DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

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Musculo-skeletal function in young gymnasts: association with training loads and low-back pain

TARTU UNIVERSITY
PRESS

Institute of Exercise Biology and Physiotherapy, University of Tartu, Tartu, Estonia

Dissertation is accepted for the commencement of the degree of Doctor of Philosophy in Exercise and Sport Sciences (Kinesiology and Biomechanics) on 19 September 2008 by the Council of the Faculty of Exercise and Sport Sciences, University of Tartu, Tartu, Estonia

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Commencement: room of the Council of the University of Tartu, 18 Ülikooli Street, Tartu on 14 November 2008 at 2 p.m.

Publication of this dissertation is granted by the University of Tartu

ISSN 1406–1058
ISBN 978–9949–11–980–6 (trükis)
ISBN 978–9949–11–981–3 (PDF)

Tartu Ülikooli Kirjastus
www.tyk.ee
Tellimus nr. 452

In memory
of my mother Aino Kums

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original papers, which will be referred to in the text by Roman numerals (I–IV):

I. **Vain A, Kums T.** Criteria for preventing overtraining of the musculoskeletal system of gymnasts. *Biology of Sport*, 2002,19(4): 329–345.

II. **Kums T, Ereline J, Gapeyeva H, Pääsuke M**. Vertical jumping performance in young rhythmic gymnasts. *Biology of Sport*, 2005, 22(3): 237–246.

III. **Kums T, Ereline J, Gapeyeva H, Pääsuke M, Vain A.** Spinal curvature and trunk muscle tone in rhythmic gymnasts and untrained girls. *Journal of Back and Musculoskeletal Rehabilitation*, 2007, 20(2–3): 87–95.

IV. **Kums T, Pääsuke M, Leht M, Nurmiste A.** Intervertebral disc height, spinal curvature and low-back pain in young rhythmic gymnasts. In: Jürimäe T., Armstrong N., Jürimäe J. (eds). *Children and Exercise: The Proceedings of the 24th Pediatric Work Physiology Meeting.* Routlege Taylor & Francis Group, 2008, pp. 199–202.

The contribution of the dissertant to the compiling of the doctoral thesis:

Paper I. The dissertant conducted the experimental part of the studies, had responsibility for collecting and analysing data, as well as outcome assessment and participated in the writing of the paper (the chapters of results and discussion have been written by the dissertant indenpendently).

Paper II. The dissertant conducted the experimental part of the studies, had responsibility for protocol development, outcome assessment, data analysis and wrote the preliminary version of the manuscript.

Paper III. T. Kums conducted the experimental part of the studies, developed the protocol, assessed the outcome, conducted data analysis and wrote the manuscript.

Paper IV. T. Kums developed the protocol and conducted data analysis, assessed the outcome and wrote the manuscript.

ABBREVIATIONS

BM – Body mass
BMI – Body mass index
CMJ – Counter-movement jump
DJ – Drop jump
EMG – Electromyography
I – Intensity of the taining loads
L after – Height difference after training session
L before – Height difference before training session
L change – Changes in height difference in supine and standing position after training session compared with pre-training level
L – Height difference in supine and standing positions
LBP – Low back pain
LL – Angle of lumbar lordosis
MRI – Magnetic resonance imaging
MSS – Musculo-skeletal system
Q – Wolume of the training loads
S – Sacral inclination angle
SJ – Squat jump
SSC – Stretch-shortening cycle
TK – Angle of thoracic kyphosis
U% – Percentage of the impact including elements
Ỵ – Oscillation frequency
θ – Logarithmic decrement of oscillation damping

1. INTRODUCTION

An increase in sport efficiency necessitates a constant increase in training and competition load, which presents continuously higher requirements to athletes' musculo-skeletal system (MSS). If the requirements presented do not exceed the organism’s physiological abilities, the loads assume a forming role ensuring an adequate morpho-functional reconstruction of the MSS. In case of long-term maximum and forced loads, readaptation of the MSS function occurs, fatigue, overstrain and microtraumas develop. The latter may be assessed as functional disorder, pre-pathological conditions, after which serious pathology develops. However, due to insufficient clinical symptoms, they are often left unnoticed and untreated (Orava, 1985; Caine *et al.,* 1989; Micheli, 1995; Brüggemann, 1999; Sands, 2000). This tendency is particularly dangerous in children.

In gymnastics a significant decrease has occurred in the age of athletes in recent decades, 12–14 year-old children who have reached top level train 6–7 hours per day (Caine *et al*., 1989; Sands, 1990; Georgopoulos *et al*., 2001, 2004). They perform training loads, with the volume and intensity that were previously allowed only to adult athletes. The percentage of elements related to jumping load and hyperextensions in artistic as well as rhythmic gymnastics remains high in all periods of the training cycle. In connection with this, high requirements are presented to the MSS of girls (Micheli, 1985; Letts *et al*., 1986; Brüggemann, 1999; Mc Cormack & Athwal, 1999; Brüggemann & Krahl, 2000). However, medical statistics data show that women’s MSS is less adaptive to stroke mechanical load than the MSS of men. On the basis of a study conducted by Dixon and Fricker (1993), it was shown that women in artistic gymnastics experience twice as many chronic lower limb and vertebral column illnesses than men. We must hereby also take into account that due to the plasticity of children's MSS, it is not yet ready to experience intensive jump and hyperextension training loads (Obyssoff, 1971; Pope *et al*., 1993; Micheli, 1995; Krivickas, 1997; Standaert *et al*., 2000).

Many studies have shown that inadequate repetitive training loads related to stroke and hyperextension in speed and strength training induce several side effects: flattening of children’s foot arches, cases of osteochondrosis, Achilles tendon ruptures in artistic gymnastics; spondylolisthesis, spondylolysis, cases of lower back pain in rhythmic gymnastics; deformative arthrosis of knee joint surface in figure skating; early synostosis of knee joint slit in 12–13 year-old children in football (Nielsen & Yde, 1989; Gould, 1993; Micheli, 1995; Caine, 2003).

Most specialists in sports medicine agree that the degenerative changes of the MSS result from chronic overload and repetitive microtrauma (Kibler *et al*., 1992; Claessens *et al*., 1996; Ariyoshi *et al*, 1999; Sands, 2000; Standaert, 2000; Hochmuth *et al*., 2002). Researchers have constantly emphasized that forced training of talented children is unjustified (Gould, 1993). The level of physical loading may not exceed the boundaries of an organism’s adaptational capacity. At the same time, Doiser (1980) noted that there exist no excessive training loads, but the organism’s capacity to tolerate the latter. The level of permissible load is individual and it is difficult to determine its optimal features.

Based on the above, it appears that research in the effect of training load on the MSS of gymnasts is relevant. One of the most topical problems to be solved in sports today is the individualisation of training load, and monitoring its adequacy and effect on the functional condition of an athlete's MSS with the purpose of preventing the occurrence of pre-traumatic conditions.

In addition, the determination of the function of the passive (vertebral column) and active (muscles) part of the MSS and the assessment of the adaptive reaction of the neuromuscular system to jumping load and its comparison with data concerning an untrained population assume a great role in managing a knowledgeable training process. This would provide the opportunity to discover earlier signs of MSS readaptation in due time, which is of essential interest for coaches, sports medicine specialists, and researchers. This study focuses on the given topic.

2. REVIEW OF THE LITERATURE

2.1. Specifics of training in rhythmic and artistic gymnastics

Gymnastics is an acyclic, aesthetic sport requiring from the athletes complicated coordination qualities. Its peculiarity lies in its being close to art as not only an athlete's technical preparation but also the accuracy of movements, expression, artistry, musicality and choreography are taken into account. Hard work and great dedication lie hidden behind the ease of movement and the seeming simplicity (Theodoropoulou *et al*., 2005; Salbach *et al*., 2007; Klinkowski *et al*., 2008).

Nowadays, training starts at the age of 3–4 years, while 6-year-old children already participate in official competitions, 16-year-old girls are in the senior class and 20-year-old girls are veterans. As a rule, advanced gymnasts train twice a day, 1.5–2 hours in the morning and 3–3.5 hours in the evening 6 times per week. Thus, the average number of training hours per week is 27–33 (Caine *et al*., 1989; Dixon & Fricker, 1993; Theintz *et al*., 1993; Sands, 2000; Georgopoulos *et al*., 2004).

However, there are several differences between the two types of gymnastics. Artistic gymnastics is an athletic field of gymnastics, where an athlete must demonstrate his/her skills by performing combinations on apparatus (beam, skids, vault, freestyle); the main elements are balances, jumps, turns, bends, which are intertwined with complex acrobatic combinations. The characteristic constitution type of artistic gymnasts is muscular and thoraco-muscular. Most of them are short, 150–160 cm, body weight 38–50 kg, with broad shoulders and narrow hips; the length of upper limbs is 42–47%, and lower limbs 52–56% of total body height (Tumanyan & Martirossoff, 1976; Claessens *et al*., 1999; Weimann *et al*., 1999; Filaire & Lac, 2002; Theodoropoulou *et al*., 2005).

Rhythmic gymnastics is characterized by plasticity and extreme gracefulness, which in its nature is similar to classical ballet. The main instruments are hoop, ball, clubs, skipping-rope, ribbon and the main elements are balances, jumps, pivots, bends and waves body movements. Within a relatively short time of 1.5 min, a rhythmic gymnast must demonstrate a combination including hyperextensions, jumps, turns, which are performed in the conditions of insufficient balance, and perfect command of the instrument. The characteristic constitution of rhythmic gymnasts is leptosomic, which is similar to ballerinas. The build of advanced rhythmic gymnasts is relatively frail, average or above average height, with long upper and lower limbs, narrow shoulders and long neck (Klentrou & Plyley, 2003; Theodoropoulou *et al*., 2005; Klinkowski *et al*., 2007; Salbach *et al*., 2007; Soric *et al*., 2008).

Regardless of the abovementioned differences, both types are characterized by great jumping load and elements related to hyperextension. It must be mentioned that elements related to hyperextension are more characteristic of rhythmic gymnastics, while high jumping loads are more typical in artistic gymnastics (jumps, landings, dismounts), which constitute 60–70% of the total training volume. Jumping load may be viewed as stroke, which by nature has a damaging effect on the MSS, particularly in case of extensive and intensive training loads (Caine & Lindner, 1985; Caine, 1990; Kibler *et al.*, 1992; Meeusen & Borms, 1992; Sands, 2000; Hochmuth *et al.*, 2002).

In the jumping loads, the force generated during the encounter of MSS with the support surface is nature a stroke, particularly because of the very short duration of the impact not exceeding 1 s (Sergeyeff, 1967; Nigg, 1986; Bobbert *et al.*, 1992; Pain & Challis, 2004). The energy of stroke, which arises as a result of a bounce spreads in the shape of waves in biomechanical chains from distal body parts to proximal ones (Hochmuth, 1967; Dupius, *et al.*, 1976; Nigg, 1980; Chu *et al.*, 1986). In more dense tissues, jolts and stroke spread faster. The higher the thickness of the tissue, the more damaging is the process. As a result, the destructive force of stroke load is mostly evident in bone tissue as the latter has less elasticity compared to soft tissue (Kudrin *et al.*, 1980; Huiskes *et al.*, 1989; Beaupre' *et al.*, 1990).

As a rigid system, a human body reacts to acceleration at 1–8 m/s^2, because a contact link is unable to meet a stroke load in a corresponding extent due to the short duration of the impact of the stroke force. The MSS reacts as an elastic system to acceleration with the duration of 60–100 m/s^2 (Gozuloff & Stupakoff, 1986). The level of the biological effect of a stroke depends on the duration, size and the increase of its growth in time, i.e. the gradient of the acceleration occurring as a results of the force of the stroke. The more abrupt the acceleration and the larger its value, the greater changes it is able to induce in an organism (Girke & Brinkly, 1975; Gozuloff & Stupakoff, 1986). During jumps and landings, the duration of the impact of acceleration on MSS is so short that a contact link may react as a rigid system, which creates favourable conditions for microtrauma of the MSS (Panzer, 1984; Mc Nitt-Gray *et al.*, 1993; Harringe *et al.*, 2006; Orendurff *et al.*, 2008; Mills *et al.*, 2008).

In case of repetitive loads in take – off from support surfaces and landings, pressure deformations of the MSS occur as pressure loads may exceed the force of body weight manifold. It has been observed (Kuryss, 1974) that the load on lower limbs during the first half of the handspring is 270–350 kG, while in pushing off in pirouettes, the mechanical load on an athlete's MSS is 700 kG. Maximum bone-on-bone forces in the tibio-talar joint are calculated at about 11.000 N (23 time body weight). For the talo-navicular joint about 8.000 N were calculated (Panzer, 1984; Brüggemann, 1999). As a result of pressure loads, the foot arches, ankle and knee joint deform. Pressure loads have a significant influence on intervertebral discs of the vertebral column, which tolerate the inertia force occurring and increasing in movements (Hellström *et al.*, 1990; Swärd *et al.*, 1991; Brüggemann, 1999; Bennett *et al.*, 2006). In the location of the stroke, various injuries may occur, the nature of which depends on stroke force, the speed and direction of the object and anatomical peculiarities of the MSS (Andrish, 1985; Jensen, 1998; Harringe *et al.*, 2006). It is therefore important to observe how movement potential is used in the performance of different jumps in order to prevent the occurrence of overstrain in MSS.

Specific flexibility is characteristic of rhythmic gymnastics, which is due to peculiarities in the biomechanical structure of elements and in accordance with the field requirements and competition rules (Lisitskaya, 1982).

Most rhythmic gymnastics elements are movements and static postures performed in the conditions of insufficient balance. The movement of joints must exceed a standard to perform the elements. The standard value of the extension of the vertebral column corresponds to 30º (Lindh, 1989; Hall, 1991), while in rhythmic gymnastics the extension of the vertebral column must exceed the limit of 90º for an element to be taken into account (Tsarkoyva, 1980; Lisitskaya, 1982). Elements including hyperextensions are exercises with a significant pressure force on the vertebral column, which are included under exercises with a high risk factor (Hutchinson, 1999; Soler & Calderon, 2000; Hochmuth *et al*, 2002; Bennett *et al*., 2006).

As a result of repetitive pressure loads, surfaces of joints become worn out, which is reflected in thinning of cartilage tissue. Elasticity is an important property in the cartilage tissue. It is known that cartilage tissue fibres, which are part of the primary makeup of a joint’s cartilage tissue, are bow-shaped. They are thus able to depreciate mechanical strokes and resist pressure loads. As a result of the load, cartilage tissue flattens. As a result of compressing the cartilage tissue, only the edges of the wavy surface flatten at first and the pressure in the cartilage decreases and the liquid part of the synovia moves in that direction. A part of the liquid, high in viscosity and containing hyaluronic acid remains between joint surfaces covered with cartilage, due to which the joint continues to function even in case of compressing large joint areas even when friction force significantly increases. When the pressure load in cartilage decreases, liquid moves from the deeper layers of the cartilage inside the joint and the friction coefficient of joint surfaces decreases (Adams & Hutton, 1986; Porterfield & De Rosa, 1991; Bogduk, 1997; Bartel, 2006). While performing elements using vertebral column hyperextension, it is important to not only pay attention to developing the flexibility of joints but also to the proper employment of muscle strength as the movements are active (Porterfield & De Rosa, 1991).

