0.38 ± 0.06
10–11 yrs left leg	0.44 ± 0.08	0.43 ± 0.08	0.41 ± 0.08
13–14 yrs right leg	0.42 ± 0.09	0.44 ± 0.10	0.42 ± 0.09
13–14 yrs left leg	0.46 ± 0.10	0.45 ± 0.10	0.39 ± 0.06

In the gymnastic actions, there were some differences between the PRE and POST tests, between the age groups and between the movements or phases of movements. The EMG values in gymnastic movements were normalized to the value recorded in MVIC; for *biceps femoris* from knee flexion and for *vastus lateralis* and *vastus medialis* from knee extension. These normalized values are presented as percentages.

8.1 Split leap results

Differences between PRE and POST results

In the longitudinal study, the two age groups had different changes according to split leap. The younger group showed a decrease ($p < 0.05$) in time for the eccentric part of the take-off leading to a decrease ($p < 0.05$) in the total time for the take-off. Also, the RFD of leaps increased ($p < 0.05$), as well as the reaction force of landing ($p < 0.01$). In the older group, there were no differences in these variables; however, the flight time did increase ($p < 0.01$). In general, there was a trend for higher muscle activities of all three muscles in the POST results; however, several increases were statistically non-significant. Phases of split leap and an example of an increase in activation of *vastus lateralis* are presented in figure 22. All the statistically significant changes of muscle activation are collected in table 6.

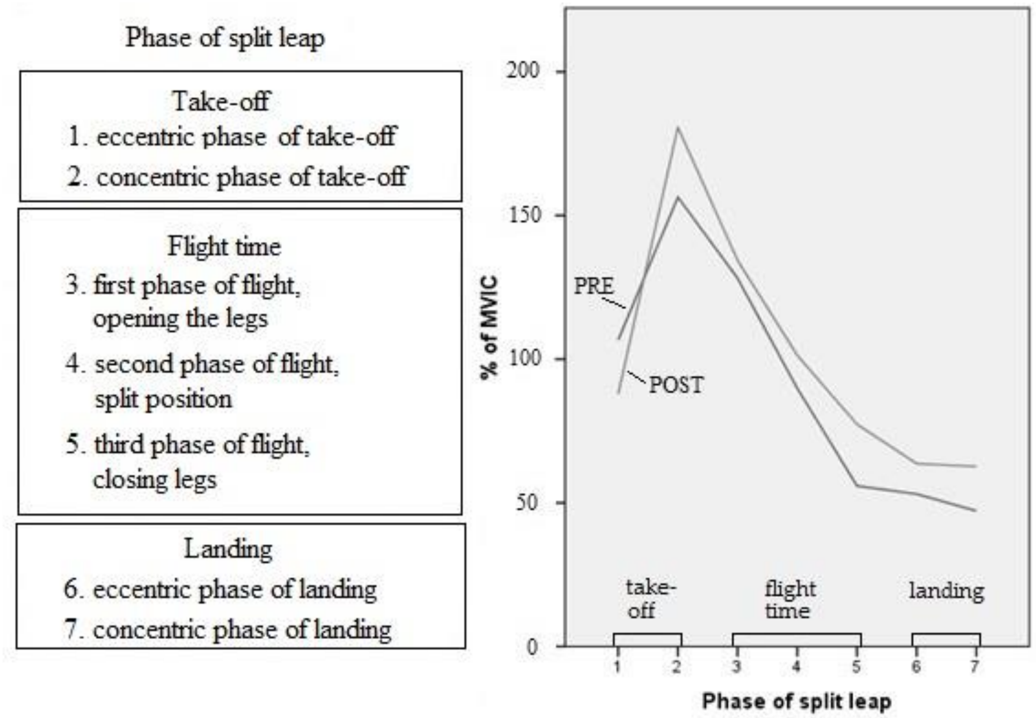


FIGURE 22. Phases of split leap and statistically non-significant increases in activation of *vastus lateralis*.

TABLE 6. Changes in split leap EMG values between PRE and POST tests.

	Pushing leg	**Leading leg**
Age groups considered as one group	a decrease in VM in phase 1 ($p < 0.05$)	a decrease in VL in phase 7 ($p = 0.01$) an increase in VL in phase 5 ($p < 0.05$) a decrease in BF in phase 6 ($p < 0.05$)
10–11 yrs	a decrese in VL in phase 7 ($p < 0.05$)	no changes
13–14 yrs	no changes	an increase in BF in phase 1 ($p < 0.05$) an increase in VM in phase 6 ($p < 0.05$)

Differences between age groups

When considering PRE & POST –results as one group, both RFD and flight time were significantly higher in the older group compared to the younger group ($p < 0.001$ and $p < 0.01$, respectively). The RFD difference was observed in both PRE and POST tests separately and indicates of more explosive take-off in the older gymnasts. The longer flight time of older gymnasts ($p < 0.05$) was observed only in the POST test; however, there was a statistically non-significant difference ($p < 0.053$) slightly outside the significance level also in the PRE test. The reaction forces did not differ between the groups when normalized to body weight, except for the older group producing higher force in the take-off ($p < 0.05$) in the POST tests. In the EMG values, there were no statistically significant differences between the groups.

Differences between the pushing and leading leg

The pushing leg and leading leg appeared to have different kind of muscle actions during the split leap (figure 23 and 24). These muscle actions were compared to describe the activation patterns during the leap. Differences were observed in both phases of take-off, in two of the three phases of flight and in the second phase of landing. In general, the take-off activities in the pushing leg were higher than in the leading leg. The differences in the muscle activities between the leading and pushing leg are collected in table 7.

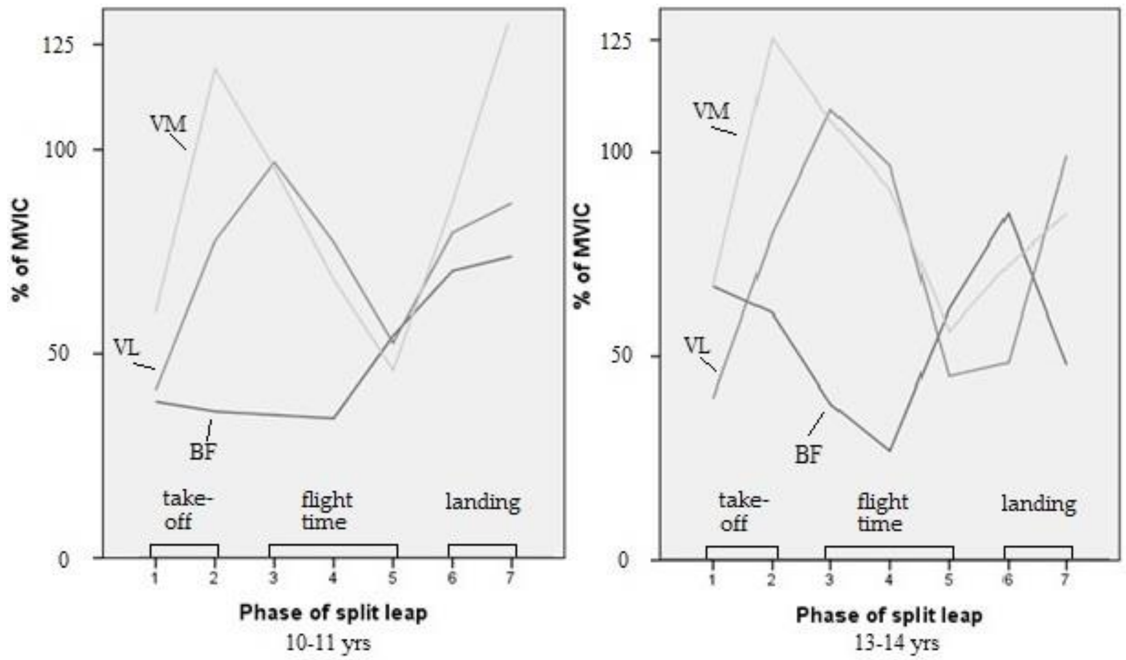


FIGURE 23. EMG-pattern of the leading leg. BF= *biceps femoris,* VL= *vastus lateralis,* VM= *vastus medialis.* Notice the decrease in BF activity and simultaneous peak of VL activity during flight in the older group. No statistically significant differences between age groups.

