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COMPARISON OF ANKLE TAPING AND BRACING ON ANKLE BIOMECHANICS DURING LANDING IN FUNCTIONAL ANKLE INSTABILITY

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Abstract. Lateral ankle sprains are one of the most common injuries in athletics. Injury to lateral ankle ligaments can result in persistent instability of the ankle joint, known as functional ankle instability (FAI). Two methods of treating FAI are ankle taping and ankle bracing. The purpose of this study was to compare the effects of ankle taping and ankle bracing on ankle joint kinematics and kinetics during a landing task. Methods: Seven individuals with FAI and seven healthy controls performed three landing trials in each of three conditions: control, taped and braced. Ground reaction forces and three-dimensional kinematics were collected simultaneously while participants performed single-leg step-off landing trials from a box with a height of 0.6m. Peak ankle joint angles and moments were calculated using customized software. Results: Individuals with FAI produced significantly smaller inversion moments compared to healthy controls (p = 0.006). Ankle stabilization did not significantly alter ankle joint angles, ranges of motion or moments. Discussion: The present findings suggest that individuals with FAI exhibit unique ankle biomechanics independent of ankle stabilization modality. Future research may seek to investigate the multi-joint biomechanical adaptations associated with ankle stabilization in individuals with FAI compared to healthy controls.

Key words: ankle biomechanics, taping, bracing, landing, injury, treatment

Introduction

Ankle ligament injury is a common occurrence in athletics (Garrick 1977; Arendt and Dick 1995; Fong et al. 2007; Hootman et al. 2007), accounting for 15% of collegiate sports injuries (Hootman et al. 2007) and approximately 25% of all time lost from physical activity (Ashton-Miller et al. 1996). Lateral ankle sprain is the most
common ankle ligament injury and is typically caused by excessive inversion during ankle plantarflexion (De Clercq 1997; Cordova et al. 2000; Wright et al. 2000; Zhang et al. 2009a). Athletes often experience residual symptoms following lateral ankle sprain including pain, instability and recurrent ankle sprains (Zhang et al. 2012). Previous research has demonstrated that of athletes experiencing ankle sprains, 79% experienced a recurrence of ankle sprain (Yeung et al. 1994) while 59% exhibited functional disability and significant residual symptoms (Yeung et al. 1994). Recurring instability at the ankle following initial ankle ligament injury is commonly referred to as functional ankle instability (FAI) (Hertel 2002).

Retrospective studies have identified several potential mechanisms responsible for reduced ankle stability associated with FAI. Intrinsic factors that may be responsible for FAI include anatomical alignment, ankle joint laxity, inadequate muscular strength and insufficient reaction time (Beynnon et al. 2002). However, in addition to reduced structural stability of the ankle joint, it has been suggested that lateral ankle sprain may interrupt the availability of sensory information to the central nervous system resulting in injury-induced reductions in sensory-motor function (Madras and Barr 2003). The reductions in sensory-motor function may place athletes with a history of ankle ligament injury at an exaggerated risk of subsequent ankle ligament injury (Madras and Barr 2003).

A common intervention to combat the deleterious effects of FAI is the implementation of an ankle stabilizer. Two methods of ankle stabilization often available to sports medicine personnel include ankle taping and ankle bracing (Zhang et al. 2009b). Ankle taping is the application of adhesive cloth tape in specific patterns to enhance the stability of the lateral aspect of the ankle joint by restricting the range of motion (Cordova et al. 2002). Though ankle taping has been shown to increase ankle stability, it has been demonstrated that mechanical support offered by ankle taping is reduced by 18% to 40% within thirty minutes of the onset of physical activity (Thonnard et al. 1996). It has been suggested that this reduction in mechanical stiffness offered by ankle taping is associated with a thermally driven loss of adhesive properties within the tape (Alt et al. 1999). Though the loss of mechanical support with activity raises questions to the efficacy of ankle taping, some researchers have suggested that taping is the optimal method of ankle stabilization (McKay et al. 2001). An alternative to ankle taping is the implementation of an ankle brace. Ankle braces are commonly composed of a soft cloth interior and an anterior lacing system extending from the midfoot to a point several inches proximal to the ankle joint (Zhang et al. 2012). Some models of ankle brace include external plastic components to increase the rigidity of the brace and enhance stability. Ankle braces are designed to mechanically restrict plantar flexion and inversion movements at the ankle (Cordova et al. 2002; Chen et al. 2012; Zhang et al. 2012). Two advantages of ankle bracing compared to ankle taping are reusability and adjustability of ankle braces. For example, ankle braces can be used for multiple training and competition sessions to provide consistent ankle support while ankle taping can only be used for a single session. Further, support offered by ankle tape may be highly variable and is dependent upon the skill and consistency of sports medicine personnel. Conversely, ankle braces may be adjusted by the athlete during training or competitions to his or her personal comfort.

The vast majority of research studies pertaining to ankle stabilization have been conducted on healthy adults. The efficacy of ankle stabilization in individuals with FAI compared to healthy controls during a landing task has not been well investigated. Further, the optimal method of ankle stabilization in individuals with FAI has not been clearly identified. Therefore, the purpose of this study was to compare the efficacy of two common methods of ankle stabilization (taping vs. bracing) on ankle biomechanics in individuals with FAI compared to healthy controls during a landing task. It was hypothesized that: (1) individuals with FAI would exhibit significantly greater ankle joint ranges
of motion and peak ankle joint moments compared to healthy controls, (2) changes in frontal plane ankle ranges of motion and moments would be disproportionately greater in individuals with FAI compared to healthy controls following ankle stabilization, (3) ankle bracing would be associated with disproportionately greater changes in ankle joint ranges of motion and joint moments than ankle taping.

**Methods**

**Participants**

Seven individuals with FAI (5 M, 2 F) and seven healthy controls (3 M, 4 F) were recruited for participation in this study. Each participant was a recreational athlete and regularly performed vigorous activity for a period of at least 30 minutes three times per week. Participants were assigned to either the Control group or the FAI group based on self-reported scores on the Functional Ankle Instability Questionnaire (Hubbard and Kaminski 2002). Specifically, those individuals that answered “yes” to questions 3, 5, 6, 7 and 9 while concurrently answering “no” to questions 4, 8 and 10 were assigned to the FAI group. Individuals that responded “no” to all questions were assigned to the Control group. Participants were excluded if they had experienced a lower extremity injury within the six months preceding this study. Participants were also excluded if a neuromuscular or musculoskeletal condition was present that would render them incapable of performing the required landing tasks. All participants signed a written informed consent form approved by the university Institutional Review Board prior to participating in this study.

**Experimental Protocol**

A National Board Certified Athletic Trainer (HMU) assessed ankle instability by performing anterior drawer (Docherty and Rybak-Webb 2009; Vaseenon et al. 2012) and talar tilt tests (Hertel et al. 1999) for each participant to confirm Functional Ankle Instability Questionnaire scores. Anthropometric measurements including participant height and mass were recorded.

After being assigned to a group, participants completed a ten-minute warm up using a stationary cycle. Each participant then performed three single-leg landing trials in each of three conditions: normal, braced and taped. The order of presentation of experimental conditions was randomized. The normal condition was characterized by no external support for the ankle. The braced condition consisted of the participant completing the single-leg landing trials while the ankle was supported by an ankle brace (Mueller Sports Medicine, Inc, Prairie du Sac, WI, USA). The ankle taped condition was characterized by the participant completing the single-leg landing trial while the ankle was supported by a Closed Basket Weave Taping Technique using 1.5 inch athletic tape. To reduce taping variability and to ensure consistency in taping technique, a single certified athletic trainer completed all taping for this study. Landing trials were characterized by the participant performing a single-leg step-off landing from a box with height of 0.60 meters onto the center of a force platform. The trial was considered successful if the participant landed on a single leg and maintained an upright posture. Unsuccessful trials were repeated. Ground reaction forces and three-dimensional (3D) kinematic data were collected.

**Instrumentation**

A four-camera motion capture system (120 Hz, ViconPEAK, Inc., Centennial, CO, USA) and force platform (960 Hz, OR-6, AMTI, Watertown, MA, USA) were used to collect 3D kinematic data and ground reaction forces.
from the right side of the lower extremity of each participant, respectively. Retro-reflective markers were placed over anatomical landmarks bilaterally including the sacrum, anterior superior iliac spine, lateral femoral condyle, posterior aspect of the calcaneus, lateral malleolus and the distal portion of the second metatarsal. A tibial wand was placed on the leg at the point of greatest circumference of the gastrocnemius and projected laterally. A laterally projecting femoral wand was placed over the point of greatest circumference of the thigh.

**Data Analysis**

Three-dimensional kinematic data were low-pass filtered using a fourth order Butterworth filter with a cut-off frequency of 10 Hz. Ground reaction forces were low-pass filtered with a cut-off frequency of 50 Hz. Lower extremity joint angles and internal joint moments were calculated using Visual 3D (C-Motion, Inc., Bethesda, MD, USA) and custom software (MatLab 2009, MathWorks, Natick, MA, USA). All data were analyzed between initial contact and peak knee flexion. Joint ranges of motion were defined as the difference between the maximum and minimum joint angles. Joint moments were normalized to body mass. For kinematic and kinetic variables, a subject mean was calculated as the average of the three trials from each movement condition and used in all statistical analyses.

**Statistical Analyses**

Student’s t-tests were used to compare anthropometric measurements between the FAI group and the Control group. A 2 × 3 (group by condition) repeated measures analysis of variance (ANOVA) was used to determine significant effects of group and bracing condition as well as group × bracing condition interactions for each variable. In the presence of a significant group × condition interaction, a Tukey’s post-hoc analysis was conducted to determine the source of the significant interaction. Significance was set at p < 0.05. All statistical analyses were conducted using SPSS 21.0 (IBM, Chicago, IL, USA).

**Results**

The FAI and Control groups had similar anthropometric measurements. The groups were similar in age (Control: 22.6 ±2.9 yrs; FAI: 24.4 ±5.6 yrs; p = 0.448), height (Control: 1.74 ±0.10 m; FAI: 1.69 ±0.11 m; p = 0.497), mass (Control: 72.3 ±12.6 kg; FAI: 67.6 ±12.7 kg; p = 0.392) and BMI (Control: 23.6 ±2.6; FAI: 20.2 ±2.2; p = 0.820).

**Joint Ranges of Motion**

Ankle joint ranges of motion in the sagittal and frontal planes are presented in Figures 1 and 2, respectively. Individuals with FAI did not have significantly different ankle joint ranges of motion in either the sagittal (p = 0.784) or frontal planes (p = 0.863). Ankle stabilization did not significantly affect joint ranges of motion in the sagittal (p = 0.863) or frontal planes (p = 0.208). No significant group by condition interactions were observed in the sagittal (p = 0.982) or frontal plane ranges of motion (p = 0.445).
Figure 1. Mean sagittal plane ankle joint ranges of motion in individuals with functional ankle instability compared to healthy controls during a single-leg landing task. Presented as mean (SEM)

Figure 2. Mean frontal plane ankle joint ranges of motion in individuals with functional ankle instability compared to healthy controls during a single-leg landing task. Presented as mean (SEM)

**Joint Moments**

Figure 3 presents peak ankle plantarflexor moments in individuals with FAI and healthy controls when landing in normal, braced and taped conditions. Figure 4 illustrates peak ankle inversion moments in individuals
with FAI and healthy controls when landing in the normal, braced and taped conditions. Peak ankle plantarflexor moments were not significantly different between the FAI group and Controls (p = 0.885). Ankle stabilization did not significantly affect ankle plantarflexor moments (p = 0.058). No significant group by condition interactions were observed (p = 0.739).

Figure 3. Peak ankle plantarflexion moments in individuals with functional ankle instability and healthy controls during a single-leg landing task. Presented as mean (SEM)

Figure 4. Peak ankle inversion moments in individuals with functional ankle instability compared to healthy controls during a single-leg landing task. Presented as mean (SEM).
A significant group effect was observed for ankle inversion moments \((p = 0.006)\). Specifically, across all conditions, individuals with FAI exhibited significantly smaller ankle inversion moments compared to healthy controls. Ankle stabilization did not significantly affect ankle inversion moments \((p = 0.492)\), and no significant group by condition interaction was observed \((p = 0.835)\).

**Discussion**

The purpose of this study was to assess the efficacy of ankle taping and ankle bracing in individuals with FAI compared to healthy controls during a single-leg landing task. The findings of this study demonstrate that individuals with FAI exhibit unique ankle joint biomechanics compared to healthy adults, and that these aberrant biomechanics are not responsive to external ankle stabilization.

A suggested mechanism of efficacy of ankle stabilization methods is to limit ankle plantarflexion and ankle inversion ranges of motion \((Zhang et al. 2009b)\). In the present study, ankle stabilization did not significantly reduce ankle ranges of motion in the sagittal or frontal planes. Though both ankle bracing and taping are purported to reduce ankle range of motion and the associated risk of injury, neither bracing nor taping were effective in reducing ankle joint range of motion. These findings are not consistent with previously reported data investigating the efficacy of ankle bracing in individuals with FAI and healthy adults \((Zhang et al. 2009a; Zhang et al. 2009b; Chen et al. 2012; Zhang et al. 2012)\). Several studies have reported that semi-rigid ankle braces are associated with significant reductions in ankle plantarflexion at initial contact, peak ankle plantarflexion and sagittal plane ankle ranges of motion during bilateral landing tasks \((Zhang et al. 2009a; Zhang et al. 2009b; Zhang et al. 2012)\). Zhang et al. \((2012)\) reported significant reductions in dorsiflexion range of motion as well as reduced eversion range of motion and peak eversion velocity during a bilateral landing task. Further, Chen et al. \((2012)\) reported that landing with an ankle brace resulted in reduced ankle dorsiflexion range of motion and plantarflexion angle at initial contact when landing on a flat or inverted surface.

Ankle joint kinematics are the manifestation of the interaction of external loading and internal joint kinetics. Ankle stabilizers are designed to reduce the kinetic forces associated with mechanisms of lateral ankle sprain including ankle plantarflexion and ankle inversion moments. In the current study, individuals with FAI and healthy controls exhibited similar ankle plantarflexion moments. However, individuals with FAI produced significantly smaller peak ankle inversion moments during the single-leg landing task compared to healthy controls. These findings are in contrast to previous research reports which have demonstrated that ankle bracing is associated with significant increases in ankle plantarflexion moments, but have no demonstrated effects on frontal plane joint moments \((Zhang et al. 2009b; Chen et al. 2012; Zhang et al. 2012)\). Specifically, Zhang et al. \((2012)\) reported increases in ankle plantarflexion moments of nearly \(0.1\) Nm/kg in response to ankle bracing in individuals with FAI and healthy controls. This significant increase in ankle joint moments was attributed to the reduced dorsiflexion range of motion, a shock attenuation mechanism. Further, Zhang et al. \((2012)\) observed small reductions in peak ankle eversion moments \((0.85\) Nm/kg), however, these reductions were not statistically significant \((p = 0.067)\). The smaller ankle inversion moments observed in the FAI group compared to the healthy controls may be an adaptive strategy intended to reduce the most common mechanism of ankle sprain, ankle inversion during plantarflexion. The reduced inversion moment may allow the external forces associated with landing to place the ankle into a more everted position, or to allow passive structures on the medial aspect of the ankle to absorb a greater proportion of the load during the landing task. In the presence of reduced ankle joint stability following repeated ankle sprains, the adaptive strategy...
may inherently place greater stress on the healthy tissues, reducing the inversion joint moments; however, this strategy would not seem to be completely effective as the athlete continues to suffer from joint instability.

Several factors may have led to the unique results presented in this compared to previous research studies pertaining to the mechanisms of efficacy of ankle stabilization methods. One methodological aspect that may underlie these differences is the use of a single-leg landing task in this study. Most previous research studies have utilized a bilateral landing task on either a flat or inverted surface to assess ankle bracing efficacy (Zhang et al. 2009a; Zhang et al. 2009b; Chen et al. 2012; Zhang et al. 2012). The single-leg landing task would increase the mechanical demand required for successful shock attenuation as well as increasing the motor control complexities with a reduced base of support. Increased motor control demands may result in exaggerated performance variability and therefore statistically non-significant findings. A second factor affecting comparison of current findings to previous research data is the ankle bracing and taping strategies utilized in this study. Each ankle brace is designed to combat specific mechanisms of ankle injury, however the construction of these designs varies in the efficacy of resisting ankle plantarflexion and inversion motions. Therefore, different ankle brace designs may have altered performance characteristics. A third factor that was not controlled in the present study was foot type. Previous research has revealed that individuals with high- compared to low-arched feet exhibit unique landing kinematics and kinetics during a bilateral landing task (Powell et al. 2012). It is possible that the two groups tested in the present study exhibited unevenly distributed foot types, and that the unique landing mechanics associated with foot type resulting in heterogeneous landing strategies.

The findings of the present study, in conjunction with previous research studies, have demonstrated that ankle stabilization alters ankle joint mechanics during a landing task. However, limited research has investigated the effect of ankle stabilization on more proximal joint mechanics. It could be postulated that, by increasing ankle plantarflexion joint moments and ankle joint stiffness, the magnitude and rate of loading at the knee joint would be amplified, and that these increased loads may place the knee at an exaggerated risk of injury. Future research should address the multi-joint biomechanical responses of the lower extremity to current ankle stabilization techniques.

The authors acknowledge several limitations in the current study. Specifically, the small sample size of 7 participants in each group limited the statistical power of the study. However, few comparisons in the present study exhibited a trend (p < 0.10), suggesting that meaningful differences were detected statistically. A second limitation of the present study was the use of only four motion capture cameras. The use of only four motion capture cameras limited the quantity of data collected and may have resulted in less precise detection of three-dimensional marker data leading to greater noise-to-signal ratios. This may underlie the relatively large variations in performance within each group. Alternatively, the large variations in performance may be a manifestation of the relatively high mechanical and motor control demands placed on participants by the single-leg landing task from a height of 0.60 meters. Finally, recent research has revealed that when kinematics and kinetics are filtered at 10 Hz and 50 Hz, respectively, peak hip and knee joint moments may be exaggerated (Kristianslund et al. 2012). While these filter frequencies were used in the present study, the focus of this study pertained solely to ankle joint biomechanics. The recent paper did not suggest that ankle joint moments would be affected by these filtering parameters.

This research study revealed that ankle stabilization alters frontal plane ankle joint moments during a single-leg landing task, but does not significantly alter ankle joint kinematics. However, with altered ankle joint moments, forces transmitted to higher joint structures including the knee and hip will be affected. Potentially, the previously
reported increases in ankle joint stiffness may exaggerate the risk of injury to the knee and hip joints. Future research may investigate the multi-joint biomechanical adaptations associated with ankle stabilization.

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EFFECTS OF GENDER AND RECURRENT LOW BACK PAIN ON LIFTING STYLE

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Abstract. Objective: The purpose of this study was to examine the influence of gender and existing, recurrent low back pain (rLBP) on lower extremity and trunk mechanics, as well as neuromuscular control, during a lift task. Design: A multivariate design was used to examine the effects of gender and group on biomechanical and neuromuscular control variables in randomized symmetric and asymmetric lifting. Methods: 68 Males and females with rLBP and healthy performed symmetric and asymmetric weighted box lifting trials to a 1 meter height table. Results: Lifting style was different between gender and between the rLBP versus healthy groups during a 1m box lifting. A significant two-way interaction effect between gender and group was observed for multifidus muscle activity and knee rotation in asymmetric lifting. Several gender and group main effects were observed in pelvis obliquity, trunk flexion and side flexion, knee abduction angles in symmetric lifting; and in pelvis obliquity and rotation, trunk flexion and side flexion, hip abduction, knee abduction angles, external oblique and internal oblique muscles activity in asymmetric lifting. Conclusions: Females and individuals with rLBP appear to use different lifting styles that emphasize movement at the pelvis accompanied by poor kinematic control features at the hip, trunk and knee. Clinicians should be mindful of these changes when developing prevention and rehabilitation programs aimed at improving trunk control in preparation for lifting tasks during domestic and occupational activities.

Key words: low back pain, lifting, clinical biomechanics, injury prevention

Introduction

Lifting is a major activity in daily life, where individuals are required to manually manage materials and loads throughout occupational tasks and activities of daily living. Individuals are required to manage those materials while perform tasks in restricted areas as they negotiate different body positions (Gallagher et al. 2011; Ulrey and Fathallah 2013). Such lifting behaviors are used in a repeated fashion during various occupational engagements, such as healthcare (Karahan et al. 2009; Theilmeier at al. 2010), farm animal management (Pal at al. 2010), labor employment (Ropponen et al. 2012) and performing arts (Alderson et al. 2009).
Individuals typically sustain a slouched posture during a lift sequence that is accentuated when returning to upright position with the load (Maduri et al. 2008). Such a pattern appears to increase the compressive forces between the lumbar vertebrae (Arjmand et al. 2009). Moreover, the shear forces on the lumbar spine region are increased when lifting from that slouched position. Lumbar spinal segments in individuals without lower back pain (LBP) appear to be tolerant of a 700 N versus 1000 N shear force during repetitive versus occasional shear exposures, respectively (Gallagher and Marras 2012). However, repeated lifting in a slouched posture appears to increase those shear forces during manually demanding activities, especially when the individual has a history of LBP (Pal et al. 2010). Such repeated loading places the individual at a higher risk for injuries to the lumbar spine and lower extremity, in part because the lower extremities share similar neuromuscular control specifically anterolateral aspects of the leg, medial foot, and toe region (Schafer 2012).

Low back pain is reported in 75–80% of the population and can significantly influence an individual’s quality of life (Martin et al. 2009). Low back pain is the second can lead to cause for missed days at work, potentially leading to disability and major socioeconomic consequences (Hayden et al. 2012). Low back pain can result from mechanical irritations of selected anatomical structures, such as the intervertebral disc (Manchikanti at al. 2009a; Manchikanti et al. 2009b; Wolfe et al. 2008), zygapophyseal joint (Datta et al. 2009; Manchukonda et al. 2007) and lumbar spinal nerve root (Konnai et al. 2000). While low back pain can develop in response to various pathological conditions, such as degenerative arthritis (Goode et al. 2013; Igarashi et al. 2004) or intervertebral disc disease (Gawri et al. 2014; Saleem et al. 2013), it commonly results from abrupt or repetitive mechanical stressors, such as heavy lifting, a fall or prolonged periods of sitting or standing (Handout on Health: Back Pain... 2013). The majority of individuals with LBP experience the condition on a recurrent basis, suggesting that once individuals experience an acute LBP episode it is more likely that they will experience further episodes (Stanton et al. 2010). Symptoms of recurrent low back pain (rLBP) can range from muscle ache to shooting or stabbing pains, which can limit flexibility and/or range of motion (Handout on Health: Back Pain... 2013). As a result of limitations in flexibility and range of motion, rLBP can alter an individual’s overall functional capacity and ultimately heighten the risk for additional lower extremity injury (Haddas et al. 2014). Moreover, the onset and persistence of rLBP is complex, compounded by many risk factors that are personal (age, smoking habits, weight), psychosocial (stress, social support), and physical (lifting, twisting, compression) in nature (Handout on Health: Back Pain... 2013).

Lifting performance appears to be influenced by gender Gross and Battie (2005). examined the association between maximum amount of weight lifted during the floor-to-waist lift and various clinical and psychosocial factors. They found that women demonstrated lower maximum weight during five consecutive lifts versus male counterparts. Smeets et al. (2007) compared male and female subjects with non-specific LBP in the number of fully completed floor to waist-test lifting cycles during a progressively increasing lift task. They discovered that female subjects performed fewer lifting cycles versus male subjects. The authors concluded that this decrease was disproportionate to the females’ lower body mass. Similarly, Reneman et al. (2007) found that males out performed females during a high-intensity lifting task. The female subjects demonstrated significantly lower maximal weight that was lifted five times within 90 seconds. In addition, the females’ observed level of lifting intensity was not significantly different from the males’ score, based on the Borg CR-10 scale.

The female’s differences in lifting response, coupled with their disproportionate decrease in lifting performance when compared to male counterparts, implies increased vulnerability to injury and subsequent clinical consequences. Such a disparity places the female at greater risk for injury and resulting rLBP, which is reinforced...
by their reduced functional capacity across various tasks (Chenot et al. 2008; Takala and Viikari-Juntura 2000). Because employees in such occupational endeavors are exposed to intense, repetitive lifting encounters, such findings support the connection between gender, lifting response, and injury. Moreover, the presence of existing rLBP symptoms may complicate the gender differences and the resulting female’s vulnerability. However, data that describe the underlying mechanisms responsible for such differences are limited. The purpose of this study was to examine the influence of gender and existing, rLBP on lower extremity and trunk mechanics, as well as neuromuscular control, during a 1m box-lift task. Such findings will help elucidate the underlying mechanisms that contribute to the connection between gender, lifting response and the risk for developing and sustaining rLBP.

Methods

Experimental Approach to the Problem

A multivariate design was used to examine the effects of gender and group (healthy versus rLBP) on biomechanical and neuromuscular control variables in symmetric (forward) and asymmetric (right and left) lifting.

Subjects

Thirty-seven healthy individuals (20 males and 17 females) and thirty-one rLBP individuals (16 males and 15 females) participated in the study (Table 1). All subjects were between the ages of 18 and 35 years. Volunteers were excluded if they had a history of knee pain, surgery to the knee or lumbar spine, active abdominal or gastrointestinal conditions, or pregnancy (all documented by self-report). All participants read and signed an informed consent form approved by Texas Tech University review board.

Table 1. Subjects anthropometrics data

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<td>Age (years)</td>
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<td>21.29 ±4.22</td>
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<td>Mass (kg)</td>
<td>77.25 ±12.20</td>
<td>58.81 ±7.21</td>
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<td>Height (m)</td>
<td>1.77 ±0.09</td>
<td>1.65 ±0.05</td>
</tr>
<tr>
<td>Box mass (kg)</td>
<td>17.12 ±3.89</td>
<td>9.20 ±2.51</td>
</tr>
<tr>
<td>Same day pain*</td>
<td>0.13 ±0.57</td>
<td>0.00 ±0.00</td>
</tr>
<tr>
<td>Last week average pain*</td>
<td>0.12 ±0.36</td>
<td>0.03 ±0.11</td>
</tr>
<tr>
<td>Last week worst pain*</td>
<td>0.62 ±1.61</td>
<td>0.01 ±0.02</td>
</tr>
</tbody>
</table>

*Visual analog scale from least to worst (1–10).