The impact of strength and stretching exercises on the condition of muscles was studied. It was shown that after performing exhausting stretching and strength exercises, total recovery occurred only on the fourth day (Andersson *et al*., 2008). This implies that in connection with specific load, the vertebral column of a rhythmic gymnast must be particularly enduring as there is a great danger of trauma due to insufficient recovery. Therefore, in the interests of preventive measures, it is important to know how the vertebral column functions and to which extent does it differ in comparison with the untrained population, and in comparison with training companions, who already show signs of readaptation.

2.2. Adaptation of the musculo-skeletal system to training

In the course of every movement activity, adaptation of the organism and its organ systems occurs with the constantly changing surrounding environment. Adaptation to an influence is reflected in the condition of all organ systems of the organism. Each movement activity is performed due to MSS and its systems (bones, their combinations, muscles), which directly participate in the performance of a movement act, while the organism as a whole participates in the performance of movements (Micheli, 1995).

Adaptation depends on many conditions, most important of which include the specifics and intensity of external influences and an organism's standard reaction, which determines receptivity and resistance to the factors of the given environment. An athlete's organism suffers from many external influences during training and competitions, but the most important of these is physical load. Adaptation to physical load is expressed in the conformity of the organism's build and function to the needs of the physical activity (Micheli 1982, 1995; Kibler & Chandler, 1998).

Training loads with different volume and intensity have a different impact on the organism. Weak loads do not cause particular changes, loads with average intensity stimulate the morpho-functional reconstruction of an organism and accelerate growth. Large loads hinder these processes as a result of which an inconformity between the organism's biological abilities and the impacting load occurs. Extreme loads cause functional as well as structural changes. The inconformity between the organism's abilities and actual needs becomes too great. This inconformity may become a source of trauma, as a result of which an athlete must stay away from his/her activity for a prolonged time. The above-mentioned implies that loads of average volume and intensity may be considered optimal. However, an organism's receptivity to external influences is individual (Fry *et al.,* 1991; Kibler & Chandler, 1998; Kenttä & Hassmen, 1998;).

Adaptation to external influences results in the occurrence of no stress reaction while reaching homeostasis. The purpose of the training process is to adapt the athlete's organism to gradually increasing loads (Kibler *et al*., 1988; Micheli, 1995).

In the course of adaptation, the development and disintegration of various morphological structural units of the organism takes place. If the loads exceed the actual limits of an organism – the standard reaction – functional inhibition occurs, recovery processes slow down or are not completed and at this background, trauma of organ systems may occur.

The degenerative-dystrophic processes are a result of interruption of adaptation and chronic functional overload of the MSS. They tend to progress slowly leading to a decrease in sports performance or its complete loss (Herring, 1990).

The amortization function of the MSS, in the course of which the deformation of the MSS occurs is one form of its adaptational reaction to mechanical influence. The deformation of MSS must be viewed as a protective function of the support and movement organs from thrusts, strokes and bounces, and other occurring pressure loads, e.g. during the performance of elements related to hyperextension, in the course of intensive training process. This is a natural reaction of live tissue to mechanical influence. An important feature playing a major role in the deformation is the elasticity of live tissue (cartilages, ligaments, muscles), and its ability to react to external stressors in due time. Naturally, the proper technical performance of movements ensuring an optimal load on MSS is also important (Karzarian, 1975; Taylor & Twomey, 1980; Wutscherk & Herm, 1984; Leatt *et al.*, 1986; Corlett *et al.*, 1987; Pope & Beynnon, 1993).

It is known from biomechanics that the more rigid the system, the faster the stroke energy spreads in the MSS chains, and the smaller are its dissipative damages, which also ensures better performance, e.g. during jumping. However, in case of this method of realization of effort, the MSS tissues are unable to react to outside stressors in time and the athlete's body reacts to mechanical influence as a rigid system. In case of repetitive loads related to jumping and hyperextension on the background of a decrease in the elasticity of MSS tissues, overload leading to MSS trauma may occur. In the readaptation stage, MSS loses its elasticity and the tissues of the support and movement organs become rigid. Thus, supervision of morpho-functional changes occurring in the course of MSS adaptation plays an important role (Talag, 1973; Brown *et al.*, 1988; Chandler *et al.*, 1992; Kibler *et al.*, 1992; Krivickas, 1997).

2.2.1. Spinal curvature and trunk muscle tone in rhythmic gymnasts

Spinal curvature increases the spine's load-bearing capacity during compression and provides a greater margin of safety against both instability and tissue injury (Shirazi-Adl & Parnianpour, 2000). Lumbar curvature plays an important role in influencing equilibrium load sharing and internal tissue stresses and strains (Shirazi-Adl & Parnianpour, 1999; Rajnics *et al.*, 2001; Keller *et al.*, 2005). The shock absorbing qualities of the MSS are very important in performing movements such as jumping and landing, that are characteristic of power sports, in order to prevent injuries of the spine by reducing the force of the impact. We can therefore suppose that the shape of the vertebral column in sagittal profile may have a role in reducing the stress on the MSS during the training process of gymnasts.

The normal shape of the vertebral column help the body to bear the compressive loads. It is important to note if the vertebral column in an upright position is stable and balanced or not, because highly repetitive and exclusive movement pattern in adolescent athletes may produce imbalance in muscle tension between antagonistic muscle groups of the trunk. Imbalance in muscle tension between back and abdominal muscles may result in functional imbalance (also reffered to as muscle imbalance), which predispose the individual to musculoskeletal disorder or injury (Grace, 1985; Newcomer *et al.*, 2002; Hildebrandt, 2003). Injury, disease, or overload of the spine can cause deformities of the vertebral column or alteration of spinal curvatures, e.g. flat back. These deformities often result in altered force distribution patterns and pathological tissue adaptations.

The difference in body height in supine and standing positions (L) characterizes indirectly the scope of deformation of the vertebral column in the sagittal profile. A higher value of L indicates greater tolerance of impacts including stress on MSS (Vain, 1981; Kums, 1996; Kums & Vain, 1997). Dysfunction of the spine's stability system (muscles, ligaments and central nervous system) could lead to lower back injury and pain (Panjabi, 1992; Mannion, 1999). Injury associated with spinal instability (Panjabi, 1992), functional instability of the spine plays major role in the development of back pain (Hildebrant, 2003). Overuse injuries of the vertebral column are common in gymnasts. According to Hutchinson (1999), 86% of the gymnasts studied complained of back pain. Dixon and Fricker (1993) showed, using summarized data from the years 1982–1991, that among the athletes doing gymnastics, women have twice as many chronic injuries of the spine as men do. Guillodo *et al.* (2000) reported that 75% of young elite female gymnasts have had low back pain (LBP).

A principle in the maintenance of vertebral column stability is the use of the minimum energy to reach a certain goal. In other words, the system's resources, including muscular energy, should be used as economically as possible. This view is shared and supported by many researchers. For example Cholewicki's structural spine stability analysis based on the principle of minimum potential energy (Cholewicki *et al.*, 1997) and minimum muscle stiffness required for stability (Stokes & Gardner-Morse, 2003). Cholewicki *et al.* (1997) found that the EMG signal levels recorded from the trunk muscles in a neutral posture were very low. Stability analyses by Stokes and Gardner-Morse (2003) provided an estimate of the minimum muscle stiffness required for stability. The stabilizing flexion moment is generated primarily by the off-centeredness of the gravity load. Relatively small muscle forces are required to balance the entire lumbar spine L1–S1 in erect postures (Shirazi-Adl & Parnianpour, 1996). Subjects in a standing posture demonstrate relatively small superficial muscle activities (Shirazi-Adl & Parnianpour, 1999).

However, the above line of reasoning is being questioned by other researchers. For example, Daggfeldt and Thorstensson (2003) claim that equilibrium in the lumbar spine is mainly regulated by passive mechanical properties, rather than due to complex muscle coordination. "The manual medicine practitioner may interpret pattern of muscle coordination and posture as indicative of instability", by statement, of Mc Gill *et al.* (2003). Biomechanical measurements illustrate that antagonistic co-contraction of the trunk musculature is increased in high risk postures (Pope *et al*, 1987; Marras & Mirka, 1992, 1999).

It has been suggested that the subjects with low LBP had difficulties in activating their rectus abdominis muscle, which can cause the asymmetric contraction of the *m. erector spinae and m. rectus abdominis* (Newcomer *et al.*, 2002; Nourbakhsh & Arab, 2002). Silfies *et al.* (2005) demonstrated, that subjects with chronic LBP had significantly higher activation levels of abdominal muscles. It has been reported that the magnitude of the lumbar lordosis in standing is not associated with the force production of the abdominal muscles (Youdas *et al.*, 2000). An imbalance in trunk muscle strength can induce a significantly lordotic curve of lumbar spine and might be one risk factor for potential LBP (Kim *et al.*, 2006). It is clear, that the spinal flexors' and extensors' part in maintaining the spinal stability in neutral posture is quite controversial and not well understood. The relationschip between the shape of the vertebral column and LBP is unknown. It has been showed that 20% of the female gymnasts have experienced LBP, whereas they had significantly larger lordosis degrees than girls without LBP (Ohlen *et al.*, 1989). A pronounced lordosis has been observed in female students with LBP (Mellin, 1990). In standing position, in patients with LBP exhibited an increased lumbar lordosis compared with controls, whereas patients with acute LBP had an increased thoracic kyphosis (Christie *et al.*, 1995). Controversially, Widhe (2001) suggested, that in children aged 15–16 years, back pain was not related to posture.

Lund *et al.* (1991) demonstrated an increased muscle tone around painful side in patients with musculoskeletal disorders. It has been suggested that in athletes with LBP muscle spasm is not a rare clinical feature (Bono, 2004).

Most studies of the stability of the vertebral column in a neutral upright position, either observe the active component, the muscles stabilizing the vertebral column (Lee *et al.*, 1999; Granata & Wilson, 2001; Essendrop *et al.*, 2002), or the passive component, either the vertebral column at a single segmental level (Crisco & Panjabi 1991; Shirazi-Adl & Parnianpour, 2000), or spinal curvature in sagittal profile as a whole (Wojtys *et al.*, 2000; Panjabi, 2003). In study III was compared spinal curvature and muscle tone characteristics in female rhythmic gymnasts, and untrained controls in order to establish the characteristic features of the spine that is under considerable stress, resulting from adaptation.

Rhythmic gumnastics requires high hypermobility of the lumbar spine. Repetitive loading causes mostly an abnormality in the posterior elements of the spine. The true significance of early degenerative findings of the lumber disc is not known (Salminen *et al.*, 1999; Bono, 2004; Kjaer *et al.*, 2005; Harrison *et al.*, 2005). In study IV was evaluated the effect of trunk posture on the disc height in thoracal and lumbar spine in gymnasts with and without low back pain (LBP), because the relatioship between trunk posture and stresses acting on the intervertebral disc is not well understood.

2.2.2. Vertical jumping performance measurement

Children have become increasingly involved in athletic training at younger ages, especially those competiting in female rhythmic gymnastics. To learn and perform the complex gymnastics skills and to reach the top level of performance in rhythmic gymnastics, it is obvious that girls have to begin intensive training at very young age.

In rhythmic gymnastics, the movements of lower limbs performed at high speed against resistance provided by the body weight are often used, and, therefore explosive strength of the leg extensor muscles plays a major role in the performance. Vertical jumps can be used as a model to assess explosive force-generating capacity and anaerobic power of the leg extensor muscles. The squat jump (SJ) is used as the functional expression of explosive muscle strength of the leg extensor muscles that requires only concentric contraction (Bosco *et al.*, 1982; Bobbert *et al.*, 1996). Vertical jumps are preceded by an eccentric contraction – counter-movement jump (CMJ) and drop jump (DJ), i.e. jumping down from a height and performing a maximal vertical jump upon landing, are exercises characterized by stretch-shortening cycle (SSC) (Bosco *et al.*, 1982, 2002; Bobbert *et al.*, 1996). It has been shown that vertical jumps preceded by an eccentric contraction result in greater vertical jump heights (Asmussen & Bonde-Petersen, 1974; Bobbert *et al.*, 1996). The jump height ratios CMJ:SJ and DJ:SJ have been used to evaluate the ability to use SSC during vertical jumping (Bosco *et al.*, 2002). Several studies have validated the use of repetitive jump tests to assess anaerobic power of the leg extensor muscles during the explosive SSC type exercise in athletes (Bosco *et al.*, 1983; Hoffman & Kang, 2002). However, the ability to use SSC in vertical jumping and anaerobic power during repetitive jumping exercise in young female rhythmic gymnasts is poorly understood. Few studies have investigated the vertical jumping performance in young female gymnasts (Bencke *et al.*, 2002).

2.2.3. Criteria for preventing overtraining of the musculo-skeletal system of gymnasts

Biomechanics of the adaptive processes of gymnasts' MSS presents not widely investigated area of the theory of sports training. Further studies in the field would certainly help to prevent MSS overloading may occur as a result of inappropriate physiological, biomechanical or anatomical stresses. Appropriate stresses to the musculoskeletal system cause positive adaptation. Inapropriate volume or intensity of exercise may cause a maladaptive cellular or tissue response due to an imbalance between load and recovery. These maladaptive responses occur to some extent in most of all sports; however, they can certainly become a part of the overtraining syndrome. The maladaptive responses may be objectively documented as distinct musculoskeletal injuries, such as alterations in muscle strength, flexibility or balance, changes in joint range of motion, or stress reactions in bone.

The exact mechanisms underlying musculoskeletal overtraining are not completely understood, but accumulating evidence indicates that disruptions in cellular homeostasis appear to be basic to the process. Tissue effects arise from these cellular disruptions. These changes may be seen as a possible contributing factor to the musculoskeletal aspects to the overtraining syndrome (Kibler & Chandler, 1998). The monitoring of adaptive reactions of MSS is of particular importance in the fields of sports where the exercises including impacts to MSS prevail. The intensive performance of such exercises evokes great mechanical tensions in muscles, tendons and joint surfaces, which cause overloads and injuries of the muscles as well as joint surfaces (incl. the intervertebral discs).

The published data of medical statistics show that the MSS of women is less adaptable to mechanical loads than that of men. Bak *et al.* (1994) have pointed out that the percentage of traumas among female gymnasts is much higher than among men, the same fact is pointed out by De Loes (1995) and Backx (1995) on the basis of statistical data. Dixon and Fricker (1993) showed, using the summarized data from the years 1982–1991, that among the athletes going in for artistic gymnastics, women have twice as many cases of chronic injuries of lower extremities and the vertebral column as men.