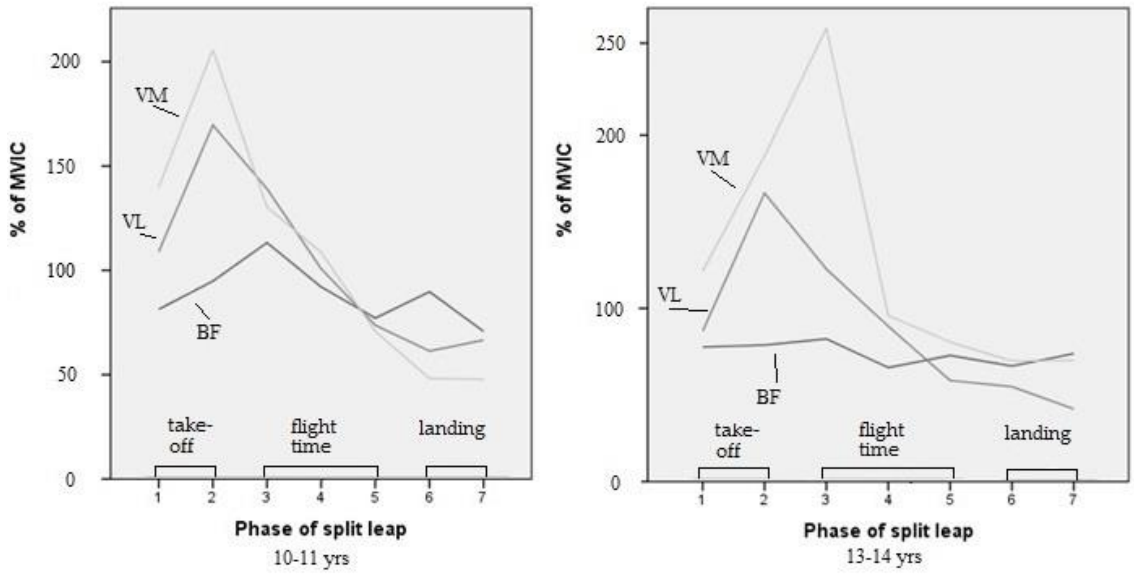


FIGURE 24. EMG-pattern of the pushing leg. BF= *biceps femoris,* VL= *vastus lateralis,* VM= *vastus medialis.* Notice the peak of BF in the phase 3 (statistically non-significant increase of 39 % from phase 1) of the younger group and the simultaneous peak of VM in the older group. No statistically significant differences between age groups.

TABLE 7. Differences in muscle activities between the leading and pushing leg in the split leap. PRE and POST results and both age groups are considered as one group.

Phase of the split leap	***Biceps femoris***	***Vastus lateralis***	***Vastus medialis***
1: eccentric phase of take-off	higher in pushing leg ($p < 0.05$)	higher in pushing leg ($p < 0.01$)	no significant differences
2: concentric phase of take-off	higher in pushing leg ($p < 0.05$)	higher in pushing leg ($p < 0.001$)	higher in pushing leg ($p < 0.05$)
3: first phase of flight, opening legs	higher in pushing leg ($p < 0.001$)	no significant differences	no significant differences
4: second phase of flight, split position	higher in pushing leg ($p < 0.01$)	no significant differences	no significant differences
5: third phase of flight, closing legs	no significant differences	no significant differences	no significant differences
6: eccentric phase of landing	no significant differences	no significant differences	no significant differences
7: concentric phase of landing	no significant differences	higher in leading leg ($p < 0.05$)	higher in leading leg ($p < 0.05$)

In addition to differences in the actions between the leading and pushing leg, muscle activation patterns were examined either by differences between muscles activating in the same phase of the split leap (differences between agonist and antagonist muscle activities), or by differences in muscle activation between phases of the leap (muscle activation pattern trough split leap). The muscle activation did not correlate with mechanics of the split leap.

Differences between agonist and antagonist muscle activities

Between muscle activities, there was a trend of quadriceps muscles activating relatively more than hamstrings. This activation pattern was evident for phases 2, 3, 4 and 7 in the leading leg ($p < 0.05$). In phases 2, 3 and 4, the leading leg was raised up and held anteriorly by quadriceps femoris. In phase 7, which describes the eccentric part of landing, the higher activation of quadriceps femoris compared to *biceps femoris* indicates that eccentric force production of quadriceps femoris is evident in landing. Furthermore, in the pushing leg, *vastus lateralis* and *vastus medialis* were activated relatively more in phases 1 and 2 ($p < 0.05$), compared to *biceps femoris*. In other words, the take-off was performed with quadriceps femoris dominant manner.

Muscle activation pattern trough split leap

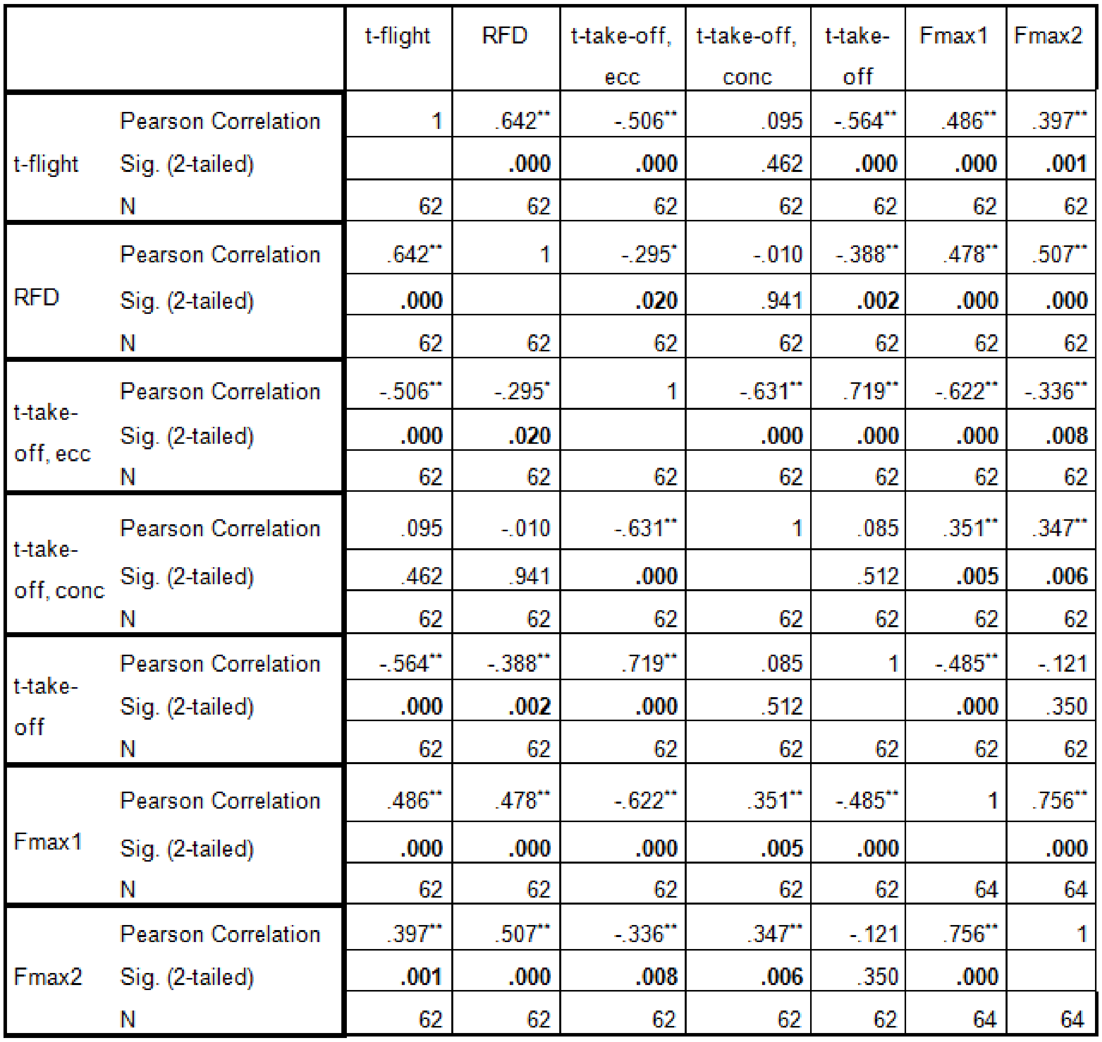
There were differences in muscle activities between phases of the leap. For the leading leg, the *vastus lateralis* and *vastus medialis* activated more ($p < 0.05$) in the second phase of the take-off compared to the first. This was the point of time, when the leading leg was raised anteriorly. During the flight time, there was an increase in *biceps femoris* (BF) activity, when reaching the landing phase. Furthermore, in the last phase of the flight (phase 5), BF activity was higher ($p < 0.01$) compared to the activities in the beginning of the flight and during the split position. At the same time, the activities of *vastus lateralis* and *vastus medialis* decreased ($p < 0.05$). From the actual split position during the flight, to the first phase of landing, an increase ($p < 0.001$) in the activation of *biceps femoris* was observed. In the older age group, also a decrease ($p < 0.02$) in the activity of this muscle was evident from the take-off to the split position (figure 23).

In the pushing leg, *vastus lateralis* was activated more ($p < 0.05$) in the second phase of the take-off. While comparing the phases of flight, the activation of both *vastus lateralis* (VL) and *vastus medialis* (VM) was lower in the end of the flight time. Also, when comparing the split position (phase 4) and the first part of landing (phase 6), there was a significant difference in VL and VM activities suggesting that activation was lower during the first part of landing ($p < 0.05$). Some differences in the muscle activation patterns can be observed from figures 23 and 24 for both age groups separately.

Timing and force production patterns

When comparing all the performances together, there were several correlations observed (table 8). The eccentric part of the take-off, as well as the total time for take-off correlated negatively ($p < 0.001$) with flight time indicating a relation of shorter contact time and longer flight time. Furthermore, the RFD correlated ($p < 0.001$) with the flight time indicating that more explosive take-offs relate with longer flight time. The total time for take-off (the contact time), was 0.23 ± 0.03 s (mean ± SD) for both age groups and the flight time was 0.35 ± 0.04 s for the younger group and 0.39 ± 0.04 s for the older group. The vertical ground reaction force produced during take-off was 3.2 ± 0.6 and 3.0 ± 1.1 times body weight for the younger and older group, respectively. The vertical force produced during landing was higher; 4.4 ± 1.0 (younger group) and 4.8 ± 1.3 (older group) times the body weight. As there were no bilateral differences observed in these mechanical properties, the leaps may be considered similar with right leg leading versus left leg leading.