Procedures

Subjects filled out a visual analog pain scale to indicate if they were experiencing any pain, along with a map defining the pain location (Table 1). Participants were excluded if they had pain that was referred into the lower extremity. The subjects were then taught how to perform the protocol of symmetric and asymmetric lifting. Lifting technique was based on the discretion of the individual and the subject’s box weight was determined by their maximum psychophysically acceptable weight (Table 1). Electromyography (EMG) (Delsys Inc. 2000Hz) sensors were then placed on the right side internal oblique (IO), external oblique (EO), erector spinae (ES), and multifidus
(Mf) at the fifth lumbar (L5) spinal level, as well as the rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), gluteus maximus (GMx) and gluteus medius (GMd) all on the subjects right side (Barbero, Merletti, Rainoldi, 2012). Ground reaction forces (GRFs) were collected for each leg (AMTI 2000Hz). The skin was cleaned with alcohol, shaved if necessary, and then lightly abraded to reduce impedance. Subjects then performed maximum voluntary contraction (MVC) tests for all muscles listed above. The MVC outcomes were used later to normalize subjects’ muscle activity during the lifting maneuver. Forty-seven reflective markers were then placed on bony landmarks on the trunk and lower extremity in order to calculate joint angle (Figure 1). A static trial was then collected to note marker placement.

![Marker set](image)

Participants performed nine weighted box (0.65 m long, 0.35 m wide, 0.15 m high) lifting trials to a 1m height table in forward, right and left side directions (Figure 1). All trials were randomized. Three-dimensional kinematics (VICON Nexus) were collected from the lower extremities and lumbar spine at a sampling rate of 100 Hz.

**Data Reduction**

Dependent variables included 3D trunk, hip, knee joint angle and EMG linear envelop magnitude for lower extremity and trunk muscles. Kinematics and linear envelop variables were analyzed at two times - 0.05s after lifting was initiated and again 0.05s before the subject placed the box on the table. All raw data were exported from the Vicon Nexus system and imported into a custom Matlab program (Mathworks Inc., v7.10.0, Natick, MA) and Visual3D for processing.
Statistical Analyses

All dependent variables were assessed for distribution normality using the Shapiro-Wilk test. A multivariate design was used to examine the effects of gender and group on biomechanical and neuromuscular control variables in symmetric (forward) and asymmetric (right and left) lifting.

A MANOVA was used to determine the effect of gender (males versus females) and group (Healthy versus rLBP) for each dependent variable. The alpha level was initially set to 0.05 but corrections were made within each statistical family using the Holm-Sidak correction for the multiple dependent variables, resulting in an initial alpha level of 0.008 for the kinematic variables and 0.012 for the EMG variables, based on the number of dependent variables within each family. Follow-up tests were conducted as necessary, with alpha correction at each step. Statistical analyses were conducted using SPSS, Version 21.0 (IBM, Inc., Chicago, IL).

Results

Lifting style was different between gender and between the rLBP versus healthy group during the 1m box lifting. A significant two-way interaction effect between gender and group was observed for Mf muscle activity at the initial position ($p = 0.012, \eta^2_p = 0.181$) in symmetric lifting (Figure 2) and knee rotation angle at final position ($p = 0.004, \eta^2_p = 0.126$) in asymmetric lifting (Figure 3). No other dependent variables exhibited a significant two-way interaction effect. Several significant main effects for group and gender were observed during the 1m lifting maneuver (Tables 2–3).

![Figure 2](image_url)

**Figure 2.** Significant two-way interaction effect between gender and group for Multifidus muscle activity at initial position in symmetric lifting

Several significant group main effects were observed during the 1m lifting. The rLBP presented a larger pelvis rotation angle at final position ($p = 0.003, \eta^2_p = 0.128$), and larger hip abduction angle at final position ($p = 0.001,$
\( \eta_p^2 = 0.093 \) in asymmetric lifting when lifting to the right. Furthermore, the rLBP group produced more EO muscle activity at initial position (\( p = 0.012, \eta_p^2 = 0.183 \)) (Table 2).

### Table 2. Group main effect variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symmetric Lifting</th>
<th>Asymmetric Lifting – Right</th>
<th>Asymmetric Lifting – Left</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg ± SD</td>
<td>95% CI</td>
<td>Avg ± SD</td>
</tr>
<tr>
<td>Pelvis Anterior</td>
<td>26.60 ± 25.25</td>
<td>9.64 ± 11.98</td>
<td>13.01 ± 11.98</td>
</tr>
<tr>
<td>Pelvis Obliquity Initial</td>
<td>3.76 ± 3.65</td>
<td>0.63 ± 0.97</td>
<td>2.62 ± 2.97</td>
</tr>
<tr>
<td>Pelvis Rotation Initial</td>
<td>1.50 ± 1.45</td>
<td>0.27 ± 0.38</td>
<td>1.50 ± 1.45</td>
</tr>
<tr>
<td>Trunk Flexion Initial</td>
<td>3.76 ± 3.65</td>
<td>0.63 ± 0.97</td>
<td>2.62 ± 2.97</td>
</tr>
<tr>
<td>Hip Flexion Initial</td>
<td>3.76 ± 3.65</td>
<td>0.63 ± 0.97</td>
<td>2.62 ± 2.97</td>
</tr>
<tr>
<td>Pelvis Anterior</td>
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<td>2.62 ± 2.97</td>
</tr>
<tr>
<td>Hip Flexion Initial</td>
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<td>2.62 ± 2.97</td>
</tr>
<tr>
<td>Hip Flexion Initial</td>
<td>3.76 ± 3.65</td>
<td>0.63 ± 0.97</td>
<td>2.62 ± 2.97</td>
</tr>
</tbody>
</table>

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Several significant gender main effects were observed during the 1m lifting. Females produced a greater pelvis anterior tilt angle at final position ($p = 0.006$, $\eta_p^2 = 0.114$), a reduced trunk flexion angle at initial position ($p = 0.001$, $\eta_p^2 = 0.333$), reduced trunk side flexion angle at final position ($p = 0.002$, $\eta_p^2 = 0.139$) and reduced trunk flexion angle at final position ($p = 0.001$, $\eta_p^2 = 0.202$), accompanied by a greater knee abduction angle at initial ($p = 0.001$, $\eta_p^2 = 0.202$) and final position ($p = 0.004$, $\eta_p^2 = 0.127$) in symmetric lifting (Table 3).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Males</th>
<th>Females</th>
<th>Males</th>
<th>Females</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis Anterior</td>
<td>±10.07*</td>
<td>±13.76*</td>
<td>±10.07*</td>
<td>±13.95*</td>
<td>±9.93*</td>
<td>±13.85*</td>
</tr>
</tbody>
</table>
| Haddas, James Yang, Philip Sizer
| Pelvis Obliquity Initial | ±4.28   | ±5.55   | ±3.33   | ±4.44   | ±2.31   | ±4.02   |
| Pelvis Rotation Initial  | ±0.73   | ±1.92   | ±0.26   | ±1.65   | ±0.41   | ±1.48   |
| Trunk Flexion            | ±6.21*  | ±11.66* | ±6.28*  | ±11.72* | ±6.72*  | ±12.10* |
| Hip Flexion Initial      | ±5.89   | ±7.76   | ±5.47   | ±7.31   | ±5.48   | ±7.30   |
| Trunk Rotation Initial   | ±6.52   | ±11.71* | ±6.76   | ±13.12* | ±6.52   | ±13.83* |
| Hip Adduction            | ±16.69* | ±23.39* | ±18.41* | ±27.52* | ±21.24* | ±37.36* |
| Pelvis Anterior          | ±21.53* | ±39.02* | ±35.27* | ±43.65* | ±38.26* | ±47.98* |
| Hip Rotation             | ±57.32* | ±53.23* | ±59.91* | ±62.73* | ±58.68* | ±61.65* |
| Kneeh Flexion            | ±12.09* | ±14.80* | ±12.18* | ±17.51* | ±16.47* | ±22.36* |
| Kneeh Adduction          | ±12.75* | ±17.37* | ±17.47* | ±21.59* | ±16.47* | ±22.36* |
| Pelvis Anterior          | ±31.45* | ±17.12* | ±26.96* | ±23.34* | ±31.49* | ±44.34* |
| Tilt Final               | ±4.95*  | ±12.17* | ±4.78*  | ±9.20*  | ±4.39*  | ±8.86* |
| Pelvis Obliquity Final   | ±2.02   | ±1.81   | ±0.62   | ±2.32   | ±0.45   | ±1.16   |
| Pelvis Rotation Final    | ±0.20   | ±0.18*  | ±0.32   | ±0.70   | ±0.32   | ±1.16   |
| Trunk Flexion            | ±3.09   | ±3.58   | ±0.57   | ±0.45   | ±0.57   | ±1.16   |
| Hip Flexion Final        | ±3.41   | ±0.57  | ±8.19   | ±0.57   | ±7.63   | ±8.08   |
| Hip Adduction            | ±4.69   | ±3.19   | ±5.68   | ±3.19   | ±5.68   | ±8.08   |
| Pelvis Anterior          | ±4.52   | ±6.99   | ±7.68   | ±8.69   | ±8.69   | ±11.73* |
| Haddas, James Yang, Philip Sizer
| Pelvis Obliquity Initial | ±5.18   | ±3.49   | ±0.46   | ±1.33   | ±0.89   | ±2.79   |
| Pelvis Rotation Initial  | ±4.99   | ±4.24   | ±0.53   | ±1.57   | ±1.00   | ±1.64   |
| Trunk Flexion            | ±16.47*| ±13.05*| ±21.88*| ±24.97*| ±23.72*| ±28.13*|
| Hip Flexion Final        | ±10.11*| ±13.73*| ±11.59*| ±14.47*| ±13.02*| ±16.99*|
| Hip Adduction            | ±5.92   | ±1.90   | ±4.77   | ±6.73   | ±5.00   | ±7.41   |
| Pelvis Anterior          | ±0.40   | ±0.55   | ±3.67   | ±3.96   | ±3.96   | ±4.46   |

**Table 3. Gender main effect variables**

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Additional significant findings for the females included a significantly greater pelvis obliquity angle at final position ($p = 0.001$, $\eta^2_p = 0.216$), reduced trunk flexion angle at initial position ($p = 0.001$, $\eta^2_p = 0.377$), reduced trunk side flexion angle at final position ($p = 0.006$, $\eta^2_p = 0.116$) and reduced trunk flexion angle at final position ($p = 0.001$, $\eta^2_p = 0.246$), accompanied by a greater hip abduction angle at initial position ($p = 0.003$, $\eta^2_p = 0.132$), and greater knee abduction angle at initial position ($p = 0.001$, $\eta^2_p = 0.160$) in asymmetric lifting when lifting to the right. Females presented a greater pelvic rotation at final position ($p = 0.002$, $\eta^2_p = 0.147$), reduced trunk flexion angle at initial position ($p = 0.001$, $\eta^2_p = 0.315$), reduced trunk flexion angle at final position ($p = 0.001$, $\eta^2_p = 0.261$),
greater hip abduction angle at initial position ($p = 0.002, \eta^2_p = 0.140$), and greater knee abduction angle at initial position ($p = 0.001, \eta^2_p = 0.247$), accompanied by greater IO muscle activity at final position ($p = 0.010, \eta^2_p = 0.189$), and greater EO muscle activity at final position ($p = 0.015, \eta^2_p = 0.171$) in asymmetric lifting when lifting to the left.

Discussion

Our findings support that gender and the presence of existing rLBP influence lifting style. The female's differences in lifting response, coupled with their disproportionate decrease in lifting performance when compared to male counterparts, implies increased vulnerability to injury and subsequent clinical consequences. The result demonstrated that females engage in different lifting responses versus males, where the presence of rLBP appeared to amplify selected differences. It is important to identify, modify and adapt to these differences as a segue to improving lifting performance, reducing injury risk and potentially avoiding consequences of lifting in the presence of rLBP, especially in the female population.

Two significant interactions emerged from our findings. First, we observed a significant interaction between gender and group in Multifidus activity at the initial position during symmetrical lifting (Figure 2). Females with rLBP used their Multifidus to a great extent versus males, while healthy females used their Multifidus less than healthy males. This could indicate increased muscle use in attempt to stabilize the segments and to decrease trunk flexion, as evidenced by females using approximately 15 degrees less trunk flexion than males overall. (Kavcic et al. 2004; Moseley et al. 2002; Ward et al. 2009)

![Knee Rotation Interaction Gender X Group](image)

**Figure 3.** Significant two-way interaction effect between gender and group for knee rotation angle at final position in asymmetric lifting

Females with rLBP presented with less knee rotation versus their male counterparts in the final position of asymmetrical lifting, while healthy females presented more knee rotation versus healthy males (Figure 3). Upon further examination, one can note that rLBP did not appear to have a significant influence on knee rotation in male...
subjects during this asymmetric lift. This suggests that rLBP exerts a notable influence on this variable in females. This appears to be consistent with the females’ observed increase in the use of knee abduction, where they moved more in the frontal versus transverse planes, as well as increased rotation at the pelvis during the same movement. These interactions reflect the females choosing a different total lifting style in the entire lower extremity and trunk, especially when troubled with rLBP.

Our significant gender main effects further support the females’ choice to utilize a different lifting style. During the symmetrical lifting task, we observed females demonstrated less trunk flexion angle at initial position accompanied by increased pelvic obliquity and less trunk flexion angle at final position. In addition, we observed significantly more knee abduction during the initial and final lifting position. All of our findings may reflect differences in trunk and lower extremity control capabilities in the females during a lifting task. Two studies by Marras et al. (Marras et al. 2002; Marras et al. 2003) reported significantly different loading responses during a sagittal lifting task. These differences appeared to be related to compensations at the pelvis for the female subjects, possibly related to lower trunk strength capacity. Moreover, the investigators reported that the female subjects were closer to their expected lifting tolerances versus the males. These findings suggested that females are not simply proportionally scaled down versions of males, but rather exhibit different control strategies in response to the lifting load and demand.

Damecour et al. (2012) found that postural kinematics, trunk extensor muscle activity and subjective rating of both comfort and effort changed with differences in how their subjects executed during asymmetric two-handed reach in standing. Our significant gender main effects exhibited during the asymmetrical lifting tasks further support the females’ choice to utilize a different lifting style. In a similar fashion to the symmetrical lifting task, we observed females demonstrated less trunk flexion angle at initial position accompanied by increased pelvic rotation and less trunk flexion angle at final position when the task was completed to both the right and left sides. Accompanying these trunk movement response findings were significantly increased hip abduction during the initial position and increased knee abduction at the final position when the task was completed to both the right and left sides. Finally, the same tasks produced significant increases in the females’ IO and EO muscle activation versus the males in the final position. This again may suggest the females are functioning at a level closer to their maximum trunk capacity as earlier described, thus requiring increased muscle response.

Three group main effects were observed during the asymmetrical lifting task. We observed a significant group main effect for pelvis rotation at final position during right asymmetrical lifting, where the rLBP subjects demonstrated greater right pelvis rotation versus healthy subjects. In addition, we observed a significant group main effect for right hip adduction during the same task, where the rLBP subjects demonstrated greater right hip adduction versus healthy subjects. These finding work together; as the pelvis rotates right over fixed lower extremities, the right hip naturally adducts. Finally, we observed a main group effect for right EO activity during left asymmetrical lifting, where subjects with rLBP produced less EO muscle activity versus healthy subjects.

These group main effects suggest that the subjects with rLBP appear to demonstrate greater pelvis and hip movement and possible reduced dynamic stability during asymmetrical lifting, in contrast to using proximal stability and more distal movement and control. Other investigators have demonstrated increased unwanted pelvic movement during different functional strategies. (Scholtes et al. 2009) found that people with rLBP demonstrated increased maximal lumbopelvic rotation angle and earlier lumbopelvic rotation initiation versus healthy subjects during knee flexion and hip lateral rotation in a prone position. Similarly, Luomajoki et al. (2007, 2008) observed excessive, maladaptive lumbopelvic control during selected movement control tests in subjects with rLBP.
Maladaptive movement patterns in the lumbopelvic region appear to correspond with the incidence and persistence of rLBP (Scholtes et al. 2009; Van Dillen et al. 2003). Evidence has been steadily growing that persistent rLBP disorders do exist where maladaptive movement and motor control impairments in the lumbopelvic region appear to result in ongoing abnormal tissue loading and mechanically provoked pain (Burnett et al. 2004; Dankaerts et al. 2006; O’Sullivan 2005; Solomonow et al. 2003). These findings reflect a change in lumbopelvic control strategy that is similar to the findings in our study.

Due to our conservative alpha correction, several interactions and main effects were not significant but were below alpha level of 0.05. These findings may suggest changes in control strategies during lifting for females and individuals with rLBP. While we cannot draw definitive conclusions, the following variables are worth further investigation in the future. First, we observed the following two-way interactions between group and gender: pelvis rotation angle at final position ($p = 0.036$, $\eta^2_p = 0.068$), and MG activity at final position ($p = 0.023$, $\eta^2_p = 0.152$) in symmetric lifting; knee rotation angle at final position ($p = 0.048$, $\eta^2_p = 0.061$ right), knee rotation angle at initial position ($p = 0.011$, $\eta^2_p = 0.098$ left), Mf muscle activity at initial position ($p = 0.019$, $\eta^2_p = 0.161$), and ES muscle activity at final position ($p = 0.047$, $\eta^2_p = 0.118$) in asymmetric lifting.

Similarly, several group main effects merit additional investigation: ST activity at initial position ($p = 0.036$, $\eta^2_p = 0.130$) in symmetric lifting; and hip rotation angle at initial position ($p = 0.029$, $\eta^2_p = 0.073$), hip abduction angle at final position ($p = 0.013$, $\eta^2_p = 0.093$) in the right side, pelvis rotation angle at final position ($p = 0.010$, $\eta^2_p = 0.100$), EO muscle activity at initial position ($p = 0.025$, $\eta^2_p = 0.148$), IO muscle activity at initial position ($p = 0.033$, $\eta^2_p = 0.134$) and ST activity at final position ($p = 0.036$, $\eta^2_p = 0.130$) in the asymmetric lifting (Table 2).

Several gender main effects suggest future additional investigation: pelvis rotation angle at final position ($p = 0.032$, $\eta^2_p = 0.071$) in symmetric lifting; and pelvis rotation angle at final position ($p = 0.014$, $\eta^2_p = 0.092$ right), trunk side flexion angle at initial position ($p = 0.029$, $\eta^2_p = 0.074$), knee abduction angle at final position ($p = 0.024$, $\eta^2_p = 0.078$), and EO muscle activity at initial position ($p = 0.015$, $\eta^2_p = 0.171$) in asymmetric lifting (Table 3).

Limitations

Subjects in our study were not guided on lifting technique and the subject’s box weight was determined by their maximum psychophysically acceptable weight. We limited our subject to lifting to a 1m height, with the aim to control for external validity. Our analysis focuses only on the subject’s right side, thus assuming symmetry between sides. Additionally, we acknowledge limitations associated with use of a marker set that included skin movement, anthropometric model, system tracking error and data smoothing procedure error.

Conclusions

Females and individuals with rLBP appear to use different lifting styles that emphasize movement at the pelvis accompanied by poor kinematic control features at the hip, trunk and knee. While we did not observe changes in muscle coordination across the lower extremities, we did observe changes in core muscle control at the trunk (IO, EO and Mf). These findings exhibit the influence of gender and rLBP on trunk control, which may relate to the incidence and persistence of rLBP. Clinicians should be mindful of these changes when developing prevention and rehabilitation programs aimed at improving trunk control in preparation for lifting tasks during domestic and occupational activities. Future research should examine the influence of sensorimotor and functional training on these parameters in both normal individuals and those with rLBP for the purposes of injury prevention and rehabilitation.
References


POST-TRANSPLANT METABOLIC SYNDROME (PTMS) 
AFTER LIVER TRANSPLANTATION — REVIEW OF THE LITERATURE

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2 Faculty of Physical Culture and Health Promotion, University of Szczecin, Poland
A Study Design; B Data Collection; C Statistical Analysis; D Manuscript Preparation

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Abstract. Liver transplant provides a definitive therapeutic measure for patients with chronic and acute liver diseases. Apart from the improvement of overall health, an organ transplant entails several metabolic complications. They are multi-agent and depend, among others, on the function of organ being transplanted, adverse effects of immunosuppression being applied, organ complications induced by failure of the organ being transplanted, current treatment, concomitant diseases and consequences of the acute and chronic rejection processes. Improvements in surgical techniques, peritransplant intensive care, and immunosuppressive regimens have resulted in significant improvements in short-term survival. Focus has now shifted to address long-term outcomes of liver transplantation. Therefore, this paper presents the current review of literature referring to specificity of the prevalence of metabolic syndrome and its complications in patients after liver transplantation.

Key words: metabolic syndrome, liver transplantation

Introduction

Liver transplantation is a life-saving therapy for patients with end-stage liver disease, acute liver failure, and liver tumors. The liver is currently the second most commonly transplanted major organ after the kidneys. Improvements in surgical techniques, peritransplant intensive care, and immunosuppressive regimens have resulted in significant improvements in short-term survival. Focus has now shifted to address long-term outcomes of liver transplantation.

Cardiovascular events

The liver transplant technique advance allows to treat older and higher risk patients with orthotopic liver transplantation (OLT) with good outcomes. Unfortunately, excessive weight gain, hypertension, hyperlipidemia, and diabetes are frequently observed in transplanted patients. Metabolic syndrome and its individual components
are increasingly being identified and contributing to cardiovascular complications, and late morbidity and mortality. Cardiovascular (CV) complications after OLT are the leading cause of non-graft-related deaths of recipients (Pruthi et al. 2001). Recently published meta-analysis of observational studies by Madhwal et al. showed that the 10-year risk of developing CV complications among patients after OLT was 13.6%, with 64% greater risk of experiencing them than control group. Among OLT recipients, those with metabolic syndrome were approximately 4 time more likely to have a CV event, without any significant increase in all-causes mortality (Madhwal et al. 2012). This 10-year risk of developing a cardiovascular event is consistent with a Framingham moderate- to high-risk category (Grundy et al. 1998), with indication for therapeutic lifestyle changes, although there are no practice guidelines addressing these goals. The metabolic syndrome is also common after kidney transplantation (Faenza et al. 2007) with poor outcomes and reduced graft survival. Multivariate analysis of CV risk factors after OLT showed that independent predictors of CV events were older age at transplantation, male gender, posttransplant diabetes mellitus and arterial hypertension, as well as mycophenolate mofetil (MMF). However, it is important to notice that MMF was used in this study as an adjuvant medication, and this association was indirect, related to an underlying renal insufficiency, caused by calcineurin inhibitors (cyclosporine and tacrolimus, CNI). Concomitant renal dysfunction is well established risk factor of CV events (Balamuthusamy et al. 2008). The cumulative risk of CV event at 5-year was 13.5%, and approximately 10% of patients might expect 1 or more CV events in Albeldawi et al.study. Patients with posttransplant hypertension and diabetes are twice as likely to experience CV event (Albeldawi et al. 2012).

**Diabetes mellitus**

Detection and management of posttransplant diabetes mellitus should be crucial parts of post-OLT care, because of its impact on graft function/outcome and cardiovascular disease morbidity and mortality. Diabetes is among the main risk factors for coronary heart disease, cerebrovascular disease, and peripheral occlusive arterial disease in transplant recipients. The mean reported incidence of posttransplant diabetes varying between 7% and 30%, and the predictors included a family history of diabetes, age >45 years, glucose intolerance prior to OLT, central obesity, metabolic syndrome, use of corticosteroid over a long period, use of tacrolimus, and hepatitis C (Pageaux et al. 2004). The prevalence of diabetes, hypertension and hyperlipidemia increased steadily from the time of transplant to 7 years after OLT, and the estimated risk for all-cause mortality, and mortality secondary to CV events, infections with multiorgan failure and allograft failure increased for each additional year of diabetes mellitus in Parekh et al. study (Parekh et al. 2012). The study of Hanouneh et al. showed that in the setting of recurrent hepatitis C after liver transplantation, diabetes mellitus and metabolic syndrome were associated with progression of graft fibrosis by univariable analysis, and metabolic syndrome with hyperinsulinemia was independently associated with progression of fibrosis beyond 1 year after OLT in multivariable analysis (Hanouneh et al. 2008). The management of diabetes in liver transplant recipients is not substantially different from its management in nontransplant patients, except that steroid reduction or withdrawal and minimizing doses of calcineurin inhibitor are beneficial (Reuben 2001).

**Hyperlipidemia**

After liver transplantation in adults, between 16% and 43% of recipients have increased plasma cholesterol levels and about 40% have hypertriglyceridemia. The cause of hyperlipidemia is multifactorial. Calcineurin inhibitors are associated with hypertension, hyperglycemia, and dyslipidemia, via increasing oxidative stress and lipid peroxidation.
Mammalian target of rapamycin (mTOR) inhibitors (i.e. sirolimus and everolimus), a non-nephrotoxic drugs, can also contribute independently to dyslipidemia (Hakeam et al. 2008). Hypercholesterolemia and hypertriglyceridemia secondary to sirolimus therapy are independent from concomitant tacrolimus use. Corticosteroids enhance appetite and food intake contributing to obesity, enhance hepatic secretion of very low-density lipoprotein and its conversion to low-density lipoprotein, and cause diabetes – all of which promote hyperlipidemia. Mycophenolate mofetil (MMF), as well as rarely used now azathioprine, are free from this side-effect.