It is known that the vertebral column, due to its curvatures and the intervertebral discs, has certain elastic and absorptive characteristics apparent in situations where impact-including loads are applied (Naylor, 1962; Eklund & Corlett, 1984; Garbutt *et al.*, 1990; Pope & Beynnon, 1993). The vertebral column, which is considered to occupy the second place in the hierarchy of the impact absorption systems of MSS, decreases the magnitude of impact impulses reaching the head about 3.0–3.5 times (Vain, 1976). At present time it is understood that the impulse which influences an intervertebral disc is received by a pulpous nucleus, which consists of homogeneous substance. This substance is surrounded by a fibrous ring, above and below which the adjacent cartilage plates are situated. It has been established (Nachemson, 1960; Ehricht, 1978) that this pulpous nucleus is the functional centre of an intervertebral disc. An estimation exists, according to which this nucleus absorbs up to 80% of the impulse applied to the segment of vertebral column (Nachemson, 1960; Ehricht, 1978; Bogduk, 1997; Bartel *et al.*, 2006). To summarise up the above-given material we can conclude that in case the MSS undergoes repeated overloading for a prolonged time period, certain degenerative changes develop in intervertebral discs (Pope & Beynnon, 1993; Lotz & Chin, 2000; Race *et al.*, 2000). As a result the adsorptive function of the connective tissue structures of the latter is impaired and the vertebral column is not able to absorb the energy of mechanical impulses, the influence of impact type loads on upper MSS segments, brain and retina increases. The present study was designed to establish the quantitative parameters reflecting the state of overloading of the MSS of young female gymnasts in the training process. The working hypothesis was that the MSS morphologic structures, which determine the adaptability of the MSS to impact-including training loads, change the quantitative characteristics of their biomechanical properties depending on the magnitude of the training loads. The existence of statistical relationships between the quantitative characteristics of immediate adaptation reactions and parameters of training process allows to predict the possible overloads.

3. OBJECTIVES OF THE STUDY

The purpose of the present study was to examine the adaptive reactions of MSS to training loads in young female gymnasts and to identify factors associated with LBP in gymnasts.

The specific objectives were:

(1) To assess the changes in function of MSS in artistic gymnasts with association of training loads (Study I).

(2) To compare the vertical jumping performance in rhythmic gymnasts and untrained controls (Study II).

(3) To determine the peculiarity of the spinal curvature and muscle tone in rhythmic gymnasts compared to untrained controls (Study III).

(4) To determine the peculiarity of spinal curvature and intervertebral disc in rhythmic gymnasts with LBP compared to asymptomatic gymnasts (Study IV).

4. MATERIALS AND METHODS

4.1. Subjects

In total 133 female subjects aged 10–17 years participated in this study. Whereas 70 from them were gymnasts at national and international level, and 63 age- and gender-matched untrained girls as controls. The training experience in gymnasts was 5–12 years. Control subjects took part in regular physical education 2 hours per week at school. Wherease none of these subjects had any background in regular sports training of any kind. The studies carried the approval of the Ethics Committee for Human Studies of the University of Tartu.

The anthropometric characteristics of the measured subject groups are presented in Table 1. The rhythmic gymnasts showed less ($p<0.05$) BM and BMI than controls. The body height did not differ significantly between groups.

Table 1. Anthropometric characteristics of the subjects.

Studies	**n**	**Age (yrs)**	**Height (cm)**	**BM (kg)**	**BMI ($kg \cdot m^{-2}$)**
Study I (Paper I) (mean±SE)					
Asymptomatic artistic gymnasts	8	11.4±0.3	134.4±1.9	29.8±0.1	16.5±0.9
Artistic gymnasts with traumas	7	12.3±0.2	136.4±0.8	31.9±0.2	17.1±0.5
Study II (Paper II) (mean±SD)					
Rhythmic gymnasts	11	12.7±1.7	153.9±8.7	36.1±6.4	15.4±1.6
Untrained controls	15	12.7±0.7	158.4±8.3	44.8±7.5*	18.1±2.4*
Study III (Paper III) (mean±SD)					
Rhythmic gymnasts	32	14.7±1.4	159.9±5.3	42.7±5.5	16.7±1.6
Untrained controls	48	14.4±1.8	160.5±6.2	47.3±4.4*	18.3±2.1*
Study IV (Paper IV) (mean±SD)					
Rhythmic gymnasts with LBP	7	13.3±1.0	152.9±8.2	37.0±7.1	15.1±2.4
Rhythmic gymnasts without LBP	5	13.7±0.6	158.6±8.1	40.6±6.8	15.9±1.7

Note: BM – body mass; BMI – body mass index; LBP – low back pain;
* $p<0.05$ compared with rhythmic gymnasts.

4.2. Study design

Study **I** has been carried out during a five-year period (1986–1990) as a pedagogical observation program allowed by sport officials to be performed in the course of the official training program of the Olympic Team reserve. The aim of the study was to establish the quantitative parameters reflecting the state of overloading of the MSS of young female gymnasts in the training process.

Fifteen female gymnasts at national level Estonia, going in for artistic gymnastics (age from 10 to 14 years), were under observation. They had gone in for artistic gymnastics for 6–9 years. In five years 326 observation cycles vere performed. Each separate observation cycle lasted for one week. The training hours were every day in the morning and in the evening, except Sundays, when only one training took place. The measurements were performed immediately before and after training. During each observation cycle the number of gymnastic elements Q performed by an athlete was registered, also the duration of the training period on every gymnastic apparatus T_t in minutes and S_A – the number of approaches on this apparatus. Using these data the training load (number of performed elements) and intensity I were calculated, by formula (Affonyn & Krivenko, 1976):

$$I = \frac{\sum Q^3}{T_t \cdot S_A \cdot 5000},$$

also the percentage U of the impact-including elements (jumps, landing, acrobatic somersaults etc.) in the whole training load Q.

The training volume and intensity of the gymnasts' training process were recorded, also the percentage of the elements including impact loads in the daily training. Changes in linear dimensions of the vertebral column and the biomechanical characteristics of skeletal muscles were recorded using original biomechanical methods developed at the University of Tartu (Vain, 1995).

In Study **II** participated a total of 26 children aged 12 to 13 years: 11 female rhythmic gymnasts and 15 age- and gender-matched untrained control subjects. Rhythmic gymnasts' group consisted of the young high-performance (elite) gymnasts at national level. Gymnasts completed a questionnaire regarding hours of training per week and onset of regular training in rhythmic gymnastics in years. None of the control subjects had any background in regular sports training of any kind. Pubertal stage was determined according to the criteria of Tanner (1962) by a female pediatrician. The vertical jumping performance in female rhythmic gymnasts was recorded in the Laboratory of Kinesiology and Biomechanics, University of Tartu before the international level competition. Prior to testing, each subject underwent a 10-min warm-up with stretching exercises. To assess the explosive force of the leg extensor muscles all subjects performed three different types of vertical jumps: SJ, CMJ and jump from 40 cm height (DJ40), a modified (30s) Bosco anaerobic jumping power test was performed on force platform.

In Study **III** the subjects were 32 elite female rhythmic gymnasts aged 13–17 years, competing at the national and international level. The study was carried out during three "Miss Valentine" international competitions in rhythmic gymnastics in Tartu (Estonia) during three subsequent years. Gymnasts had been trained for 8–12 years, 6–7 hours per day, whereas several of them had experienced LBP. All gymnasts completed Oswestry questionnaires concerning their back pain history, current back pain and functional disability. As a control group, 48 age-matched untrained schoolgirls without LBP incidence measured. Pubertal stage were determined according to the criteria of Tanner (1962) by a female peditrician. The spinal curvature in the sagittal plane was recorded using pantography, the tone of skeletal muscles was investigated using myotonometer. The difference in height in supine and standing positions was determined. This parameter characterizes indirectly the scope of deformation of the vertebral column in the sagittal profile.

In Study **IV** the subjects were 12 young female rhythmic gymnasts aged 13–14 years. Gymnasts had been training for 5–6 years, 12–15 hours per week. Seven female rhythmic gymnasts with idiopathic LBP were compared with 5 asymptomatic gymnasts. Idiopathic back pain score was determined in the subjects in accordance with the score of Oswestry questionnaire. Spine curvature in the sagittal plane were made from lateral radiographs clinically and radiografically. All the 12 girls were included in magnetic resonance imaging (MRI) studies. The intervertebral disc height and the difference in body height in supine and standing positions was determined. All studies was performed at 14 to 16 p.m. time in Department of Radiology, Tartu University Clinic.

4.3. Methods

4.3.1. Myotonometery

The mechanical properties of skeletal muscles was investigated (Study I and III) using an original myotonometer designed and constructed at the University of Tartu (Vain, 1985 a, b, 1990, 1995; Gavronski *et al.*, 2007). The principle of its functioning lies in giving the muscle under investigation via special myometric pickup a dosed mechanical impact and recording the mechanical response of the muscle. Due to the elastic reaction of the tissue the testing end together with the underlying tissue performs damped oscillations. These oscillations are acquired by the acceleration transducer situated in the myometric pickup.

The frequency of the oscillations charasterises the stiffness of muscular tissue, i.e. its property to resist the forces trying to change its shape. The oscillation frequency and stiffness of the muscle are functionally related in accordance with the following equation:

$$C = 4\pi^2 \cdot m^2 \cdot Y^2 + \frac{\Theta}{4m},$$

where m – the oscillating mass (the myometric pickup together with the area of the muscle under investigation), Y – oscillation frequency, Θ – the logarithmic decrement of oscillation damping. The osclillation frequency was calculated by formula:

$$Y = \frac{1}{T} \quad \text{(Hz)},$$

where T – oscillation period (s).

When we have established the stiffness of a muscle, then we are also able to estimate the ability of the muscular tissue to resist external forces. The stiffness of relaxed muscles characterises the tone of the muscle. The stiffness of a contracted muscles characterises the ability to generate force. The logarithmic decrement of oscillation damping $\varTheta$ characterises the dempferity properties (or viscosity) of the muscle, i.e. the ability of the muscle to dissipate mechanical energy. The parameter characterises the degree of intramuscular resistance to stretching. The logarithmic decrement of oscillation damping is calculated using the ratio of the oscillation curve amplitudes, starting with the first one:

$$\varTheta = \ln \frac{a_1}{a_3},$$

where $\varTheta$ – decrement of damped oscillation, a_1 ... a_3 – amplitudes of damped oscillation.

To estimate the functional state of skeletal muscles two indices were used:
I_Y – stiffness index, characterising the contraction ability of the muscles;
$I_\varTheta$ – dempferity index, which characterises the intramuscular resistance to stretching. These indices were calculated by formulas (Vain, 1985 a):

$$I_Y = \frac{Y_c - Y_r}{Y_r} \quad ; \quad I_\Theta = 1 + \frac{\varTheta_r - \varTheta_c{}^2}{\varTheta_c(1 + \varTheta_r)},$$

where Y_r – oscillation frequency of the relaxed muscle, Y_c – oscillation frequency of the contracted muscle, $\varTheta_r$ – logarithmic decrement of the relaxed muscle, $\varTheta_c$ – logarithmic decrement of the contracted muscle.

The mechanical properties of skeletal muscles was recorded using myotonometer:

(1) at the beginning of each training session after performing the warm-up exercises;

(2) immediately after termination of each training session.

The subjects were in supine position, and the above-mentioned parameters of the following surface muscles of lower extremities were recorded: *m. tibialis anterior*; *m. rectus femoris; m. gastrocnemius c. lateralis et c. medialis* and *m. biceps femoris.* The characteristics were recorded in the relaxed state as well as in the state of maximal voluntary contraction of the above-mentioned muscles. The index of the change in the functional state of muscles during the training (as compared to the state before training) *D%* was calculated using the following formulas:

$$Dy = \frac{I_{Yb} - I_{Ya}}{T_0} \cdot 100\ (\%),$$

$$D_{\Theta} = \frac{I_{\Theta b} - I_{\Theta a}}{T_0} \cdot 100\ (\%),$$

where I_{Yb} and $I_{\theta b}$ – the summary indices of the muscle stiffness and dempferity before applying training loads respectively; I_{Ya} and $I_{\theta a}$ – the summary indices of the muscle stiffness and dempferity after applying training loads respectively; T_0 – duration of the training (min).

The tone (oscillation frequency in Hz) of skeletal muscles in Study III was investigated using new version of myotonometer Myoton 2 (Gavronski *et al.*, 2007) constructed at the University of Tartu. In this study the term "muscle tone" denotes the mechanical tension of skeletal muscle that helps to insure the body's balance, the position of body parts, including posture of the body, and creates the background tension needed for active movements (Thews *et al.*, 1980). Because "slow" postural muscles play an important role in the postural control and stability of the spine (Hildebrandt, 2003), the tone of the following surface muscles of the trunk were recorded: *m. trapezius* (upper region), *m. erector spinae* (longissimus thoracis muscle central part), *m. rectus abdominis* (upper region). The characteristics were recorded after warm-up exercises in a motionless standing position (Fig. 1). Three measurements of each muscle on the right and left side were performed and a mean result was accepted for analysis.

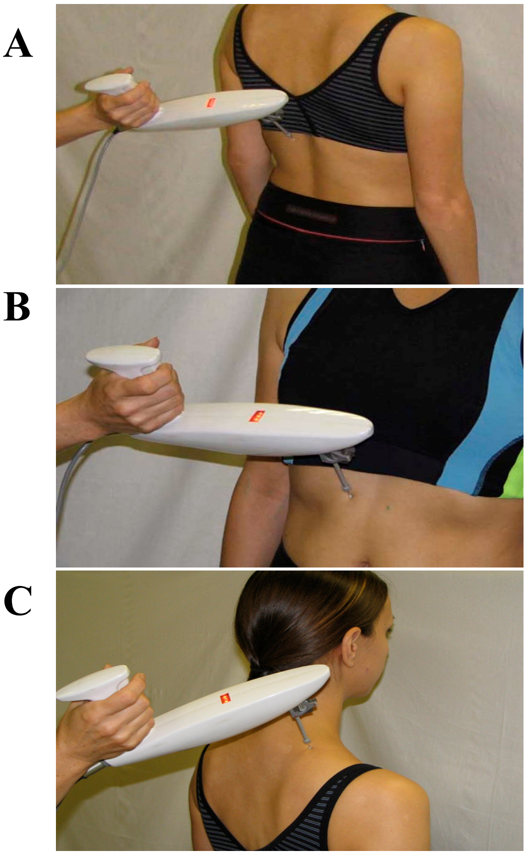

Figure 1. Measurement of tone of *m. erector spine* (A), *m. rectus abdominis* (B) and *m. trapezius* (C) by myotonometer Myoton 2 (Study III).

4.3.2. The indirect methods for measurement the range of the vertebral column deformation

Anthropometric method (Studies I, III, IV). Using a Martini metal anthropometer the subject's height in standing and supine positions was measured with the accuracy of ±1.0 mm. When the subject's height in the standing position was measured, the subject stood on an (organic) glass plate, for supine measurements the plate was placed in vertical position, so that the subject was able to place both soles on it. This measure helped to keep the accuracy of measurements in the range of 3% relative error. After that the indices of height differences were calculated:

$$L = L_{lying} - L_{standing},$$

where L_{lying} – height in lying position; *Lstanding* – height in standing position;

$$L_{change} = L_{after} - L_{before},$$

where $L_{before} = L_{lying} - L_{standing}$ height difference before training session and $L_{after} = L_{lying} - L_{standing}$ height difference after training session.