TABLE 8. Correlations of flight time (t-flight), RFD of take-off, eccentric part of take-off (t-take-off, ecc), concentric part of take-off (t-take-off, conc), the total take-off time (t-take-off), ground reaction force of take-off (Fmax1) and ground reaction force of landing (Fmax2). Both age groups and PRE and POST results are considered as one group. When observing the age groups separately, there were correlations ($p < 0.05$) in all the same variables.



		t-flight	RFD	t-take-off, ecc	t-take-off, conc	t-take-off	Fmax1	Fmax2
t-flight	Pearson Correlation	1	.642**	-.506**	.095	-.564**	.486**	.397**
	Sig. (2-tailed)		**.000**	**.000**	.462	**.000**	**.000**	**.001**
	N	62	62	62	62	62	62	62
RFD	Pearson Correlation	.642**	1	-.295*	-.010	-.388**	.478**	.507**
	Sig. (2-tailed)	**.000**		**.020**	.941	**.002**	**.000**	**.000**
	N	62	62	62	62	62	62	62
t-take-off, ecc	Pearson Correlation	-.506**	-.295*	1	-.631**	.719**	-.622**	-.336**
	Sig. (2-tailed)	**.000**	**.020**		**.000**	**.000**	**.000**	**.008**
	N	62	62	62	62	62	62	62
t-take-off, conc	Pearson Correlation	.095	-.010	-.631**	1	.085	.351**	.347**
	Sig. (2-tailed)	.462	.941	**.000**		.512	**.005**	**.006**
	N	62	62	62	62	62	62	62
t-take-off	Pearson Correlation	-.564**	-.388**	.719**	.085	1	-.485**	-.121
	Sig. (2-tailed)	**.000**	**.002**	**.000**	.512		**.000**	.350
	N	62	62	62	62	62	62	62
Fmax1	Pearson Correlation	.486**	.478**	-.622**	.351**	-.485**	1	.756**
	Sig. (2-tailed)	**.000**	**.000**	**.000**	**.005**	**.000**		**.000**
	N	62	62	62	62	62	64	64
Fmax2	Pearson Correlation	.397**	.507**	-.336**	.347**	-.121	.756**	1
	Sig. (2-tailed)	**.001**	**.000**	**.008**	**.006**	.350	**.000**	
	N	62	62	62	62	62	64	64

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed).

8.2 Balance movement results

Differences between PRE and POST results

In the muscle activities, there were no statistically significant differences observed between PRE and POST results. However, in the balance with leg in front, there was statistically non-significant increase of the activity of *biceps femoris* (figure 25). For the older group, the increase was from 58 % to 74 % of MVIC and for younger group from 53 % to 87 % of MVIC. For the younger group, the change was close to the significance level (p = 0.059). For the balance with leg behind, there were no significant changes, and the individual variation was high (figure 26).

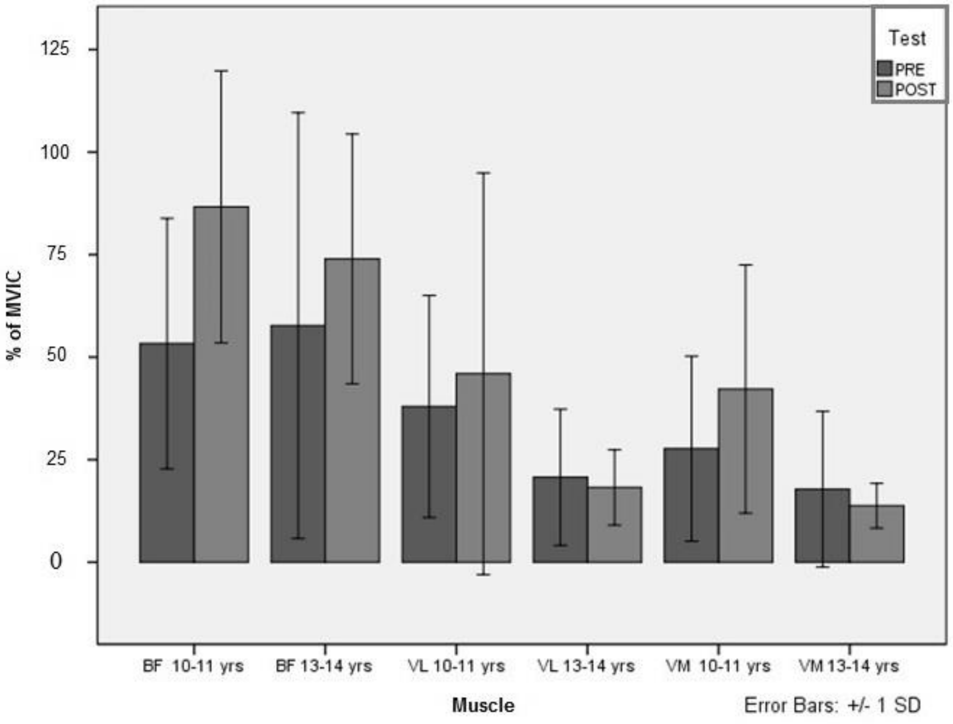


FIGURE 25. Balance with leg in front. PRE and POST EMG-values from *vastus lateralis* (VL), *vastus medialis* (VM) and *biceps femoris* (BF). Both age groups are presented.

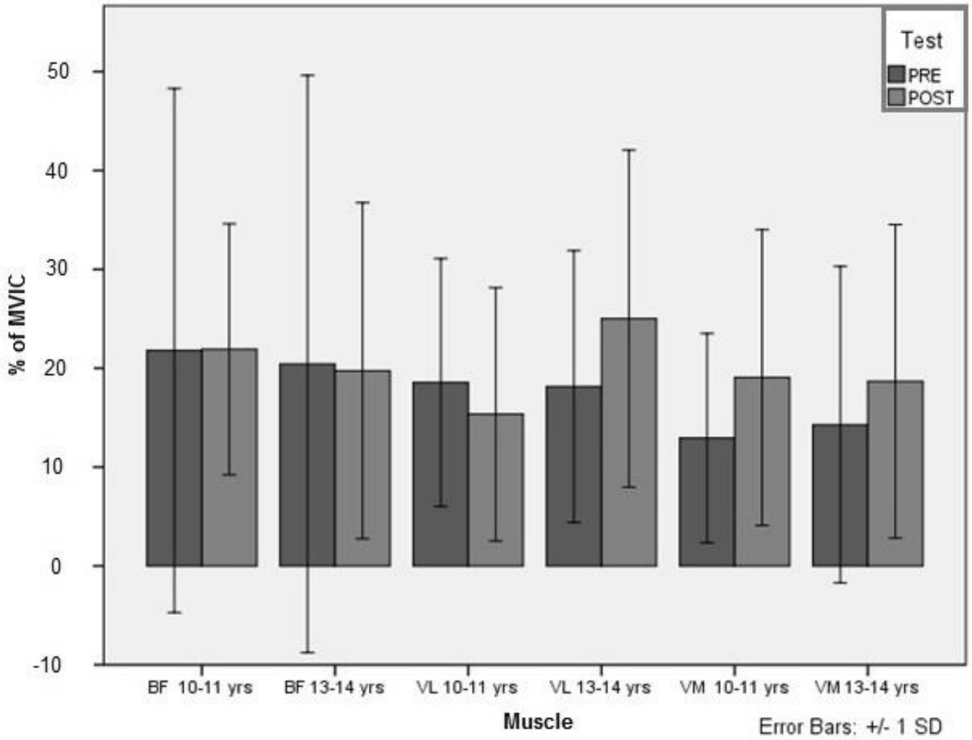


FIGURE 26. Balance with leg behind. PRE and POST EMG-values from *vastus lateralis* (VL), *vastus medialis* (VM) and *biceps femoris* (BF). Both age groups are presented.

The velocity moment in the balance with leg in front was significantly different between the PRE and POST results when right leg was supportive. In both age groups, the velocity moment decreased ($p = 0.02$ for each group) indicating better balance (figure 27). There was also statistically non-significant decrease in velocity moment with left leg. When considering results from both legs as one group, the decrease of velocity moment was 20 % for the younger and 29 % for the older group. For the balance with leg behind, there were no changes. Also, the distances of COF travel did not change between the PRE and POST measurements, with one exception of a decrease ($p = 0.03$) in the mediolateral distance with the older group. This decreased distance occurred in the same balance movement in which the velocity moment decreased significantly (balance with leg in front, right leg supportive). Although there was a high, but statistically non-significant increase in activation of *biceps femoris* together with significant decreases in velocity moment during the balance with leg in front, there was no statistical correlation between these variables.