**Metabolic syndrome**

The rate of metabolic syndrome in liver transplant recipients is more than twice that reported for the general population. 2/3 of grafted patients will develop metabolic syndrome in 5 years after liver transplantation, and 10-year risk of cardiovascular event in such a patients is 13.6% (Madhwal et al. 2012). Metabolic syndrome appeared to be associated with an increased risk of major vascular events in liver transplant population in Laryea et al. study, affecting 58% of analyzed patients (Laryea et al. 2007). Posttransplant metabolic syndrome (PTMS) was associated with cardiovascular morbidity but not mortality, and it might be predicted by pre-transplantation conditions, i.e. age, pretransplant nonalcoholic fatty liver disease, body mass index (BMI), diabetes mellitus and high triglycerides (Laish et al. 2011). Pretransplant hepatitis C virus infection was also associated with PTMS, because of its relationship to diabetes or insulin resistance (Laish et al. 2011). The rate of metabolic syndrome in liver transplant recipients was more than twice that reported for the general population in this study of Laish et al., however, cardiovascular mortality was lower than in the others papers (Laish et al. 2011). Johnston et al. found that the relative risk of death from cardiovascular disease was 2.56 in transplant recipients relative to an age-matched non-transplant population, and liver grafted patients had 64% higher risk of CV events than control group. Among all transplanted patients, those with PTMS had 4-fold higher risk of this complication (Johnston et al. 2002). As metabolic syndrome is associated with increased risk for major vascular complications, its definition after liver transplantation is based on The US National Cholesterol Education Program Adult Treatment Panel III (2001). The diagnosis requires at least three of the following:

- Central obesity: waist circumference ≥102 cm (male), ≥ 88 cm (female),
- Dyslipidemia: Triglycerides (TG) ≥1.7 mmol/L (150 mg/dl),
- Dyslipidemia: HDL-Cholesterol <40 mg/dL (<1 mmol/L) in men, <50 mg/dL (<1.3 mmol/L) in women,
- Blood pressure ≥130/85 mmHg (or treated for hypertension),
- Fasting plasma glucose ≥5.6 mmol/L (100 mg/dl) (NCEP 2001).

Even 44.5% [16] to 58% (Hanouneh et al. 2008) transplant recipients might be affected with PTMS, and patients with metabolic syndrome had a significantly higher average age, BMI post-OLT, fasting glucose, high-density lipoprotein levels, and serum triglycerides (Laryea et al. 2007). The novel study of Sprinzl et al. showed that de novo metabolic syndrome affected 32.9% of analyzed population within 2 years after OLT (Sprinzl et al. 2013). The component of PTMS, i.e. hypertension, hyperlipidemia, high glucose, enlarged waist circumference and insulin resistance was seen in 53%, 51%, 37%, 32% and 41% of patients, respectively. The prevalence of metabolic syndrome after liver transplantation was found to be significantly higher than that estimated in the general population and PTMS appeared to be associated with an increased risk of major vascular events after OLT (Laryea et al. 2007). The rates of hypertension, dyslipidemia, and diabetes were also more common in pediatric liver transplant recipients than in general children population, and these conditions might lead to significant long-term
morbidity (Rothbaum et al. 2012). Metabolic syndrome was also an important risk factor for graft failure, especially secondary to hepatitis C recurrence, malignancy, infections and renal failure in liver transplant recipients (Charlton 2009). On the other hand, patients who developed chronic kidney disease after OLT, were a 4-fold increased risk of death (Tinti et al. 2012), and hypertension, and dyslipidemia were associated with a faster rate of decline in renal function after OLT (Leithead et al. 2012).

Strategies to reduce the development of PTMS after liver transplantation should include lifestyle modifications involving alterations in diet and increased physical activity. Mediterranean diet rich in omega-3 fatty acids, fruit, vegetables, and dietary fiber, is recommended. Additional measures that may be potentially beneficial include also the optimal control of blood glucose, and the use of tacrolimus instead of cyclosporine (Pagadala et al. 2009).

Weight

Disorders related to PTMS are frequent in patients after liver transplantation, and are related to both pre-OLT conditions and to weight gain. The pretransplant risk factors include a higher age at OLT, male gender, a history of smoking, the pretransplant BMI, pretransplant diabetes, the etiology of the underlying disease (hepatitis C, NAFLD/cryptogenic cirrhosis, alcohol), as well as an increased donor BMI, and marital status (Pagadala et al. 2009). Weight control, due to its association with insulin resistance, seems to be mandatory after OLT to prevent risk factors of premature atherosclerosis (Bianchi et al. 2008). In the study of Wawrzynowicz-Syczewska et al. mean weight gain and BMI change were the highest within the first six months after OLTx and men gained more weight than women, especially in the first half-year after OLTx. The only clear predictive factor of overweight and obesity was the baseline weight; dietary mistakes and lack of physical activity might play a major role in the weight increase after OLT (Wawrzynowicz-Syczewska et al. 2009). The impact of metabolic changes on PTMS development after liver transplantation is showed in Table 1.

Table 1. The metabolic changes in PTMS development

<table>
<thead>
<tr>
<th>Feature</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatic steatosis</td>
<td>Increased absolute hepatic free fatty acids (FFA) uptake, increased esterification of hepatic FFA to from triglycerides (TG), increased FFA synthesis from cytosolic substrates</td>
</tr>
<tr>
<td>Decreased apoB-100 synthesis</td>
<td>Decreased export of FFA and TG from the liver</td>
</tr>
<tr>
<td>Decreased hydrolysis of TG</td>
<td>Diminished hepatic TG and FFA export</td>
</tr>
<tr>
<td>Increased oxidative stress</td>
<td>Increased beta oxidation of mitochondrial long-chain fatty acids</td>
</tr>
<tr>
<td>Mitochondrial dysfunction</td>
<td></td>
</tr>
<tr>
<td>Increased leptin and decreased adiponectin circulation</td>
<td></td>
</tr>
<tr>
<td>Tumor necrosis factor alpha</td>
<td>Down-regulation of insulin-induced phosphorylation of insulin-receptor substrate-1</td>
</tr>
<tr>
<td>Genetic polymorphism of adiponutrin or patatin-like phospholipase domain containing protein 3 (PNPLA3)</td>
<td>Reduction of the expression of the insulin-dependent glucose-transport molecule Glut 4</td>
</tr>
</tbody>
</table>

Arterial hypertension

Arterial hypertension is one of the most frequent complications of solid organ transplantation; about 70–90% of transplanted patients have high blood pressure or require antihypertensive therapy. Hypertension was observed during the first weeks to months in 50% to 75% of the liver transplant recipients, and more than 50% of them
Abnormal blood pressure is a potent non-immunological risk factor directly related to patient and graft survival. In liver and heart transplantation, hypertension is mainly due to impaired kidney function, profound by the use of CNI (Textor et al. 2000). The number of patients with hypertension rises as well as the severity of the disease with time after OLT. Within 10 years of follow up, the percentage of all OLT recipients on a double or triple antihypertensive drug regimen almost double from 12% to 23% (Guckelberger 2009). Steroids medication should be minimized or completely withdrawn, and the conversion of a calcineurin-based regimen to mycophenolate or sirolimus-based immunosuppression may be considered (Mells and Neuberger 2009). However, only MMF is a drug free of metabolic side effects, but monotherapy with MMF is not recommended due to increased risk of graft rejection.

**Nonalcoholic fatty liver disease**

Nonalcoholic fatty liver disease (NAFLD) is a common form of chronic liver disease, progressing to advanced fibrosis in about 30% of patients. According to the 2011 United Network for Organ Sharing registry database for liver transplant recipients, NAFLD is the fourth most common cause of OLT, due to rising prevalence of obesity and diabetes mellitus. NAFLD in the posttransplant setting may represent either recurrent or the novo disease (Lim et al. 2007; Seo et al. 2007). De novo fatty liver occurs in ~20%, and de novo steatohepatitis in ~10%. However, studies providing detailed histological criteria, have found that the recurrent steatosis is often mild (<50%) and usually develops within a period of 6 months, whereas >50% steatosis is seen after 1 year after OLT. Steatohepatitis after OLT is almost always proceed by steatosis, however, progression is seen in minority of patients (Contos et al. 2001). The rate of steatosis and steatohepatitis were 20% and 32%, respectively, and fibrosis developed in 2 of 5 patients with posttransplant nonalcoholic steatohepatitis (NASH), and it was not seen in patients without posttransplant steatosis (Ong et al. 2001). Patil and Yerian in 2012 showed that NAFLD recurrence was common, advanced fibrosis was rare, and graft and patients survival rates were comparable to the other indication to OLT (Patil and Yerian 2012). However, NAFLD patients are in increased risk for postoperative cardiovascular events, independently of traditional cardiac risk factors (Vanwagner et al. 2012). Treatment should be directed at managing obesity and complication of metabolic syndrome, with steroid minimization in immunosuppression (Charlton 2009). However, it is important to notice that recurrent NAFLD and NASH can occur despite normal liver enzymes, and features of metabolic syndrome, as associated with disease recurrence, should point to such a possibility (Malik et al. 2009).

The frequencies of PTMS components are summarized in Table 2.

### Table 2. The frequency of metabolic syndrome and its feature before and after OLT (%)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Frequency before OLT</th>
<th>Frequency after OLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes mellitus</td>
<td>15</td>
<td>30–40</td>
</tr>
<tr>
<td>Arterial hypertension</td>
<td>15</td>
<td>60–70</td>
</tr>
<tr>
<td>Obesity</td>
<td>*</td>
<td>~60</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>unusual</td>
<td>50–70</td>
</tr>
<tr>
<td>HTG</td>
<td>unusual</td>
<td>44–58</td>
</tr>
<tr>
<td>Frank steatohepatitis</td>
<td>*</td>
<td>60</td>
</tr>
</tbody>
</table>

* No clear data available.


**Immunosuppressive therapy**

Immunosuppressive agents may contribute to increased CV complications risk, e.g. cyclosporine is associated with new-onset hypertension and dyslipidemia, tacrolimus leads to posttransplant diabetes mellitus and, to a lesser extent, to hypertension and dyslipidemia, and sirolimus accelerates hypercholesterolemia and hypertriglyceridemia. Mycophenolate mofetil in general has a better safety profile with respect to metabolic risk, whereas corticosteroids induce hypertension, insulin resistance, hypercholesterolemia and weight gain (Miller 2002). Calcineurin inhibitors induce hypertension causing changes in vascular tone, particularly in the kidney, leading to diminished glomerular filtration and enhanced sodium retention. Disturbances of endothelial function stimulate of endothelin and impair nitric oxide synthesis. Increased vasoconstriction leads to arterial hypertension, with its complication, including disturbances in circadiac rhythm, left ventricular hypertrophy, and acceleration of atherosclerotic and renal injury (Textor et al. 2000; Hryniewiecka et al. 2011). These give the possibility for early intervention with modification of immunosuppressive regimens and early initiation of statins, as showed by Soveri et al. and Charlton (Charlton 2009; Soveri et al. 2009). Additional measures that may potentially beneficial include also the optimal control of blood glucose, and the use of tacrolimus instead of cyclosporine (Pagadala et al. 2009). Cyclosporine increases circulation levels of low-density lipoprotein, and tacrolimus appears less likely to cause hypercholesterolemia (Reuben 2001). Data regarding the impact of immunosuppressive agents on metabolic syndrome are summarized in Table 3.

| Table 3. The impact of commonly used medication after OLT on PTMS development |
|---------------------------------|---------------------------------|
| **Agent**                       | **Effect**                      |
| Calcineurin inhibitors (cyclosporine, tacrolimus) | mitochondrial inhibition         |
|                                 | impaired beta cell insulin production |
|                                 | dyslipidaemia                     |
|                                 | hypertension                      |
|                                 | renal insufficiency               |
| Corticosteroids                 | insulin resistance                |
|                                 | hypertension                      |
|                                 | dyslipidaemia                     |
| mTOR inhibitors (sirolimus)     | dyslipidaemia                     |

**Physical activity**

One of the important elements of positive health preservation is to take up physical activity, being also a preventive measure with respect to many diseases: ischaemic heart disease, arterial hypertension, diabetes mellitus, lipid disorders, osteoporosis, overweight or obesity. Physical activity is a useful prophylactic tool of both mental and physical health, reducing number of cardiovascular events, risk of arterial hypertension, diabetes mellitus, dyslipidemia, osteoporosis and weight gain. However, the number of studies regarding physical activity and metabolic syndrome is scanty. Reduced aerobic capacity (decreased peak oxygen consumption \( [\text{VO}_2]\) during symptom-limited cardiopulmonary exercise testing) is frequently present in cirrhosis and peak \( \text{VO}_2 \) during cardiopulmonary exercise testing may predict short-term outcome after hepatic transplantation. The study of Epstein et al. showed that 6 patients (10.2% of analyzed cohort), who died within 100 days of liver transplantation, had reduced aerobic capacity (peak \( \text{VO}_2 \) <60% predicted and \( \text{VO}_2 \) at anaerobic threshold \( [\text{VO}_2\text{-AT}] \) <50% predicted
peak VO$_2$) compared to survivors. Using a multiple logistic regression model controlling for duration and severity of liver disease and time to transplantation, reduced aerobic capacity was independently associated with 100-day mortality, and reduced aerobic capacity during cardiopulmonary exercise testing was associated with decreased short-term survival after hepatic transplantation (Epstein et al. 2004).

Exercise training resulted in significant improvements on the physical condition of liver transplanted Familial Amyloidotic Polyneuropathy (FAP) patients in Tomas et al. study (Tomas et al. 2013). The exercise training program improved body composition, isometric quadriceps muscle strength, functional capacity, fatigue, and levels of physical activity before and after a 6-month period of combined exercise training in FAP female patient (49 years of age; body mass index = 18.8 kg/m$^2$), who underwent a liver transplantation 133 months before assessment, with improvement of quality of life (Tomas et al. 2011). On the other hand, pediatric kidney and liver transplant recipients have significantly reduced cardiorespiratory fitness (CRF), muscle strength, and physical activity and approximately 44% of both groups had percent fat greater than the upper criterion value of the Healthy Fitness Zone (HFZ) (Krasnoff et al. 2006).

**Conclusion**

The survival rates after liver transplantation have improved in recent decades, but cardiovascular disease has become a source of major concern in long term follow up. The rate of metabolic syndrome in liver transplant recipient is more than twice that reported for the general population, and significant independent predictors of PTMS are age, pretransplant nonalcoholic fatty liver disease, BMI, diabetes mellitus and triglycerides. PTMS is associated with the higher risk of CV events. The number of cardiovascular events correlate well with the increased prevalence of cardiovascular risk factors. Up to 20% of all deaths of long-term survivors after OLT have been attributed to cardiovascular disease, giving the reason for PTMS screening and management. Lifestyle changes, e.g. diet, weight control, treatment of comorbidities and regularly taken up physical activity is one of the effective types of metabolic syndrome treatment.

**References**


Post-transplant Metabolic Syndrome (PTMS) after Liver Transplantation — Review of the Literature


GENDER DIFFERENCES IN LIMB AND JOINT STIFFNESS DURING THE FENCING LUNGE

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Abstract. The aim of the current investigation was to examine gender differences in limb and joint stiffness characteristics during the fencing lunge. Ten male and ten female fencers completed simulated lunge movements. Lower limb kinematics were collected using an eight camera optoelectric motion capture system which operated at 250 Hz. Measures of limb and joint stiffness were calculated as a function of limb length and joint moments divided by the extent of limb and joint excursion. Gender differences in limb joint stiffness parameters were examined statistically using independent samples t-tests. The results showed firstly that both limb (male = 64.22 ±19.12, female = 75.09 ±22.15 N.kg.m) and hip stiffness (male = 10.50 ±6.00, female = 25.89 ±15.01 Nm.kg.rad) were significantly greater in female fencers. In addition it was also demonstrated that knee moment (male = 1.64 ±0.23, female = 2.00 ±0.75 Nm.kg) was significantly larger in females. On the basis of these observations, the findings from the current investigation may provide further insight into the aetiology of the distinct injury patterns observed between genders in relation to fencing.

Key words: fencing, biomechanics, limb stiffness

Introduction

Epee fencing is a recognised Olympic discipline during which the athletes are required to make contact with their opponent with their sword (Sinclair et al. 2010). Clinical research investigating the prevalence of injury in both elite and recreational fencers has demonstrated that injuries and pain connected specifically to training/competition were apparent in 92.8% of all fencers (Harmer 2008). Importantly it was also shown that a high proportion of all injuries were experienced by the lower extremities (Harmer 2008). The repetitive high impact dynamic motions associated with fencing training and competition are considered to expose the lower extremity musculoskeletal structures to high levels of strain (Sinclair et al. 2010; Greenhalgh et al. 2013; Sinclair and Bottoms 2014). The lunge
movement in particular which is the foundation of the majority of offensive fencing motions repeatedly exposes fencers to potentially detrimental impact forces (Sinclair et al. 2010).

In clinical biomechanics literature the importance of lower limb stiffness is now becoming acknowledged (Butler et al. 2003), as researchers and clinicians attempt to achieve more knowledge of how the musculoskeletal system responds to applied loads and attain additional insight into the aetiology of chronic lower limb injuries. Limb stiffness calculated as a function of the vertical force that is applied to a body divided by the resultant deformation of the limb as a function of the applied load (McMahon and Cheng 1990). During dynamic movements the contact limb is represented using a spring mass system (Latash and Zatsiorsky 1993), during which the contact limb is symptomatic of a linear spring and the mass of the athletes body is representative of the overall point mass (McMahon and Cheng 1990). Clinically, higher limb stiffness has been linked to an increased risk from bone-related injuries whereas insufficient limb stiffness has also been linked to soft tissue injury (McMahon et al. 2012).

Fencing is undertaken by both male and female athletes, previous analyses have examined gender differences in the mechanics of the fencing lunge. Sinclair and Bottoms (2013) investigated the kinetics and lower body kinematics of the lunge movement as a function of gender. It was demonstrated that females exhibited significantly greater knee abduction and hip adduction of the lead limb. Sinclair and Bottoms (2015) examined differences between genders in patellofemoral forces between male and female fencers who performed the lunge movement. Their results showed that female fencers were associated with significantly greater patellofemoral kinetics than males. Sinclair and Bottoms (2014) explored gender differences in the load experienced by the Achilles tendon, it was demonstrated that males were associated with a significantly larger Achilles tendon loads than female fencers.

However, gender differences in limb and joint stiffness parameters during the fencing lunge have not yet been explored in biomechanical literature. Therefore the aim of the current investigation was to examine gender differences in limb and joint stiffness characteristics as a function of the lunge movement.

**Methods**

**Participants**

Ten male and ten female epee fencers volunteered to take part in the current investigation. All were injury free at the time of data collection and provided written informed consent in accordance with the declaration of Helsinki. Participants were active competitive epee fencers who engaged in training a minimum of 3 sessions per week and were all right handed. The mean characteristics of the participants were males; age 27.22 ±4.08 years, height 1.75 ±0.05 m and mass 74.31 ±6.05 kg and females; age 24.88 ±5.87 years, height 1.67 ±0.07 m and mass 63.52 ±4.66 kg. The procedure was approved by the University of Central Lancashire ethics committee.

**Procedure**

Participants completed 10 lunges during which they were required to hit a dummy with their weapon and then return to a starting point which was determined by each fencer prior to the commencement of data capture. This allowed the lunge distance to be maintained. The fencers were also required to contact a force platform (Kistler Instruments Ltd., Alton, Hampshire) embedded into the floor (Altrosports 6mm, Altro Ltd,) of the biomechanics laboratory with their right (lead) foot. The force platform sampled at 1000 Hz.
Kinematic information was obtained using an eight camera optoelectric motion capture system (Qualisys Medical AB, Goteburg, Sweden) using a capture frequency of 250 Hz. The current investigation utilized the calibrated anatomical systems technique (CAST) to quantify kinematic information (Cappozzo et al. 1995). To define the anatomical frame of pelvis, thigh, shank and foot retroreflective markers were positioned unilaterally to the medial and lateral malleoli, medial and lateral epicondyle of the femur and greater trochanter. Rigid technical tracking clusters were positioned on the shank and thigh segments. The tracking clusters comprised four retroreflective markers mounted to a thin sheath of lightweight carbon fibre with length to width ratios in accordance with Cappozzo et al. (1997). Static trials were obtained with participants in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking clusters, following which markers not required for tracking were removed.

Data processing

Retroreflective marker positions were identified using Qualisys Track Manager in and then exported as C3D files to Visual 3D (C-Motion, Germantown, MD, USA) for further analysis. Ground reaction force and retroreflective marker trajectories were filtered at 50 and 12 Hz using a low pass Butterworth 4th order zero-lag filter (Sinclair, 2014). Hip, knee and ankle joint kinematics were calculated using an XYZ sequence of rotations (where X represents sagittal plane; Y represents coronal plane and Z represents transverse plane rotations) (Sinclair et al. 2013). Newton-Euler inverse-dynamics were also adopted which allowed knee and ankle joint moments to be calculated. Kinetic/kinematic measures from the hip, knee and ankle extracted for statistical analysis were 1) joint angular excursion (representing the angular displacement from footstrike to peak angle) and 2) peak joint moment.

Limb stiffness was quantified using a mathematical spring-mass model (Blickhan 1989). Limb stiffness was calculated from the ratio of the peak vertical GRF to the compression of the limb spring. Limb compression was calculated as the change in thigh length from footstrike to minimum thigh length during the stance phase (Farley and Morgenroth 1999). The torsional stiffness of the hip, knee and ankle joints were obtained as a product of the ratio of the change in joint moment to joint angular excursion (Farley and Morgenroth 1999).

Statistical analyses

Means and standard deviations were calculated as a function of gender for each outcome measure. Gender differences in limb and joint stiffness parameters were examined using independent samples t-tests with significance accepted at the p≤0.05 level. Effect sizes for all significant observations were calculated using partial eta squared (pη²). All statistical procedures were conducted using SPSS v22.0 (IBM SPSS, Inc., Chicago, IL, USA).

Results

Table 1 presents the gender differences in limb and joint stiffness. The results indicate that limb and hip joint stiffness parameters were significantly influenced as a function of gender.

Joint kinetics and kinematics

The results show that peak hip moment was significantly greater (t(18) = 3.27, p < 0.05, pη² = 0.33) in female fencers in comparison to males (Table 1). The results also indicate that hip excursion was significantly larger.
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\((t_{18}) = 3.05, p < 0.05, \eta^2 = 0.27\) in male fencers (Table 1). Finally, peak knee moment was shown to be significantly \((t_{18}) = 3.11, p < 0.05, \eta^2 = 0.28\) greater in female fencers in comparison to males (Table 1).

Table 1. Limb and joint stiffness parameters as a function of gender

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>SD</th>
<th>Female</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRF (N.kg)</td>
<td>18.15</td>
<td>6.56</td>
<td>18.41</td>
<td>7.02</td>
</tr>
<tr>
<td>Limb compression (m)</td>
<td>0.30</td>
<td>0.07</td>
<td>0.28</td>
<td>0.09</td>
</tr>
<tr>
<td>Limb stiffness (N.kg.m)</td>
<td>64.22</td>
<td>19.12</td>
<td>75.09</td>
<td>22.15</td>
</tr>
<tr>
<td>Hip excursion (rad)</td>
<td>0.32</td>
<td>0.20</td>
<td>0.27</td>
<td>0.19</td>
</tr>
<tr>
<td>Hip moment (Nm.kg)</td>
<td>2.43</td>
<td>0.89</td>
<td>3.05</td>
<td>1.46</td>
</tr>
<tr>
<td>Hip stiffness (Nm.kg.rad)</td>
<td>10.50</td>
<td>6.00</td>
<td>25.89</td>
<td>15.01</td>
</tr>
<tr>
<td>Knee excursion (rad)</td>
<td>0.42</td>
<td>0.15</td>
<td>0.51</td>
<td>0.11</td>
</tr>
<tr>
<td>Knee moment (Nm.kg)</td>
<td>1.64</td>
<td>0.23</td>
<td>2.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Knee stiffness (Nm.kg.rad)</td>
<td>4.58</td>
<td>2.54</td>
<td>4.24</td>
<td>2.22</td>
</tr>
<tr>
<td>Ankle excursion (rad)</td>
<td>0.18</td>
<td>0.08</td>
<td>0.21</td>
<td>0.13</td>
</tr>
<tr>
<td>Ankle moment (Nm.kg)</td>
<td>0.97</td>
<td>0.33</td>
<td>1.25</td>
<td>0.55</td>
</tr>
<tr>
<td>Ankle stiffness (Nm.kg.rad)</td>
<td>7.88</td>
<td>6.70</td>
<td>7.93</td>
<td>4.35</td>
</tr>
</tbody>
</table>

* significant difference.

Spring mass parameters

Limb compression was found to be significantly larger \((t_{18}) = 3.14, p < 0.05, \eta^2 = 0.29\) in male fencers in relation to females (Table 1). Limb stiffness was therefore shown to be significantly larger \((t_{18}) = 3.22, p < 0.05, \eta^2 = 0.31\) in female fencers (Table 1). In addition hip stiffness was shown to be significantly larger in female fencers (Table 1).

Discussion

The current investigation aimed to determine whether there are gender differences in limb and joint when performing the lunge movement in fencing. To the authors’ knowledge this represents the first study to examine gender differences in limb stiffness parameters in fencing.