The index of height difference characterises indirectly the range of the vertebral column deformation. The higher the index, the more favourable is the functional state of MSS for receiving and absorbing impact-including loads and the higher the reserve for softening impacts. For each subject the mean index L_{mean} (the mean of the four measurement values) for the day was calculated:

$$L_{mean} = \frac{\sum_{i=1}^{4} L_i}{4},$$

where L_i – first, second, third and fourth measurement on a day.

On basis of the L_{mean} the functional state of each subject's MSS at the observation time was estimated. The higher the index, the more favourable for impact-including loads is the functional state of MSS. Our working hypothesis was that in case the subject's height difference after training session (L_{after}) increases significantly from the initial difference (L_{before}), measured before the training session, then we can consider the functioning of MSS impact absorption system normal and there exists no danger of residue deformation. Otherwise there exists the danger to overload MSS and cause degenerative changes. In this case training loads cannot be considered adequate for the functional state of MSS (Vain, 1981).

Spinal pantography. The normal shape of the vertebral column helps the body to bear the compressive loads. Injury, disease, or overload of the spine can cause deformities of the vertebral column or alteration of spinal curvature, e.g. flat back. The spinal curvature in the sagittal plane was recorded using pantography (study III) (Willner, 1983; Wilner & Johnson, 1983). The angle of thoracic kyphosis (TK) and the angle of lumbar lordosis (LL) were measured (Fig. 2). Sacral inclination angle (S) was measured between the vertical line and a line drawn tangential to the posterior border of the S1 vertebra according to Evcik and Yucel (2003). Three trials were performed and the mean result was calculated.

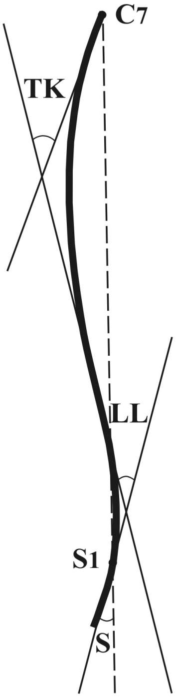

Figure 2. Measurement of the spinal curvatures in the sagittal plane.

Spine curvature determination in the sagittal plane (study IV). Measurements were made from the lateral radiographs clinically and radiografically. The technique of using a digital level has already proven to be accurate and reproducible by Jackson *et al.* (1998). Gobb measurements of the thoracic kyphosis (TK) (T1-T12), the angle measured between the tangent lines along the vertebral body superior end plates of T1 and T12. The total segmental lumbar lordosis (LL) (L1-S1), the angle measured between the tangent lines along the vertebral body superior end plates of L1 and S1 (Gardocki *et al.*, 2002).

4.3.3. Magnetic resonance imaging

To investigate "abnormality" (degenerative changes) in lumbar spine, MRI finding and their prevalence and associations with LBP was (Study IV) assessed. Each subject received a T1- and T2- weighted MRI scan of the spine. MRI of the spine were acquired using a 1.5 T Siemens Symphony magnet (Siemens Medical Solutions, Erlangen, Germany). Sagittal T1- and T2- weighted images of the spine were obtained. Imaging parameters for the T1-weighted spin-echo sequence were: repetition time 500–600 ms, and eho time 15 ms. The corresponding parameters for the T2-weighted turbo spin-echo sequence were 5000/122. MRI were analyzed by two experienced radiologists. The disc height was determined according to Frobin *et al,* (1997).

4.3.4. Pubertal stage determination

Pubertal stages were determined (Study II, III) according to the criteria of Tanner (1962) by a female pediatrician. Tanner stage was estimated by breast development and pubic hair. The written informed parental consent was obtained prior to the children's participation in the experiment. The study carried the approval of the University Ethics Committee.

4.3.5. Oswestry Questionnaire

Idiopathic back pain score was determined (Study III, IV) in the subjects in accordance with the score of Oswestry questionnaire. The Oswestry index covers 10 different areas of activities of daily living. These include pain intensity, personal care, lifting, walking, sitting, sleeping, social life, traveling and changing degree of pain (Cole *et al.*, 1994).

4.3.6. Measurement of vertical jumping performance

The vertical jumping performance tests (Study II) were performed on force platform (PD-3A, VISTI, Russia) with the dimensions of 0.75 x 0.75 m and natural frequency of 150 Hz.

To assess the explosive force of the leg extensor muscles all subjects performed three different types of vertical jumps: SJ, CMJ and drop jump from 40 cm height (DJ40). The SJ started from a static semi-squatting position followed by subsequent action, during which the leg and hip extensor muscles contracted concentrically. The CMJ started from upright standing position and then subjects countermoved until the knee was flexed to ~ 90°. These angles were controlled by an electrogoniometer attached to the lateral side of the subject's right knee. Maximal explosive extension in opposite direction (concentric contraction) immediately followed a fast preparatory counter-movement that stretched the leg extensor muscles (eccentric contraction). The standing position during DJ was similar to that of the CMJ, but the subject stood on box at a height of 40 cm. The subject dropped from the box and rebounded after a short contact with the ground to maximal height. The leg muscle work during the ground contact constituted the SSC. The subjects were instructed to jump with their hands on the hips to eliminate the influence of the arms swing impulse. Prior to the testing, the subjects performed several preliminary trials.

The testing jumps had to be performed reactively with maximal effort. By measuring the time of flight (t_f) from the force-time record, the vertical velocity of take-off (V_v) was calculated by formula:

$$V_v = ½\, t_f g,$$

where g is the acceleration of gravity (9.81 $\mathrm{m \cdot s^{-2}}$). Jump height (H) was then calculated as

$$H = Vv^2 \cdot (2g)^{-1}.$$

Each jump was repeated for three times with 1 min rest periods and the best result was used for further analysis. To evaluate the ability of utilization of SSC on vertical jumping the jump height ratios CMJ:SJ and DJ40:SJ (%) were calculated (Bosco *et al.*, 2002).

A modified (30 s) Bosco anaerobic jumping power test was performed on force platform (PD-3, VISTI, Russia). The CMJs were repeated consecutively with maximal leg extension during 30 s without any recovery between jumps. To standardise the knee angular displacement during the contact phase, the subjects were asked to bend the knees to about 90° and jump. The subjects were instructed to jump with their hands on the hips. The mean mechanical power per kilogram of BM was computed by using the total number of jumps, total flight time, and total contact time over the first (0–15 s) and last (15–30 s) 15 s period, and the total 30 s period on repetitive jumping (Bosco *et al.*, 1983). The difference between mean power during first and last 15 s periods of jumping was calculated relative to first 15 s period and used as fatigue index (%).

4.4. Statistical evaluation of the data

Standard statistical methods were used to calculate the means standard errors of the mean (±SE) (Study I) and standard deviations of the mean (±SD) (Study II, III and IV). One-way analysis of variance (ANOVA) followed by Fischer (Study I and III) and Tukey (Study II and IV) *post hoc* comparisons were used to test for differences between groups. In Study I, III and IV Pearson's linear correlations were calculated to observe the relationship between the measured characteristics. A level of $p<0.05$ was selected to indicate statistical significance.

5. RESULTS

5.1. The adaptive reactions of the musculo-skeletal system to training loads in artistic gymnasts

It was established that the reaction of the MSS of artistic gymnasts without and with traumas of MSS to the equal (in their intensity and duration) training loads differed significantly (Table 2). We established that the adaptive reaction assessed by (L_{change}) of the MSS of gymnasts varied, the fact proves that the resistance ability of MSS is multileveled in case of impact including training loads. In the group of gymnasts (number of observations n=60), serious traumas of MSS occurred (see Paper I).

Table 2. Comparison of the vertebral column deformations in gymnasts without and with traumas of (mean ± SE).

Study I	**Gymnasts without traumas (n = 42)**	**Gymnasts with traumas (n = 60)**
Age (years)	11.4 ± 0.25	12.3 ± 0.16**
Body mass (kg)	29.8 ± 0.19	31.9 ± 0.21
Height (mm)	1344.1 ± 10.88	1364.4 ± 7.63
Q (elements)	265.5 ± 4.78	232.3 ± 1.83
I (relative unit)	0.24 ± 0.04	0.23 ± 0.02
U (%)	69.47 ± 1.39	67.15 ± 3.08
L (mm)	15.29 ± 0.81	11.06 ± 0.69***
Lbefore	14.15 ± 0.64	10.79 ± 0.94**
Lafter	16.74 ± 1.05#	10.69 ± 0.81**

Note: ** $p<0.01$, *** $p<0.001$ compared to gymnasts without traumas; # $p<0.05$ compared to changes in linear dimensions of the vertebral column after and before training loads in gymnasts without traumas.

On the basis of our observations three training groups were formed with high, medium, and low training loads (Affonyn & Krivenko, 1976) (Table 3). It was established that training loads of different volume and intensity evoke different adaptive reactions of MSS. We assumed that in result of applying high training loads negative shifts in the functional state of MSS would appear. The observations show that even average in volume and intensity training loads can cause negative tendencies in the MSS of gymnasts (Table 3). In case of low volume and intensity of training loads we observed the positive type of MSS adaptive reaction (L_{change} = 3.14±0.71) (Table 3).

Table 3. Comparison of the groups with different training loads (mean ± SE).

Study I	**I** **n=44** **(high load)**	**II** **n=203** **(medium load)**	**III** **n=79** **(low load)**	**p** **I–II**	**p** **I–III**	**p** **II–III**
Age (yrs)	11.82 ± 0.28	13.80 ± 0.12	12.58 ± 0.19	***	*	**
Height (mm)	1373 ± 12	1430 ± 6	1416 ± 10	***	**	
Body mass (kg)	31.95 ± 0.81	34.90 ± 0.39	33.20 ± 0.69		*	
L change (mm)	0.45 ± 0.99	0.25 ± 0.46	3.14 ± 0.71		*	***
Q (elem.)	437 ± 9.50	247 ± 5.12	126 ± 5.17	***	***	***
I (rel.unit)	0.67 ± 0.05	0.25 ± 0.08	0.06 ± 0.003	***	***	***
U%	73.68 ± 1.22	66.45 ± 1.21	62.70 ± 2.87	***	***	
Lmean	16.17 ± 0.98	16.83 ± 0.38	17.57 ± 0.53			
Lbefore	16.16 ± 1.02	16.89 ± 0.43	16.27 ± 0.75			
Lafter	16.48 ± 1.16	17.18 ± 0.46	19.34 ± 0.60		*	**

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

On the basis of these observations Table 4 is complected. The index of the MSS impact absorption ability (L_{change}) characterizes the type of reaction to impact-including loads. In this situation L_{change} = 7.21 ± 0.56 mm. It is evident that we have to estimate the functional state of MSS connective tissue structures in this case as a positive adaptive reaction to high training loads. In case of zero type adaptive reaction the functional state of MSS is not restored immediately in the course of training process, its impact absorption ability is impaired. In this situation no positive statistically significant shift after applying training load was observed, the functional state of MSS connective tissue structures is characterized by L_{change} = 0.57 ± 1.91 mm. This state was observed in pre-trauma period (the Achilles tendon rupture and the Achilles tendon attachment rupturein the area of bone growth), when the zero type MSS adaptive reaction was observed even in case of significantly lessened training loads. The disposition to reach pretraumatic state of MSS was observed in two gymnasts: (number of observations n=7) (Table 4).

Table 4. Training loads and changes in linear dimensions of the vertebral column in two groups (mean ± SE).

Study I	**I group**	**II group**
Q (elem.)	377.38 ± 10.68	74.14 ± 12.10 ***
I (rel.unit)	0.47 ± 0.05	0.03 ± 0.01 ***
U%	74.38 ± 2.20	35.86 ± 17.18 ***
Lmean (mm)	19.82 ± 0.98	9.91 ± 1.98 ***
Lchange (mm)	7.21 ± 0.56	0.57 ± 1.91 ***
Lbefore (mm)	16.68 ± 1.13	7.43 ± 1.95
Lafter (mm)	23.71 ± 0.87 #	8.00 ± 2.07

Note: I group – of the period before competitions (4 gymnasts, 34 observations)
II group – of the period preceding traumas (2 gymnasts, 7 observations)
*** $p<0.001$ compared to I group; # $p<0.001$ compared to changes in linear dimensions of the vertebral column before training loads.

5.2. Vertical jumping performance in rhythmic gymnasts and untrained girls

The jump heights in SJ, CMJ and DJ40 were greater ($p<0.01$–0.001) in rhythmic gymnasts than controls (Fig. 3A, see Paper II). The jump height in DJ40 was greater ($p<0.001$) compared with SJ and CMJ only in rhythmic gymnasts. No significant differences between CMJ and SJ heights were found in two groups of children. The jump height ratio CMJ:SJ did not differ in rhythmic gymnasts and controls (Fig. 3B). The rhythmic gymnasts had greater ($p<0.05$) jump height ratio DJ:SJ than controls.

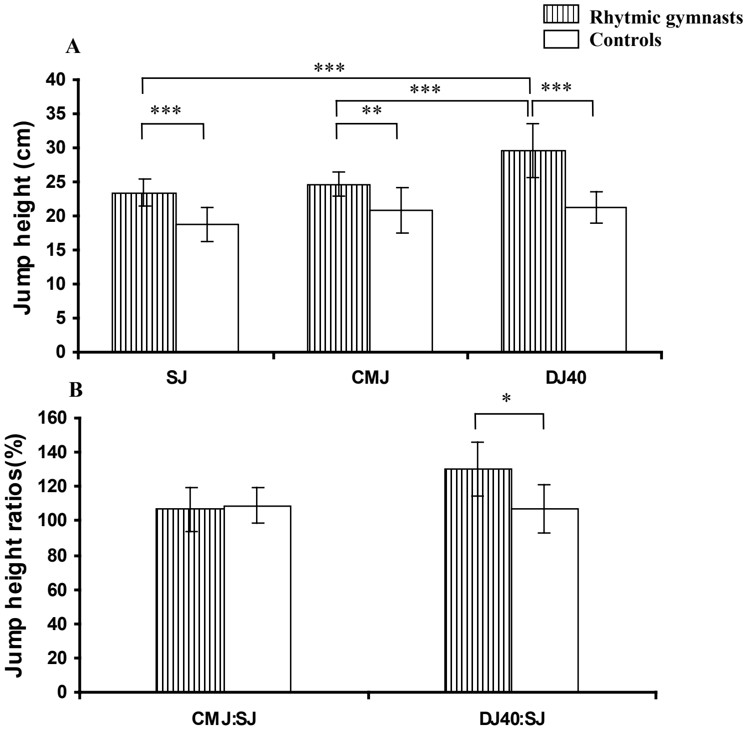

Figure 3. Jump height in squat jump (SJ), counter-movement jump (CMJ) and drop jump from 0.40 m height (DJ40) (A) and jump height ratios CMJ:SJ and DJ:SJ (B) in rhythmic gymnasts (n=11) and controls (n=15). Values are means±SD; *$p<0.05$; **$p<0.01$; ***$p<0.001$.

Mean mechanical power output calculated for every 15 s period of the repeated jumping, and average power output for 30 s repetitive jumping exercise were greater (p<0.01–0.001) in rhythmic gymnasts than controls (Fig. 4A). The rhythmic gymnasts had higher (p<0.05) fatigue index during repetitive jumping exercise than controls (Fig. 4B).