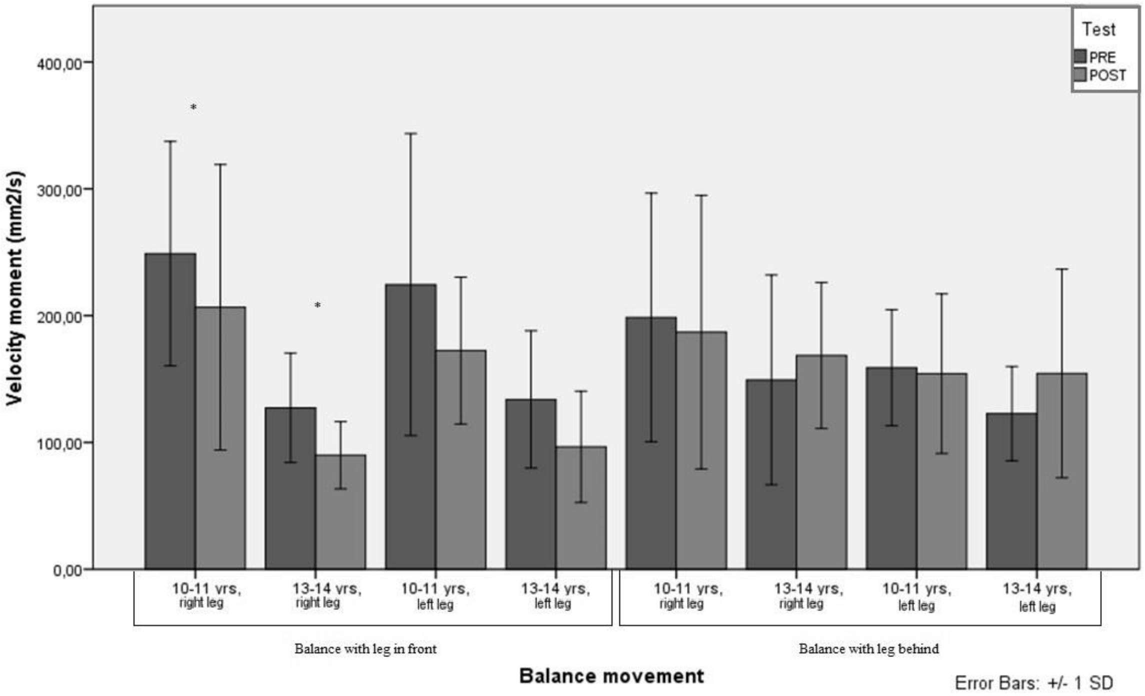


FIGURE 27. Velocity moment in balance movements, PRE and POST results. * = $p < 0.05$

Differences between age groups

In the results of travelled distances of COF, several statistically significant differences between the two age groups were observed. In the balance movement with leg in front, there was a strong trend for older gymnasts travelling shorter distances than the younger ones (figure 28a). It appeared that in this balance movement, the older group had also significantly lower side of the square (S-S) compared to the younger group. In the balance with leg behind, no differences were observed between the age groups (figure 28b).

In addition to the differences in distances of COF travel, also the velocity moment differed in balance movement with leg in front (figure 29), as the older group performed the balance with lower velocity moments. When comparing the age groups with PRE & POST –results as one group, the difference was observed for both legs, however, it was greater for right leg as supportive leg. In PRE test separately, the difference was statistically significant for right leg only, and the difference for left leg ($p = 0.07$) did not reach the significance level. In the POST test, the difference was statistically significant for both legs. Again, there was no difference in the balance movement with leg behind.

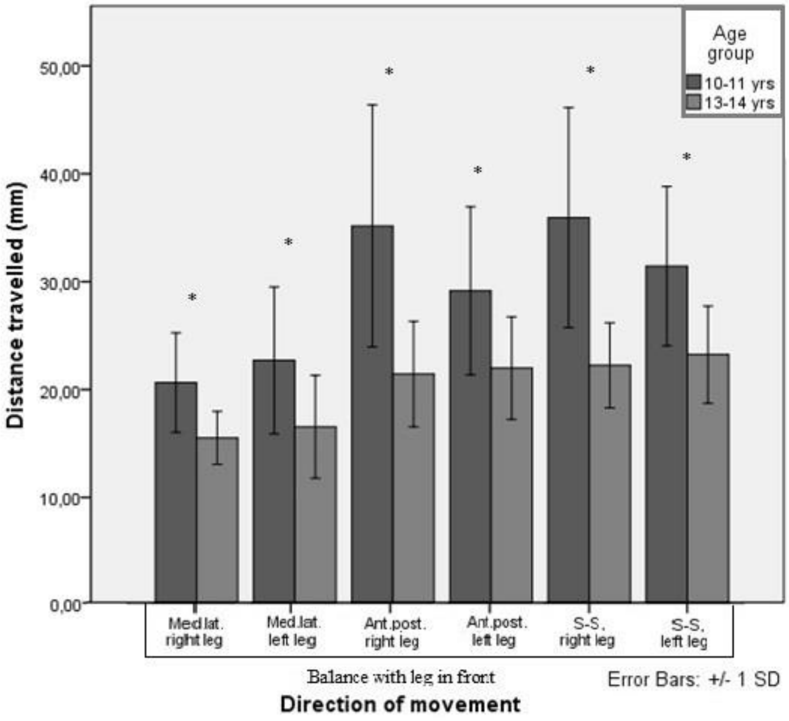


FIGURE 28a. Distances of COF travel, balance with leg in front. * = $p < 0.05$

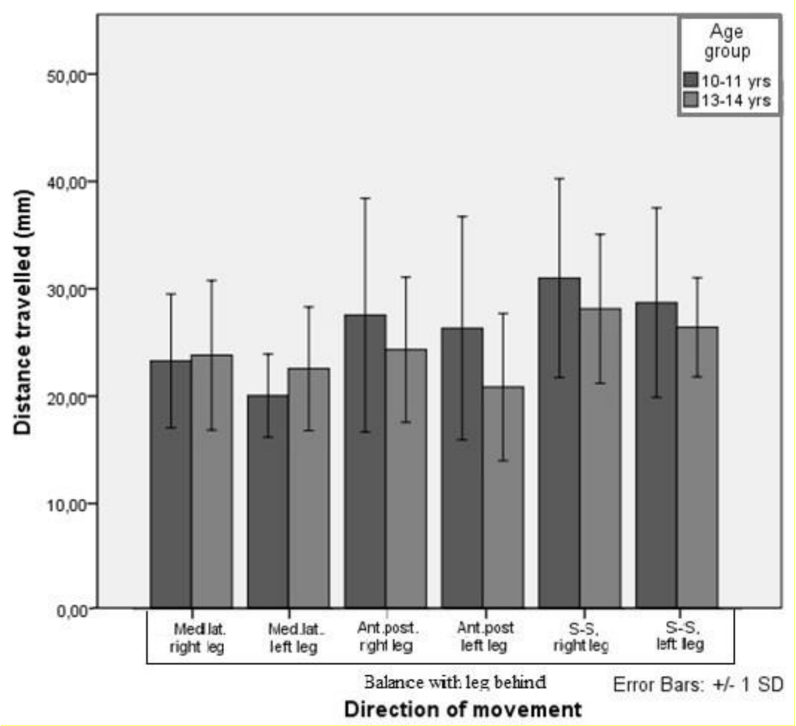


FIGURE 28b. Distances of COF travel, balance with leg behind. * = $p < 0.05$

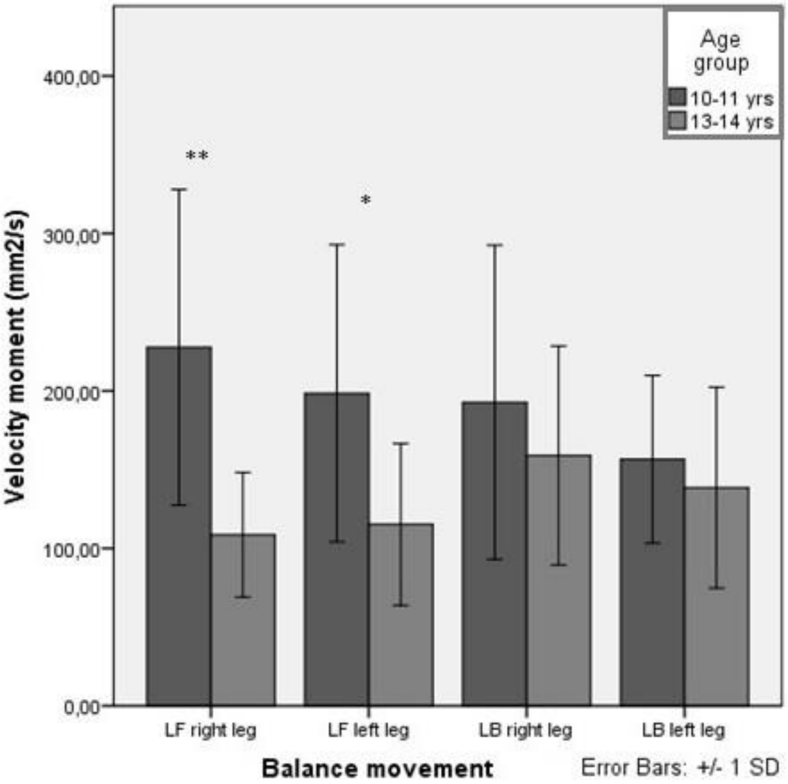


FIGURE 29. Velocity moment in balance movements. PRE and POST results considered as one group. LF = leg in front, LB = leg behind. * = $p < 0.05$, ** = $p < 0.001$

Differences between the balance movements

The supportive leg appeared to be activated differently in the balance movement with leg in front compared to the balance movement with leg behind (figure 30). Especially the *biceps femoris* activated more ($p < 0.01$) in the balance with leg in front compared to holding the leg behind. To examine the differences in balance movements, the age groups were considered as one group.