The first key observation from the current investigation is that female fencers were associated with increased limb stiffness in relation to males. This finding does not agree with those of Granata et al. (2001) who showed that females were associated with reduced limb stiffness in relation to males when performing a hopping task. It is proposed that this difference relates to the different functional demands of hopping tasks in comparison to the fencing lunge (Sinclair and Bottoms 2013). This finding relates principally to the significant increases in limb compression that were observed in females as the peak vertical GRF magnitude did not differ significantly between genders. This observation may have relevance clinically as increased levels of limb stiffness, such as those observed in female runners, have been linked to the aetiology of bony injuries (McMahon et al. 2012). In addition to this, the findings from this study also confirmed that hip joint stiffness was significantly larger in female fencers. This observation relates to the significant reduction in hip excursion and corresponding increase in hip moment noted in females. Given the similar joint stiffness parameters observed between genders at the knee and ankle joints at appears that hip stiffness is the key contributor to the differences in limb stiffness.
A number of studies have examined the relationship between limb stiffness and athletic performance (Bret et al. 2002; Farley and Gonzalez 1996; Heise and Martin 1998; Hobara et al. 2010). The extent of limb stiffness has been shown to be related to the utilization of the stretch-shortening cycle in dynamic movements (Brughelli and Cronin 2008). During the eccentric phase enhanced limb stiffness as a function of a reduction in limb compliance allows for maximum return of the stored energy during the concentric phase (Latash and Zatsiorsky 1993). This suggests that female fencers may be able to make more effective use of the stretch shorten cycle than males, indicating that they may be able to recover their position and progress onto the next attack more efficiently. Therefore whilst the increased limb stiffness observed in female may place them at increased risk from lower limb injury, it may also promote a corresponding increase in movement efficiency around the piste.

The increase in peak sagittal knee moment may also provide insight into the distinct injury patterns in females. Female athletes are at much greater risk of developing patellofemoral pain than age matched males (Wilson 2007). This finding concurs with the observations of Sinclair and Bottoms (2015), who demonstrated that both knee moment and patellofemoral loads were greater in female fencers. The knee joint moment profiles from the current study indicate that the load at the knee is larger in female fencers. Therefore, this finding re-enforces the conclusions from Sinclair and Bottoms (2015) as the consensus regarding the aetiology of patellofemoral pain is that symptoms are the function of excessive knee joint loading (Fulkerson and Arendt 2000).

In conclusion, although gender differences the mechanics of the fencing lunge have been examined extensively, the current knowledge regarding the effects of gender on limb and joint stiffness parameters is limited. The present investigation therefore adds to the current knowledge by providing a comprehensive comparative evaluation of the limb and joint stiffness characteristics of male and female fencers. On the basis that hip/ limb stiffness and knee moment were shown to be significantly greater in female fencers, the findings from the current investigation may provide further insight into the aetiology of the distinct injury patterns that have been noted between male and female athletes. Clinically the outcomes from the current investigation indicate that female fencers may be more susceptible to overuse injuries than males.

Acknowledgements

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ANALYSIS OF MATCH PERFORMANCE OF FULL-BACKS FROM SELECTED EUROPEAN SOCCER LEAGUES

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Abstract. The aim of the present study was the analysis of match activities of full-backs from selected European national soccer leagues. The study sample comprised 30 full-backs playing in the autumn round of the 2014/15 season from five European national top-tier leagues: English Premier League, Spanish Primera Division, German Bundesliga, Russian Priemjer Liga and Italian Serie A. The performance of full-backs (left-back and right-back) from each selected team was analyzed using a professional match analysis system OptaPro which tracks every possible type of ball touch and on the ball action in match covered by a rigid set of definitions. The data for analysis included the total number of passes, total number of crosses, and total number of ball touches performed by the full-backs in three zones of the pitch: attack, midfield and defense. The study results showed that the full-backs from the Spanish Primera Division executed the highest number of passes and crosses as well as ball touches in the attack zone. They also performed the lowest number of passes in the midfield and defense zones, in which the highest percentage of passes was achieved by the full-backs from the German league teams. The study indicates that in modern soccer defenders must possess a high level of offensive skills that can be necessary in the last stage of a team’s attack.

Key words: soccer, match performance, motor activity, kinematic analysis

Introduction

Rapid technological developments of the last years have made it possible to carry out accurate match analyses in various team sports. Advanced IT systems coupled with human intelligence are important research tools for examining multiple aspects of match-play. The Global Positioning System enables motor activity analysis of players in different playing positions, from different clubs or national leagues (Buchheit et al. 2010; Carling et al. 2008; Di Salvo et al. 2013). Differences in players’ motor activity during matches were found between playing positions (defenders, midfielders, and forwards) as well as between particular types of any of these positions, e.g.
full-backs or center backs, or center midfielders or side midfielders (Andrzejewski et al. 2012; Bradley et al. 2013; Carling et al. 2008). Although successful performance in soccer match-play requires superior levels of physical fitness to sustain a high work rate during matches, it is the technical and tactical skill level that usually separates successful soccer players and team performance during first division match play (Sforza et al. 1997).

Advanced match kinematic analysis systems allow for assessment of players’ motor activity as well as tracking all actions during match play. All soccer playing positions, including the full-backs, require from players versatile motor preparation with a particular emphasis on endurance and speed skills (Andrzejewski et al. 2014). During a match full-backs in top national European leagues cover a mean distance between 10,650 m and 10,814 m, 11,063 m in the UEFA Europa League, and up to 11,410 m in the UEFA Champions League (Andrzejewski et al. 2014; Dellal et al. 2010; Dellal et al. 2011, Di Salvo et al. 2007; Djaoui et al. 2014). Depending on an assumed range of intensity (>23 km/h) full-backs may also cover a sprinting distance up to 402 m during match play. In terms of match-play actions, the mean number of ball touches by full-backs is from 41 to 59 in a match, the number of accurate passes is from 78 to 81%, and the number of won one-on-one plays is from 54 to 56% (Stølen et al. 2005).

Differences between the motor activity profiles of players in various playing positions (Andrzejewski et al. 2012; Bradley et al. 2009) may indicate that similar differences may also occur in a quantitative analysis of match-play actions. Few authors have discussed the actions of full-backs during match play (Bradley et al. 2011; Carling 2010; Dellal et al. 2010; Lago-Peñas et al. 2011). In comparison with players in other positions in the French, Spanish and English leagues these authors noted that full-backs and center-backs lose the ball during a match significantly less often than players in other positions. Moreover, full-backs perform a significantly greater percentage of accurate passes than center-backs, and attain significantly shorter ball possession time than center-midfielders and forwards. This is related to the implementation of tactical tasks by players in these positions (Dellal et al. 2010; Dellal et al. 2011).

When analysing the physical performance of soccer players, the tactics of the game needs to be taken into account. The observed differences in physical demands for different playing positions may be partly explained by the different tactical roles involved in each position (Bradley et al. 2011). The positioning of players on the field and their offensive and defensive tasks are determined by, inter alia, the assumed team match formation (Bangsbo and Peterson 2000). In contemporary soccer there are various match formations which determine the motor activity profiles of players. In soccer the development of a team’s game strategy should account for players’ individual motor skills as well as technical and tactical skills (Carling 2011; Stølen et al. 2005). Studies have shown that the defenders in the 1-4-4-2 formation cover a significantly longer total distance than the defenders in the 1-4-5-1 and 1-4-3-3 match formations (Bradley et al. 2011). For the 1-4-4-2 formation the mean number of passes by full-backs in a match was 53, for the 1-4-3-3 formation it was 54, and for the 1-4-2-3-1 formation – 50. These differences were, however, statistically non-significant (Carling 2011).

The attainment of top sport results requires the knowledge about determinants of players’ performance, in particular, the playing position. The majority of studies of European soccer leagues have used various systems of match analysis, and this thwarts any attempts of objective comparison of the obtained results. The application of the same match analysis system on players from different national leagues will allow for objective and reliable use of match analysis data in sport theory and practice (Drust et al. 2007).
In modern soccer a high variability of full-backs’ activities can be observed. Depending on the assumed game strategy, the full-backs perform more defensive or offensive tasks. The aim of the present study was an analysis of match-play actions of soccer full-backs from selected European national leagues.

**Methods**

The study sample comprised 30 full-backs from five European national leagues, who played the most full-time games in the 2014/15 autumn season. The analyzed matches included 78 matches of the English Premier League, 82 of the Spanish Primera Division, 61 of the German Bundesliga, 66 of the Russian Priemjer Liga, and 66 of the Italian Serie A. Three top table teams from each league at the end of the autumn round, which used 4 defenders in match formation, were considered. If a top team played its matches in a match formation with a different number of defenders, the next consecutive team from the table with 4 defenders was taken into account. For example, in the Spanish and Italian leagues, the top teams after the autumn round had to be replaced in the study with teams from the 4th places. The performance of the left-back and the right-back from each team were analyzed. The research project has been approved by the local ethics committee.

The data for analysis was provided by an OptaPro match analysis system. Data from each match were taken in real time by three analysts (one for the home team, one for the away team, and one data verifier) and by an IT system tracking the players movements during match play (Liu et al. 2013). Every possible type of ball touch and on the ball action in match was covered by a rigid set of definitions which were recorded in the system. The analysts have undergone strict training to learn thoroughly about the definitions and to become familiar with the shortcut keys of different actions in the system before formally operating. During the training, an analyst is allowed to use “test servers” to imitate a live match situation (Liu et al. 2013; OPTA 2012). The analyzed match variables included the total number of passes, total number of crosses, and total number of ball touches in three zones of the playing field: attack, midfield and defense (each being a 1/3 of the pitch length). According to the OPTA system definitions (Bateman 2010; OPTA 2012) a pass was understood as an intentional played ball from one player to another; a cross as any ball played into the opposition team’s area from a wide position; and a touch as a sum of all events where a player touches the ball.

The statistical analysis was made with the use of Statistica 10.0. All variables were checked against normal distribution. The normality of distribution was checked with the Shapiro-Wilk test (p ≤ 0.05). Arithmetic means and standard deviations were calculated. To compare the data an ANOVA was used. To measure the statistical significance between the means Fisher’s least significant difference (LSD) test was applied. Three levels of statistical significance were set at p ≤ 0.05, p ≤ 0.01, and p ≤ 0.001.

**Results**

**Passes**

The data revealed statistically significant differences between the numbers of passes performed by full-backs from the Spanish and Russian national leagues (p ≤ 0.001), and from the Spanish and Italian leagues (p ≤ 0.01) (Table 1). No significant differences in the number of passes were noted between the other leagues.
Table 1. Total number of passes by full-backs from selected European national leagues and Fisher’s LSD test results

<table>
<thead>
<tr>
<th>National league</th>
<th>English</th>
<th>Spanish</th>
<th>German</th>
<th>Russian</th>
<th>Italian</th>
</tr>
</thead>
<tbody>
<tr>
<td>x ± SD</td>
<td>47.60 ±13.55</td>
<td>51.85 ±20.87</td>
<td>47.43 ±15.89</td>
<td>42.84 ±13.07</td>
<td>44.17 ±16.92</td>
</tr>
<tr>
<td>English</td>
<td>–</td>
<td>0.103</td>
<td>0.952</td>
<td>0.095</td>
<td>0.214</td>
</tr>
<tr>
<td>Spanish</td>
<td>0.103</td>
<td>–</td>
<td>0.113</td>
<td>0.001***</td>
<td>0.005**</td>
</tr>
<tr>
<td>German</td>
<td>0.952</td>
<td>0.113</td>
<td>–</td>
<td>0.117</td>
<td>0.266</td>
</tr>
<tr>
<td>Russian</td>
<td>0.085</td>
<td>0.001***</td>
<td>0.117</td>
<td>–</td>
<td>0.641</td>
</tr>
<tr>
<td>Italian</td>
<td>0.214</td>
<td>0.005**</td>
<td>0.266</td>
<td>0.641</td>
<td>–</td>
</tr>
</tbody>
</table>

Statistically significant differences: * (p ≤ 0.05); ** (p ≤ 0.01); *** (p ≤ 0.001).

Crosses

The data revealed that a full-back in the Spanish league performed the mean number of 4.52 ±2.45 crosses during a match. This number was significantly different from the mean numbers of crosses by full-backs from the English, German and Russian leagues (p ≤ 0.001), and Italian league (p ≤ 0.01) (Table 2). The differences in the number of crosses by full-backs were significant between the Italian and German leagues (p ≤ 0.001), and between the Italian and English leagues (p ≤ 0.01). The lowest level of statistical significance was found in the differences between the Russian and Italian leagues (p ≤ 0.05). The other differences were statistically non-significant (Table 2).

Table 2. Total number of crosses by full-backs from selected European national leagues and Fisher’s LSD test results

<table>
<thead>
<tr>
<th>National league</th>
<th>English</th>
<th>Spanish</th>
<th>German</th>
<th>Russian</th>
<th>Italian</th>
</tr>
</thead>
<tbody>
<tr>
<td>x ± SD</td>
<td>2.17 ±0.83</td>
<td>4.52 ±2.45</td>
<td>1.54 ±0.91</td>
<td>2.32 ±0.95</td>
<td>3.33 ±1.64</td>
</tr>
<tr>
<td>English</td>
<td>–</td>
<td>0.001***</td>
<td>0.141</td>
<td>0.715</td>
<td>0.005**</td>
</tr>
<tr>
<td>Spanish</td>
<td>0.001***</td>
<td>–</td>
<td>0.001***</td>
<td>0.001***</td>
<td>0.004**</td>
</tr>
<tr>
<td>German</td>
<td>0.141</td>
<td>0.001***</td>
<td>–</td>
<td>0.079</td>
<td>0.001***</td>
</tr>
<tr>
<td>Russian</td>
<td>0.715</td>
<td>0.001***</td>
<td>0.079</td>
<td>–</td>
<td>0.019*</td>
</tr>
<tr>
<td>Italian</td>
<td>0.005**</td>
<td>0.004**</td>
<td>0.001***</td>
<td>0.019*</td>
<td>–</td>
</tr>
</tbody>
</table>

Statistically significant differences: * (p ≤ 0.05); ** (p ≤ 0.01); *** (p ≤ 0.001)

Ball touches in the attack, midfield and defense pitch zones

The analysis of data showed that the full-backs from the German league performed the mean 32.14 ±9.39% ball touches in the defense zone per match (Figure 1). This is significantly different from the full-backs’ results from the English, Russian and Italian leagues (p ≤ 0.05) and from the Spanish league (p ≤ 0.001). The full-backs from the Spanish league featured the lowest number of ball touches in the defense zone (24.61 ±9.84%), which was significantly lower than the number of ball touches by the full-backs from the Russian and Italian leagues (p ≤ 0.05), and the English league (p ≤ 0.01). No other statistically significant differences in the number of ball touches were found.

In the midfield zone the number of ball touches by the full-backs from the Spanish league (41.79 ±8.94%) (Figure 2) was significantly lower than by their counterparts from the English, Italian and German leagues (p ≤ 0.001). In the German league the number of ball touches performed by the full-backs was 49.70 ±8.92%, i.e. 4.63% significantly higher than
in the Russian league (p ≤ 0.01), and 3.32% in the English league (p ≤ 0.05). Furthermore, the number of ball touches by the full-backs in the midfield zone in the Russian league was significantly lower than in the teams from the Italian league, and significantly higher than in the Spanish league (p ≤ 0.05). No other differences were statistically significant.

**Figure 1.** Mean number of ball touches in the defense zone by full-backs from selected European national leagues

**Figure 2.** Mean number of ball touches in the midfield zone by full-backs from selected European national leagues
The full-backs from the Spanish league had 33.59 ±10.98% ball touches in the attack zone (Figure 3), which was significantly higher than the number of ball touches by players from the other leagues (p ≤ 0.001). The differences in the number of ball touches in the attack zone were statistically significant (p ≤ 0.001) between the full-backs from the German league, and full-backs from the English and Russian leagues. The number of ball touches in the attack zone by the full-backs from the Italian league was 23.17 ±8.85%, and from the German league – 18.16 ±6.86%. This was a statistically significant difference (p ≤ 0.01).

**Figure 3.** Mean number of ball touches in the attack zone by full-backs from selected European national leagues

**Discussion**

In the autumn round of the 2014/15 soccer season the full-backs from the Spanish league performed the greatest number of passes and crosses as well as ball touches in the attack zone, among all studied teams from the selected European national leagues. The Spanish league teams featured also the lowest number of passes in the midfield and defense zones. In these two zones the greatest percentage of passes was performed by players from the German league.

Dellal et al. (2011) found differences between the activity profiles (in motor skills and match performance) of full-backs from various national soccer leagues. Similar observations were made in the present study. We noted that the number of passes performed by full-backs from the Spanish league was significantly higher than the number of passes performed by their counterparts from the Italian and Russian leagues. The differences may result from the offensive playing style preferred by the Spanish teams, which can be illustrated by their greatest number of ball touches in the attack zone. The differences may be also due to the applied match strategy consisting of performing a large number of short passes in the opponent’s half. Dellal et al. (2011) also revealed that the full-backs from the English league perform fewer passes per match, while possessing the ball for a significantly longer time than
the full-backs from the Spanish league (59.76 s – English league full-backs, 54.40 s – Spanish league full-backs). This probably results from a greater number of one-on-one plays won by the Premier League defenders (Dellal et al. 2011). In terms of accuracy of passes, the highest percentage of accurate passes, i.e. 82.27%, was attained by the Spanish league full-backs, and the lowest, i.e. 75.64% by the German league full-backs (unpublished data). The accuracy percentage of Europa League full-backs was 72% (Andrzejewski et al. 2014), and of full-backs from top European teams 80% (Dellal et al. 2011).

The results of the present study confirm the fact that the full-backs from the Spanish league do participate in numerous offensive actions of their teams, concluded with cross passes from a wide position. The ratio of the number of performed crosses to the total number of passes by full-backs from the Spanish league is 11.47. This is comparable with the result of full-backs from the Italian league (13.26), despite a significantly lower total number of passes in the studied teams from Serie A. This difference may have been caused by the relatively lower number of ball touches in the attack zone of the Italian league players. With similar numbers of passes by full-backs from the Italian and Russian leagues, the Premier Liga full-backs attained the ratio of 18.46, which indicates lower contribution of the Russian league full-backs to their teams’ offensive actions concluded with cross passes from a wide position.

The analysis of the number of ball touches in different pitch zones showed that the full-backs from the Spanish league demonstrated the most offensive tactics. They possessed the ball for the shortest time and covered a significantly shorter distance with high intensity than the full-backs from the Premier League (Dellal et al. 2011). Despite these results they performed a greater number of passes, crosses and ball touches in the attack zone. The main reason for this could be ball possession time by the top Primera Division teams in the opposing team’s half. The number of their ball touches in the attack zone does, in fact, correspond to the total number of passes in a game. The full-backs from the German league executed the biggest number of ball touches in all analyzed matches, in the defense and midfield zones. This figure was most likely determined by the high number of inaccurate passes, which did not permit the team to advance to the attack zone since it lost ball possession (unpublished data). This is confirmed by the small number of executed cross passes by the German league full-backs and by only 18.16% of ball touches in the attack zone of the field.

The execution of the analyzed match actions depends to a great extent on the players’ level of motor preparation. The analysis of motor activity profiles of players during a match revealed significant differences between players in different positions. In defensive positions, the full-backs cover the longest distance and feature the highest accuracy of passes (Barros et al. 2007; Clemente et al. 2013; Di Salvo et al. 2007). The majority of studies of full-backs from various European national leagues did not reveal significant differences in their motor activity during matches (Barros et al. 2007; Dellal et al. 2010; Dellal et al. 2011; Di Salvo et al. 2007; Mohr et al. 2003), however, such differences were noted in the Europa League (Andrzejewski et al. 2014).

According to the UEFA Club Ranking (June 2015) the top five European teams include three teams from the Spanish Primera Division (1st, 2nd and 5th positions). These standings are calculated on the basis of results of the teams attained in European cup matches, which means that the ranked teams are not only the leading teams in their top national leagues but also in the UEFA Champions League or the UEFA Europa League. The other studied leagues are also top European national leagues, however, not all the analyzed teams were highly positioned in the club ranking. It can be assumed that the numbers of passes, crosses and active involvement of full-backs in the attack zone contribute to the attainment of good sports results by a team. In order to more precisely determine
the differences in the match performance of full-backs from various European national leagues, studies should be carried out on a greater number of teams from each league for much longer periods of time.

Conclusions

1. Among the studied European national leagues the full-backs from the Spanish Primera Division contribute the most to the offensive play of their teams. This is evidenced by the highest number of passes, crosses and ball touches in the attack zone of the playing field performed by the Spanish league full-backs.

2. The training process of full-backs must involve development of offensive playing actions, in particular, cross passes.

3. The selection process of full-backs must account for their tasks within the team’s general match strategy. In modern soccer a full-back must possess a high level of playing skills necessary for team actions in the final phase of attacks.

4. The effective offensive play of full-backs may greatly affect the results of top-level soccer competitions, which is evidenced by the top positions of teams from the Spanish national league in the UEFA Club Ranking.

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RESEARCH ANALYSIS OF SELECTION CRITERIA AT THE INITIAL STAGE OF SWIMMING TRAINING OF PRIMARY SCHOOL JUNIOR STUDENTS

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Abstract. This article serves as a review of literature dedicated to the issue of selection criteria at the initial stage of swimming training of children in junior grades of primary school. Research methods used by the reviewed authors were varied. Only in some cases the overall anthropometric examination was used. This paper presents research results of multiple authors concerned with the swimming initiation age, basic somatic features (height and body mass), physical (motor) fitness, and physical function as major criteria for selection. The literature presented in this article lacks, however, information about potential correlations between the sports skills and measurements of motor skills and somatic features of children who are at an initial stage of competitive swimming. Therefore, this issue has not been discussed in the article.

Key words: selection in competitive swimming, junior primary school

Review of literature

Every sportsperson strives to reach a champion’s level in their respective discipline. For most, it is a guarantee of participation in the greatest sports competition, namely in the Olympic Games. Only the very best can accomplish their sports goals for which they prepared for many years (Eider and Eider 2012).

Knowledge of particular features (such as age, body mass, age at which trainings commenced, years of experience etc.) of medalists and other Olympic finalists in respective disciplines, is extremely valuable to coaches. It is them who should be on the lookout for future sports champions with these specific, promising features, or ‘champion models’. Therefore the general effectiveness of the whole sports training process depends greatly on: correct selection of children and adolescents for particular disciplines (Łaski 2006; Siewierski 2006; Haleczko et al. 2010a; 2010b; Rakowski 2010), and effectiveness of the training system (Jagiello 2000; Leonard 2002; Cięszczyk 2005; Cięszczyk and Stępiński 2007; Bergier 2011), which needs to consider changes of the ‘model’ features of champions (Karpiński and Rejdych 2008; Karpiński and Opyrchał 2008).
In the literature, there are studies describing various aspects of beginner swimmers aged 7–12 (Dybińska and Ostrowski 2003; Paradowski et al. 2003; Cardon et al. 2004; Dybińska 2004; Geladas et al. 2005; Nowacka-Chiari 2005; Ostrowski 2005; Kucia and Dybińska 2007; Rocznik et al. 2007; Kucia-Czyszczon and Dybińska 2008; Stachowicz et al. 2011; Zarzeczny et al. 2011; Ziara 2011). As it has been noticed by Łubkowska et al., physical activity in the water environment is crucial for human health (Łubkowska et al. 2014).

The literature about 7-year-olds is, however, limited (Głąb and Pietrusik 1980; Pietrusik 1980, 1981c, 1995; Waade et al. 2000; Light 2012; Leko and Grcieacute-Zubčevié 2013). Research by Głąb and Pietrusik (1980) was focused on the assessment of physical and motor agility of children that participated in competitive swimming trainings. The main aim of that research was to determine whether differences in terms of physical development and agility in 7-year-old boys influenced their training results, i.e. technical skills in freestyle, backstroke and breaststroke swimming. The authors examined 50 boys from Poznań, Poland, who attended primary school's 1st grade (specialized in swimming). Their physical development was assessed with basic somatic features (height and body mass), while their overall physical fitness was determined with an International Physical Fitness Test. The assessment was conducted at the beginning of the school year.

The analysis of the gathered data revealed that the average height and body mass of swimmers only slightly exceeded norms determined by Wolański (1975) for this age category. 7-year-old boys with higher body mass and height than their swimming peers, who had lower parameters, found it easier to master the technique of freestyle, breaststroke and backstroke swimming. Young swimmers with better physical and motor development than their swimming peers were able to master the front crawl better and with more precision. The presented data undoubtedly proves a need for detailed research focused on physical development of schoolchildren, which may be used for pre-selection or organizational decisions at the stage of teaching swimming techniques to children (Głąb and Pietrusik 1980).

Pietrusik authored a number of papers related to competitive swimming of children in primary school’s junior grades (Pietrusik 1980, 1981c, 1995, 1997a). In one of his works (Pietrusik 1981c), he presented results of a 2-year experiment conducted amongst 93 children from Poznań, Poland in which he examined their physical development, motor fitness and physical functions. These children were divided into 2 groups: swimmers (n = 47) and control group (n = 48). In the swimmers’ group, there were 25 girls and 20 boys who could not swim when they started the 1st grade. They were divided into two subgroups: one had a basic swimming program (3 hours per week), and the other had an intensive sports curriculum (6 hours per week). The control group consisted of their peers (27 girls and 21 boys) who did not pursue any sports activities. They only participated in the obligatory Physical Education classes. The assessment was conducted 4 times, in autumn and spring while children attended the 1st and 2nd grade. The measurements included height and body mass, dynamics of body function development (speed, strength, endurance, motor coordination), agility and physical functions (cardiovascular system, Ruffier’s test, functional and anatomical characteristics of the respiratory system).

The statistical analysis of the obtained results revealed no significant differences between the height and body mass development in the group of swimmers and the control group. An increase of somatic values was in accordance with the development of their young organisms. At the beginning of the experiment (Assessment I), both groups displayed a similar level of motor fitness. In the swimming group, the last assessment (IV) revealed an overall increase (statistically highly significant) in all motor skills of all subjects. In the control group, however, this significance was not observable in four aspects (strength of upper limbs, shoulder muscles, motor coordination and
agility). Participation in regular swimming classes had a positive impact on the progression of functional indicators of the circulatory and respiratory system, held breath time, and oxygen efficiency of the swimming boys and girls (Pietrusik 1981c).