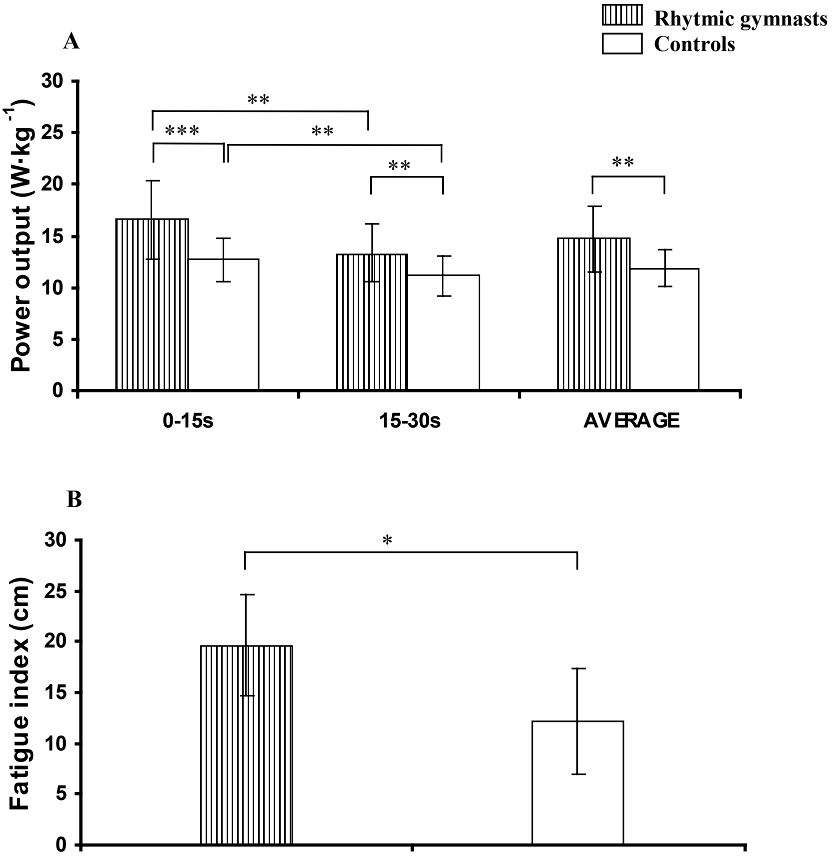

Figure 4. Mean mechanical power output calculated for every 15 s period of the repeated jumping, and average power output for 30 s repetitive jumping in rhythmic gymnasts (n=11) and controls (n=15) (A). Fatigue index during repetitive jumping exercise in rhythmic gymnasts (n=11) and controls (n=15) (B). Values are means±SD; *p<0.05; **p<0.01; ***p<0.001.

5.3. The spinal curvature and muscle tone in rhythmic gymnasts and untrained controls

The spine's angle of S shape was significantly deeper in the control group compared to that of gymnasts (32.7 ± 8.1° and 23.1 ± 7.6°, $p < 0.001$), and the angles of lumbar lordosis and thoracic kyphosis were also significantly lower in gymnasts in comparison with the control group (28.8 ± 4.9° and 37.5 ± 8.0°, $p < 0.001$, respectively, and 20.9 ± 7.4° and 31.1 ± 8.9°, $p < 0.001$, respectively) (Fig. 5, see Paper III).

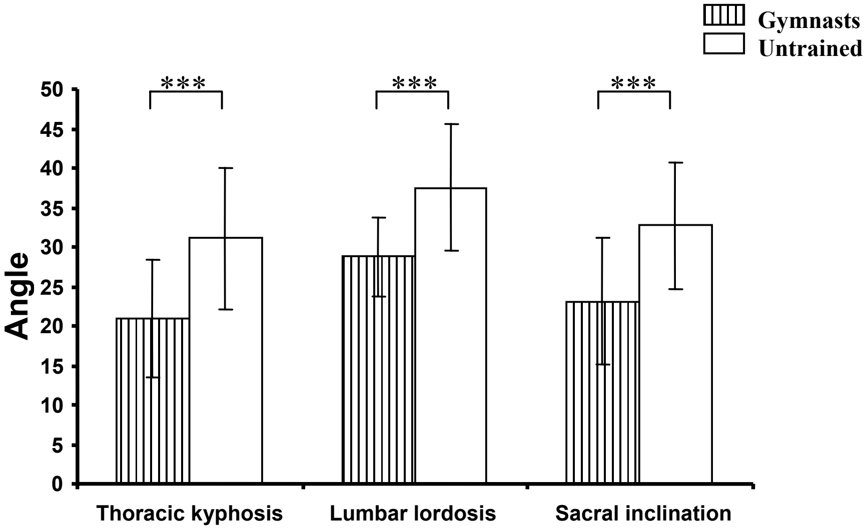

Figure 5. The angles of thoracic kyphosis, lumbar lordosis and sacral inclination in rhythmic gymnasts (n = 32) and in untrained girls (n = 48). Values are mean ± SD. *** $p<0.001$.

The tone of *m. rectus abdominis* (upper region) was lower ($p < 0.001$) in gymnasts compared to the control group (11.4 ± 2.7 Hz and 16.5 ± 6.0 Hz, respectively). No significant difference in the tone of *m. trapezius* and *m. erector spinae* (longissimus thoracis muscle) was found between the groups (Fig. 6, see Paper III). The tone of spinal muscles was higher ($p < 0.001$) than that of abdominal muscles (the difference was 4.4 ± 0.9 Hz) in gymnasts, whereas the tone of these two muscles did not differ significantly in control group (the difference was 1.9 ± 0.9 Hz).

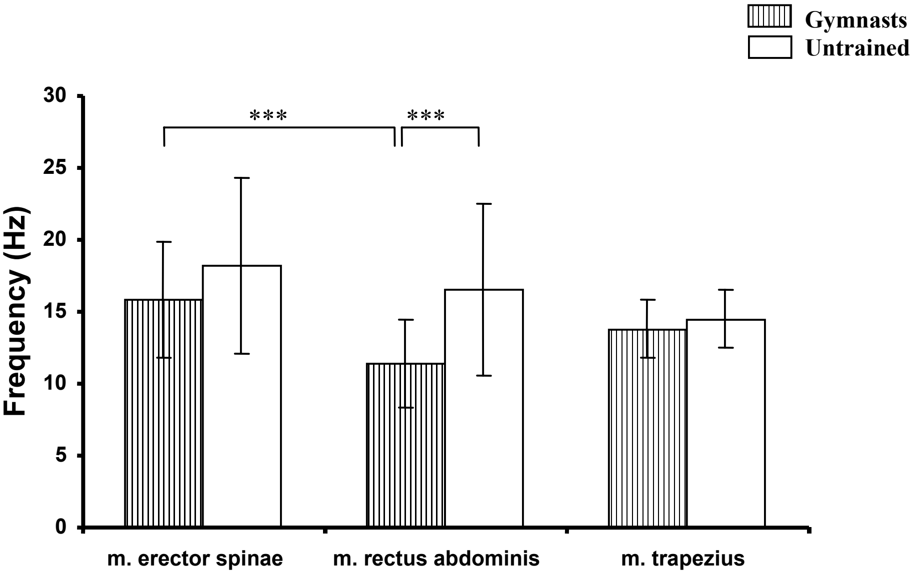

Figure 6. The tone of *m. erector spinae* (longissimus thoracis muscle), *m. rectus abdominis* (upper region) and *m. trapezius* (upper region) in gymnasts (n = 32) and in untrained girls (n = 48). Values are mean ± SD. *** $p<0.001$.

The difference in height in supine and standing positions L was lower ($p < 0.05$) in gymnasts than in the control group (Fig. 7, see Paper III). A medium level negative correlation ($r = -0.56$, $p < 0.001$) between the tone of the trunk extensors and the difference in height L (mm) and a medium positive correlation ($r = 0.51$, $p < 0.01$) between the tone of the trunk flexor and difference in height L was observed in gymnasts (n = 32). Whereas correlation between the tone of the trunk extensors, trunk flexors and difference in height L in the control group (n = 48) was low ($r = -0.26$, $p < 0.05$, and $r = 0.31$, $p < 0.05$, respectively). A negative correlation between difference in tone of trunk extensor and flexor muscles and L was observed in gymnasts ($r = -0.66$, $p < 0.001$, n = 32). In gymnasts (n = 32) the angle of lumbar lordosis and thoracic kyphosis correlated positively with difference in height L ($r = 0.63$, $p < 0.05$ and $r = 0.60$, $p < 0.05$, respectively).

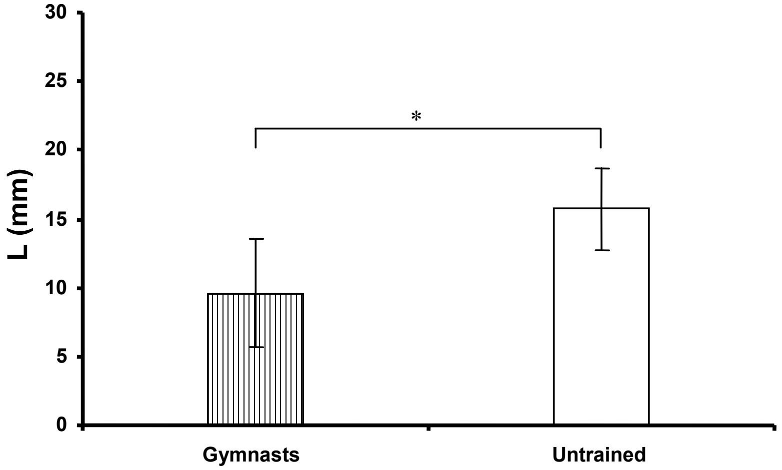

Figure 7. Height difference in lying and standing position in gymnasts (n = 32) and in untrained girls (n = 48). Values are mean ± SD. * $p<0.05$.

Oswestry questionnaire showed that LBP incidence (mean score 20%) appeared in 50% of gymnasts. Idiopathic LBP appeared in 10 gymnasts, spondylolisthesis was diagnosed in 4 gymnasts and spondylolysis in 2 gymnasts. Three gymnasts with idiophathic LBP had pain in spine during flexion. Oswestry score in gymnasts correlated negatively with the angles of lumbar lordosis and thoracic kyphosis ($r = -0.68$, $p < 0.05$ and $r = -0.66$, $p < 0.05$, respectively).

5.4. The spinal curvature and intervertebral disc height in rhythmic gymnasts with and without idiopathic low back pain

The spines angles of TK and LL were significantly lower ($p < 0.001$) in gymnasts with idiopathic LBP in comparison with the asymptomatic gymnasts (Table 5, see Paper IV). In gymnasts with LBP, disc height in thoracal and lumbar spine was significantly lower ($p < 0.001$) than in the asymptomatic gymnasts. The difference in height in supine and standing position (L) was lower ($p < 0.05$) in LBP gymnasts, than in the asymptomatic group. Oswestry questionnaire score form 19.8% and this correlated significantly ($p < 0.05$) negatively with TK, LL and mean disc height in L1 – S1 part ($r = -0.87, -0.86, -0.89$, respectively) (see Paper IV). A high positive correlation between mean lumbar L1 – S1 disc height and L was observed in LBP gymnasts ($r = 0.96$, $p < 0.01$, $n = 7$).

Table 5. Mean (±SD) spinal curvature, disc height and anthropometric measurements in gymnasts with and without LBP.

Parameter	Gymnasts with LBP (n = 7)	Gymnasts without LBP (n = 5)
TK (º)	17.7 ± 3.1	33.5 ± 7.9 ***
LL (º)	19.7 ± 5.3	34.2 ± 4.2 ***
T7-T12 (mm)	4.1 ± 0.2	7.6 ± 1.2 ***
L1-S1 (mm)	7.0 ± 0.9	9.0 ± 1.7 ***
L (mm)	4.0 ± 1.7	16.7 ± 6.6 *

Note: TK – thoracal kyphosis; LL – lumbar lordosis; T7-T12 – intervertebral disc morphology in thoracal and L1-S1 – lumbar part of the spine; L – the difference in height in supine and standing position. * $p < 0.05$; *** $p < 0.001$ compared to gymnasts with idiopathic LBP.

6. DISCUSSION

6.1. The adaptive reactions of the musculo-skeletal system to training loads in artistic gymnasts

The results of our study (see Paper I) show that the training intensity is significantly correlated with shifts in the values of the muscle stiffness and dempferity indices. The range of index value changes when average training loads were applied was about 36.9–40.4% (Kums & Gapeyeva, 1994). The investigation of the influence of individual parameters of the training load on the functional state of the muscles under investigation established, that the most influential component of the training load in this aspect is the intensity of training. In the group of gymnasts (n=42) without traumas of MSS, in result of our measurements of the parameter *Lchange* we ascertained the positive adaptive reaction to training loads. The ability of MSS connective tissue structures to resist loads was significantly lower in the group of gymnasts with than without traumas (Table 2, see Paper I). The analysis of the measurement data of our study shows that individual parameters of training loads influence the functional state of muscles differently. The training load volume increase causes decrease in changes of the muscle stiffness and dempferity indices. The intensity increase causes the increase of these changes. The correlation of the intensity of training process and changes of the functional state of muscles, reflecting in the stiffness indices, was in the range of $r = 0.82–0.85$, in dempferity indices – $r = 0.80–0.88$ ($p<0.001$). Correlation of the volume of training loads and the shifts in the values of stiffness and dempferity indices was weaker: from $r = –0.41$ to $–0.46$ and from $r = –0.36$ to $–0.43$ ($p<0.001$) respectively (see Paper I, p. 341).

The established negative influence of the impact-including training loads on the MSS of athletes underlines the necessity to individualise the training process. At present the coach often works blindfold, planning training loads using solely his intuition and earlier experience. There are very few objective data reflecting the functional state of his students' MSS in his possession. This approach often leads to negative results. It is known that the ability of MSS to resist impact-including loads can be characterised through the extent of elastic deformations (Adams *et al.*, 1986; Pope *et al.*, 1993; Bartel *et al.*, 2006). One of the criteria used in such estimations is the gravity-caused changes in the body height (Eklund & Corlett, 1984; Leatt *et al.*, 1986; Fowler *et al.*, 1994; Wojtys *et al.*, 2000). The latter reflects mainly the elasticity of intervertebral discs. On the basis of our study we can state that if the intervertebral discs function narmally, then the height difference after training hours must be greater than the initial value before applying the training loads. It can be supposed that in this case the internal pressure in intervertebral discs increases in result of the muscular tone increase and intensified metabolic processes (Nachemson, 1960; Naylor, 1962;

Bogduk, 1997; Bartel *et al.*, 2006) and the training load can be considered adequate to the functional state of intervertebral discs. This means that it is obligatory for the height difference to be greater after applying training loads than before training (Vain 1981, 1985 b).

In case the training is not planned in accordance with the functional state of intervertebral disc, there occur no height increases in supine position. In this situation the intervertebral discs are not able to perform their shock-absorption function. In case the regulation of intervertebral discs' internal pressure is disturbed (which phenomenon appears in case of inadequate loads), the internal pressure of intervertebral discs decreases and they do not act as hydraulic impact absorbers.