Besides the higher activation of *biceps femoris* in the balance with leg in front, differences were observed in the distance of COF travel in mediolateral direction; for the balance with leg in front the distance was significantly lower ($p < 0.05$) both in PRE and POST tests. This indicates that in side-to-side direction the balance was better with leg in front compared with leg behind. Also, in the balance with leg in front, the anterioposterior movement was higher ($p < 0.05$) than mediolateral movement. There were no bilateral differences in these variables in either of the balance movements.

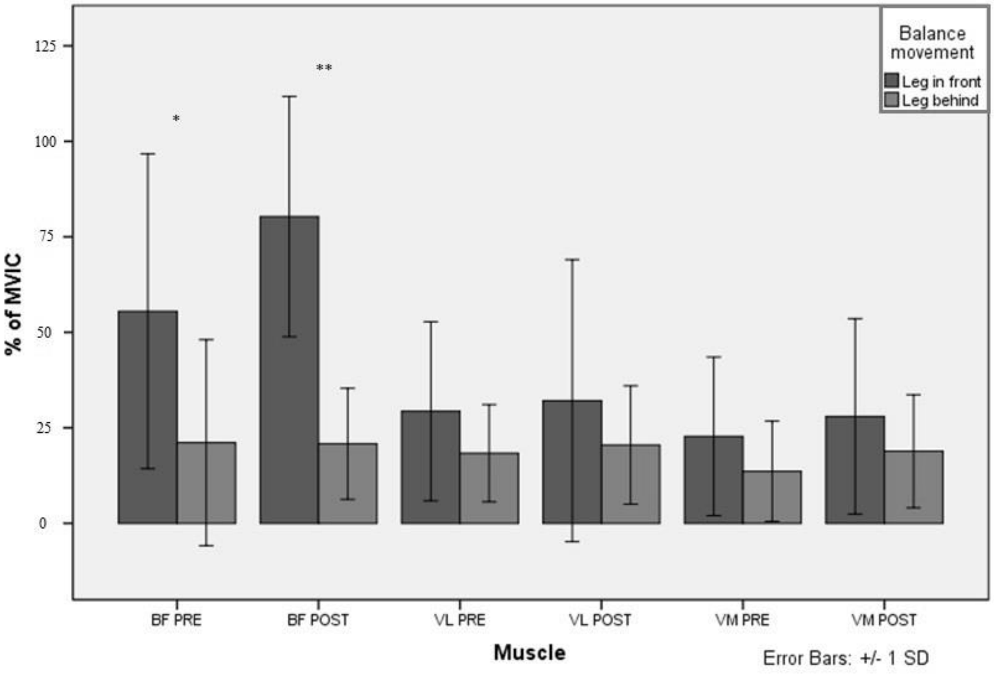


FIGURE 30. EMG from *vastus lateralis* (VL), *vastus medialis* (VM) and *biceps femoris* (BF). The age groups are considered as one group. Notice the statistically significant differences in BF activation between the two balance movements. * = $p < 0.05$, ** $p < 0.001$

8.3 Body swing results

Differences between age groups and between PRE and POST results

When comparing the body swing with the two age groups, there were some differences in activation of quadriceps femoris muscles, indicating that younger gymnasts activated their quadriceps more than older gymnasts. Higher activities in the younger group occurred for *vastus lateralis* in phases 1, 2 and 4 ($p < 0.05$) and for *vastus medialis* in phases 2 and 4 ($p < 0.05$). For *biceps femoris*, there was no difference. Between the PRE and POST results, there were no statistically significant differences in either of the age groups.

Differences in activities between agonists and antagonists and between phases of movement

The movement of body swing was divided into four phases; 1 = first knee flexion, 2 = first knee extension, 3 = second knee flexion, 4 = second knee extension. Differences in activation between the three muscles were observed in both phases of knee flexion (phases 1 and 3). In the phase 1, both the VM and VL activated relatively more than BF ($p = 0.04$ for both). In the phase 3, VM activated relatively more than BF ($p = 0.03$). Furthermore, quadriceps femoris muscles were observed to activate relatively more than hamstrings in the phases 1 and 3. In the phases of knee extension (phases 2 and 4), there were no statistically significant differences between the muscle activities. Between the phases of the movement, differences were observed. Activation of *biceps femoris* was significantly higher in the last phase (phase 4) of the body swing compared to the phases 1–3. Also *vastus lateralis* activated more in the last phase compared to phases 1 and 2. For activation of *vastus medialis*, there were no statistically significant differences. Differences in muscle activation between phases 1–4 are presented in figure 31.

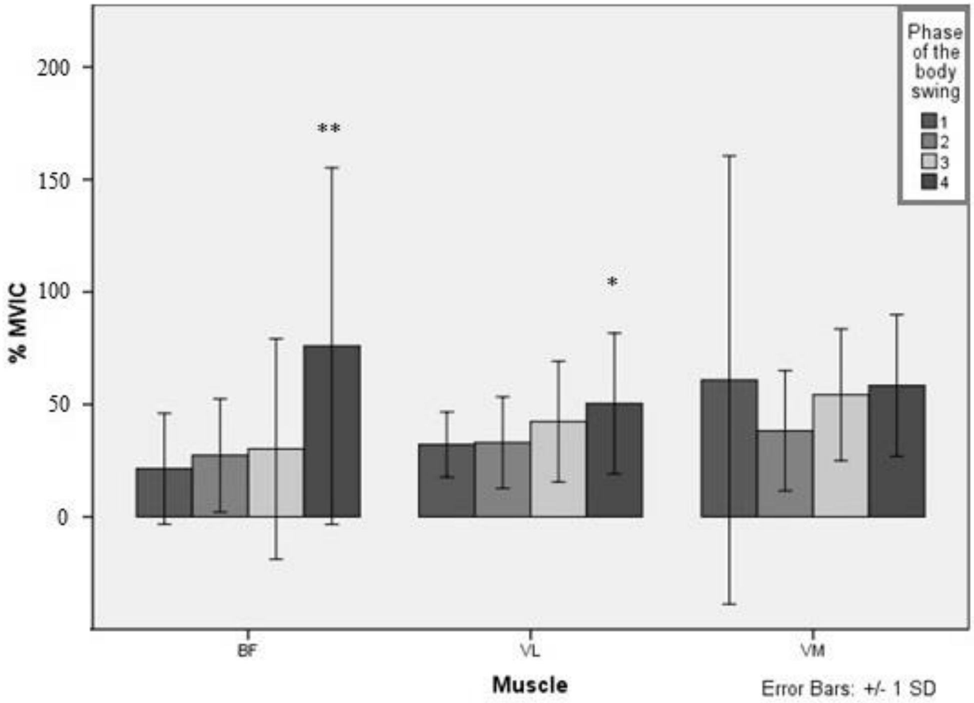


FIGURE 31. Differences in muscle activation between phases of body swing. BF = *biceps femoris*, VL = *vastus lateralis*, VM = *vastus medialis*. * = BF in phase 4 differs from BF in phases 1–3, $p < 0.05$, ** = VL in phase 4 differs from VL in phases 1–2, $p < 0.001$

9 DISCUSSION

The primary results of the present study were related to balance movement with leg in front. The main finding was that balance performance in this movement improved during the intervention period. All the research questions (p. 43) about muscle activation were answered: Muscle activation patterns were found for split leap and body swing, and differences in muscle activation of hamstrings were observed, especially for the two different balance movements. Also, age differences were found, primarily within the balance results. Research questions to determine effects of low-load strength training intervention were also answered; Training-induced changes in muscle activation in gymnastic movements were not observed. However, in addition to the improved balance performance, also some improvements in split leap mechanics were found.

The finger-ground distance test was used as a control for hamstring flexibility during the intervention period. There was no change in FGD results, indicating that the flexibility did not change. Therefore, either the hamstring strength training did not cause chronic shortening of muscle, or if it did, the normal flexibility training in AGG compensated for maintaining the previously gained flexibility. Based on this result, it can be suggested that low-load strength training period does not shorten the hamstring muscles, and this type of training is safe when considering the importance of maintaining the required flexibility in AGG. However, it should be noted, that FGD does not measure only hamstring flexibility, but also body segments and flexibility of the hip and lumbar spine (Alter 2004, p. 121–122; Calais-Germain & Lamotte 2008, p. 152; Wild *et al.* 2013). A more specific measure should be used for determining the absolute changes in the hamstring length.

The average H/Q strength ratios in the present study varied from 0.38 to 0.46, whereas the reference values of Alter (2004) and Yeung *et al.* (2009) state that values below 0.5 may be related to injuries. The results of the present study should be interpreted carefully, as the reported H/Q ratios are not fully comparable with isokinetically measured MVC, or with MVIC measured with different knee angle. However, as Lord *et al.* (1992) reported that isometric strength correlates highly with isokinetic strength for both quadriceps femoris and hamstrings, it is reasonable to suggest that strengthening of the hamstrings is important for AGG gymnasts. The intervention period of the present study was inefficient to produce an increase in the H/Q strength ratio, when measured from a maximal contraction. This may be due to the low-load protocol of the intervention period, in which significant neural adaptation or hypertrophy is difficult to achieve. With resistance training, strength gains could be more easily achieved. However, resistance training on active high level AGG gymnasts may be inappropriate, as AGG consists primarily of skill training.

9.1 Gymnastic actions

In the balance movements, improvements in performance were recorded. However, the improvements were evident only for the balance movement with leg in front. On the contrary, for the balance with leg behind, split leap, and body wave, there were no consistent changes during the intervention period, indicating a lower response for hamstring strength training. Muscle activation patterns and age differences in some variables were, however, observed and with these results it is possible to discuss the mechanics of the movements.