Another research focused on 10-year-olds who attended 3rd grade of primary school. Wieczorek and Witkowski (1990) conducted a study on somatic structure and motor fitness amongst 102 girls who – at the beginning of the experiment – were 3rd-grade students in primary schools in Łódź, Poland. In the experimental group, there were 45 girls who attended sports classes specialized in swimming. All of them had 2 years’ experience in swimming (selection at the age of 7). For the control group, 57 of their peers were selected, who attended schools where there were only 2 hours of Physical Education weekly. Physical fitness of subjects was assessed by Denisiuk’s test (1975); upper and lower limb speed was assessed by Bondarowicz’s test (1976), and flexibility of shoulder girdle and spine was measured by Groszenków and Wolański’s method (Wolański and Pariżkowa 1976). Body structure was described with 19 somatic characteristics. They included length, girth and width measurements. The measurements were conducted 3 times, with 6 months’ intervals.

The statistical analysis of the results showed that girls in the experimental group obtained (on average) better results than the control group in terms of strength, agility, leg speed and flexibility of the shoulder girdle. There was no statistically significant difference in terms of speed, power, endurance and upper limb speed and agility. Young swimmers achieved better results in majority of somatic characteristics, compared to their peers who did not train any sport. Most of all, there were highly noticeable, statistically significant differences in terms of length parameters (body height, foot length) torso girth, its flexibility, as well as lung capacity.

Wieczorek and Witkowski (1992) conducted the same research amongst 95 boys from Łódź. At the beginning of the experiment, subjects attended 3rd grade at primary schools. There were 46 boys in the swimming group (with 2 years’ experience in competitive swimming), while the control group included 49 of their peers. The authors used similar research methods as in case of the girls (Wieczorek and Witkowski 1990). The statistical analysis of results included 6 measurements of fitness and anthropometric values, which were taken with 6-month intervals (October and April). Detailed statistical calculations revealed that the swimming group displayed better strength, power and agility results than the control group. In terms of speed and endurance, arithmetical average values in both groups were similar. In majority of anthropometric measurements, swimmers achieved better results, especially in terms of length (body height, arm, hand and foot length). According to the authors, ‘better length parameters of the experimental group may indicate a correct selection at sports schools in Łódź’ (Wieczorek and Witkowski 1992).

In her research on physical development and motor skills, Antosiak (1998) examined girls (n = 18) who were about to start competitive swimming compared to their peers (n = 22) who did not pursue any sport. All subjects were 2nd-grade students (aged 8–9) of primary school in Konin, Poland. Girls from the experimental group trained 3 times per week for one hour, as well as participated in 2 hours of obligatory PE classes at school. To measure the physical development, the author examined height, body mass and skinfold measurement. The level of selected motor skills was assessed with strength tests (strength: explosive, static, functional, and of torso muscles) from the European Physical Fitness Test. The assessments was conducted twice: in October and in May of the same school year, when all girls attended 2nd grade at primary school. Based on the statistical (comparative) calculations, Antosiak (1998) concluded that swimming trainings did not have any significant impact on the anthropometric parameters she had measured. There were no significant differences between body height between the groups,
and there was a slightly significant difference in terms of body mass and average skinfold measurements. Regular swimming classes had a positive impact on the assessed motor skills and strength.

Another paper was authored by Dziedziczak and Witkowski (1998). It focused on the physical development and agility of children who participated in the swimming experiment in Łódź (Wieczorek and Witkowski 1990, 1992). The analysis of earlier studies (Wieczorek and Witkowski 1990, 1992) was based on the results of assessments I–III, which were published separately for girls (Wieczorek and Witkowski 1990) and boys (Wieczorek and Witkowski 1992). Dziedziczak and Witkowski (1998) added the results of assessments IV–VI of the swimming girls and their non-training peers, which were not included in the statistical analysis in the earlier paper (Wieczorek and Witkowski 1990). Therefore, research conducted by Dziedziczak and Witkowski (1998) includes complete results of the experiment (6 measurements from the 3-year period). The statistical analysis of the results revealed that longer training period influenced better progress of the anthropometric parameters and skills amongst swimming boys and girls.

Białecki and Czekalska (2000) studied completely different issues related to swimming, compared to the previously discussed works. They assessed the level of swimming skills amongst children and adolescents from Warsaw, Poland, in terms of the following parameters: age, fear of water, time to swim 50 m in 3 styles (freestyle, backstroke, breaststroke), swimming technique evaluation (freestyle, backstroke), using two subjective tests. The research included one-time assessment of 195 subjects, who were divided into three groups based on age: 10–11, 12–13, and 14–19-year-olds. To answer the question: ‘Does the skill level, expressed as an assessment of swimming technique, determine the speed of swimming at a particular distance?’ (Białecki and Czekalska 2000), the authors used Spearman’s correlation coefficient. Statistical calculations revealed that the correlation coefficient was not significant in some cases.

Another study, focused on motor coordination, was conducted amongst 7–8-year old swimmers. Waade et al. (2000) examined 74 children (38 girls and 36 boys) from Gdańsk, Poland, who attended 1st grade specialized in swimming. The assessments was conducted twice: in September and June of the school year 1996/1997. To assess motor coordination, the authors used the German Körper-Koordinationstest für Kinder (KTK), which included four tests (balancing backwards, jumps on one leg, jumps sideways). The sum of points from the tests determined the final ‘indicator of motor coordination’. Based on the result of the statistical analysis, Waade et al. (2000) showed that development of motor coordination in children in both studies was moderate (scale: high, good, moderate, impaired, highly impaired). There was, however, a moderately significant progression of the motor coordination indicator after 1-year of swimming trainings. It was also revealed that not all children were able to reach a high sports level in a particular sports discipline in the future.

Focus on swimming can also be found in studies by authors from Kraków, Poland (e.g. Dybińska 2004; Ostrowski 2005; Kucia and Dybińska 2007; Ziara 2011). Dybińska’s research (2004) was significantly different in terms of methodology from studies of other authors before her (Pietrusik 1981c; Wieczorek and Witkowski 1990; Wieczorek and Witkowski 1992; Antosiak 1998; Dziedziczak and Witkowski 1998; Białecki and Czekalska 2000; Waade et al. 2000). In her experiment, Dybińska (2004) wanted to obtain information about potential correlations between theoretical and visual information (motor representation) which the students received before swimming classes, and the effectiveness of learning and teaching freestyle swimming. The final statistical analysis took into consideration full results of 532 subjects (out of 597 who began the experiment) from three primary school grades in Kraków, Poland. Subjects were divided randomly into two groups: experimental (n = 279 at the end of
the experiment) and control group (n = 253). The difference between groups was that the experimental group would have short meetings with their coach before every class, during which they were given visual information about a particular swimming style (e.g. observing program card). The experiment was conducted between February and June and included 1 lesson (40 minutes) per week. There were 2 assessments (7th and 14th lesson), which measured swimming skills and motor imagination. A detailed analysis of the results proved a strong correlation between the level of motor imagination of children and their ability to learn and be taught swimming motions. Children with a higher level of motor imagination tended to master freestyle swimming quicker and better. In the teaching process of junior primary school children ‘...teachers should consider using such teaching methods (not only visual, but also verbal, and more importantly, practical activities) that aim at a precise and long-lasting image of the motor activity that is being taught’ (Dybińska 2004). ‘It must be remembered that if we teach a child incorrect technique of a certain motion, it will be very difficult and time-consuming to eliminate it and correct it’ (Paczyńska-Jędrycka and Łubkowska 2014).

Research similar to Dybińska’s (2004) was conducted by Zysiak (2004). The main aim of the author in that experiment was to determine whether verbal and visual information (charts, photos) about freestyle swimming style would impact how quickly subjects learned that style. Her research included 58 children (28 girls and 30 boys), primary school 2nd-graders from Wrocław, Poland. Before the research, boys and girls had no theoretical knowledge nor swimming skills in terms of freestyle swimming. They were divided into two groups: experimental and control group. In the experimental group, the teacher presented information about swimming technique before each lesson, either verbally or visually (photos of motion phases), which was not presented in the control group. The experiment took two months (45 minutes twice per week). After 16 lessons, researchers assessed skills and knowledge of subjects with tests (knowledge, skills and swimming skills tests). Zysiak’s research (2004) showed that children from the experimental group learnt the freestyle swimming technique better and quicker, compared to their peers from the control group. The theoretical knowledge they received as well as memorized technical details significantly facilitated the process of learning the new style.

Nowacka-Chiari’s (2005) research was also related to analysis of body structure of young female swimmers. The author studied 129 girls aged 11–12 from Wrocław, Poland. The swimming group consisted of 25 girls with 2–6 years’ of experience in sports training, who practiced swimming 12–19 hours per week, depending on their experience. The control group consisted of 104 peers who did not pursue any sport nor activities, expect for the obligatory PE classes at school. The assessment was conducted once. Swimmers were assessed in terms of 16 anthropometric characteristics, while the subjects from control group were assessed in terms of only eight parameters. The analysis of statistical data revealed that swimmers in both age categories (11 and 12 years old) were taller, compared to their non-training peers, their chests were larger in girth, and they had a higher body mass.

Ostrowski’s (2005) research was aimed at assessing swimming skills of 10-year-olds who participated in swimming classes in Kraków, Poland. These classes took place during the obligatory PE lessons (30 hours) throughout the whole school year, when the subjects were 3rd-graders. Swimming skills test was conducted at the beginning and at the end of the experiment, i.e. when subjects started and finished the 3rd grade. Ostrowski (2005) determined criteria and points to create four groups of children with a varied level of swimming skills (non-swimmers; those adapted to water environment; those with basic swimming skills; those able to swim at least one style). In the initial test, 981 subjects took part; among them, the non-swimmers were the biggest group (57.19%), while only 8.56% of subjects already had some swimming skills.
However, only 541 children participated in regular classes throughout 1 year (30 hours). The final test revealed that as many as 66.15% children knew how to swim one style. ‘The biggest increase of skills was noticed in children that were adapted to water environment, and the lowest increase was noted in children who knew how to swim and those who started from scratch’ (Ostrowski 2005).

Ziara’s (2011) research was also based on children from Kraków, Poland. who participated in a scientific experiment. The main aim of the study was to determine the impact of somatic parameters (height and body mass), functional parameters (lung capacity), and motor parameters (eight basic tests of coordination & motor skills (Raczek et al. 2002) on the speed of learning swimming skills amongst boys and girls who were 3rd graders at primary schools in Kraków, Kraków. Children (n = 100) participated in swimming classes once per week (obligatory PE classes) throughout one year. They were divided into two groups: one group had classes in a shallow pool, the other swim in deep water. Children themselves decided which group they wanted to be a part of, which may be related to the so-called ‘behavioral fear’. The study encompassed 37 girls and 30 boys. The analysis of statistical data revealed that there were no statistically significant differences between height, body mass and lung capacity of children who swam in shallow and deep water. There was also no correlation between the speed of learning and the level of somatic measurements and lung capacity. Therefore, speed of learning amongst primary school junior students seemed to be determined not by somatic parameters, but by motor and mental skills, as well as teaching environment (Ziara 2011).

Conclusions

1. There are many available studies focused on competitive swimming.
2. Studies focus on boys and girls who have just taken up swimming or had 3-years’ experience in trainings.
3. Only single studies focused on detailed anthropometric measurements.
4. Majority of authors focused on the swimming initiation age, basic somatic features (height and body mass), physical (motor) fitness, and physical function as the key criteria for selection in swimming.
5. The available literature does not present results which could illustrate potential correlations between sports skills, motor skill measurements and somatic characteristics of children who begin their swimming training.

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BIOMECHANICAL PERFORMANCE FACTORS FOR DEVELOPMENT OF MINIMUM DISABILITY REQUIREMENTS IN PARA-TAEKWONDO — PART 1

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Abstract. Objective: To assess taekwondo sparring performance variables, such as joint ranges of motion, reaction times, and kicking foot speeds, to serve as a framework for developing sport-specific classification in Para-taekwondo competition. Methods: After a standard taekwondo warm up, athletes executed five popular scoring techniques, back kick, cut kick, fast kick, turning kick, and tornado kick five times each (25 total). Kinematic and kinetic variables were recorded by a motion capture system of seven infrared cameras and two force plates. Maximum joint range of motion, foot velocities, and reaction time were calculated. Results: Collapsed over kick, maximum hip abduction motion, maximum hip flexion, maximum knee flexion, peak foot velocity, reaction time for male athletes were 47.8 ±10.4°, 46.3 ±7.6°, 105.3 ±14.0°, 11.5 ±2.4 m/s, and 0.46 ±0.06 s respectively. maximum hip abduction motion, maximum hip flexion, maximum knee flexion, peak foot velocity, reaction time for female athletes were 49.1 ±6.8°, 43.9 ±11.0°, 94.2 ±13.7°, 10.9 ±2.2 m/s, and 0.48 ±0.11 s respectively. Conclusions: The results of this study provide a foundational framework for future studies designed to compare and assess Para-taekwondo athletes with various physical and neurological impairments. From this, future studies may move towards developing practical on-site sport specific testing methods which may ultimately assist in making taekwondo-specific classification for Para-taekwondo competitions.

Key words: para-taekwondo, classification, kinematics

Introduction

The World Taekwondo Federation (WTF) is one of the largest international sport federations with 205 member nations including approximately 80 million practitioners worldwide (www.wtf.org/wtf_eng/site/about_wtf/intro.html). In this sport’s relative young history, several significant milestones have been passed such as inclusion as an official Olympic medal sport for the 2000 Sydney Games by 1994, just six years after holding demonstration sport
status at the 1988 Seoul Games. At the 2012 Games in London 63 nations were represented by 128 athletes. Along with the success of taekwondo as an Olympic sport, participants representing numerous physical and intellectual impairments have represented the Paralympic movement via different taekwondo competition formats (full contact sparring (i.e. kyorugi) and pattern presentation (i.e., poomsae). In 2015, taekwondo was officially included to the 2020 Paralympic Games program. Along with this addition, the taekwondo community has been fostering other partnerships with groups, such as the International Federation for Persons with Intellectual Disability, International Blind Sports Federation, and the Cerebral Palsy International Sports and Recreation Association.

In 2009, the 1st World Para-taekwondo Championships were held in Baku, Azerbaijan where 38 competitors (representing four disability classes; athletes with upper-limb amputations) from 19 countries participated. In 2013 the 4th World Para-taekwondo Championships were held with 86 competitors representing 25 WTF member nations. Current full-contact sparring championships include four classes of athletes with upper-arm amputations and peripheral neurological impairments.

As athletes present with a number of physical impairments (acquired limb deficiency, congenital limb deficiency, and paralyses), the current classification has been divided into single and double amputations, where levels of impairment are defined by the location of amputation (e.g., K41: bilateral arm amputation or dysmelia, through the shoulder joint with a total loss of humerus, K42: unilateral, through the shoulder amputation or dysmelia, or bilateral above the elbow amputation, K43: bilateral amputation through or below the elbow, K44: unilateral through the wrist amputation or a monoplegia, or a significant loss in muscle strength (loss of 2 grades) in elbow flexion or extension or cannot complete one heel raise to 25 degrees. Athletes participating with various congenital limb deficiencies are also included within these classes and compete within the four aforementioned classes depending on the location of the limb deficiency. Although the WTF has seen increasing participation at the World Para-taekwondo Championships, a young history with 32 total divisions (male and female categories, four weight categories each with four impairment classifications) has at times led to joint classifications (K43 joined with K44 participants into K44/K43 class). This dilemma for ensuring fairness, presented by joint classifications in competition, warrants evidence-based classification.

As the popularity of Para-taekwondo movement demands a more comprehensive sport specific classification, the WTF has recently launched an aggressive effort to institute research aimed at providing groundwork for understanding biomechanical parameters that effect performance among non-Paralympic participants (i.e., those with no physical impairments) and athletes with physical impairments (e.g., upper limb amputations and other limb impairments). The IPC calls for evidenced-based study to develop minimum disability criteria to aid in an understanding of fundamental movements and other performance characteristics among able-bodied competitors (Beckman and Tweedy 2009); therefore, an investigation of these components in Para-taekwondo is warranted. In line with recommendations by Tweedy and Vanlandewijck (2011) the objective of this study was to work towards correctly classifying eligible impairments according to the extent of activity limitation they cause. Thus, we set out to measure biomechanical performance characteristics (i.e., joint range of motion during kicking, functional reaction time, and peak kicking velocity) which are vital factors for success in elite taekwondo sparring competition. This study is the first step of a multi-part series of investigations aimed at developing minimum disability requirements and ensuring an evidence based classification system is adopted WTF sanctioned Para-taekwondo competitions.
Methods

Athletes participating in this study executed five kicks (offensive turning kick, fast kick, cut kick, jump back kick, and tornado kick) used during Para-taekwondo competition. Each athlete performed five repetitions of the five kicks in blocked randomization. All kicks were performed at torso height as the WTF Para-taekwondo competition rules prohibit head kicks.

Although it is understood that sparring performance is a multitude of various physical attributes (speed, agility, reaction time, execution time, strategy, timing, power, distance management, etc.) we aimed to observe the most common techniques used during sparring in the most realistic, however controlled, environment as possible. In an effort to ensure this environment existed, participants were asked to execute each technique as quickly as possible in response to an LED light situated near the kicking target. Participants executed each technique a total of five times yielding 25 total trials.

Motion capture data were collected using seven MX-13 Vicon infrared cameras (Vicon Motion Capture Systems Ltd., Oxford, England) and two BP400600 AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA USA). Kinematic data were collected at 150 Hz. Ground reaction force data and the LED analog signal were used to obtain reaction time were collected at 1500 Hz. Kicking speeds, joint angles, and body positions were obtained by using a 40 retro-reflective marker set with markers placed on bony anatomical landmarks.

Participants

Six elite sparring (3 female [22 ±5 years, 170 ±5 cm, 67 ±3 kg], 3 male [22 ±5 years, 170 ±5 cm, 67 ±3 kg]) competitors volunteered for this study. All participants reported more than 10 years of taekwondo experience and were members of a first division university sparring team.

Testing procedures

This study was approved by an internal ethics board of the WTF adhering to the Helsinki Accord. Participants were orally briefed on the study objectives, testing procedures, and were provided an informed consent to sign prior to participation. All participants were asked to warm-up prior to testing and given a period of time to become familiar with the testing protocol. Participants were asked to execute all techniques with both feet on two force plates, and were instructed to engage in natural footwork movements prior to kicking. A teammate was asked to hold the kicking target (hand-held pad for all kicks and a kicking shield for the jump back kick) at an individually determined distance from the kicking stance. All athletes were prompted to kick by the LED light flashing, by which time the athlete was to execute the selected kick as quickly as possible.

Data acquisition

All data were acquired using the Vicon Nexus platform. The raw kinematic data were labeled, then exported as C3D files and imported into Visual 3D (C-Motion, Germantown, MD, USA). All motion capture data were processed using the interpolation function for a maximum of 10 frames and a low pass filter with a cut off frequency at 15 Hz. Reaction time was calculated as the time period from the point of stimulus, an LED signal, until the raising of the kicking foot off the force platform. The maximum kicking foot speed was calculated as the maximum of the kicking foot segment speed before the point of impact. For the three components, flexion/extension, adduction/
abduction and internal/external rotation hip angle was calculated as the relative angle between the pelvis and the thigh segment. Similarly the knee angle was calculated as the relative angle between the thigh and shank segment.

**Statistical Analysis**

This was an observational study in which the objective was to quantify the biomechanical measures that have the greatest affect on performance in taekwondo. As this project was the first step in a series of observational studies aimed at ultimately developing a highly standardized Para-taekwondo-specific activity limitation test protocol, data in this study were assessed in descriptive terms. As males and females do not compete in combined divisions, statistical comparisons were not performed between genders.

**Results**

The means and measures of central tendency for peak foot velocity (FVEL), maximum hip abduction motion, maximum hip flexion, maximum knee flexion, foot velocity and reaction time for each individual kick for males and females are presented in Tables 1 and 2 respectively. Additionally, the mean and standard deviation collapsed over all kicks for each measure are presented for males and females.

**Table 1** Descriptive statistics (mean ±SD) of biomechanical measures of kicking performance by type of kick among female participants

<table>
<thead>
<tr>
<th>Kicking Technique</th>
<th>Maximum Hip Abduction</th>
<th>Maximum Hip Flexion</th>
<th>Maximum Knee Flexion</th>
<th>Foot Velocity (m/s)</th>
<th>Reaction Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>52.1 ±3.7°</td>
<td>33.0 ±6.6°</td>
<td>84.6 ±3.9°</td>
<td>10.1 ±0.7 m/s</td>
<td>0.52 ±0.09 s</td>
</tr>
<tr>
<td>Cut</td>
<td>53.3 ±4.6°</td>
<td>43.2 ±11.0°</td>
<td>99.0 ±25.1°</td>
<td>7.7 ±1.1 m/s</td>
<td>0.53 ±0.09 s</td>
</tr>
<tr>
<td>Fast</td>
<td>44.3 ±8.1°</td>
<td>45.9 ±8.9°</td>
<td>90.3 ±3.8°</td>
<td>10.9 ±0.5 m/s</td>
<td>0.41 ±0.13 s</td>
</tr>
<tr>
<td>Turning</td>
<td>44.5 ±5.1°</td>
<td>53.5 ±7.2°</td>
<td>93.7 ±10.1°</td>
<td>13.5 ±0.9 m/s</td>
<td>0.45 ±0.12 s</td>
</tr>
<tr>
<td>Tornado</td>
<td>53.5 ±6.0°</td>
<td>43.2 ±11.0°</td>
<td>103.1 ±3.1°</td>
<td>12.6 ±0.7 m/s</td>
<td>0.53 ±0.09 s</td>
</tr>
<tr>
<td>All Kicks</td>
<td>49.1 ±6.8°</td>
<td>43.9 ±11.0°</td>
<td>94.2 ±13.7°</td>
<td>10.9 ±2.2 m/s</td>
<td>0.48 ±0.11 s</td>
</tr>
</tbody>
</table>

**Table 2** Descriptive statistics (mean ±SD) of biomechanical measures of kicking performance by type of kick among male participants.

<table>
<thead>
<tr>
<th>Kicking Technique</th>
<th>Maximum Hip Abduction</th>
<th>Maximum Hip Flexion</th>
<th>Maximum Knee Flexion</th>
<th>Foot Velocity (m/s)</th>
<th>Reaction Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>46.4 ±8.7°</td>
<td>38.6 ±7.1°</td>
<td>102.2 ±14.9°</td>
<td>10.7 ±0.5 m/s</td>
<td>0.50 ±0.05 s</td>
</tr>
<tr>
<td>Cut</td>
<td>55.2 ±7.6°</td>
<td>44.2 ±4.8°</td>
<td>108.3 ±9.8°</td>
<td>8.0 ±1.1 m/s</td>
<td>0.46 ±0.05 s</td>
</tr>
<tr>
<td>Fast</td>
<td>43.4 ±7.3°</td>
<td>46.0 ±2.8°</td>
<td>107.0 ±13.5°</td>
<td>11.3 ±0.3 m/s</td>
<td>0.42 ±0.06 s</td>
</tr>
<tr>
<td>Turning</td>
<td>41.9 ±6.6°</td>
<td>53.8 ±5.2°</td>
<td>103.0 ±14.7°</td>
<td>13.8 ±1.5 m/s</td>
<td>0.43 ±0.04 s</td>
</tr>
<tr>
<td>Tornado</td>
<td>53.0 ±13.1°</td>
<td>46.9 ±5.6°</td>
<td>103.3 ±17.6°</td>
<td>14.1 ±0.8 m/s</td>
<td>0.50 ±0.06 s</td>
</tr>
<tr>
<td>All Kicks</td>
<td>47.8 ±10.4°</td>
<td>46.3 ±7.6°</td>
<td>105.3 ±14.0°</td>
<td>11.5 ±2.4 m/s</td>
<td>0.46 ±0.06 s</td>
</tr>
</tbody>
</table>

**Discussion**

The results from the current study hold value from a few different standpoints. Although there are a number of earlier studies (Capozzo et al. 1997; Curran and Frossard 2012; Fife et al. 2012) that have reported kinematic and
kinetic assessment of taekwondo kicks, our study present three (i.e., cut, fast, tornado kick) techniques that have not been presented in the literature before. Because we included three additional kicks that are most often used for scoring during competition, the results of this study provide a base of comparison for future studies aiming to evaluate the effects of various impairment types on taekwondo performance variables.

As there are no published studies reporting the biomechanical characteristics of the cut, fast and tornado kick, it may be difficult to verify the validity these measurements in comparison to other existing studies. However, the maximum kicking foot speeds reported for both back kick and the turning kick are similar to those reported by Fife et al. (2012) respectively, 9.67 to 11.45 ms\(^{-1}\), 10.8 to 13.02 ms\(^{-1}\). Furthermore, the reaction times were similar to the reaction times of elite karate practitioners (Curran and Frossard 2012). Results from these previous studies and the current study indicate, even with a low number of recruited participants, results can be confirmed as performance levels to be expected among this level of athletes.

Recent recommendations (Beckman and Tweedy 2009) from the IPC, guide researchers to conduct a process-focused approach encompassing evaluations of the validity and methods used to characterize classes from an empirical basis rather that of the judgment of a community of experienced classifiers. The measurement of impairments is most appropriate when conducted with a battery of test(s) that are simple, convenient and have objective methodology that can be confirmed through further analyses of validity and reliability (Beckman and Tweedy 2009). As our study has selected the most common kicks used during competition with objective biomechanical measures (reaction time, kicking velocity, etc.) that are important for performance during competition, it may be possible to develop a convenient field test (Mori et al. 2002) to determine minimum disability requirements based on performance characteristics evaluated in the current study.

Beckman and Tweedy (2009) provided a simple battery of tests that are common movements used during athletics training and can be easily administered during a competition as a measure of minimum disability requirements as well as activity limitation test batteries. As the techniques measured in the current study were simply kicks used during competition, it may serve as a framework towards development of standardised sport-specific tests such as reaction time tests incorporating lower body movements. Because taekwondo does combine facets of game strategy, distance management between competitors, and situational game management techniques it will be important to pull from a representative knowledge base of successful coaches (Mori et al. 2002) in an effort to assess other important performance characteristics that may not have been measured in the current study. Performance measures obtained in this study, although from a small subject pool, may serve as a comparative data set for when data are obtained from future developed field tests of related performance variables.