The higher the index L_{change}, the more convenient is the applied training load for the present state of MSS. This means that the load has been adequate to the functional state of the gymnast's MSS and the adaptive reaction of the MSS has been positive. In case there is no noticeable difference between the L_{before} and L_{after}, the zero type reaction to the training load is apparent. This proves that there is no positive shift in the state of MSS in result of the training, i.e. the training load was not adequate to the functional state of MSS and evoked its stagnation. In this case the impact absorption function of MSS is impaired.

It has been observed that well-trained gymnasts have as a rule the positive adaptive MSS reaction type (Kums, 1996) before competitions. Among the factors causing the decrease of gymnasts' MSS functional state, the dominant one was the low level of functioning (L_{mean}) of MSS (92 cases). As we understand, the increase of the volume and intensity of training loads causes the MSS reaction type index (L_{change}) to decrease, as the impact absorption ability of MSS connective tissue structures decreases. The intensity increase of training loads causes more noticeable negative influence on the gymnasts' MSS than the training volume increase. This statement is affirmed by the correlation of $r = -0.50$ of the index L_{change} and the training intensity I. The correlation of L_{change} and the training volume Q was $r = -0.43$ ($p<0.001$, $n = 92$) (Kums, 1996). In addition the character of the reaction of MSS connective tissue structures is influenced by the functional state of the muscles of gymnasts' lower extremities. When the muscle stiffness index decreases (which tendency suggests the decrease of muscle contractility), the MSS reaction to training loads becomes unsatisfactory (the index L_{change} decreases). We can conclude that the decrease of the muscle contractility of lower extremities causes irregularities of the impact absorption ability of the MSS connective tissue structures. Correlation between of L_{change} and the stiffness index I_y was $r = 0.22$ ($p<0.001$, $n = 92$). This fact shows that disturbances in the functional state of muscles of lower extremities cause overloading of the vertebral column connective tissue structures. In situations when the degree of strain applied to muscles and their relaxation velocity disagree, increased tension in the Achilles tendon occurs and the possibility of tendon rupture exists, as it is a well-known fact that the degree of stretch is much more limited for tendons than muscles.

We established that disturbances of the impact absorption ability of MSS connective tissue structures is related to intensified training loads, to the abrupt increase of their volume and intensity. Even an average in volume and intensity training load causes negative shifts in the functional state of gymnasts' muscles are caused by the intensity increase of training loads. This factor must be taken into consideration when designing training programs. We established two main types of the MSS adaptive reaction to impact-including training loads: the positive and the zero type. The positive reaction type denotes a satisfactory functional state of MSS connective tissue structures, the zero type points to disturbances of their impact absorption ability.

The normal functional state of MSS of athletes in good shape can be expressed through the positive adaptive reaction type even if high training loads are applied. In pre-traumatic state (rupture of Achilles tendon) the zero type of MSS adaptive reaction has been observed even when very small training loads are used. The results of our study lead to the conclusion that the shifts recorded using the anthropometric method are of regular character. The above-described method is simple and trainers can use it with success to test the adequacy of training loads to the functional state of the MSS of girls going in for gymnastics.

6.2. Vertical jumping performance in rhythmic gymnasts and untrained girls

The 12–13-year-old female rhythmic gymnasts, participating in this study, (see Paper II) started their regular specialized rhythmic gymnastic training at the mean age of 7 years. The anthropometric measurements indicated that rhythmic gymnasts were significantly lighter (19.4%) and had smaller BMI (14.9%) than age- and gender-matched controls. BMI in respect of pubertal development, all rhythmic gymnasts were classified in Tanner stage I–II, while control girls were classified in Tanner stage II–III. The delay in both breast and pubic hair development in rhythmic gymnasts in our study is in agreement with previous reports (Gollhofer & Schmidtbleicher, 1988; Georgopoulos *et al*., 2002). In female rhythmic gymnasts, intensive physical training, chronic psychological stress and modifications in nutrition, resulting inadequate energy intake relative to energy output are factors that can contribute to the observed delay in pubertal development, growth and biological maturation as compared to age-matched untrained girls and individuals in other sports (Peltenburg *et al*., 1984; Theintz *et al*., 1993; Georgopoulos *et al*., 1999; Georgopoulos *et al*. 2001).

In the present study, (see Paper II) explosive force-generating capacity of the lower extremities was assessed by vertical jumps, performed without (SJ) and with preliminary counter-movement (CMJ and DJ). CMJ and DJ are exercises characterized by so-called SSC, in which the action of the muscles during the eccentric phase influences the subsequent concentric phase (Asmussen &

Bonde-Petersen, 1974; Bobbert *et al.*, 1996). The most common measure of vertical jumping performance is jump height. In this study, rhythmic gymnasts had greater jump heights in SJ, CMJ and DJ40 than controls. However, the SJ and CMJ heights for female gymnasts were lower than average values for age- and gender-matched gymnasts published previously by Bencke *et al.* (2002).

The vertical jump height depends on the physiological processes that take place in the muscular and nervous systems. It is well known that dynamic force of the knee extensor muscles is one important factor limiting performance in jumping exercises. Vertical jumping is a multijoint movement and requires the intra- and intermuscular coordination, i.e. the ability of agonists, antagonists and synergists to co-operate in performing the task. The present study may indicate an effect of rhythmic gymnastic training, which includes rapid ballistic movements with short explosive force (power) production. It has been suggested that a training program with ballistic movements induces only minor hypertrophic changes in skeletal muscles (Schmidtbleicher & Buehrle, 1987; Moss *et al.*, 1997), and, therefore, neural adaptation mechanisms predominates.

When performing different types of vertical jumps, the intrinsic mechanism of muscle activation by central nervous system is remarkably different. The SJ can be used as the functional expression of explosive strength of the leg extensor muscles, as it requires only concentric muscle activation. The CMJ requires moderate eccentric muscle activation followed by high concentric muscle activation. The DJ requires high eccentric muscle activation followed by high concentric muscle activation, which requires a very precise coordination and extensive activation of the motor units. The ability to use SSC in vertical jumping can be evaluated by jump height ratios CMJ:SJ and DJ:SJ (Bobbert *et al.*, 1996). In this study, no significant differences between CMJ and SJ heights were found in the measured groups of 12–13-year-old girls. This is in agreement with previous findings for 11-year-old boys (Pääsuke *et al.*, 2001). Also, the jump height ratio CMJ:SJ did not differ significantly in rhythmic gymnasts and controls. Thus, no potentiating effect of SSC on jumping performance when performing CMJ has been observed in the present study in 12–13-year-old girls. The jump height in DJ40 was greater compared with SJ and CMJ only in rhythmic gymnasts. The rhythmic gymnasts had also significantly greater jump height ratio DJ:SJ than controls, indicating an effective utilization of SSC when performing drop jumps. Several mechanisms have been proposed to explain the potentiating effect of SSC on vertical jumping performance. During the preceding muscle action occurs the storage and re-utilization of elastic energy (Asmussen & Bonde-Petersen, 1974; Bosco *et al.*, 1982) and myoelectric potentiation by spinal reflexes as well as longer-latency reflexes (Melvill-Jones & Watt, 1971) which are used during the subsequent concentric action. It has been shown that high stiffness of series elastic component of muscles in combination with high stretching velocities migh facilitate the storage and re-utilization of elastic energy during movements (Shorten, 1987). The specific power (jumping) training can increase the muscle stiffness and myoelectric potentiation, and also intramuscular coordination (Bosco *et al.*, 1982; Gollhofer & Schmidtbleicher, 1988). The performance in DJ as a more complex motor task may be more dependent on training specificity in rhythmic gymnastics. The performance in the less complex motor tasks like SJ and CMJ may not be influenced by training to the same extent.

In the present study (see Paper II), evaluation of the anaerobic power was based on the method described by Bosco *et al.* (1983). This method offers a possibility of determining the mechanical power of the leg extensor muscles during the explosive SSC type exercise. The study indicated that rhythmic gymnasts had greater mechanical power calculated for the first and last 15 s, and for the total 30 s repetitive jumping exercise as compared to controls. It is well known that in adults can increase training the maximal glycolytic power. However, only few studies have measured the effect of training on anaerobic energy production in children. One of these studies (Kuno *et al.*, 1995) did not find any differences between trained and untrained boys. In this study, fatigue index during repetitive jumping exercise was higher in rhythmic gymnasts than controls. Thus, the control subjects were better able to sustain a high power development through the 30 s repetitive jumping exercise than rhythmic gymnasts. In rhythmic gymnastics, the bursts of highly intense activity are mostly so short that it is not likely to tax the anaerobic system to any high extent, and it is therefore not likely that children going in for gymnastics will perform repetitive jumping test better than untrained children. On the other hand, the high level power produced by the gymnasts may also make it impossible to sustain after depletion the phosphagen stores, and this may explain the greater drop in power in rhythmic gymnasts.

In summary, the results of the present study demonstrated that young elite female rhythmic gymnasts have greater jump height in SJ, CMJ and DJ than age-matched controls. They demonstrated a markedly greater ability to use the potentiating effect of SSC to vertical jumping performance than control subjects during DJ, but not during CMJ. The rhythmic gymnasts produced greater mechanical power during repetitive jumping maximal exercise, but fatigued faster than controls.

6.3. The spinal curvature and muscle tone in gymnasts and untrained girls

The results of the present study (see Paper III) showed that the vertebral column of the female gymnasts is significantly flatter in the thoracic and lumbar spine, than in the control group. Similarly, the sacral inclination in the gymnasts is significantly smaller than in the control group. These results are consistent those of Tsai and Wredmark (1993), which showed that elite gymnasts had a flattened thoracic kyphosis. This phenomenon may be explained by somewhat smaller body mass and BMI in gymnasts compared to that of the control group. The body height of gymnasts was the same as that of untrained girls. This has also been shown by anthropometric studies done in space, where in microgravitational conditions the spine curvature of astronauts flattened (Lee *et al.*, 1999) and body height increased. According the Thornton *et al.* (1974), weightlessness in space increases height up to 3%. However, the BMI correlation with the spinal curvatures in gymnasts was low and not significant. This gives us reason to suppose that the spinal curvature in the sagittal profile in rhythmic gymnasts is largely determined by the specifics of training.

It is known that spinal shrinkage has been used as an indicator of the effects of spinal stress (Eklund & Corlett, 1984). The functional condition of the human MSS can be characterized indirectly by changes in stature. Change in height has been used to indicate the influence of training load on the spine (Garbutt *et al.*, 1990; Wojtys *et al.*, 2000). The vertebral column, which is considered to occupy second place in the hierarchy of the impact absorption systems of the MSS, decreases the magnitude of impact impulses reaching the head about 3.0–3.5 times (Vain, 1981). At the present time, it is understood that the impulse which influences an intervertebral disc is received by a pulposus nucleus, which consists of homogeneous substance (Nachemson, 1960; Ehricht, 1978; Bogduk 1997; Bartel *et al.*, 2006). It may be presumed that changes in height depend not only on connective tissue but also on the functional condition of skeletal muscles and the spinal curvature in sagittal profile. In faulty posture, those muscles in slightly shortened positions tend to be stronger, and those in slightly elongated positions tend to be weaker than the muscles that work in opposition to them. Muscle tension or shortness may cause faulty alignment, which in turn may give rise to stretch – weakness or adaptive lengthening of muscles. Muscle balance involves restoration of both normal strength and normal length (Kendall & Kendall, 1983).

The height difference (height in supine position minus height in standing position) in the gymnasts was significantly lower than in the control group. Consequently, the vertebral column as a shock absorber functioned far better in the control group than in gymnasts, whose vertebral column was rather rigid.

In addition, assuming that another important role of the curvature of the vertebral column is to keep the spine in balance, we examined the tone of trunk flexor and extensor muscles in a standing position. It appears that a deeper curvature of the vertebral column in sagittal profile, which was evident in the control group, keeps the body muscle tone in balance. In this group no significant statistical difference was found between trunk flexors and extensors. Sparup (1960) and Asmussen and Heebol-Nielsen (1958) reached similar results, showing that the strength of the back and abdominal muscles (as measured during maximum isometric contractions) varied only slightly – less than 10 per cent in the control subjects of age 20–50 years.

A recent study by Dieen *et al.* (2003) confirmed this tendency – ratios of antagonist to agonist and lumbar to thoracic erector spinae muscle electromyographic activity and estimated moment contributions were greater in the patients than in the control subjects. Increased muscle tone around the painful site has been observed by Lund *et al.* (1991).

Our study (see Paper III) showed that in gymnasts, the trunk flexor muscles tone was reduced in comparison with the tone of extensor muscles and this difference was statistically significant, indicating that gymnasts have disproportionately balanced trunk muscles around the spine. Muscle imbalance occurs when muscles are exercised persistently to develop strength and opposing muscles are not equally strengthened, or if muscles remain habitually in a shortened position while the opposing muscles remain lengthened (Kendall & Kendall, 1983).

Typical training of rhythmic gymnasts includes repeated movements of hyperextension, which cause stretching of the abdominal muscles or the trunk flexors. "Hyperextension may vary from slight to extreme" (Kendall & Kendall, 1983), which is distinctive of rhythmic gymnasts (Kujala *et al.*, 1997; Mc Cormack & Athwal, 1999; Mannor & Lindenfeld, 2000; Gupisti *et al.*, 2004). As the result of an intense training load, the abdominal muscles are unable to return to their initial position and this leaves the flexors of vertebral column at a disadvantage. In order to keep the vertebral column naturally in balance we need to increase the tone of the trunk extensors.

Hyperextension in the rhythmic gymnasts causes the tone of the trunk flexors to decrease, which is reflected in the lower values of the tone of *rectus abdominis* muscle in gymnasts in comparison with control group ($p < 0.001$). This allows us to deduce that intra-abdominal pressure (IAP), which is caused by tension in the muscles of trunk flexors (Cresswell & Thorstensson, 1989; Mc Gill & Sharratt, 1990; Cresswell *et al.*, 1992) has decreased. This situation induces an increase in intra-thoracic pressure (ITP), and thus IAP was negatively correlated with ITP ($r = -0.91$) (Cholewicki *et al.*, 2002). ITP was correlated positively with activity of the thoracic *erector spinae* muscle ($r = 0.81$) (Cholewicki *et al.*, 2002), therefore the trunk extensors could remain under excessive pressure. Thereby, the tone of trunk flexor muscles in gymnasts was reduced, and the tone of trunk extensor muscles was increased ($p < 0.001$) in comparison with flexors which creates serious imbalance in the distribution of tone of trunk muscles around a neutral spine posture.