9.1.1 Balance

In the younger group, the activity of *biceps femoris* increased 34 % in the balance with leg in front during the intervention period. This increase was, though, statistically non-significant as the change was slightly outside the significance level. For the older group, the increase was 12 %, and also, statistically non-significant. These increases might be due to the hamstring strength training, if the training had improving effects on the ability to recruit or synchronize motor units. These types of effects are reported to induce strength gains especially with untrained subjects (Merletti & Parker 2004, p. 373). The subjects of the present study were untrained in terms of hamstring strength training.

In the balance with leg in front, the velocity moment decreased during the intervention period indicating improved performance. This was the main finding in the present study. For right leg supporting, the decrease was significant in the younger group. An interesting aspect is that, in the younger group, the EMG measurements were done from the right leg for all subjects, with one left leg exception. This indicates that in the same balance, with the same leg supporting, both the muscle activity of *biceps femoris* increased and the velocity moment decreased, suggesting a possible connection. However, there was no statistically significant correlation between these variables.

The older group had lower velocity moment during the balance movements compared to the younger group. In the balance with leg in front, also the distances travelled were significantly lower with the older group. This suggests that the older group had better performance in balance compared to the younger group. The training loads and intensity of normal AGG training was higher with the older group, which could be one factor explaining the differences. Also maturation and neuromuscular development might contribute to the differences. As the anterioposterior movement was higher than mediolateral movement in the balance with leg in front, it is reasonable to strengthen prior the muscles anterior and posterior to the leg to decrease the velocity moment.

The most interesting aspect is the amount of decrease in the velocity moment during the intervention period. For both groups, the velocity moment decreased in the balance with leg in front for 20 % or more during the 9-week intervention period. As age and normal AGG training influence the balance, involving better balance with older gymnasts, a decrease in the velocity moment is considered normal during a typical AGG training period. However, it remains questionable whether as high as an increase of 20 % or more can be due to normal AGG training only. If the younger group would improve of the same magnitude for the next months, the velocity moment level of the older group would be reached in 6 months. As the older group was, however, two years older than the younger group, a question arises, whether there were also other factors, besides normal growth and AGG training, influencing the fast improvement of balance. As strength training performed with untrained subjects may induce enhanced motor unit synchronization and changes in motor unit firing rate (Merletti & Parker 2004, p. 373; Semmler *et al.* 1998), also these factors may have had effect on improved balance movements.

Neurological effects of strength training may also be speculated for the non-significant improvements in the activity of *biceps femoris* in the younger group. It might be possible that hamstring strength training led to increased muscle activity, which in turn could have contributed to the decrease in velocity moment during the balance with leg in front. Furthermore, it is possible that the hamstring strength training improved the balance via non-significantly increased muscle activation. However, as there was a lack of statistically significant correlations, these speculations are not scientifically valid. All the improvements in balance were evident only for the balance movement with leg in front. In the balance with leg behind, neither the activity of muscles nor the velocity moment improved, indicating that this movement might not have any response to hamstring strength training.

Furthermore, the activation of *biceps femoris* seems to be highly more essential in the balance with leg in front, versus leg behind. The differences might be resulted from the different body position. This is in line with the results of Draganich *et al.* (1989), as they reported of differences in coactivation of hamstrings (in knee extension) depending on the body position. In the balance movement with leg in front, the upper body is held vertically and a slight lean in posterior direction is possible. As a large proportion of the body weight is located in the upper body (George 1980), a lean backward might need muscle activation from muscles locating posterior of the leg and trunk, for minimizing the risk of falling backwards. In the balance with leg behind, however, the upper body is bent in front, close to the horizontal line. The horizontal position of the trunk in front might help the balance to move less to the posterior direction; furthermore, high activation of *biceps femoris* would then not be needed. This could partly explain why hamstring strength training did not increase the activity of *biceps femoris* in this particular balance movement.

Another explanation for the differences in *biceps femoris* activity between the two balance movements might be related to the length of the *biceps femoris* muscle, which is also dependent on the position of the body. As the pelvis is anteriorly tilted in the balance with leg behind, the position causes a stretch in the hamstrings of the supportive leg (Alter 2004, p. 221–223). In the balance with leg in front, the pelvis is not anteriorly tilted and, therefore, does not produce similar stretch. As the length of the muscle affects the muscle's capacity to produce force (Komi *et al.* 2003, p. 119–120), it can be suggested that the stretched *biceps femoris* in the balance with leg behind might not even be capable to produce force in the same amounts than in the balance with leg in front.

As the similarly positioned balance movement can be performed with several slightly different techniques, the results of the present study must be interpreted carefully. The changes during the intervention period might not be a result from the strength training or normal AGG training, but only a result from a slightly different balance movement performed. Furthermore, it could be that the balance movements were performed better in the POST tests for reasons that did not relate to the intervention period.

9.1.2 Split leap

There were no bilateral differences observed in the vertical ground reaction forces, or timing of the jumps, indicating that split leap performance was similar for right versus left leg leading. This bilateral work is evaluated in competitions (IFAGGb 2012) and is also beneficial for decreasing injury risks (Alter 2004, p. 221–226, Van Praagh 1998, p. 229).

The differences between the age groups indicate that older gymnasts have higher RFD values during take-off, creating a more explosive push-off. However, there were no statistically significant differences in the muscle activities between the age groups, so the produced explosive action might not be due to higher muscle activation. The RFD was observed to correlate with the flight time, and the flight time was also observed higher in older gymnasts, non-significantly in PRE and significantly in POST tests. The flight time was 0.35 s for the younger group (10–11 yrs) and 0.39 s for the older group (13–14 yrs). As Takala (2010) reported flight times of 0.46 s with subjects with mean age of 17.0 years, it may be suggested that older gymnasts indeed have higher flight times. Also Dyhre-Poulsen (1987) reported values of 0.49 s measured from top rhythmic gymnasts aged 17.6.

The contact time of take-off was 0.23 s ± 0.03 for both groups, whereas Takala (2010) and Dyhre-Poulsen (1987) reported of slightly shorter contact times (0.20 s). The contact time of take-off was found to be negatively correlating with flight time; the longer flight times and shorter contact times were also reported by Takala (2010). This suggests that speed and explosive strength training would be advisable in AGG for improving the take-off and performing optimal split leaps. However, Takala (2010) observed no relation between the flight time and vertical force of landing, but in the present study, when the vertical force was normalized to body weight (BW), a positive relation was found. During landing, the gymnasts produced force of approximately 4.4 ± 1.0 (younger group) and 4.8 ± 1.3 (older group) times of body weight to the ground. In the study of Takala (2010), the force of landing was higher, 6.4 ± 1.3 times the body weight. As a correlation between the flight time and BW-normalized force of landing was observed in the present study, the higher landing force reported in the study of Takala (2010) could be explained by the longer flight times compared to the flight times in the present study.

In the longitudinal study, the changes in the split leap variables were not consistent with the two age groups, indicating that error factors of split leap performances might have contributed to the results. In the younger group, the contact time of take-off decreased and RFD increased, whereas the older group showed increase in flight time. However, all these variables indicate that the leaps of both groups improved during the intervention period, as both the speed of the take-off and the flight time is evaluated in competitions (IFAGGa 2012). In muscle activities, there were no statistically significant changes suggesting that the hamstring strength training did not change the activity of *biceps femoris* during split leap. It cannot, however, be determined whether the mechanical changes of the leap were due to normal AGG training or the intervention of hamstring strength training.

Muscle activation patterns based on the results from the present study can be further discussed. Overall, the activation of quadriceps femoris muscles was, in many phases, greater than the activation of hamstrings. This is logical for the leading leg, as its actions are to flex the hip and extend the knee. For the pushing leg, however, a high activation of quadriceps femoris muscles may be due to high extension of the pushing leg in order to prevent deduction in competitions from slightly flexed knee (Takala 2010). Relatively high activation of quadriceps femoris compared to hamstrings, however, might result in lower activation of its antagonist, hamstrings, which in this case should be activated in the pushing leg while it is hyperextending from the hip (Alter 2004, p. 221–227, Takala 2010). Takala (2010) reported of relatively higher activation of quadriceps femoris in take-off and flight phases in the pushing leg. In the present study, however, relatively higher activation of quadriceps femoris was observed consistently only in the take-off phase. This indicates that the extension of the knee during the flight was perhaps not as high as in the study of Takala (2010). However, when observing the first phase of flight with age groups separately, it was found that in the older group, the activation of *vastus medialis* increased, and activation of *biceps femoris* did not change. On the contrary, the younger group performed lower amplitude of increase in *vastus medialis* activity with non-significant increase of 39 % in *biceps femoris* activity (figure 24, p. 63). Therefore, the younger group may have had more opportunities to activate the hamstrings while the simultaneous activation of the antagonist (quadriceps femoris) was not as high as in the older group.

Another interesting aspect of *biceps femoris* activation was its decrease in the leading leg while the split position of flight. This significantly low activation in the middle phase of the flight, compared to take-off and landing, was observed only in the older group, and no change was noticed in the younger group. The reasons for the significant decrease of the activation remains unknown, but it might be reasonable to suggest that the decrease is related to flexibility, as the split leap is an action of fast dynamic flexibility (Alter 2004, p. 4). In a split leap position, the leading leg is raised to the horizontal level, and while the pelvis stays anteriorly tilted, the position is described to cause a stretch in the hamstrings of the leading leg (Alter 2004, p. 221–223). The stretch is more efficient when the muscle is relaxed (Alter 2004, p. 6–14), and therefore it might be that the decrease in *biceps femoris* activity during the split leap position could relate to flexibility of hamstrings in the movement. However, as the older group did not have significantly better hamstring flexibility in statistics, and the split leaps were not video analyzed, the topic needs further research.