**Limitations**

Due to this study being a preliminary step to set the stage for a larger study aimed at comparing performance variables among Para-taekwondo athletes, it should be understood that the number of participants may be insufficient to claim conclusive results from our elite taekwondo athlete pool. Future comparative studies should collect data that holds sufficient power on a representative cohort of those with various physical impairments and those with no impairments. As this sport is not performed in the confines of a laboratory setting and holds a sport-combative environment, the physical and psychological demands that at times may affect performance were non-existent during our data collection effort. As with many biomechanical motion analyses the challenge of employing the most reliable methods for tracking reflective markers exists. It should be understood that the use of cluster set
markers or even bone-embedded pin markers may present more accurate data (O’Sullivan et al. 2009), however the use of these methods was not available during this study.

Suggestions

Future studies should consider observing performance of the variables presented in this study among a representative (i.e., of all current WTF Para-taekwondo Classes and from an ethnically diverse population (Beckman and Tweedy 2009) group of Para-taekwondo athletes. As the variables measured in this study do not encompass all performance characteristics important in taekwondo competition success, future groups should aim to gain in-depth input from expert coaches to ensure face validity of field tests used to determine minimum disability and classification status. As a field test is developed, the reliability and validity of the testing battery must be confirmed along with subsequent large data collection efforts from a large number of subjects of an ethnically representative cohort that may serve as a standardized testing battery used in parallel with appropriate regression analyses (Beckman and Tweedy 2009). As suggested earlier (Tweedy and Vanlandewijck 2011), an option for ensuring that a large data pool is analysed is to employ the use of a mobile biomechanics laboratory to be used in conjunction with competition classification activities.

An important taekwondo-specific consideration for athletes in the current four classifications (K41-K44) is the role of amputee upper limb length. As taekwondo employs the use of a body protector with the function of real-time electronic scoring, it must be understood that athletes with longer amputated limbs paired with athletes with shorter limbs could be placed at a disadvantage in regards to blocking ability. If an athlete with no neurological function of the entire arm is paired with an athlete of K41 (amputation of both limbs above the elbows) status, an obvious advantage in the case of the athlete with neurological impairment could be evident. Future studies should investigate the role of limb length on ability to block (intended or un-intended) the electronic chest protector.

Conclusions

The results of this study provide an objective measure of normative performance ranges for performance variables important to taekwondo sparring success. From these results, future studies will have a basis for comparison among Para-taekwondo athletes. Components of techniques used in this study may provide a framework for developing field-tests used for classification at competitions. It is important for future studies to consider the results of this study when comparing results with Para-taekwondo athletes that represent all current WTF classifications to move towards improving the existing classes.

What this study adds / what are the new findings?

- Normative performance for key components of sparring
- A steppingstone towards development of a battery of tests to be used for evaluating the core components of sparring performance
- Introduction to the discussion of developing evidence based study of taekwondo-specific classification field tests
How might this study impact clinical practice in the future

The results of this study provide a framework for conducting future studies that are recommended to compare able-bodied taekwondo athletes and athletes with physical limitations. Techniques tested in this study, as they are the most common techniques used during competition, may serve as a possible on-site taekwondo-specific testing protocol.

Acknowledgements

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www.wtf.org/wtf_eng/site/about_wtf/intro.html.

DIETARY INTAKE OF ANTIOXIDANT VITAMINS
IN DIETS OF AMATEUR ADULTS PREPARING FOR A MARATHON

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Abstract. The aim of this study was to evaluate the content of antioxidant vitamins in the diet of amateurs preparing for a marathon. The study group consisted of 92 women (30.8 ±6.7 years old) and 66 men (33.2 ±6.6 years old). Assessment of the content of antioxidant vitamins in the diet of the subjects was made on the basis of the 3-day dietary records. The average content of vitamin A in the diets of women surveyed was 1,296.8 mg/day and 1,499.7 mg/day in the diets of men. The vitamin A content of less than 90% of the norm was observed in the diets of 2.2% women and 9.1% men. The average content of vitamin C in the diet amounted to 130.6 (women) and 111.4 (men) mg/day. Significantly more men than women (30% vs 13%) did not fulfill the norm for vitamin C. The average vitamin E content was higher in the diets of men than in women (15.2 vs 13.0 mg/day; p < 0.0001). The vitamin E content was insufficient compared to norms in the diets of 10% of women and 12% of men. The average content of vitamins A, C and E in the diet of the subjects significantly exceeded the recommendations. The largest proportion of diets, not meeting the stated norms for vitamin C were in the group of men.

Key words: antioxidant vitamins, marathon, 3-day dietary records

Introduction

One of the factors contributing to the occurrence of oxidative stress is increased physical activity. The formation of reactive oxygen species (ROS) in the body is a natural process that occurs as a result of aerobic respiration, but their production is significantly greater during physical activity. Athletes consuming a high energy diet, compared to those with low and moderate physical activity, provide the body more nutrients that are substrates of metabolism, for which free radicals are byproducts (Radak et al. 2001; Sachdev and Davies 2008).

ROS in small quantities are signaling molecules in the course of many life processes. However, the disturbance of homeostasis in the body, i.e. their overproduction, beyond the capacities of the cells to neutralize them, leads
to accumulation of large amounts of these molecules, referred to as oxidative stress. This condition, as well as insufficient antioxidant defense of cells, may lead to a number of defects in tissues and cells (Valko et al. 2007; Czajka 2006).

Protective mechanisms against oxidative stress of cells are formed at three levels. In the first level, antioxidant enzymes such as superoxide dismutase, catalase and glutathione peroxidase take part. The second line of defense are the non-enzymatic antioxidants such as glutathione and food derived antioxidant vitamins and flavonoids. Antioxidants that are ingested with the diet are therefore, an important support for the enzymatic antioxidant defense mechanisms. In the last stage of the antioxidant defense of the body, repair proteins, which rebuild modified or damaged DNA molecules and others, are involved (Chajka 2006; Grajek 2007).

During prolonged endurance exercises, there is an overproduction of free radicals, which contributes to a number of changes in the tissues, organs and cells. With the failure of endogenous antioxidant defense systems and comorbid insufficient supply of exogenous antioxidants results in the worsening of oxidative stress (Radak et al. 2001; Sachdev and Davies 2008; Bloomer et al. 2006). To restore homeostasis, the organism should be neutralized by food ingredients, with antioxidant and anti-free radicals properties, such as vitamins A, C, E, and bioflavonoids (Sen 2001; Morillas-Ruiz et al. 2006).

It is therefore important to monitor the composition of the diet of people who undertake prolonged exertion e.g. preparing for a marathon, in terms of the supply of the substances of an antioxidant nature to help mitigate the effects of oxidative stress.

The aim of this study was to evaluate the content of antioxidant vitamins in the diet of adults – amateurs, preparing for a marathon.

Material and methods

The study group consisted of 158 people, 92 women and 66 men who took part in the “I Ty możesz zostać maratończykiem” program in 2012 and 2013. The average age of women was 30.8 ±6.7 years, and 33.2 ±6.6 years for men. Abnormal BMI (body mass index) was found in 18% of women and 45% men. The characteristics of the study group are shown in Table 1.

<p>| Analyzed | Women (n = 92) | Men (n = 66) |</p>
<table>
<thead>
<tr>
<th>paramaters</th>
<th>U</th>
<th>X ±SD</th>
<th>Me</th>
<th>X ±SD</th>
<th>Me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>years</td>
<td>30.8 ±6.7</td>
<td>30.0</td>
<td>33.2 ±6.6</td>
<td>32.5</td>
</tr>
<tr>
<td>Height</td>
<td>cm</td>
<td>166.0 ±6.1</td>
<td>165.0</td>
<td>178.9 ±7.1</td>
<td>179.0</td>
</tr>
<tr>
<td>Body weight</td>
<td>kg</td>
<td>61.8 ±9.1</td>
<td>60.8</td>
<td>81.2 ±11.9</td>
<td>79.2</td>
</tr>
<tr>
<td>BMI</td>
<td>kg/m²</td>
<td>22.4 ±2.7</td>
<td>21.7</td>
<td>25.3 ±2.8</td>
<td>24.9</td>
</tr>
</tbody>
</table>

n- number of people studied; X- arithmetic average; SD – standard deviation; Me – median; U- unit; BMI- body mass index.

The program “I Ty możesz zostać maratończykiem” began at the end of March and was aimed at preparing amateur runners to compete in the Wroclaw marathon, which takes place every year in mid-September. The program was implemented in the form of endurance training. During the program, volunteers participated in organized training units twice a week. They were also supposed to perform additional units in their own free time.
Assessment of the content of antioxidant vitamins in the diet of the subjects was made on the basis of the current 3-day dietary records. Participants received detailed, written instructions on how to record intake of products, food and beverages during a 3-day period, including: 1 training day, 1 day without training and a special day (weekend). Dietary interviews were collected in May and June. The composition of the food recorded using households measures was then verified by trained interviewers using the “Album of photographs of products and dishes” (Szponar et al. 2008) by assigning appropriate weight to all products. Nutritional analysis of collected interviews was carried out using a computer program, “The Food Processor SQL” containing the Polish database by Kunachowicz et al. (2005).

The average content of antioxidant vitamins in the 3-day daily food rations was calculated for each person, and then compared with the norms (Jarosz 2012) using two parameters: the average fulfillment of norms and percentage of people who have vitamin contents in their diets below the norms. The content of vitamins A and C were compared with the norms at the level of the EAR (Estimated Average Requirement), and vitamin E with the norm at the level of AI (Adequate Intake), assuming the values specified in the amendment of nutrition norms for the Polish population, for the appropriate gender and age (Jarosz 2012). In addition, the percentage of respondents fulfilling the standard dietary requirements for antioxidant vitamins were rated in the following ranges: <90%, 90–110%, 111–150%, 151–200%, >200%.

**Statistical analysis**

Comparison of vitamins in the diets of women and men was performed using a non-parametric U Mann-Whitney test, and categorical variables using a Chi² test. Statistical analysis of the results was carried out using a computer program STATISTICA PL v.10, by StatSoft Inc. (USA).

**Results**

The daily food rations (DFR) were evaluated in terms of the content of antioxidant vitamins A, E and C (Table 2).

### Table 2. The mean content of antioxidant vitamins in the diets of the surveyed women and men preparing for a marathon

<table>
<thead>
<tr>
<th>Vitamins</th>
<th>U</th>
<th>Women (W) n = 92</th>
<th></th>
<th></th>
<th></th>
<th>Men (M) n = 66</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>Me</td>
<td>% fulfillment of standards (X ± SD)</td>
<td></td>
<td>X ± SD</td>
<td>Me</td>
<td>% fulfillment of standards (X ± SD)</td>
<td></td>
</tr>
<tr>
<td>A* µg</td>
<td>1296.8 ±911.6</td>
<td>1139.8</td>
<td>259.4 ±182.3</td>
<td>1499.7 ±1465.4</td>
<td>1194.2</td>
<td>238.0 ±232.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retinol µg</td>
<td>492.1 ±700.4</td>
<td>345.8</td>
<td>–</td>
<td>832.7 ±1224.7</td>
<td>538.6</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>β-carotene µg</td>
<td>4812.9 ±3376.0</td>
<td>3673.1</td>
<td>–</td>
<td>3983.9 ±2591.5</td>
<td>3252.2</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C* mg</td>
<td>130.6 ±76.2</td>
<td>115.4</td>
<td>217.7 ±127.0</td>
<td>111.4 ±66.5</td>
<td>101.2</td>
<td>148.6 ±88.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E** mg</td>
<td>13.0 ±5.6</td>
<td>11.9</td>
<td>163.0 ±70.2</td>
<td>15.2 ±5.4a</td>
<td>15.0</td>
<td>151.6 ±54.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n – number of people studied; * EAR (Estimated Average Requirement), ** AI (Adequate Intake), X- mean, SD – standard deviation, Me – median; U- unit; * statistically significant difference W vs M p < 0.05.

Average daily vitamin A content, expressed as retinol equivalent, in the diets of women surveyed was 1,296.8 mg, of which 62% came from β-carotene, and 38% of retinol. The average daily content of vitamin A in the diets of men was 1,499.7 mg, of which 44% came from β-carotene, and 56% of retinol. An insufficient content of vitamin A, compared to the EAR was recorded in the diets of 2.2% of women and 9.1% of men (Figure 1). DFR
of the surveyed women fulfilled the norm for vitamin A on average by 259.4%, and the DFR for the men surveyed by 238.0%. The intake of vitamin A in the diets of approximately 60% of women’s and 46% of men’s was higher by 200% of the norm.

![Figure 1](image1.jpg)

**Figure 1.** Distribution of dietary daily intake of vitamin A in the study group: a) women, b) men

Average daily vitamin C content in the DFR of surveyed women and men amounted to 130.6 mg and 111.4 mg, respectively (Table 2). Although the energy value of diets was significantly higher for men than for women (2,808.1 ±731.6 vs 1,982.3 ±506.5 kcal; p < 0.05) significantly more men’s than women’s diet did not fulfill the norm for vitamin C. Diets of 13% of women and 30% of men did not provide sufficient amounts of vitamin C. In the diets of approximately 46% of women and 17% of men, intake of vitamin C exceeded the norm two-fold (Figure 2). DFR of the surveyed women fulfilled the norm for vitamin C on average by 217.7%, and the diet of men by 148.6% (Table 2).

![Figure 2](image2.jpg)

**Figure 2.** Distribution of dietary daily intake of vitamin C in the study group: a) women, b) men

The average content of vitamin E was significantly higher in the diets of men than women (15.2 vs 13.0 mg/day; p < 0.0001) (Table 2). Insufficient levels of vitamin E compared to the level of AI were reported in the diets of 10% of women and 12% of men. In addition, it was found that the diets of 25% of women and 21% of men vitamin E
content exceeded 200% of the norm (Figure 3). DFR of surveyed women fulfilled the norm for vitamin E on average by 163%, and the diet of men by 151.6% (Table 2).

![Figure 3. Distribution of dietary daily intake of vitamin E in the study group: a) women, b) men](image)

**Discussion**

The basic task that an athlete's diet must fulfill is optimal supply of energy needs and building blocks of the body. At the same time, the dietary needs should encourage the development of functional capacity and counter the effects of training overload.

During increased physical activity, not only is the supply of energy to the needs of the body important, but also building and regulating nutrients. Physical activity increases the intensity of metabolic processes. There are many by-products of metabolism, and an excessive amount of free radicals, which can have a negative effect on the body and hinder regeneration. It is therefore necessary to provide the body, together with the diet, adequate amounts of dietary antioxidant vitamins to restore the homeostasis of the organism.

In addition to the deficit of glycogen and the presence of lactic acid, one of the factors causing exercise-induced muscle fatigue, is the production of free radicals in the active skeletal muscles. A key role in protecting against oxidative damage of muscles caused by exercise, is played by antioxidants from food. An increased dietary intake of antioxidant vitamins has been observed both in our study and among other Polish athletes (Zapolska et al. 2014), and among volleyball players from Greece (Papadopoulou et al. 2002). Extra vitamin supplements can be helpful in improving the overall efficiency of the body, because they prevent the lowering of blood antioxidant capacity and reduce the activity of ROS. However, it should be noted that, under certain conditions, too high dose of some antioxidants, administered in the form of supplements can operate pro-oxidant. The best sources of antioxidants are natural foods, especially fruits and vegetables, tea, chocolate, the consumption of which does not put one in danger of an overdose.

Insufficient intake of vitamin E leads to increased oxidative stress, neurodegenerative changes, hemolysis, and muscle wasting (Lukaski 2004). Vitamin E is a strong antioxidant and α-tocopherol is a component of all biological membranes in the body and thus prevents oxidation of fatty acids in cell membranes (Biesalski and Grimm 2012). This prevents oxidative cell damage which may be severe during prolonged physical exertion.
In addition, vitamin E promotes the transformation of slow-twitch fiber (type I) into the fast-twitch (type II), which may impair the capacity of the organism (Lukaski 2004). These changes will be particularly disadvantageous for people undertaking prolonged exertion, i.e. endurance activities such as marathon. Muscles, which consist mainly of fast-twitch fibers contain more glycogen as well as enzymes involved in the release of energy in anaerobic conditions, yet also contain little myoglobin are called white. This type of muscle on one hand shrinks faster and stronger, but also quickly loses energy reserves and gets tired. By contrast, muscles containing slow-twitch fiber (called red, because they contain large amounts of myoglobin) are adapted to long-term physical exertion (Nazar 2013). Types I and II muscle fiber have different oxidative metabolism. Type I fibers may use larger amounts of vitamin E than type II fibers (Lukaski 2004). Vitamin E causes the increase in the activity of circulating creatine kinase, which may indicate an increase in skeletal muscle repair (Evans 2000).

Nutritional deficiencies of vitamin E are higher in physically inactive people than in athletes (Wierniuk and Włodarek 2013). In our study, insufficient content of vitamin E in the diet was found on average in every 10th woman and every 8th man. In a study conducted by Wierniuk and Włodarek (2013) too low vitamin E content was observed in the diets of 40% of men who carry out aerobic sports. In contrast Gogojewicz et al. (2012) estimated that the average content of vitamin E in the diet of women involved in fitness was an average of 4.1 mg/day and was lower than the values obtained in our study and in studies of other authors (Pliis et al. 2014; Gacek 2010). The vitamin E content in the diets of about 80% of the people surveyed in our study exceeded the norm. Similar results were obtained in a group of athletes involved in football (Lange et al. 2007), whereas there was a deficiency in the DFR of football players during the match season (Chalcarz et al. 2008).

The role of vitamin C in the body is mainly related to its antioxidant activity, but it takes part in a number of different processes, which may affect the physical fitness of the organism. Vitamin C is involved, among other things, in the synthesis of carnitine in the muscles, which is required for handling and transport of fatty acids into the mitochondria where they are used for energy production. Vitamin C is also involved in the synthesis of neurotransmitters, iron absorption and transport, reduced forms of intermediate folic acid. Vitamin C is also involved in the synthesis of collagen, which is approximately 1/3 of the proteins of the body and is present in the skin and bones. Ascorbic acid deficiency and reduced collagen synthesis will lead to more frequent injuries. Vitamin C deficiency can also lead to fatigue and muscle weakness, and even anemia. Insufficient intake of vitamin C is also associated with weakening of the immune system. Due to the important role of vitamin C in the body, its deficiency may affect the player’s performance and stamina during training (Naidu 2003; Lukaski 2004). Increased physical activity is a factor that increases the demand for this vitamin. The average content of vitamin C in the diets of the group of women studied was more than twice the norm, while in the diets of men was about half the norm. Moreover, a significant percentage of men did not fulfilled the dietary recommended value for vitamin C. Mullinix et al. (2003) obtained similar results in a group of physically active women who fulfilled DFR norm for vitamin C by 171%. Other authors have received different results from their studies, which reported an abnormal concentration of vitamin C in the diet of women and men who participate in a variety of sports (Zapolska et al. 2014; Wierniuk and Włodarek 2013; Gogojewicz et al. 2012; Burke and Read 1988).

Vitamin A is consumed in the diet as retinol from animal products or as pro-vitamin A in the form of carotenoids from plant products. Thanks to its antioxidant properties, it neutralizes the effects of free radicals in the body and prevents DNA damage and oxidation of fatty acids. It is also responsible for ensuring the immunity of the body, especially the prevention of respiratory infections because it is involved in the processes of cell growth and
differentiation of respiratory mucosa (Biesalski and Grimm 2012). People preparing for a marathon should therefore pay special attention to the adequate supply of this vitamin from the diet. Moderate activity can increase the body’s immunity compared to people with sedentary lifestyles, but athletes who are involved in prolonged and intense exercise have more frequent infections of the upper respiratory tract compared with less active people (Moreira et al. 2009; Gleeson 2007). Immune function disorders occur most commonly in persons engaged in continuous, prolonged (approx. 1.5 hours) exercise of moderate to high intensity (55–75% VO\textsubscript{2} max). Another factor that may aggravate these disorders is the lack of food intake during prolonged exercises (Gleeson 2007).

Our study found that the vitamin A in the diets of about 80% of women and 66% of men exceeded the EAR norm. Abnormal levels of vitamin A was also reported by other authors, assessing the diet of athletes in other disciplines (Chalcarz et al. 2008; Burke and Read 1988). The results of researches conducted in a number of groups of athletes, including endurance runners, however, showed normal dietary intake of vitamin A (Peters et al. 1993; Keith 1997; Lukaski 2004). To maintain a healthy supply of vitamin A in the diet of physically active people, attention should be paid to the type of food consumed. In physically active young women a decreased intake of vitamin A was noted, which was not related to a reduction in the supply of energy from the DFR. Probably, this decline was associated with a high intake of dietary fat and very low intake of fruit and vegetables (Johnson et al. 1972).

A significant part of the vitamin A in the diets of studied men and women was beta-carotene. In Hosegawa’s (1993) studies, the effect of beta-carotene on the metabolism of sportsmen was investigated. Men were given a single dose of carotene two hours before training, while the control group received a placebo. The test results showed that the control group had significantly elevated levels of stress hormones. The elevated levels of these hormones were gradually reduced with an increasing dose of carotene and completely eliminated in men who received 30 mg of carotene in a single dose. In a study conducted by Hyżyk and Romankow (2005) it was found that the DFR in the majority of physically active people are properly composed and included foods that are good sources of vitamins C and E. A balanced nutritional ration for a whole day should cover the body’s need for vitamins for physically active people as well, but for the people in these groups it is also popular to use dietary supplements. Research conducted by Frączek et al. (2012) showed that a vast majority of athletes (86.5%) declared using dietary supplements. In addition, about 3/4 of athletes declared that they take the vitamin and mineral preparations as antioxidant supplementation. Significantly more women than men enriched their diets with vitamin supplements.

A deficiency of certain vitamins can increase the time of recovery of protein and glycogen in the muscles and cause a decrease in mental and physical performance. Studies in a group of young rowers (Skarpańska-Stejnborn et al. 2001) showed that daily intake of antioxidant vitamins increases the antioxidant capacity of cells, increasing the body’s protection against the effects of increased oxidative stress. Other authors have also demonstrated the role of antioxidants in preventing tissue damage after exertion (Sadowska-Krępa and Kłapcińska 2005). This was confirmed in studies by Poprzędzki (2003), in which supplementation with antioxidant vitamins and selenium resulted in improvement in exercise capacity, especially among endurance athletes. Athletes also declared using single vitamins, especially antioxidant in addition to multivitamins.

Athletes are exposed to chronic overexertion of the body during trainings and competitions, which may lead to a suppression of the immune system and increased oxidation of tissues and cells. Negative energy balance and insufficient supply of foods rich in antioxidants may also interfere with the immune system and antioxidant mechanisms. Moreover, the stress of exercise leads to a proportional increase in stress hormones and lowered immunity, including increased levels of pro-inflammatory cytokines. In addition to providing an appropriate
amount of calories, during training exertion, the diet must also be enriched with antioxidant ingredients to re-
synthesize components of the immune system. Both shortages and excesses of these components may lead to
immunosuppression. In some cases, supplementation with antioxidants may improve the immune system and
replenish nutrients (Venkatraman and Pendergast 2002).

Conclusions

Most of the analyzed diets contained the correct amount of antioxidant vitamins. The average fulfilling of
norms for vitamins A, C and E significantly exceed the reference values established for the Polish population in the
study group of men and women training for a marathon.

An insufficient supply of vitamin C was found in the diets of approx. 1/3 of the men, which may indicate an
inadequate intake of fruits and vegetables or their improper selection in this group of people.

Athletes engaging in regular, long-term exercise should pay attention to the correct balancing of daily food
rations, since the deficit of nutrients, including antioxidant vitamins may cause a reduction in efficiency of the
organism, and thus obtain a poorer performance during competitions.

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Dietary Intake of Antioxidant Vitamins in Diets of Amateur Adults Preparing for a Marathon


THE PREVALENCE OF ARTERIAL HYPERTENSION AMONG STUDENTS OF WEST POMERANIAN VOIVODESHIP

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Study Design; Data Collection; Statistical Analysis; Manuscript Preparation

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Abstract. The research was carried out as part of the research project N N 404 260335 “The lifestyle of children and adolescents and their level of athleticism, fitness and somatic development” during Crampton test in 2633 students of elementary, secondary and high schools in West Pomeranian Voivodeship. 214 subjects, that is 8.1% of the whole group, were qualified for the group with the hypertension. The arterial hypertension was reported in 7.9% of girls and 8.4% of boys. The statistically significant dependencies between the prevalence of arterial hypertension and the size of metropolitan area where the children and adolescents live, as well as their sex were observed.

Key words: hypertension, children, adolescents

Introduction

Among the factors favorable for the development of arterial hypertension among children and adolescents the most common are: genetic factors, low birth weight, excessive consumption of salt, obesity and insufficient physical activity. Untreated or irregularly or ineffectively treated arterial hypertension leads to the occurrence of changes in most of the organs (for instance, heart, brain, kidneys, eyes) and tissues. The problem of the prevalence of hypertension is an urgent issue which can be testified by the formulation of Guidelines for the management of arterial hypertension published in 2013 by the European Society of Hypertension (ESH) and European Society of Cardiology (ESC) which are the continuation of the previously issued guidelines (in the years 2003 and 2007) (Wytyczne... 2013). The hypertension among children and adolescents is understood as an average systolic or diastolic blood pressure on three independent occasions equal or higher than the 95th percentile appropriate for the sex, age and height (Lurbe et al. 2009). The phenomenon is defined in subsequent stages of ontogeny, that is: prehypertension, stage 1 hypertension and stage 2 hypertension. Prehypertension includes the systolic
or diastolic blood pressure that is greater than or equal to the 90th percentile, but less than the 95th percentile, in adolescents BP > 120/80 mm Hg, even if the value is less than 90th percentile. The control measurement should be taken after 6 months. In stage 1 hypertension systolic or diastolic blood pressure is between the 95th percentile and the 99th percentile plus 5 mmHg. The control measurement should be repeated with an interval of 1–2 weeks. Pharmacological treatment is implemented in case of the prevalence of secondary hypertension. Stage 2 hypertension is in the range >99th percentile plus 5 mmHg. The diagnostic procedure in this case should take place immediately. In case of overweight people the weight loss, taking up physical activity and a proper diet are advisable (Chobanian 2003; The Fourth Report… 2004).