Muscle tone imbalance potentially causes the decrease of the MSS's ability to endure the training load in gymnasts. The results indicated that the difference in the tone of trunk flexors and extensor muscle (tone imbalance) correlated negatively with the difference in body height in supine and standing positions in gymnasts ($r = -0.66$, $p < 0.001$). This fact comes out when we look at the correlation between the difference in body height in supine and in standing positions L and trunk muscle tone, which were significant among gymnasts: for trunk extensors' tone ($r = -0.56$, $p < 0.001$) and for trunk flexors' tone ($r = 0.51$, $p < 0.01$). The corresponding relationship in the control group was much lower: ($r = -0.26$, $p < 0.05$ and $r = 0.32$, $p < 0.05$, respectively). This indicates that the imbalance of the trunk muscle tone in the group of gymnasts may considerably reduce difference in body height in supine and standing positions. The more rigid vertebral column in gymnasts compared with control group was observed, because the difference in body height in supine and in standing position in gymnasts was significantly lower ($p < 0.05$) in comparison with control group. In 50% of measured gymnasts, LBP incidence was observed (mean Oswestry score 20%), whereas control group were without LBP incidence. In gymnasts, thoracic kyphosis and lumbar lordosis correlated negatively with Oswestry score ($r = -0.68$, $p < 0.05$ and $r = -0.66$, $p < 0.05$, respectively) and positively with difference of body height in supine and standing position ($r = 0.63$, $p < 0.05$ and $r = 0.60$, $p < 0.05$, respectively). This indicates that the more rigid vertebral column, flattened in thoracal and lumbar part, that appeared in gymnasts, associated with imbalance in trunk muscle tone and LBP. This conclusion is consistent with that of Lee *et al*. (1999) – "An imbalance in trunk muscle strength, i.e., lower extensor muscle strength than flexor muscle strength, might be one risk factor low back pain", and that of Eguchi (2004) – …" low back pain is believed to be the result of the back extensor muscles induced by prolonged contraction". According to Kibler and Chandler (1998) the muscle imbalance that is created by training may predispose the athlete to overload injury.

6.4. The spinal curvature and intervertebral disc height in rhythmic gymnasts with and without idiopathic low back pain

Clinically accepted radiographic values of thoracic kyphosis in growing children range from 20º to 40º , and lumbar lordosis from 20º to 45º (Willner & Johnson, 1983; Nissinen, 1996). Current study (see Paper IV) showed that the gymnasts with LBP had more flattened spine in thoracal and lumbar part. On the whole in asymptomatic gymnasts sport activity elicit of the development of normal curves. These results are consistent those of Tsai and Wredmark (1993), which showed that elite gymnasts had a flattened thoracic kyphosis. But majority of the investigators however reported an the association between larger degrees of kyphosis and lordosis and incidence of LBP (Ohlen *et al*, 1989; Salminen *et al*., 1992).

In present study (see Paper IV) it appeared that gymnasts with LBP have reduced disc height in thoracic and lumbar spine in comparison with asymptomatic gymnasts. Oswestry questionnaire scored high and negatively correlated with disc height in lumbar spine ($r = -0.89$, $p < 0.05$) and with angle of the thoracic kyphosis, and lumbar lordosis ($r = -0.87$, $p < 0.05$; $r = -0.86$, $p < 0.05$, respectively). This indicates, that gymnasts with more presented LBP, have flattened spinal curvature in thoracal and lumbar part and more reduced disc height in lumbar part. These data suggest that the flattened posture decreases the elasticity of the vertebral column, and spine is stiff and prone to injuries. Because only the normal lumbar spine is best suited to witstand compressive loads (Schirazi-Adl & Parnianpour, 2000; Rajnics *et al*., 2001; Keller, 2005). Smaller height difference in supine and standing position in gymnasts with LBP in comparison with asymptomatic gymnasts showed this in present study. These height differences hight and positively correlated with lumbar disc height in gymnasts with LBP ($r = 0.96$, $p < 0.01$).

Hypolordotic spine is smaller still. Flatback syndrome, a product of loss of lumbar lordosis, causes decreased spinal range of motion and loss of sagittal spinal balance, which places the erector spinae muscle group at a mechanically disadvantageous position (Gardocki *et al*., 2002).

In flat-back patients, the sagittal balance is generally displaced, well anterior to normal (Jackson & Mc Manus, 1994; Booth *et al*., 1999). Harrison *et al.* (2005) has indicated that anterior trunk translation (maitaining sagittal alignment of T1–T12 anterior to S1) in a standing subject increases extensor muscle activity and increases loads and stresses on the intervertebral disc in the lower thoracic and lumbar region. We presume that this causes disc height in thoracal and particularly in lumbar part of the spine to be so much lower in gymnasts with LBP in our study. Most studies show that disc height and signal intensity have been used as indicators for disc degeneration (Swärd, 1992; Luoma *et al*., 2001; Sohn *et al*., 2004; Pappou *et al*., 2007).

In our study T2, i.e. weighted signal intensity of the nucleus pulposus of disc in thoracal T7–T12 and lumbar L1-S1 part were measured. All gymnasts with idiopathic LBP showed the lowest disc height in thoracal and lumbar part, but had highest signal intensity which not differ from asymptomatic gymnasts. We conclude, that disc degeneration was not presented in T7–T12 region and in the lumbar spine in all investigated gymnasts. Disc height reduction in our study is not related to early degeneration, but it is a result of functional overloading of the spine in gymnasts with LBP.

CONCLUSIONS

1. Two main types of the MSS adaptive reaction to impact-including training loads in artistic gymnasts were observed: the positive and the zero type. The positive reaction type denotes a satisfactory functional state of MSS structures, the zero type points to disturbances of their impact absorption ability.

2. In result of applying high and even medium training loads negative changes in the functional state of MSS in young artistic gymnasts would appear.

3. Rhythmic gymnasts demonstrated a markedly greater ability to use the potentiating effect of SSC to vertical jumping performance than control subjects during DJ, but not during CMJ. The rhythmic gymnasts produced greater mechanical power during repetitive jumping maximal exercise, but fatigued faster than controls.

4. Rhythmic gymnasts had, the more rigid vertebral column, flattened in thoracal and lumbar part that associated with imbalance in trunk muscle tone and LBP.

5. Rhythmic gymnasts with idiopathic LBP had flattened spinal curvature in thoracal and lumbar part and more reduced disc height in thoracal and lumbar part. Disc height reduction is not even related to early degeneration in gymnasts with LBP, but it is a result of functional overloading of the spine.

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SUMMARY IN ESTONIAN

TUGI-LIIKUMISAPARAADI FUNKTSIOON NOORTEL VÕIMLEJATEL SEOSES TREENINGUKOORMUSTE JA ALASELJAVALUDEGA

Sissejuhatus

Sportliku saavutusvõime kasv eeldab treeningu- ning võistluskoormuste pidevat suurenemist, mis esitab sportlaste tugi-liikumisaparaadile (TLA) üha kõrgemaid nõudmisi. Juhul, kui esitatud nõudmised ei ületa organismi füsioloogilisi võimeid, siis koormused omavad formeerivat rolli, tagades TLA adekvaatse morfofunktsionaalse ümberehituse (kohanemise). Pikaajaliste maksimaalsete ja forseeritud koormuste puhul ilmneb TLA funktsiooni readaptatsioon, arenevad üleväsimus, ülepinge, mikrotraumad. Viimaseid võib hinnata funktsionaalsete kõrvalekalletena, eelpatoloogiliste seisunditena, mille järgselt areneb tõsine patoloogia. Kuid ebapiisavate kliiniliste ilmingute tõttu neid tihti ei panda tähele ja ei ravita. Eriti ohtlik on see tendents laste puhul.

Võimlemises on toimunud viimastel aastakümnetel tunduv noorenemise tendents. Lapsed vanuses 12–14 aastat, kes on jõudnud tipptasemele, treenivad iga päev 6–7 tundi. Mahult ja intensiivsuselt rakenduvad neile koormused, mis varem olid lubatud ainult täiskasvanud sportlastele. Hüppekoormuse ning hüperekstensioonidega seonduvate elementide osakaal nii riistvõimlemises kui ka iluvõimlemises on kõrge kõikidel treeninguperioodidel, moodustades 66–74% treeningu üldmahust. Seoses sellega esitatakse tütarlaste TLA-le kõrgendatud nõudmisi. Meditsiinilise statistika andmed aga näitavad, et naistel on TLA löögilise iseloomuga mehaaniliste koormuste suhtes vähem adaptatsioonivõimeline võrreldes meestega. Dixoni ja Frickeri (1993) poolt teostatud uurimuse põhjal on näidatud, et riistvõimlemises esineb naistel kaks korda rohkem kroonilisi alajäsemete ja lülisamba haigestumisi kui meestel. Siinjuures peab arvestama ka seda, et laste TLA pole veel valmis intensiivsete hüppe- ja hüperekstensioonidega treeningukoormustega kohanemiseks.

Paljude uuringutega on näidatud, et kiirusjõu aladel kutsuvad ebaadekvaatsed korduvad löögilise iseloomuga ja hüperekstensioonidega seonduvad treeningukoormused esile mitmeid kõrvalenähte: riistvõimlemises laste jalavõlvi lamendumise, osteokondropaatia, achilleuse kõõluse rebendeid; iluvõimlemises spondülolisteesi, spondülolüüsi, alaseljavalusid; iluuisutamises põlveliigese pindade deformeeruva artroosi; jalgpallis põlveliigese pilu varajase sünostoseerumise lastel vanuses 12–13 aastat.

Enamik spordimeditsiini spetsialiste on ühisel arvamusel, et degeneratiivsed muutused TLA-s tekivad krooniliste ülekoormuste tagajärjel korduvate mikrotraumade kaudu. Uurijate poolt on pidevalt rõhutatud, et andekate laste "tulemusele vedamine" forseeritud treeningute näol on lubamatu. Kehalise koormuse tase ei tohi ületada organismi adaptatsiooniliste võimete piire. Koormuse lubatavuse aste on individuaalne ja selle optimaalsust on küllaltki raske määrata.

Ülaltoodust ilmneb, et treeningukoormuste mõju uurimine võimlejate TLA-le on aktuaalne. Treeningukoormuste individualiseerimine, nende adekvaatsuse kontroll sportlase TLA funktsionaalsele seisundile eesmärgiga ennetada trauma-eelsete seisundite teket, on tänapäeval aktuaalsemaid probleeme spordis.

Peale selle omab kiirusjõu alade treeninguprotsessi juhtimisel suurt tähtsust TLA passivse (lülisammas) ning aktiivse (lihased) osa funktsiooni määramine ja närvi-lihsaparaadi adaptiivse reaktsiooni hindamine hüppekoormusele ning nende võrdlus mittetreenitud populatsiooni andmetega. See annab võimaluse õigeaegselt avastada TLA readaptatsiooni varajasemaid ilminguid, mis pakub huvi treeneritele, spordimeditsiini spetsislistidele, sporditeadlastele. Antud teemale oligi pühendatud käesolev uuring.

Uurimistöö eesmärk ja ülesanded

Käesoleva uuringu eesmärgiks oli selgitada tugi-liikumisaparaadi adaptiivseid reaktsioone treeningukoormustele noortel võimlejatel, käsitledes sealjuures alaseljavaludega seonduvaid aspekte. Töös püstitati järgmised ülesanded:

1. Hinnata muutusi riistvõimlejate tugi-liikumisaparaadi funktsioonis treeningukoormuste mõjul.
2. Võrrelda vertikaalhüpete sooritamist iluvõimlejatel ja mittetreenitud kontrollrühmal.
3. Määrata lülisamba kumeruste ja lihastoonuse iseärasused iluvõimlejatel, võrreldes neid mittetreenitud kontrollrühmaga.
4. Määrata lülisamba kumeruste ja vaheketaste iseärasusi idiopaatiliste alaseljavaludega iluvõimlejatel võrreldes neid asümptomaatiliste treeningukaaslastega.

Vaatlusalused ja metoodika

Kokku uuriti 133 tütarlast vanuses 10–17 aastat, nendest 15 olid riistvõimlejad, 55 iluvõimlejad ja 63 kontrollrühma tütarlapsed. Esimeses uuringus osalesid Tallinna Olümpiareservi spetsialiseeritud riistvõimlemise kooli õpilased, teises, kolmandas ja neljandas uuringus – Tartu spordiklubi “Jaanika“, Narva “Paemurru” spordikooli ja Tallinna Kopli spordikooli edasijõudnud iluvõimlejad. Kolmandas uuringus, mis viidi läbi kolmel “Miss Valentine” võistlusel Tartus, osalesid peale Eesti iluvõimlejate ka neli Venemaa noortekoondise liiget, kaks nendest olid üksikaladel maailmameistrid noorteklassis. Kontrollrühma tütarlapsed olid Tartu linna gümnaasiumide õpilased, kes spordiga ei tegelenud, kuid osalesid regulaarselt kooli kehalise kasvatuse tundidest 2 korda nädalas. Laste bioloogilist vanust hinnati Tanneri skaala (Tanner, 1962) alusel. Uuringud olid kooskõlastatud Tartu Ülikooli Inimuuringute Eetika Komiteega.

I uuringus (“Tugi-liikumisaparaadi ületreenituse ennetamise kriteeriumid võimlejatel”) osales 15 edasijõudnut riistvõimlejat vanuses 10–14 aastat. Viieaastase longitudinaalse uuringu vältel sooritati 326 vaatlust.

II uuringus ("Hüppevõime näitajad noortel iluvõimlejatel") osales 11 iluvõimlejat ja 15 kontrollrühma tütarlast vanuses 12–13 aastat.

III uuringus ("Lülisamba sagitaalprofiil ja kerelihaste toonus iluvõimlejatel ja mittetreenitud tütarlastel") osales 32 iluvõimlejat ja 48 kontrollrühma tütarlast vanuses 13–17 aastat.

IV uuringus ("Vaheketaste kõrgus, lülisamba sagitaalprofiil ja alaseljavalud iluvõimlejatel") osales 12 iluvõimlejat vanuses 13–14 aastat, nendest 7 tütarlaspsel esinesid idiopaatilised alaseljavalud ja 5 tütarlapsel, kaebused puudusid.

Metoodika

Paigalt üleshüppe testid. Uuring viidi läbi Tartu Ülikooli kinesioloogia ja biomehaanika laboris. Hüppetestid sooritati dünamograafilisel platvormil (PD-3A, VISTI, Venemaa) mõõtmetega 75x75 cm. Kõik vaatlusalused sooritasid kolme liiki paigalt üleshüppeid: (SJ) poolkükkasendist, (CMJ) eelneva allaliikumisega ja (DJ40) sügavushüppe 40 cm kõrguselt. SJ testimisel sooritas vaatlusalune poolkükkasendist (nurk põlveliigeses ligikaudu 90°) plahvatusliku üleshüppe. Nurka põlveliigeses kontrolliti elektrogoniomeetriga, mis kinnitati vaatlusaluse parema alajäseme lateraalsele küljele, kohakuti põlveliigese frontaalteljega. CMJ puhul alustas vaatlusalune hüpet püstiasendist, sooritades seejärel allaiste koos sellele järgneva plahvatusliku üleshüppega. DJ40 puhul alustas vaatlusalune hüpet püstiasendist, seistes 40 cm kõrgusel platvormil. Seejärel sooritas vaatlusalune allahüppe koos sellele vahetult järgneva plahvatusliku üleshüppega. Hüpete ajal hoidis vaatlusalune käed puusal. Enne testimist sooritati mõned proovihüpped. Registreeriti toereaktsiooni vertikaalkomponent, mille alusel arvutati hüppe kõrgus (Asmussen, Bonde-Petersen, 1974). Kõigi hüppevariantide puhul sooritasid vaatlusalused kolm katset ja arvesse läks suurema hüppe kõrgusega katse. Puhkeperiood katsete vahel oli ligikaudu 1 min. Tsükli "venitus-kontraktsioon" (SSC) kasutamise efektiivsust hinnati erinevate hüpe kõrguste suhtena (%) alljärgnevalt: CMJ:SJ ja DJ40:SJ (Bosco *et al.,* 2002). Alajäsemete sirutajalihaste anaeroobse võimekuse hindamiseks viidi läbi modifitseeritud Bosco hüppetest dünamograafilisel platvormil (PD-3, VISTI, Venemaa). Testi ajal sooritasid vaatlusalused 30 s jooksul maksimaalselt kõrgeid ja maksimaalse sagedusega paigalt üleshüppeid poolkükkasendist. Hüpete ajal hoidis vaatlusalune käed puusal. Alajäsemete poolt arendatud keskmine mehaaniline võimsus kehamassi kilogrammi kohta arvutati nii kogu 30 s perioodi kohta, kui ka esimese (0–15 s) ja teise (15–30 s) perioodi kohta eraldi (Bosco *et al.,* 1983). Võimsuse suhtelist langust teisel 15 s hüppeperioodil võrreldes esimese 15 s perioodiga kasutati väsimuse indeksina (%).