9.1.3 Body swing

The muscle activities of the body swing were largely deviated and individual variation was high. There were no changes observed during the intervention period suggesting that the movement did not change due to the training. However, some muscle activation patterns were revealed, indicating that in the knee flexion phases quadriceps femoris activated relatively more than hamstrings. This type of quadriceps dominance is also observed with single limb squat in women (Youdas *et al.* 2007), which resembles the action of body swing for legs. In the knee extension phases of body swing, there were no differences found between muscle activities. The highest activation point for both *biceps femoris* and *vastus lateralis* was in the last phase of the movement. This indicates a forceful swing in the last extension phase.

Between the age groups, there were no consistent differences in muscle activation, although a trend for higher activation of quadriceps femoris (quadriceps femoris dominance) was observed for the younger group compared to the older gymnasts. As for the balance movements and the split leap, also the body swing may be performed with slightly different techniques, resulting into differences in muscle activation. Because video analyses were not used, there were variables, such as the deepness and speed of the movement, that were not controlled. Therefore, the results of the differences between phases and age groups should be interpreted critically.

9.1.4 Effect of puberty

Clear differences between prepubertal and pubertal girls were observed in RFD of the take-off and length of the flight time in split leap, as well as in the velocity moment of the balance movements. Both the RFD and flight time were higher in the older gymnasts compared to the younger gymnasts indicating a more explosive push-off within the pubertal group. Also, balance performance was better in the older group in the terms of lower velocity moment. Maturation and neuromuscular development might contribute to these differences, as force production increases (Grosset *et al.* 2008; O'brien *et al.* 2010) and antagonist coactivation decreases during maturation from child to adult (Lambertz *et al.* 2003; Grosset *et al.* 2008; Frost *et al.* 1997).

In addition to neuromuscular development, also other factors might have had contributed to the age differences observed. Longitudinal growth spurt in puberty, for example, may be associated with weakened H/Q strength ratio (Wild *et al.* 2013), and therefore, it might affect some results of H/Q muscle activation or performance. Also, the total volume of AGG training might have had large effect on the differences between the age groups in the present study, as the older group had naturally been training AGG for a longer period of time than the younger group. To conclude, maturation together with longitudinal growth and the total volume of training might be related to RFD, flight time, and balance. However, relations for the H/Q ratio or hamstring flexibility were not observed in the present study, and therefore, effects of longitudinal growth and puberty on these variables were not determined.

9.2 Strengths and limitations of the study

The present study was probably the first international study of electromyography in gymnastics actions on AGG gymnasts. The standard deviations and individual variety were high among the results, especially in the EMG values. Larger subjects groups would have lowered the standard deviations to allow higher reliability for the results. Despite the high standard deviations, some results also reached the statistical significance level. For the mechanical forces and flight times of the split leap, the results of the present study can be considered reliable when comparing with reference values from previous studies. Unfortunately, no reference values for the measured balance movements or body swings has been reported at the publication time of the present study. The selected gymnastic actions were familiar and easy for subjects, to minimize the learning effect. However, it may be that some skill learning still happened during the intervention period.

For considering the validity of the study, the main error source was that the effects of the intervention period could not be determined reliably. This is due to the lack of the control groups performing either hamstring strength training only (without normal AGG training), or performing AGG training only (without hamstring strength training). Unfortunately, for the limited amount of subjects in the present longitudinal study, the control groups could not have been organized without lowering the amount of subjects in the experimental groups.

The most probable error source for reliability was the inadequate control of the gymnastic actions. Furthermore, these types of actions would be reasonable to be controlled by video analysis for determining if variables such as technique or shape of the movement change between subjects or between tests. Slightly different techniques might not be seen visually and may affect to the EMG activities in gymnastic actions, as Takala (2010) discussed. Video analysis would also have been beneficial for more accurate separation of different phases in the movements. Larger subject groups might also have decreased the source of error.

The actual measurement protocol of EMG might as well have had error sources. As Merletti & Parker (2004, p. 251) stated, the measurement of surface EMG in dynamic movements may be challenging as the muscle may move in relation to the electrode. In static balance movements the supportive leg did not move, but the possible electrode movement was more relevant in the split leaps and body waves. Also, the existence of crosstalk and false signals were an important source of error and may have disturbed recording muscle activation patterns (Merletti & Parker 2004, p. 87–91). When comparing the results between two age groups of subjects, also the amount of volume conductor might have affected the results (Merletti & Parker 2004, p. 89–91). For longitudinal comparison, this effect was smaller because the change in the amount of volume conductor in 9 weeks for one subject is probably lower than differences between two subjects in the cross-sectional study.

For determining more specific muscle activation patterns, also activity of *gluteus maximus* and *gastrocnemius* should be measured, as they have roles in gymnastic movements, especially in split leaps (Dyhre-Poulsen 1987). The present study could be continued with measurement of other muscle activities in the same gymnastic actions and by video analyzing possible differences in the performance techniques. For determining more specific differences between age groups, also biological maturation should be estimated.

9.3 Conclusions

The low-load hamstring strength training synchronized to normal AGG training of the present study did not influence the flexibility of hamstrings, measured by FGD. As maintenance of flexibility is considered highly important in AGG, the type of strength training used in the present study may be considered as non-harmful for flexibility. Therefore, low-load hamstring strength training may be suggested for gymnasts with low H/Q strength ratios with the aim to strengthen the weak hamstrings and improve the muscle balance. In addition, the hamstring strength training may have specific improvements on balance performance in AGG.

Whether these improvements on balance performance are directly related to hamstring strength training remains uncertain, but as the performances in the present study were improved with a high magnitude in a short period of time, it might be suggested that maturation and high volume of AGG training cannot, alone, account for this high of an improvement. Further research is needed to determine more specific muscle activation patterns during AGG actions, as well as the specific effects of hamstring strength training on the performance of gymnasts.

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ATTACHMENT 1. Cover letter for the cross-sectional part of the study (in Finnish)

JOUKKUEVOIMISTELIJOIDEN ETU- JA TAKAREIDEN VOIMASUHTEIDEN MITTAUS

Ikäkausirinkien I ja III leireillä olevilla voimistelijoilla on nyt mahdollisuus päästä etu- ja takareiden voimasuhteiden mittaukseen. Mittaukset ovat osa pro gradu -työtämme, jonka teemme Jyväskylän yliopiston Liikuntabiologian laitokselle. Ohjaajanamme toimii laitoksen johtaja, professori Keijo Häkkinen. Pro gradu -työmme puitteissa yritämme muun muassa selvittää joukkuevoimistelijoilla esiintyvien takareisivammojen alkuperää tutkimalla voimistelijoiden reisilihasten voimasuhteita ja liikkuvuutta.

Tutkimuksen ensimmäisessä osassa mittaamme joukkuevoimistelua harrastavilta tytöiltä etu- ja takareiden maksimaalista voimantuottoa sekä takareiden liikkuvuutta selvittääksemme mahdollisia epätasapainotiloja. Valitsemme tutkimukseen yhteensä noin neljäkymmentä halukasta 1997/1998/2000/2001-syntynyttä voimistelijaa. Vaatimuksena on vähintään kahden (2000-2001-syntyneet) tai kolmen (1997-1998-syntyneet) vuoden lajitausta.

Mittausten analyysien valmistuttua välitämme tulokset etu- ja takareiden voimasuhteista voimistelijan päävalmentajalle, jolta perheet voivat näitä myöhemmin tiedustella. Voimasuhteiden selvittämisestä saattaa olla suoraa apua joukkuevoimistelun valmennustyöhön – voimistelijan mahdollisten epätasapainotilojen korjaaminen parantaa lihasten toimintakykyä sekä todennäköisesti ehkäisee takareisivammoja.

Mittaus yhden voimistelijan osalta kestää noin 30 minuuttia ja on urheilijalle täysin ilmainen. Testaamme molemmista jaloista etu- ja takareiden maksimaalisen isometrisen voimantuoton voimatuolissa. Tämä tarkoittaa, että voimistelija istuu tuolilla polvet 107 ° kulmassa ja yrittää suoristaa/koukistaa jalkaansa nilkkatukea vasten noin 4 sekunnin ajan niin voimakkaasti kuin pystyy. Mittauksessa ei käytetä minkäänlaisia painoja, eikä polven nivelkulma muutu. Näiden ominaisuuksien johdosta loukkaantumisriski on erittäin vähäinen. Käyttämämme menetelmä on turvallisuutensa vuoksi laajasti käytetty, erityisesti lapsilla. Koska testisuoritus on maksimaalinen, pientä urheilijoille tuttua lihaskipua voi ilmetä parina seuraavana päivänä.

Voimamittauksen lisäksi suoritamme takareisien liikkuvuutta mittaavan testin (eteentaivutus korokkeella seisten), joka onkin lähes kaikille voimistelijoille jo tuttu testi. Ennen voima- ja liikkuvuustestejä mittaamme myös taustatietoja varten voimistelijan pituuden ja painon. Koska leireillä tapahtuva testaus lasketaan osaksi voimisteluharrastusta, kuuluu se myös voimistelulisenssin vakuutuksen piiriin.