Material and methods

The research was carried out as part of the research project N N 404 260335 “The lifestyle of children and adolescents and their level of athleticism, fitness and somatic development” in the years 2008–2011. The aim of the research project was to create positive attitudes of children and adolescents towards participation in physical activities, as well as to promote the “healthy lifestyle”. Two parallel types of actions were taken:

– diagnostic, aiming at identifying the level of athleticism, somatic development and fitness, as well as eating habits, participation in physical activities and healthy attitudes among subjects of the research,

– educational, aiming at preparing the environments influencing students to create their healthy attitudes and habits.

The blood pressure measurements were taken in a supine position after 10 minutes of the patient lying flat and they were implemented as part of the Crampton test. Among the subjects, in whom high blood pressure was registered a second time, a control measurement was taken to confirm the result excluding any measurement errors. A countercheck of the measurement was carried out twice without doing the Crampton test. It was carried out in 1-week and 4-week intervals after the first measurement. Only those measurements which were positively confirmed were included in the research. It allowed to avoid various factors conditioning invalid measurement, for instance, the white coat syndrome, temporary indisposition of the student etc. Qualification for a group with hypertension has been prepared according to the tables elaborated by A. Krzyżaniak, M. Krzywińska-Wiewiorowska, B. Stawińska-Witoszyńska and others (Krzyżaniak et al. 2009).

2633 students of elementary, secondary and high schools at the age of 8, 9, 11, 12, 14, 15 and 17 from big cities, small towns and villages of West Pomeranian Voivodeship were included in the research.

Results

The results of the research are presented in the Tables 1–5 and in Figure 1. The size of metropolitan area differentiates in a statistically important way the percentage of children with arterial hypertension in a given population:

– for villages and small towns-structure index \( z_{a=0.05} = 1.96 < z = 2.87 \),

– for villages and big cities-structure index \( z_{a=0.05} = 1.96 < z = 3.14 \),

– for small towns and big cities-structure index \( z_{a=0.05} = 1.96 < z = 2.54 \).
### Table 1. Prevalence of arterial hypertension in girls

<table>
<thead>
<tr>
<th>Age</th>
<th>Norm</th>
<th>%</th>
<th>Hypertension</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>107</td>
<td>9.1</td>
<td>5</td>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>9</td>
<td>205</td>
<td>17.4</td>
<td>21</td>
<td>21</td>
<td>20.8</td>
</tr>
<tr>
<td>11</td>
<td>144</td>
<td>12.2</td>
<td>9</td>
<td>9</td>
<td>8.9</td>
</tr>
<tr>
<td>12</td>
<td>178</td>
<td>15.1</td>
<td>13</td>
<td>13</td>
<td>12.9</td>
</tr>
<tr>
<td>14</td>
<td>115</td>
<td>9.8</td>
<td>11</td>
<td>11</td>
<td>10.9</td>
</tr>
<tr>
<td>15</td>
<td>102</td>
<td>8.7</td>
<td>3</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>17</td>
<td>328</td>
<td>27.8</td>
<td>39</td>
<td>39</td>
<td>38.6</td>
</tr>
<tr>
<td>Total</td>
<td>1179</td>
<td>100.0</td>
<td>109</td>
<td>109</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: author's own research.

### Table 2. Prevalence of arterial hypertension in boys

<table>
<thead>
<tr>
<th>Age</th>
<th>Norm</th>
<th>%</th>
<th>Hypertension</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>173</td>
<td>14.0</td>
<td>14</td>
<td>14</td>
<td>12.4</td>
</tr>
<tr>
<td>9</td>
<td>240</td>
<td>19.4</td>
<td>15</td>
<td>15</td>
<td>13.3</td>
</tr>
<tr>
<td>11</td>
<td>159</td>
<td>12.8</td>
<td>14</td>
<td>14</td>
<td>12.4</td>
</tr>
<tr>
<td>12</td>
<td>183</td>
<td>14.8</td>
<td>13</td>
<td>13</td>
<td>11.5</td>
</tr>
<tr>
<td>14</td>
<td>153</td>
<td>12.3</td>
<td>21</td>
<td>21</td>
<td>18.6</td>
</tr>
<tr>
<td>15</td>
<td>89</td>
<td>7.2</td>
<td>8</td>
<td>8</td>
<td>7.1</td>
</tr>
<tr>
<td>17</td>
<td>243</td>
<td>19.6</td>
<td>28</td>
<td>28</td>
<td>24.8</td>
</tr>
<tr>
<td>Total</td>
<td>1240</td>
<td>100.0</td>
<td>113</td>
<td>113</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: author's own research.

### Table 3. Prevalence of arterial hypertension in all the subjects

<table>
<thead>
<tr>
<th>Age</th>
<th>Norm</th>
<th>%</th>
<th>Hypertension</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>280</td>
<td>11.6</td>
<td>19</td>
<td>19</td>
<td>8.9</td>
</tr>
<tr>
<td>9</td>
<td>445</td>
<td>18.4</td>
<td>36</td>
<td>36</td>
<td>16.8</td>
</tr>
<tr>
<td>11</td>
<td>303</td>
<td>12.5</td>
<td>23</td>
<td>23</td>
<td>10.7</td>
</tr>
<tr>
<td>12</td>
<td>361</td>
<td>14.9</td>
<td>26</td>
<td>26</td>
<td>12.1</td>
</tr>
<tr>
<td>14</td>
<td>268</td>
<td>11.1</td>
<td>32</td>
<td>32</td>
<td>15.0</td>
</tr>
<tr>
<td>15</td>
<td>191</td>
<td>7.9</td>
<td>11</td>
<td>11</td>
<td>5.1</td>
</tr>
<tr>
<td>17</td>
<td>571</td>
<td>23.6</td>
<td>67</td>
<td>67</td>
<td>31.3</td>
</tr>
<tr>
<td>Total</td>
<td>2419</td>
<td>100.0</td>
<td>214</td>
<td>214</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: author's own research.
Table 4. Group size according to the size of the metropolitan area

<table>
<thead>
<tr>
<th>Size of the metropolitan area</th>
<th>Norm</th>
<th>Hypertension</th>
<th>All the subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>girls</td>
<td>boys</td>
<td>girls</td>
</tr>
<tr>
<td>Village</td>
<td>114</td>
<td>156</td>
<td>17</td>
</tr>
<tr>
<td>Small town</td>
<td>607</td>
<td>680</td>
<td>42</td>
</tr>
<tr>
<td>Big city</td>
<td>458</td>
<td>404</td>
<td>42</td>
</tr>
<tr>
<td>All together</td>
<td>1179</td>
<td>1240</td>
<td>101</td>
</tr>
<tr>
<td>Total</td>
<td>2419</td>
<td>214</td>
<td>2633</td>
</tr>
</tbody>
</table>

Source: author's own research.

Table 5. The proportion of subjects with normal blood pressure and hypertension according to the size of metropolitan area [%]

<table>
<thead>
<tr>
<th>Size of the metropolitan area</th>
<th>Norm</th>
<th>Hypertension</th>
<th>All the subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>girls</td>
<td>boys</td>
<td>girls</td>
</tr>
<tr>
<td>Village</td>
<td>38.0</td>
<td>52.0</td>
<td>5.7</td>
</tr>
<tr>
<td>Small town</td>
<td>43.7</td>
<td>49.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Big city</td>
<td>48.5</td>
<td>42.8</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Source: author's own research.

Figure 1. Differentiation of the prevalence of hypertension according to the sex of the subjects [%]

Source: author's own research.

Sex and size of the metropolitan area does not differentiate in a statistically significant way the percentage of subjects with hypertension in the group of boys (structure index $z_{\alpha=0.05} = 1.96 > z = 0.82; z = 0.76; z = 0.61$).
However, as far as girls from different metropolitan areas are concerned, the differences become statistically significant:

- for villages and small towns-structure index $z_{\alpha=0.05} = 1.96 < z = 2.07$,
- for villages and big cities-structure index $z_{\alpha=0.05} = 1.96 < z = 2.55$,
- for small towns and big cities-structure index $z_{\alpha=0.05} = 1.96 < z = 2.37$.

The age of the subjects differentiates in a statistically important way the percentage of subjects with arterial hypertension (structure index $z_{\alpha=0.05} = 1.96 < z = 2.46$).

214 subjects were qualified for the arterial hypertension group which constituted 8.1% of the whole group. Among the subjects arterial hypertension was recorded in 7.9% of girls and 8.4% of boys.

Taking into account the size of the metropolitan area in which the subjects live, the highest percentage of the subjects with arterial hypertension was recorded in 17-year-old girls and boys from big cities and 9-year-old girls from villages.

No cases of arterial hypertension have been observed in 11-year-old girls from villages and 11-year-old boys from big cities as well as 12-year-old boys from villages.

Conclusions

A. Januszkiewicz claims that primary arterial hypertension occurs at a young age notably more often than it has been believed. Basing on research, 35% of young people aged 12–18 and 3% of children aged 7–11 have been diagnosed with hypertension.

A connection is sought between this fact and the cardiovascular risk factors such as obesity or lipid disorders. The prevalence of arterial hypertension in the families of the subjects is also of considerable importance. E. Lubre seeks the causes of hypertension in youth in the prevalence of obesity and the condition left untreated can lead in consequence to complications in heart and kidneys functions (Lubre 2010). The research carried out constitutes a valid diagnosis of the conditions recorded in the research project. Indicating the prevalence of changes in functioning of organisms of children and adolescents has been reported to parents and noted down in school files.

Basing on the statistical analysis of the results it has been observed that:

1. The most numerous group of subjects with arterial hypertension were 17-year-old girls (38.6%) and 17-year-old boys (24.8%).
2. The size of metropolitan area is a factor differentiating the prevalence of hypertension in girls.
3. The prevalence of arterial hypertension is the most visible in students from big cities.

References


ASSOCIATIONS BETWEEN MAJOR INDICES OF PHYSICAL DEVELOPMENT AND FITNESS AND THE LEVEL OF ELITE WRESTLER SPECIAL WORK CAPACITY

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2 National Pedagogical Dragomanov University, Ukraine
A Study Design; B Data Collection; C Statistical Analysis; D Manuscript Preparation; E Funds Collection

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Abstract. Objective: The objective of the given work consisted in studying associations between the major indices of physical development (PD) and physical fitness, on the one hand, and the level of special work capacity of elite wrestlers of different weight categories, on the other hand. Material: 147 Ukrainian athletes engaged in Greco-Roman, free-style wrestling and judo served as the subjects. The following methods of studies were used: anthropometry, caliperometry, dynamometry, methods of testing speed-strength fitness and special work capacity of wrestlers, statistical processing and computer modelling. Results: It has been demonstrated that skill level determines ratio and associations of morphometric and speed-strength indices, level of athletes’ special work capacity. Enhancement of skill level results in augmentation of speed-strength fitness, increase of body circumferences, decrease of fat component content, gain of muscular component and muscular development index. Along with the increase of weight category the level of speed-strength fitness and special work capacity decreases. Respective mathematical models were developed. Conclusions: It is recommended to use the developed regression models for modelling, predicting and evaluating special work capacity of highly skilled wrestlers of light, middle and heavy weight categories.

Key words: wrestlers, skill level, weight categories, associations, physical fitness, models

Introduction

Physical development and physical fitness are the most important constituents of fitness structure of elite wrestlers (Karelin 2002; Boyko and Danko 2004; Kolenkov et al. 2012; Jushkov and Savchuk 1985; Zaccagni 2012). Along with functional, mental and technical fitness they provide the achievement of the high level of special work capacity and sports result (Jaric 2003; Jagello et al. 2004; Zen-Pin and Ryder 2004; Pryimakov and Kolenkov 2006; Blais et al. 2007). Carried out analytical studies have allowed to accumulate enormous experimental material about the level of development of individual motor capacities, morphofunctional organization and special work capacity of wrestlers
However, these works have failed to sufficiently reflect the fitness structure (FS) of athletes from system-oriented positions, i.e., the positions of ratio and interaction of its components in the process of providing special physical work capacity (Jagello et al. 2004; Pryimakov et al. 2006; Vardar et al. 2007) and sports results (Koshelev 1996; A. Pryimakov et al. 2006) of wrestlers of different weight categories, skill level, sex, etc. Until now, there is no scientifically substantiated approach to differentiated selection of means and methods for improvement of FS of athletes, depending on the level of morphometric development, the degree of development of motor capacities (MC) and motor skills in wrestlers of different weight categories (Pryimakov 2014), skill level (Pryimakov 2013), sex (Kolenkov et al. 2012), etc. Respective criteria have not been substantiated, and the place of physical fitness (PF) in general FS of athletes of different weight categories, sex, skill level, etc., has not been determined. The necessity of system-oriented approach in the capacity of methodological basis for conducting complex studies of PF structure of athletes specialized in combat sports has been mentioned only in few works (Kolenkov et al. 2012; Pryimakov 2014).

Insufficient covering of the majority of these issues in the literature along with their significance for the theory and practice of wrestling have served as the basis for selection of the direction and the subject of study.

The objective of the given work consisted in studying associations between the major indices of the structure of physical development (PD) and physical fitness, on the one hand, and the level of special work capacity of elite wrestlers of different weight categories, on the other hand.

Methods of studies

The following methods of studies were used: anthropometry, caliperometry, dynamometry, methods of testing speed-strength fitness and special work capacity of wrestlers of different weight categories and skill levels, statistical processing and computer modelling with Statistica application program package (Borovikov 2006), etc.

Indices of height, body mass, body circumference, volume of muscular, bony and adipose tissues, etc. were utilized for evaluation of athletes’ PD (Kolenkov et al. 2012). The level of wrestlers’ PF was evaluated on the basis of recorded speed-strength indices. Test of throwing the partner of equal weight (one arm forward bending throw) in 3 or 5 sets allowed to evaluate special work capacity. In each set time of performance of 15 throws at maximum rate with 1-min interval of passive rest between the sets was recorded (Novikov 1987; Pryimakov et al. 2006; Kolenkov et al. 2012). Coefficient of wrestlers’ special work capacity was calculated (Kolenkov et al. 2012).

For the purpose of comparative evaluation of wrestlers’ PD structure, who differed in skill level, all subjects were divided into two groups (1st group – candidates master of sports/CMS/); 2nd group – masters of sports /MS/, international masters of sports /IMS/ and merited masters of sports /MMS/) in one instance, and into 3 groups (1st – CMS; 2nd – MS; 3rd – IMS and MMS) – in another.

Members of the national teams of Ukraine in different wrestling styles (free-style, Greco-Roman, judo) of different ages (from 20 to 32 years), skill levels and weight categories served as the subjects. From 14 to 110 athletes participated in different studies.

Results of studies

PD indices of wrestlers, presented in Table 1, demonstrate the increase of neck, chest and tensed shoulder circumferences, index of muscular development, the reduction of fat component percentage as well as the tendency to decrease of bony and increase of muscular components of body surface along with the enhancement of athletes’ skill level.
Table 1. Individual indices of physical development of wrestlers of relatively low (CMS) and high (MS, IMS, MMS) skill level

<table>
<thead>
<tr>
<th>Indices</th>
<th>CMS</th>
<th>MS, IMS, MMS</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>71.4 (1.80)</td>
<td>72.7 (1.72)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.5 (0.82)</td>
<td>169.1 (1.37)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Mass-height index (g/cm)</td>
<td>390.3 (7.50)</td>
<td>427.3 (7.88)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Index of muscular development</td>
<td>6.8 (0.88)</td>
<td>9.2 (0.76)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Circumferences (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>neck</td>
<td>38.2 (0.24)</td>
<td>39.4 (0.44)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>chest in rest</td>
<td>94.1 (0.94)</td>
<td>98.5 (1.37)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>chest during inspiration</td>
<td>96.0 (0.96)</td>
<td>101.2 (1.52)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>chest excursion</td>
<td>4.4 (0.24)</td>
<td>5.8 (0.62)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>tensed shoulder</td>
<td>32.45 (0.48)</td>
<td>34.5 (0.50)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>thigh</td>
<td>54.2 (0.61)</td>
<td>59.1 (1.50)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mass-height index (g/cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>50.0 (0.53)</td>
<td>51.3 (0.75)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Chest</td>
<td>17.2 (0.74)</td>
<td>13.8 (0.50)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bony component</td>
<td>17.4 (0.26)</td>
<td>16.7 (0.37)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Body surface (m²)</td>
<td>1.76 (0.02)</td>
<td>1.83 (0.05)</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

Along with the increase of skill level specific character of adaptation changes in morphological component of wrestlers’ FS is also manifested in negative correlations between fat and muscular component ($r = -0.565$, $p = 0.0008$) and between fat and bony component ($r = -0.469$, $p = 0.007$), and in positive correlations between bony and muscular component ($r = 0.421$, $p = 0.01$) and between bony component and index of muscular development ($r = 0.514$, $p = 0.03$). These associations reflect one of the mechanisms of alteration of body composition component proportions with the increase of athletes’ skill level: decrease of fat and increase of muscular components with insignificant changes in bony component.

Linear mathematical models reflecting the strongest dependences of the main morphometric parameters of PD on wrestlers’ skill level are presented in Table 2.

Table 2. Mathematical models of major PD parameter dependence on wrestlers’ skill level (x)

<table>
<thead>
<tr>
<th>Indices</th>
<th>Regression equations (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumferences (cm)</td>
<td></td>
</tr>
<tr>
<td>neck</td>
<td>35.29 + 2.404x</td>
</tr>
<tr>
<td>lower forearm</td>
<td>5.166 + 0.241x</td>
</tr>
<tr>
<td>lower thigh</td>
<td>8.681 + 0.632x</td>
</tr>
<tr>
<td>chest</td>
<td>87.06 + 5.32x</td>
</tr>
<tr>
<td>tensed shoulder</td>
<td>30.21 + 1.56x</td>
</tr>
<tr>
<td>Mass-height index (g/cm)</td>
<td>337.5 + 42.37x</td>
</tr>
</tbody>
</table>

Correlation analysis has demonstrated that skill level of athletes is most closely associated with circumference of the neck ($r = 0.660$, $P < 0.01$), the chest ($r = 0.700$, $p < 0.01$), relaxed ($r = 0.630$, $p < 0.01$) and tensed ($r = 0.565$, $p < 0.01$) shoulder.
Regression models, presented in Table 3, reflect different impact of various combinations of major PD indices of elite wrestlers (circumference of neck, head, chest, shoulder, forearm, thigh, index of muscular development, subcutaneous skinfolds) upon the level of special work capacity.

Table 3. Mathematical models of special work capacity level dependence on major morphometric indices of wrestlers’ FS

| Y₁ = 302.05 + 6.012X₁ – 3.77X₂ – 4.15X₃ ± 11.7 | r = 0.727, p < 0.01
| Y₂ = 91.372 + 1.358X₁ – 1.372X₂ ± 2.69  | r = 0.831, p < 0.01
| Y₃ = 63.684 + 2.52X₁ – 0.983X₂ – 0.0987X₃ ± 3.45  | r = 0.715, p < 0.01
| Y₁ = 249.2 + 4.58X₁ – 4.09X₂ ± 12.7  | r = 0.650, p < 0.01
| Y₃ = 213.4 + 78.5X₄ + 3.3X₅ + 1.12X₆ + 122.4X₇ + 19.5X₈ – 5.96X₉ – 3.45X₁₀ – 76.3X₁₁ ± 42.5  | r = 0.976, p < 0.01
| Y₁ = 4.9 + 0.35X₄ + 0.04X₅ – 0.029X₁₀ – 0.021X₁₁ – 0.097X₁₂ – 0.07X₁₃ ± 0.19  | r = 0.919, p < 0.01

* Notes: Y₁ – total time of executing throws in three series, 15 in each (sec); Y₂ – time of execution 15 throws in the first series (sec); X₁ – thigh circumference (cm); X₂ – chest circumference at rest (cm); X₃ – neck circumference (cm); X₄ – forearm circumference (cm); X₅ – head circumference (cm); X₆ – relaxed shoulder circumference (cm); X₇ – subcutaneous skinfolds under scapula (mm); X₈ – body surface (m²); X₉ – index of muscular development; X₁₀ – tensed shoulder circumference (cm); X₁₁ – subcutaneous skinfolds of thigh (mm); X₁₂ – subcutaneous skinfolds of chin (m); r – correlation coefficient.

Modelling by means of developed regression equations permits to predict orientation of wrestlers’ FS perfection according to different combinations of major indices of their PD in the course of controlled long-term adaptation process. In addition, the highest prediction accuracy is achieved when the 5th and the 6th models are used, determination coefficients of which are equal to 95.2% and 84.4%, respectively.

Analysis of physical fitness indices (Table 4) indicates that highly skilled wrestlers have advantage over relatively low-skill athletes in the level of special work capacity and most of strength and speed-strength indices.

Table 4. Speed-strength fitness indices of wrestlers of high (MS, IMS, MMS) and relatively low (CMS) skill level

<table>
<thead>
<tr>
<th>Indices</th>
<th>MMS, IMS, MS (1)</th>
<th>CMS (2)</th>
<th>Differences</th>
<th>t-student's, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>23.1 ± 0.36, 110</td>
<td>19.0 ± 0.35, 36</td>
<td>21.6</td>
<td>8.15 &lt; 0.01</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>78.4 ± 1.75, 110</td>
<td>76.1 ± 2.78, 36</td>
<td>3.0</td>
<td>0.70 &gt; 0.05</td>
</tr>
<tr>
<td>30 m running (sec)</td>
<td>4.33 ± 0.02, 106</td>
<td>4.44 ± 0.03, 36</td>
<td>2.5</td>
<td>2.62 &lt; 0.01</td>
</tr>
<tr>
<td>Long jump (cm)</td>
<td>249.6 ± 2.87, 42</td>
<td>236.1 ± 4.03, 20</td>
<td>5.7</td>
<td>2.73 &lt; 0.01</td>
</tr>
<tr>
<td>4 m rope climbing (sec)</td>
<td>6.04 ± 0.17, 101</td>
<td>6.84 ± 0.34, 36</td>
<td>11.07</td>
<td>2.11 &lt; 0.05</td>
</tr>
<tr>
<td>Pull-ups in 10 sec (number)</td>
<td>9.9 ± 0.12, 103</td>
<td>9.0 ± 0.31, 36</td>
<td>10.0</td>
<td>2.63 &lt; 0.01</td>
</tr>
<tr>
<td>Push-ups in 10 sec (number)</td>
<td>19.4 ± 0.23, 87</td>
<td>18.0 ± 0.69, 29</td>
<td>7.8</td>
<td>1.92 &gt; 0.05</td>
</tr>
<tr>
<td>Squats with a partner (number)</td>
<td>23.4 ± 0.88, 100</td>
<td>20.9 ± 1.92, 36</td>
<td>12.0</td>
<td>1.20 &gt; 0.05</td>
</tr>
<tr>
<td>Pull-ups (number)</td>
<td>35.4 ± 0.88, 103</td>
<td>30.5 ± 2.31, 36</td>
<td>16.1</td>
<td>1.96 &lt; 0.05</td>
</tr>
<tr>
<td>Push-ups (number)</td>
<td>72.8 ± 1.74, 103</td>
<td>60.6 ± 3.16, 36</td>
<td>20.1</td>
<td>3.39 &lt; 0.01</td>
</tr>
<tr>
<td>Time of performing 45 throws (sec)</td>
<td>88.2 ± 1.70, 105</td>
<td>109.1 ± 3.56, 36</td>
<td>19.2</td>
<td>5.30 &lt; 0.01</td>
</tr>
<tr>
<td>Special work capacity</td>
<td>Work capacity coefficient</td>
<td>1.061 ± 0.004, 105</td>
<td>1.058 ± 0.01, 35</td>
<td>–0.3</td>
</tr>
<tr>
<td>Time of performing 1 throw (sec)</td>
<td>1.96 ± 0.04, 105</td>
<td>2.39 ± 0.09, 36</td>
<td>18.0</td>
<td>5.29 &lt; 0.01</td>
</tr>
</tbody>
</table>
The most apparent advantage of highly skilled athletes is observed in special work capacity test and indices of strength endurance.

Data, presented in Table 5, show that improvement of wrestlers’ motor function along with the increase of their expertise is characterized by enhanced speed and intensity of performing throws.

<table>
<thead>
<tr>
<th>Skill level</th>
<th>Series of throws</th>
<th>Work capacity decrease (%)</th>
<th>Time of performing one throw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>MMS, IMS</td>
<td>X</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>±m</td>
<td>0.60</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>MS</td>
<td>X</td>
<td>31.29</td>
<td>31.26</td>
</tr>
<tr>
<td></td>
<td>±m</td>
<td>0.61</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>CMS</td>
<td>X</td>
<td>34.69</td>
<td>34.80</td>
</tr>
<tr>
<td></td>
<td>±m</td>
<td>1.16</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

The group of the most skilled athletes (MMS and IMS) differs in more stable work capacity in the dynamics of testing: they have the least percent of work capacity decrease by the 5th series of throws – 6.95 ±0.45 % (Table 3).

Regression and factor analysis has shown that the major factors of PF structure in groups of relatively low (CMS) and high (MS, IMS, MMS) skill level are those of special work capacity (42.2% and 31.4% of total dispersion variations, respectively) and speed-strength endurance (18.8 % and 18.1 %).

Improvement of athletes’ skill level is accompanied with the decrease in number of major PF parameters, determining enhancement of wrestlers’ special work capacity, increase of the level of their development and the number of high associations between them.

High linear dependence is manifested between the level of special work capacity and skill level of wrestlers (r = –0.740, p = 0.00001). For instance, performance of 45 throws during specialized test has been accompanied with significant reduction of total testing time along with the increase of wrestlers’ skill level – from 107.4 ±3.99 sec in CMS to 93.9 ±2.13 sec – in MS, and from 74.5 ±2.2 sec in MS to 71.4 ±4.0 sec – in MMS.