Selja pantograafia. Selja kumerusi sagitaalprofiilis registreeriti pantograafiga (Willner, 1983). Määrati torakaalküfoosi (TK) ja nimmelordoosi (LL) nurkade väärtused kraadides. Ristluu kaldenurga väärtust kehavertikaali suhtes määrati Evcik ja Vuceli (2003) järgi. Iga vaatlusaluse kohta sooritati kolm mõõtmist ning arvutati keskmised tulemused.

Müotonomeetria. Skeletilihaste toonuse määramiseks kasutati Tartu Ülikoolis väljatöötatud müotonomeetrit (Vain, Kums 2002; Gavronski *et al.*, 2007). Uuritava skeletilihase kohale nahapinnal asetati müotonomeetri löökotsik. Elektromagneti abil tekitas löökotsik uuritava lihase pinnale lühiajalise deformatsiooni. Seejärel registreeriti skeletilihase vastus mehaanilisele mõjutusele kustuva võnkekõvera näol, mille alusel võib iseloomustada lihase toonust. Lihase omavõnkesagedus $\underset{.}{Y}$ (Hz) arvutati välja järgmise valemiga:

$$\underset{.}{Y} = 1/\, T(Hz),$$

kus $\underset{.}{Y}$ on võnkesagedus ja T – võnkeperiood (s). Kuna “aeglased“ posturaallihased omavad tähtsat rolli selja stabiilsuse säilitamises, osaledes posturaalkontrolli funktsioonis (Hildebrandt, 2003), määrati toonus järgmistel pindmistel kerelihastel: *m. trapezius* (ülemine regioon), *m. erector spinae*, *m. rectus abdominis* (ülemine regioon). Uuringud teostati hommikuti pärast võimlejate soojendust (III uuring), registreerimise ajal vaatlusalune seisis liikumatus loomulikus püstiasendis. I uuringus määrati alajäsemete lihaste toonust ennne ja pärast treeningukoormust. Teostati kolm mõõtmist igal lihasel mõlemal kehapoolel ja analüüsiti nende keskväärtusi.

Antropomeetrilised mõõtmised. Vaatlusaluste keha pikkust püsti ja seliliasendis määrati Martini metallantropomeetriga (täpsus ± 1,0 mm) enne ja pärast treeningukoormusi. Püstiasendis pikkuste mõõtmise ajal seisis vaatlusalune orgaanilisest klaasist valmistatud plaadil. Selili asendis pikkuse mõõtmise ajal pandi sama plaat vertikaalasendisse nii, et vaatlusalune sai toetada sellele mõlema jalatallaga, et vältida mõõtmisvea suurenemist. Mõõtmisviga moodustas 3%. Seejärel leiti pikkuse vahe näitaja (L, mm). Teostati kolm mõõtmist ja leiti keskmine näit. See näitaja kaudselt iseloomustab lülisamba deformatsiooni ulatust sagitaalprofiilis. Kõrge L näitaja iseloomustab paremat tugi-liikumisaparaadi vastupidavust löögilise iseloomuga koormusele (Vain, Kums, 2002).

Oswestry indeks. Seda indeksit kasutatakse toimetuleku, kui ka valu tugevuse määrajana seljavaludega patsientidel. Oswestry indeks sisaldab informatsiooni 10 erinevast valdkonnast, mis puudutab isiku igapäevast elu, valu intensiivsust, toimetulekut, raskuste tõstmist, kõndimist, istumist, seismist, magamist, sotsiaalelu, reisimist ja valu tugevuse muutumist (Cole *et al*., 1994). Enne testimist täitis vaatlusalune Oswestry küsimustiku.

Magnetresonantsuuring (MRI). Selja uuring oli teostatud 1,5 T Siemens Symphony magnetiga (Siemens Medical Solutions, Erlangen, Saksamaa) Tartu Ülikooli Kliinikumi radioloogia osakonnas. Lülisamba sagitaalprofiili uuriti T-1 ja T-2 magnetvälja tugevusega. MRI tulemusi analüüsiti kahe kogenud radioloogi poolt. Vahekettaste kõrgused määrati vaheketaste keskosast Frobini *et al.* (1997) metoodika järgi.

Lülisamba kumeruste määramine sagitaalprofiilis radiograafiliselt. Mõõtmised teostati lateraalradiograafilt kliiniliselt ja radiograafiliselt. Vaatlusalused seisid loomulikus püstiasendis alajäsemed põlvedest sirged. Uuring teostati Jackson et al (1998) metoodika järgi. Torakaalküfoosi nurga (TK) (T1-T12) ja nimmelordoosi nurga (LL) (L1-S1) väärtused määrati Gobb meetodil (Gardocki *et al.*, 2002).

Järeldused

1. Võimlejatel esineb kaks TLA adaptiivse reaktsiooni tüüpi löögilise iseloomuga treeningukoormustele: positiivne ja nulltüüpi adaptatsioon. Positiivne reaktsioonitüüp viitab TLA struktuuride rahuldavale funktsionaalsele seisundile, nulltüüp aga seisundi häirumisele.

2. Kõrged ja isegi keskmised treeningukoormused võivad avaldada negatiivset mõju noorvõimlejate TLA funktsionaalsele seisundile.

3. Edasijõudnud iluvõimlejatel on märkimisväärselt suurem võime kasutada alajäsemete lihaste venituse ja kontraktsiooni koosmõju efekti sügavushüpete sooritamisel, kuid mitte poolkükkasendist sooritatud paigalt üleshüpete puhul. Iluvõimlejad arendavad suuremat mehaanilist võimsust Bosco testi sooritamisel, kuid väsivad kiiremini võrreldes kontrollrühma tütarlastega.

4. Võimlejatel seostub jäigem lülisammas, mis on torakaal- ja lumbaalosas lamendunud, kerelihaste toonuse disbalansiga ning alaseljavaludega. Ligikaudu 50% uuritud võimlejatest kaebasid alaseljavalusid.

5. Idiopaatiliste alaseljavaludega võimlejatel ilmnes lülisamba kumeruste lamendumine ning vaheketaste kõrguse vähenemine lülisamba torakaal- ja lumbaalosas. Vaheketaste kõrguse vähenemine ei ole seotud varajase degeneratsiooniga, vaid on lülisamba funktsionaalse ülekoormuse ilming.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to all the people who helped me during this effort, and in particular:

- professor *Mati Pääsuke*, my academic supervisor and co-author, for continuous support, valuable advice, and help;
- dr.habil. biol. *Arved Vain*, my academic co-supervisor and co-author, for continuous support and help;
- Coachers of the gymnastics:
  Jaanika Mölder, *Julia Fjodorova, Nadezda Zahharencova, Larissa Gorbunoyva*, *Grigory Okraszevsky*, *Ljubov Okraszevskaya*, *Sergey Nehoroschich*, *Ado Mänd* for help and support;
- *Margit Klaus*, for help in conducting the studies
- *Aleksander Kums*, my son for help in conducting the studies
- *Meelis Leht*, *Andres Nurmiste* for MRI analysis
- *Olga Mesi* for radiografy analysis
- *Kristina Hyman, Vicki Lee Edge*, *Mare Vene* for correction of this manuscript
- *Helmut Valgma* for consultations of terminology
- *Helena Gapeyeva*, PhD, my colleague co-author, for help and support
- *Jaan Ereline*, PhD, my colleague co-author, for help and support

PUBLICATIONS

I

Vain A, Kums T.
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Biology of Sport, 2002, 19(4): 329–345.

II

Kums T, Ereline J, Gapeyeva H, Pääsuke M.
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III

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IV

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1998	International Course *“Myometric Diagnostics”*, I part 29.–03.07, Tartu, Estonia; II part 24.–27.10.1998, Kaunas, Lithuania
2000	International Summer Course for teachers 05.08.–12.08. Vierumäki, Finland
2001	International Summer Course for teachers 01.08.–07.08. Väimela, Estonia
2006	Level 1 Technical Anthropometry Course ISAK, April, 2006, Tartu, Estonia
2007	Biology Feedback Course, February, 2007, Institute of Biology Feedback, St. Petersburg, Russia

Main Research Interests:

- Adaptation changes of musculo-skeletal system in athlete of the influence to impact training loads
- Resistance of the musculo-skeletal system to training loads in young rhythmics gymnasts
- Health of the musculo-skeletal system in athlete
- Old women, training, motor ability, health

Publication Summary

The total number of scientific publications is 38, including 6 papers in international refereed journals, 20 conference abstracts and 12 other papers

ELULOOKIRJELDUS

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Haridus

1969	Kohtla-Järve 13 Keskkool
1974	Tartu Ülikool, kehakultuuriteaduskond
1997	*MSc* (liikumis- ja sporditeadused), Tartu Ülikool, kehakultuuriteaduskond
1998–2002	Doktorantuur (liikumis- ja sporditeadused), Tartu Ülikool, kehakultuuriteaduskond

Erialane teenistuskäik

1974–1975	Kohtla-Järve 3 Keskkool, õpetaja
1975–1986	Laborant TÜ spordifüsioloogia kateedris
1986–1990	Õpetaja TÜ kehalise kasvatuse ja spordi kateedris
1990–1998	Laborant TÜ spordipedagoogika instituudis
1998–2002	Doktorantuur (liikumis- ja sporditeadused), Tartu Ülikool, kehakultuuriteaduskond
2003	Laborant TÜ spordibioloogia ja füsioteraapia instituudis

Erialane enesetäiendus

1998	Rahvusvaheline kursus "*Myometric Diagnostics*", I osa 29.–03.07 Tartu; II osa 24.–27.10.1998, Kaunas, Leedu.
2000	Rahvusvahelised õpetajate suvekursused 05.08.–12.08 Vierumäki, Soome.
2001	Rahvusvahelised õpetajate suvekursused 01.08.–07.08. Väimela, Eesti.
2006	ISAK Rahvusvahelised Antropomeetria kursused, aprill, 2006, Tartu.
2007	Bioloogiline tagasiside, rahvusvahelised kursused, veebruar, 2007, Bioloogilise tagasisideme instituut, St.Peterburg, Venemaa.

Teadustegevus

- Sportlaste tugi-liikumisaparaadi adaptatsioon löögi iseloomuga koormustele
- Tugi-liikumisaparaadi adaptiivsed muutused noortel iluvõimlejatel
- Tugi-liikumisaparaadi tervishoid spordis
- Treening, motoorne võimekus, tervis, vanemaealistel naistel

Kokkuvõte publikatsioonidest

Kokku on ilmunud 38 publikatsiooni, sealhulgas 6 artiklit rahvusvahelistes refereeritavates ajakirjades, 12 muud teadusartiklit ja 20 teaduskonverentside teesi.

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

1. **Lennart Raudsepp.** Physical activity, somatic characteristics, fitness and motor skill development in prepubertal children. Tartu, 1996, 138 p.
2. **Vello Hein.** Joint mobility in trunk forward flexion: methods and evaluation. Tartu, 1998, 107 p.
3. **Leila Oja.** Physical development and school readiness of children in transition from preschool to school. Tartu, 2002, 147 p.
4. **Helena Gapeyeva.** Knee extensor muscle function after arthroscopic partial meniscectomy. Tartu, 2002, 113 p.
5. **Roomet Viira.** Physical activity, ecological system model determinants and physical self-perception profile in early adolescence. Tartu, 2003, 167 p.
6. **Ando Pehme.** Effect of mechanical loading and ageing on myosin heavy chain turnover rate in fast-twitch skeletal muscle. Tartu, 2004, 121 p.
7. **Priit Kaasik.** Composition and turnover of myofibrillar proteins in volume — overtrained and glucocorticoid caused myopathic skeletal muscle. Tartu, 2004, 123 p.
8. **Jarek Mäestu.** The perceived recovery-stress state and selected hormonal markers of training stress in highly trained male rowers. Tartu, 2004, 109 p.
9. **Karin Alev.** Difference between myosin light and heavy chain isoforms patterns in fast- and slow-twitch skeletal muscle: effect of endurance training. Tartu, 2005, 117 p.
10. **Kristjan Kais.** Precompetitive state anxiety, self-confidence and ahtletic performance in volleyball and basketball players. Tartu, 2005, 99 p.
11. **Aire Leppik.** Changes in anthropometry, somatotype and body composition during puberty: a longitudinal study. Tartu, 2005, 161 p.
12. **Jaan Ereline.** Contractile properties of human skeletal muscles: Association with sports training, fatigue and posttetanic potentiation. Tartu, 2006, 133 p.
13. **Andre Koka.** The role of perceived teacher feedback and perceived learning environment on intrinsic motivation in physical education. Tartu, 2006, 137 p.
14. **Priit Purge.** Performance, mood state and selected hormonal parameters during the rowing season in elite male rowers. Tartu, 2006, 101 p.
15. **Saima Kuu.** Age-related contractile changes in plantarflexor muscles in women: associations with postactivation potentiation and recreational physical activity. Tartu, 2006, 101 p.
16. **Raivo Puhke.** Adaptive changes of myosin isoforms in response to long-term strength training in skeletal muscle of middle-aged persons. Tartu, 2006, 99 p.

17. **Eva-Maria Riso.** The effect of glucocorticoid myopathy, unloading and reloading on the skeletal muscle contractile apparatus and extracellular matrix. Tartu, 2007, 114 p.
18. **Terje Sööt.** Bone mineral values in young females with different physical activity patterns: association with body composition, leg strength and selected hormonal parameters. Tartu, 2007, 94 p.
19. **Karin Tammik.** Neuromuscular function in children with spastic diplegic cerebral palsy. Tartu, 2007, 102 p.
20. **Meeli Saar.** The relationships between anthropometry, physical activity and motor ability in 10–17-year-olds. Tartu, 2008, 96 p.
21. **Triin Pomerants.** Ghrelin concentration in boys at different pubertal stages: relationships with growth factors, bone mineral density and physical activity. Tartu, 2008, 80 p.