Kaikkien mittauksesta kiinnostuneiden perheiden tulee täyttää ja allekirjoittaa alla oleva esitietolomake ja pakata se mukaan leirille. Huomioittehan, että lomakkeeseen tarvitaan molempien huoltajien suostumukset, mikäli huoltajia on kaksi. Ilman asiallisesti täytettyä lomaketta emme suorita testejä. Kaikki tiedot pidetään luottamuksellisina, ainoastaan voima- ja liikkuvuusmittausten analysoidut tulokset lähetetään eteenpäin (omalle valmentajalle).

Otattehan meihin rohkeasti yhteyttä, mikäli teillä on kysyttävää tutkimuksesta tai esitietolomakkeen täyttämisestä.

Ystävällisin terveisin,
Jyväskylän yliopiston liikuntabiologian laitoksen valmennus- ja testausopin opiskelijat

Opri Jokelainen opri.jokelainen@jyu.fi 050 576 9800
Henni Takala henni.e.takala@jyu.fi 040 703 9886
Nähdään leirillä!

ATTACHMENT 2. Cover letter for the longitudinal part of the study (in Finnish)

ETU- JA TAKAREIDEN VOIMASUHTEET JOUKKUEVOIMISTELIJOILLA: KOEHENKILÖKSI?

Aloitimme kesällä joukkuevoimistelu-aiheisen pro gradu – tutkimuksen työstämisen. Tutkimus tehdään Jyväskylän yliopiston Liikuntabiologian laitokselle, ohjaajanamme toimii laitoksen johtaja, professori Keijo Häkkinen. Tutkimuksemme puitteissa yritämme muun muassa selvittää joukkuevoimistelijoilla esiintyvien takareisivammojen alkuperää tutkimalla voimistelijoiden reisilihasten voimasuhteita, liikkuvuutta, lihasaktiivisuutta ja kokoa. Mittaamme näitä ominaisuuksia elokuussa Xsiia – ja Lumo –joukkueilta. Tämän jälkeen joukkueet tekevät treeneissä tehostetusti takareisien voimaharjoitusliikkeitä kahdeksan viikon ajan. Treenijakson jälkeen lokakuussa teemme uudelleen reisilihasten voimasuhteiden, liikkuvuuden, lihasaktiivisuuden ja koon mittaukset.

Mittausten analyysien valmistuttua välitämme perheille tulokset mm. etu- ja takareiden voimasuhteista. Voimasuhteiden selvittämisestä saattaa olla myös suoraa apua joukkuevoimistelun valmennustyöhön – voimistelijan mahdollisten epätasapainotilojen korjaaminen parantaa lihasten toimintakykyä sekä todennäköisesti ehkäisee takareisivammoja. Koehenkilöiksi otamme 1997/1998/2000/2001-syntyneitä Xsiia – ja Lumo –joukkueiden voimistelijoita. Toiveenamme tietysti on, että koko joukkue innostuisi mukaan tutkimukseen. Vaatimuksena on vähintään kahden (2000-2001-syntyneet) tai kolmen (1997-1998-syntyneet) vuoden lajitausta.

Sekä alku- että loppumittaukset suoritetaan ilmaiseksi Liikuntabiologian laboratoriossa ja kestävät n. 2 h/voimistelija. Aluksi mittaamme taustatiedoiksi voimistelijalta pituuden, painon ja rasvaprosentin. Paino-ongelmien välttämiseksi emme paljasta voimistelijalle omaa rasvaprosenttiaan. Etu- ja takareiden liikkuvuuden mittaamme goniometrin avulla makuuasennosta, eli mittaaja venyttää koehenkilön jalkaa laitteen mitatessa lihaksen kireyttä. Lihaksen koko määritetään lepoasennossa turvallisen ultraäänilaitteen avulla.

Etu- ja takareiden voimasuhteet selvitetään isometrisen maksimivoimamittauksen avulla voimatuolissa. Tämä tarkoittaa, että lapsi istuu tuolilla polvet 107 ° kulmassa ja yrittää suoristaa/koukistaa jalkaansa nilkkatukea vasten noin 4 sekunnin ajan niin voimakkaasti kuin pystyy. Mittauksessa ei käytetä minkäänlaisia painoja, eikä polven nivelkulma muutu. Näiden ominaisuuksien johdosta loukkaantumisriski on erittäin vähäinen. Käyttämämme menetelmä on turvallisuutensa vuoksi laajasti käytetty, erityisesti lapsilla. Koska testisuoritus on maksimaalinen, pientä urheilusuorituksista tuttua lihaskipua voi ilmetä parina seuraavana päivänä.

Maksimivoimamittauksen yhteydessä etu- ja takareiden ihoon kiinnitetään tarralla muutama pintaelektrodi, joiden avulla seurataan lihasaktiivisuutta. Elektrodien kanssa suoritetaan toistoja muutamasta tutusta voimisteluliikkeestä, esimerkiksi vauhtiheitosta, harppaushypystä ja etutasapainosta. Elektrodeista voi pariksi tunniksi jäädä harmiton punertava jälki ihoon, mutta muuten ne ovat erittäin turvallinen tapa seurata lihasten aktiivisuutta.

Mittauksissa kerättyjä tietoja käytetään vain tutkimustarkoitukseen. Tuloksia ja esitietoja käsitellään luottamuksellisesti, anonyymeina. Jokaisella on myös oikeus vetäytyä tutkimuksesta milloin tahansa.

Tutkimukseen osallistuvien perheiden tulee täyttää ja allekirjoittaa alla oleva standardoitu esitietolomake ja palauttaa se omalle valmentajalle. Huomioittehan, että lomakkeeseen tarvitaan molempien huoltajien suostumukset, mikäli huoltajia on kaksi. Ilman asiallisesti täytettyä lomaketta emme suorita testejä.

Koehenkilöt on ulkoisten tapaturmien varalta vakuutettu Jyväskylän yliopiston puolesta, ja lisenssin ostaneilla kilpavoimistelijoilla on lisäksi liiton kautta oma vakuutus, joka kattaa kaiken testauksen. Otattehan meihin rohkeasti yhteyttä, mikäli teillä on kysyttävää tutkimuksesta tai esitietolomakkeen täyttämisestä.

Ystävällisin terveisin,
Jyväskylän yliopiston liikuntabiologian laitoksen valmennus- ja testausopin opiskelijat

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ATTACHMENT 3. Health queastionnaire for subjects (in Finnish)

ESITIETOLOMAKE

On tärkeää, että tiedämme lapsenne aiemmista liikuntatottumuksista ja mahdollisista sairauksista ennen kuin testaamme hänet. Vastaattehan seuraaviin kysymyksiin huolellisesti.

Lapsen nmi:______________________________Synt.aika:_____________________

Joukkue:________________ Voimistelun aloittamisen ajankohta:________________

Oireet viimeisen 6 kk aikana:	Kyllä	Ei	En osaa sanoa
1. Onko lapsella ollut rintakipuja? Levossa? Rasituksessa?			
2. Onko lapsella ollut rasitukseen liittyvää hengenahdistusta?			
3. Onko lapsella ollut huimausoireita?			
4. Onko lapsella ollut rytmihäiriötuntemuksia?			
5. Onko lapsella ollut harjoittelua estäviä kipuja/vammoja?			
Missä?			

Jos lapsella on ollut takareisivammoja, niin millaisia?

____

Todetut sairaudet: Onko lapsella ollut jokin/joitakin seuraavista? (ympyröi)

01 kohonnut verenpaine
02 aivoverenkierron häiriö
03 sydämen rytmihäiriö
04 sydänsairaus
05 kilpirauhasen toimintahäiriö
06 nivelreuma
07 pallea-, nivus- tai napatyrä
08 muu verisuonisairaus
09 muu keuhkosairaus
10 anemia
11 astma
12 diabetes
13 nivelrikko, -kuluma
14 krooninen selkäsairaus
15 tapaturma äskettäin
16 urheiluvamma äskettäin
17 leikkaus äskettäin
18 kohonnut silmänpaine

Muita sairauksia tai oireita, mitä:____

Käyttääkö lapsi jotain lääkitystä tai lääkeainetta säännöllisesti tai usein? 1 Ei 2 Kyllä,
mtä:____

Kuumetta, flunssaista oloa tai muuten poikkeavaa väsymystä viimeisen kahden viikon aikana:
1 Ei 2 Kyllä

Onko lapsen lähisuvussa ennenaikaiseen kuolemaan johtaneita sydänsairauksia? 1 Ei 2 Kyllä
Lähisukulainen? ______________________________Minkä ikäisenä?________
Onko todettu synnynnäinen sydänvika? ______________________________________

Onko lapsi harrastanut liikuntaa viimeisen 2 kk aikana? 1 Ei 2 Kyllä
Onko lapsella muita liikuntaharrastuksia joukkuevoimistelun lisäksi, mitä? ____________________

Huomioittehan, että tarvitsemme testin suorittamiseen molempien huoltajien suostumuksen.

Olen vastannut kysymyksiin rehellisesti parhaan tietämykseni mukaan. Tunnen testaustavan ja annan lapselleni luvan osallistua.

Aika__________________ Paikka_____________________

Allekirjoitus huoltaja 1_______________________________________

Allekirjoitus huoltaja 2_______________________________________