Below presented model indicates that 54.8% of the result in special work capacity test is determined by wrestlers’ skill level: y = 132.2 – 18.04x ±14.1, where y – time of performing 45 throws in sec; x – skill level of athletes in c.u. (F = 52.2, p = 0.00001).

Method of stepwise regression has allowed to develop the model, reflecting dependence of the result in special work capacity test (while performing 3 series of throws) upon the major speed-strength indices:

\[ y = 87.2 + 0.31x_1 + 0.564x_2 + 0.32x_3 + 2.66x_4 - 0.186x_5 - 4.62x_6 ±12.6, \]

where y – total time of performing 45 throws in 3 series (sec); x1 – speed of rope climbing (sec); x2 – number of squats with a partner; x3 – weight of athlete (kg); x4 – number of pull-ups; x5 – number of push-ups; x6 – speed of push-ups (number performed in 10 sec).
Modelling by means of this equation has demonstrated that the most informative speed-strength and strength indices, reflecting the level of wrestlers’ special work capacity, are the number of push-ups performed within a definite time interval, the speed of rope climbing and the number of squats with a partner.

Figure 1 illustrates the dynamics of averaged values of time of executing 45 throws in the course of increase of weight categories as well as linear and polynomial graphic models of this dynamics (Figure 1).

![Figure 1. Indices of total time (y, c), expended for execution of 45 one arm forward bending throws by wrestlers of different weight categories (x, kg). ▲ empirical mean group data; ——— linear regression; – – – – – polynomial regression](image)

Polynomial model most accurately approximates the dynamics of wrestlers’ special work capacity during increase of weight category ($r^2 = 0.954, \ p < 0.001$).

Non-linear dynamics of work capacity, significant differences between athletes of light, middle and heavy weight categories served as the basis for differentiated elaboration of model characteristics of wrestlers’ work capacity, that is, in each of three weight groups of athletes (55-60 kg, 66-74 kg, >84 kg).

**Table 6.** Standard scales for estimating special work capacity of elite wrestlers of 3 groups of weight categories

<table>
<thead>
<tr>
<th>Categories (kg)</th>
<th>5.</th>
<th>4.</th>
<th>3.</th>
<th>2.</th>
<th>1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time of 45 throws (sec)</td>
<td>≤46.9</td>
<td>47.0 ≤ 53.9</td>
<td>54.0 ≤ 60.9</td>
<td>61.0 ≤ 74.9</td>
<td>75.0 ≤ 81.9</td>
</tr>
<tr>
<td></td>
<td>≤44.9</td>
<td>45.0 ≤ 53.9</td>
<td>54.0 ≤ 62.9</td>
<td>63.0 ≤ 80.9</td>
<td>81.0 ≤ 89.9</td>
</tr>
<tr>
<td></td>
<td>≤8.9</td>
<td>59.0 ≤ 68.4</td>
<td>68.5 ≤ 77.8</td>
<td>77.9 ≤ 96.8</td>
<td>96.7 ≤ 106.2</td>
</tr>
<tr>
<td>Time of one throw (sec)</td>
<td>≤1.04</td>
<td>1.05 ≤ 1.20</td>
<td>1.21 ≤ 1.35</td>
<td>1.36 ≤ 1.66</td>
<td>1.67 ≤ 1.82</td>
</tr>
<tr>
<td></td>
<td>≤1.00</td>
<td>1.01 ≤ 1.20</td>
<td>1.21 ≤ 1.40</td>
<td>1.41 ≤ 1.80</td>
<td>1.81 ≤ 2.00</td>
</tr>
<tr>
<td></td>
<td>≤1.31</td>
<td>1.32 ≤ 1.52</td>
<td>1.53 ≤ 1.73</td>
<td>1.74 ≤ 2.15</td>
<td>2.16 ≤ 2.36</td>
</tr>
</tbody>
</table>
Method of sygmal deviations was used for elaboration of criteria for estimating special work capacity of elite wrestlers of three groups of weight categories during performance of 45 throws (Table 6).

Presented differentiated scales may be used for estimating the level of wrestlers’ special work capacity in points according to time of execution of 45 throws.

Discussion

Conducted studies demonstrate that skill level and weight category of wrestlers are the most important system-forming factors, determining the level of development, ratio and associations of morphological and speed-strength components of athletes’ fitness structure for provision of the high level of special work capacity. Special work capacity and speed-strength endurance are the major components of PF structure of wrestlers.

One of the most important criteria for improvement of general structure of wrestlers’ PF is the increase of specific role and associations of relatively small number of the major morphometric and functional parameters, determining the level of special work capacity of highly skilled athletes.

Improvement of PF structure in the dynamics of wrestler skill level enhancement is accompanied with: increase of neck, chest, tensed and relaxed shoulder, and thigh circumferences; reduction of adipose component percentage; tendency to decrease of bony component; increase of body surface and muscular component, augmentation of muscular development index.

Different level of special work capacity of wrestlers of light, middle and heavy weight categories is indicative of the necessity of differentiated approach to its estimation in athletes with different body mass.

Modelling by means of developed equations permits to predict special work capacity level in highly skilled wrestlers at different variants of ratio and associations of the major parameters of physical development and physical fitness.

Elaborated models may be also used for constructing differentiated estimation scales according to complex of the major morphometric and functional parameters as well as for revealing potential optimum combinations of the major indices of PD and PF in order to provide high physical work capacity in the course of controlled long-term adaptation process.

Conclusion

Special work capacity of highly skilled wrestlers of three groups of weight categories (light, middle and heavy) may be evaluated by means of developed differentiated standard scales according to both total time of performing 45 one arm forward bending throws and time of one throw execution.

Prospects for further development of chosen direction consists in extension of studies focused on examination of ratios and associations of PF structure components, elaboration of respective criteria, standard scales and prognostic models of special work capacity level for each group of athletes, on a case by case basis according to individual weight categories, sex and age, which is quite important for more accurate management of the process of preparation, control and selection of athletes.
References


Jagello V., Tkachuk V., Blakh V. Correlation of anthropometric parameters with a level of sporting skill of the highly qualified judoists of Poland. Physical Education of the Students of Creative Profession. 2004; 2: 36.


CHANGES IN BAR VELOCITY AND MUSCULAR ACTIVITY DURING THE BENCH PRESS IN RELATION TO THE LOAD LIFTED

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Abstract. The purpose of the study was to determine velocity changes in relation to the load lifted along with their muscular activity. Twenty athletes representing different sport disciplines, familiar with the flat bench press took part in the research project. The ANOVA analysis revealed a significantly higher effect on range of mean velocity (F = 128.34; η² = 1.22 with p = 0.001) and maximal velocity (F = 73.31; η² = 0.81 with p = 0.001) to measured loads (70÷100% 1-RM) in ascending phase. Tukey’s post-hoc tests revealed a statistically significant difference between 70% and 100% 1-RM loads, in mean velocity with p = 0.001 and maximal velocity with p = 0.001. Similarly the results revealed a statistically significant difference between 80% and 100% 1-RM loads in mean velocity (p = 0.012) and maximal velocity (p = 0.021) during the ascending phase. Relationship between velocity and the muscles activity indicates that the anterior deltoid and latissimus dorsi muscles show synergy and a significant relationship for loads 90 and 100% 1-RM. The triceps brachii muscle shows a higher relationship with velocity of the barbell for loads 70% and 80%, then the relationship of the pectoralis major muscle with velocity only for 90% 1-RM.

Key words: sticking region, EMG, bar velocity

Introduction

The bench press is one of the most popular exercises used in strength training for the upper body. A successful bench press lift is performed when the barbell is first lowered to the chest and then moved to a fully extended position. The bench press consists of two phases: the ascending and descending phase. The ascending phase seems more significant for bench press performance (Barnett et al. 1995; Requena et al. 2005; Welsch et al. 2005;
Van den Tillaar and Ettema 2009; Król et al. 2010). Several studies have investigated the kinematics of the bench press, and have shown that there is a sticking region (SR) during maximal lifts (Madsen and McLaughlin 1984). In this region, the pushing force is less than gravity on the barbell, leading to a deceleration of the barbell. It is defined as the movement region from peak velocity ($V_{\text{max}}$) to the first local minimum velocity ($V_{\text{min}}$) of the upward barbell movement (van den Tillaar and Ettema 2009). Van den Tillaar and Ettema (2009) found that the muscle activity of only the agonistic pectoralis major muscles and the anterior part of the deltoid muscles are responsible for the SR. They proposed that the start of a SR occurs, not because of a lack of strength, but due to diminishing of enhanced force (i.e., potentiation induced by the immediately preceding eccentric contraction) at the start of the concentric movement. When this strength capacity diminishes, a delayed neural reaction occurs (Walshe et al. 1998; Santana et al. 2007), enhancing the muscle activity level, so that the resultant force matches the demands of the attempt. Thus, the delay in neural activity would be the cause of the SR, whereas the increase itself results in the overcoming of the sticking region (Van den Tillaar and Ettema 2009).

In the literature there is a lack of information concerning the changes of velocity of the barbell in relation to the activity of the muscles at different loads. There is significantly more data regarding only the velocity of the bar during the bench press. Duffey and Challis (2007) studied the effects of fatigue on this kinematic parameter. On the other hand Pearson et al. (2009) assessed the velocity changes resulting from increased load of the bar on a Smith machine. Similar studies were conducted by Sakamoto and Sinclair (2006), yet the barbell was pressed slowly, moderately, very fast and explosively. This information is of great significance in assessment of the technique of the bench press motion. However, of more importance is the knowledge related to the dynamics of the movement, what is associated with the activity of the muscles engaged in this motor task.

The purpose of the study was to determine velocity changes in relation to the load lifted along with their muscular activity.

**Methods**

**Participants**

Twenty athletes representing different sport disciplines, familiar with the flat bench press took part in the research project. Their average age, body mass, height and 1-RM equalled respectively: (age: 24.7 ±0.9 yrs; body mass: 80.2 ±8.6 kg; height: 176.8 ±8.0 cm; 1-RM (one repetition maximum): 107.1 ±19.4 kg). The participants were informed about the nature of this study and, prior to data collection, they were required to sign a declaration form for participation in accordance with the Helsinki Declaration. The participants did not perform any resistance training of the upper body 72 hours prior to testing. The research project was approved by the Bioethics Committee of the Academy of Physical Education in Katowice.

**Exercise protocol**

The exercise protocol included a warm-up and the main session. The participants followed the same warm up procedure as used by Saeterbakken et al. (2011). They started with a general warm-up of 15 min, followed by a specific warm-up, which included four sets of the bench press: 1) twenty repetitions at 30% of 1-RM, 2) twelve repetitions at 50% of 1-RM, 3) six repetitions at 70% of 1-RM and 4) one repetition at 85% of 1-RM. The percentage of the 1-RM was estimated based on self-reported 1-RM of the participants. The self-reported 1RM was set
according to the information given by the participants on maximal lifts performed in the previous three weeks (Reynolds et al. 2006).

The main session included four sets of one repetition of the flat bench press, using 70, 80, 90, and 100% of the estimated maximum load. After approaching the estimated maximum load, the resistance was increased, until the subjects could not lift the bar. For velocity and electromyography analysis bench press attempts with the following loads were considered: 70, 80, 90, 100% 1-RM. In the main session each of the subjects performed from 6 to 9 sets to reach his individual 1RM. Five minute rest periods were provided between sets. After cessation of all the bench press attempts, three 3 s trials of static effort in the bench press position were performed to normalize MVIC.

The exercise protocol was conducted with free weights, with an Olympic bar and a flat bench. During the execution of the bench press, the back and head of the participants remained on the bench, their knees flexed at approximately 90 degrees, while the feet were placed flat on the ground. The width of the bar grip equaled 81 cm between the index fingers, what is the greatest value permitted by the International Powerlifting Federation. Two spotters were used during all bench press attempts to provide safety for the participants. The subjects lowered the bar in a controlled manner, until touching the chest, and then performed the pressing action, without stopping until arms were fully extended.

**3D kinematics and electromyography**

In following research a complex analysis of the movement was performed, with the use of the BTS SMART-E system (BTS Bioengineering, Italy) which consisted of six infrared cameras (120Hz) and a wireless module to measure bioelectric activity of the major muscles involved in the bench press.

The EMG signals were measured by a Pocket EMG System (BTS Company, Italy). All active channels were the same, and the measuring range was fitted to the subject (typically ±10 mV). EMG activity of 4 muscles was measured: pectoralis major, anterior deltoid, triceps brachii (long head) and latissimus dorsi. Before placing the gel coated self-adhesive electrodes (Dri-Stick Silver circular sEMG Electrodes AE-131, NeuroDyne Medical, USA), the skin was shaved, abraded and washed with alcohol. The electrodes (11 mm contact diameter and a 2 cm center-to-center distance) were placed along the presumed direction of the underlying muscle fiber according to the recommendations by SENIAM (Hermens et al. 2000; Lehman et al. 2006). To minimize noise induced from external sources, the EMG signal was amplified and filtered using a preamplifier located as near the pickup point as possible. The EMG signals were sampled at a rate of 1000 Hz. Signals were filtered with a cut off frequency of 8 Hz and 450 Hz.

**Statistical analysis**

After calculating the average values (x) and standard deviations (±SD), particular groups of presses with different loads were compared by ANOVA. The statistical analysis was directed at determining dependent variables differentiated by the independent variable (Maszczyk et al. 2011, 2012). Effect sizes (partial eta squared η² and Cohen’s d) were reported for results, where appropriate. Parametric effect sizes were defined as large d > 0.8, moderate as between 0.8 and 0.5, and a small defined as < 0.5 (Cohen 1988). Between all of the variables, correlation coefficients were determined with Pearson’s rank order test. Statistical significance was set at p < 0.05. All statistical analyses were performed using Statistica 9.1 with neural network module, and Microsoft Office – Excel 2010 packets.
Results

Changes in bench press velocity according to different loads are presented in Figure 1.

![Figure 1. Velocity of the bar during the ascending phase in the flat bench press with a load of a. 70% 1-RM; b. 80 1-RM; c. 90 1-RM; d. 100% 1-RM](image)

Multivariate analysis of variance (ANOVA) revealed a significantly higher effect on range of mean velocity ($F = 128.34; \eta^2 = 1.22$ with $p = 0.001$) and maximal velocity ($F = 73.31; \eta^2 = 0.81$ with $p = 0.001$) to measured loads (70÷100% 1-RM) in ascending phase. Tukey’s post-hoc tests revealed a statistically significant difference between 70% and 100% 1-RM loads, in mean velocity with $p = 0.001$ and maximal velocity with $p = 0.001$. Similarly the results revealed a statistically significant difference between 80% and 100% 1-RM loads in mean velocity ($p = 0.012$) and maximal velocity ($p = 0.021$) during the ascending phase.

Table 1. Bioelectrical activity muscles (MVIC): pectoralis major, deltoïd, triceps brachii and latissimus dorsi during ascending phase flat bench pressing on the load of 70, 80, 90 and 100% 1-RM

<table>
<thead>
<tr>
<th>Value of the load</th>
<th>Pectoralis major</th>
<th>Deltoid</th>
<th>Triceps brachii</th>
<th>Latissimus Dorsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% 1-RM</td>
<td>97.6 ±26.6</td>
<td>78.8 ±23.6</td>
<td>64.8 ±26</td>
<td>59.6 ±17.3</td>
</tr>
<tr>
<td>80% 1-RM</td>
<td>98.2 ±26.4</td>
<td>83.8 ±22.2</td>
<td>78.8 ±32.7</td>
<td>69.6 ±20.7</td>
</tr>
<tr>
<td>90% 1-RM</td>
<td>101.4 ±21.1</td>
<td>94.6 ±23.2</td>
<td>99.1 ±37</td>
<td>83.9 ±26.6</td>
</tr>
<tr>
<td>100% 1-RM</td>
<td>98.7 ±19.2</td>
<td>106.2 ±20.9</td>
<td>118.9 ±37.7</td>
<td>105.5 ±28.9</td>
</tr>
<tr>
<td>(\bar{X} \pm SD)</td>
<td>99.0 ±1.7</td>
<td>90.8 ±12.2</td>
<td>90.4 ±23.7</td>
<td>79.7 ±19.9</td>
</tr>
</tbody>
</table>
Values of bioelectrical activity of the evaluated muscles (MVIC): pectoralis major, deltoid, triceps brachii and latissimus dorsi during the ascending phase of the flat bench press with the load of 70, 80, 90 and 100% 1-RM are presented in Table 1.

The most statistically significant positive correlations between MVIC and the pectoralis major, deltoid, triceps brachii and latissimus dorsi muscles and velocity during the ascending phase of the bench press are presented in Table 2. Considering the relationship between the velocity of the bar and the bioelectrical activity of the main muscle groups participating in the bench press, in attempts with a load of 70 and 80% of 1 RM, the correlation coefficients were very high and positive only in case of the triceps brachii. Also a significant, positive correlation with bar velocity was observed for the pectoralis major muscle with the load of 90% of 1RM.

Discussion

In bench press attempts with a load of 70 and 80% 1RM only one peak of vertical velocity was registered during the ascending phase of the movement. On the contrary during lifts with 90 and 100% 1-RM, a sticking point appeared, during which the velocity reached minimum values (Duffey and Challis 2007; Van den Tillaar and Ettema 2009; Saeterbakken et al. 2011). Van Den Tillaar and Ettema (2009) searching for the causes of decreased velocity during the bench press movement, conclude that the sticking point is not caused by the lack of strength itself, but a delay of neural signals from the triceps brachii to the pectoralis major and deltoid muscles. The vertical component of bar velocity decreases with a rise in external load, in relations to mean values in the ascending phase as well as to maximum velocity (peak velocity).

The most significant differences for both mean and maximal bar velocity occur between 70 and 100% 1-RM, as well as between 80 and 100% 1RM. These differences are associated with a decrease in velocity and the appearance of the sticking region. Deceleration was higher in lifts with the maximal load, which may have been caused by diminishing potentiation of the contractile elements (Walshe et al. 1998; Konrad 2005; Reynolds et al. 2006; Trebs et al. 2010). Furthermore, the difference in lifted weight was strongly associated with a significant increase in bioelectrical activity of all the studied muscles.

The relationship between the velocity of the bar and the bioelectrical activity of the studied muscles, indicate that for loads 70 and 80% 1-RM, an increase in muscular activity of the triceps brachii causes an increase of bar velocity during the bench press.

The increase in bar velocity for the 90% of 1RM load is caused by increased activity of the pectoralis major, deltoid and latissimus dorsi muscles.

These relationships change significantly during lifts with a load of 100% 1RM, where the decrease in bar velocity is caused by an increase in the bioelectrical activity of the deltoid and latissimus dorsi muscles. This may indicate that a higher activity of these muscle groups is significantly related to flat bench press performance.

In the conducted research the average bar velocity decreased respectively from 0.515 ±0.09 m/s with a load of 70% 1-RM through 0.415 ±0.09 m/s with 80% 1-RM to 0.325 ±0.06 m/s with 90% 1-RM down to 0.251 ±0.07 m/s with the maximum load.

It must be indicated that during the lift with 90 and 100% 1RM the peak bar velocities are reached for the second time during the ascending phase of the bench press motion. During the minimum bar velocity in the lift with 100% load, the bar traveled 37% of the entire path of the movement.
In case of Landers et al. research (1985) it was 41.8%, in Madsens and McLaughlins studies (1984) it reached 50.2%, while Elliott et al. (1989) recorded a value of 47.9%. Duffey and Challis (2007) evaluated the effects of fatigue on bar kinematics during the bench press. In 18 subjects the peak bar velocity during the first repetition of the bench press with a load of 75% 1-RM equaled 0.46 ±0.11 m/s while in the last repetition of this set it dropped to 0.25 ±0.08 m/s. The tested subjects in this experiment performed on the average 10 ±3 repetitions. In the attempt with 100% 1-RM load peak bar velocity reached 0.35 m/s, and was attained at the end of the ascending phase.

Practical Implications

Relationship between velocity and the muscles activity indicates that the anterior deltoid and latissimus dorsi muscles show synergy and a significant relationship for loads 90 and 100% 1-RM. The triceps brachii muscle shows a higher relationship with velocity of the barbell for loads 70% and 80%, then the relationship of the pectoralis major muscle with velocity only for 90% 1-RM. Future studies in bench press should be conducted for loads over 100% 1-RM for determining the velocity changes and their relationship with muscles activity. During maximal loading (100% 1-RM) the pectoralis major muscle decreases its activity in the ascending phase compared to lower loads. Most strength training references indicate that the pectoralis major is the most significant muscle, engaged in the flat bench press. The results of our research indicate that to lift heavy loads in the flat bench press the athletes must significantly develop the anterior deltoid and triceps brachii muscles. The bioelectrical activity of particular muscles changes significantly during different external load. The results and practical implications of this research conducted on the bench press may be applied to other resistance exercises.

Acknowledgement

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References


FROM PAST TILL PRESENCE
— THE QUALITY OF GERMAN PHYSICAL ACTIVITY KINDERGARTEN (PAK)

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Abstract. Physical Activity Education (PAE) has always been playing an important role in the history of Early Childhood Education (ECE) in Germany and its institutionalized form called “Kindergarten”. As a key feature of Kindergarten quality Physical Activity (PA) was originally considered to be either a compensation for children’s health dangers along with the neglect by their hard working mothers or a mere medium for other developmental fields such as cognition or social behavior. The subjectively observed outcome for the pedagogues was far from empirically objective evidence. Till the 1970s neither the technical term “quality” nor any empirical quality standards existed in German ECE to assess the effect of PA in Kindergarten. This fairly hasn’t changed yet although some general findings of high quality effects can be reported as well as PA specific results from a recent review on systematic PAE programmes. Despite this fact, Germany’s organized sports associations (OSA) installed 1759 Physical Activity Kindergarten (PAK) with great expectations in their overall positive developmental effect. For quality assurance some criteria were developed to achieve a minimum standard level. Subsequently a very popular license originated without having evidence for its positive outcome. A randomized, controlled longitudinal study is still to come.

Key words: physical activity kindergarten, quality, early childhood education

Introduction

What makes a good or even ideal Kindergarten? And what role does Physical Activity (PA) as an educational and health dimension play in this question? As long as the researcher’s notion doesn’t only refer to a single institution of Early Childhood Education (ECE) but to the Kindergarten as such, probably the most elaborated answer given in Germany lies in the model of Tietze and Viernickel (2007). Not less than 1783 quality criteria, divided up into 21 quality dimensions and six transversal pedagogic principles claim “best practice” (dito, p. 27). The sheer amount of criteria derives from a nationwide quality initiative (NQI) by the Federal Ministry of Family, Elderly People, Women
and Youth (BMFSFJ) aiming at a consensual framework between scientists, politicians and the municipal quality managers for what the overall quality is made of in German Kindergarten (see Table 1).

**Table 1.** The 1,783 quality criteria divided up into 21 dimensions and 6 transversal pedagogical principles of German high Kindergarten quality according to the NQI by Tietze and Viernickel (2007)

<table>
<thead>
<tr>
<th>Rooms and spatial framework</th>
<th>6 transversal principles</th>
<th>21 quality dimensions</th>
<th>The 8 specific management quality criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 1 14 21 9 12 19 13 9</td>
<td>21 dimensions</td>
<td>21 quality dimensions</td>
<td>6 transversal pedagogical principles</td>
</tr>
<tr>
<td>Teacher-child-interaction</td>
<td>10 20 18 16 12 15 54 36 59</td>
<td>17 16 12 21 18 32 11 23 7 24 19</td>
<td>440 57 organization of daily work (time management)</td>
</tr>
<tr>
<td>Planning</td>
<td>14 29 27 47 20 31 26 50 39</td>
<td>12 13 15 19 24 50 24 21 13 8 27</td>
<td>509 34 human resources and personnel management</td>
</tr>
<tr>
<td>Diversity</td>
<td>7 0 6 7 4 6 26 9 26 9 10</td>
<td>4 8 12 10 6 2 0 1 0 2 129 18 conceptual development</td>
<td></td>
</tr>
<tr>
<td>Individualization</td>
<td>4 7 4 6 7 3 9 8 22 5 3 6 5 6 15 6 6 6 10 6 144 12 public relation and networking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participation</td>
<td>21 11 14 7 9 6 13 15 15 10</td>
<td>10 12 8 17 7 7 2 3 10 7 204 5 political engagement</td>
<td></td>
</tr>
<tr>
<td>Vertical summation</td>
<td>74 68 83 104 61 73 120 148 153 69</td>
<td>51 63 75 85 118 59 57 34 60 64 1619 11 quality control and development</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>↓ 8 finance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>plus: 164 total of 1,783 quality criteria</td>
</tr>
</tbody>
</table>

With a closer look from the Physical Activity Kindergarten (PAK) perspective it is crucial to know why there should be exactly 69 quality criteria and not 120 or just 5. The simple answer is: We just don’t know, because all of the 69 criteria haven’t been confirmed yet in a study design that takes the developmental outcome of children by a randomized, controlled and longitudinal empirical framework into concern. Therefore, to understand why these specific quality features might be the right ones, two ways of explanation ought to be followed: first, one throws a glance at the historical roots of PAK in Germany to deduce the consolidated experience and the knowledge of best practice throughout the last 250 years. Second, one collects all data existing in general about high quality programs designed for ECE-Physical Activity interventions in Germany. Both ways will be shown in the following.
Historical Roots

Worldwide the German pedagogue Friedrich Wilhelm August Fröbel (1782–1852) is supposed to be the inventor of the Kindergarten as the earliest type of institutional education in child development. In fact, this is a downright error in many of the literature about the history of German Kindergarten (Aden-Grossmann 2011; Konrad 2012). It was Johann Friedrich Oberlin (1740–1826) instead, a German cleric and pedagogue, who adopted the already existing idea of the Alsace-Lorraine Sara Banzet to give very young, hungry and neglected children a shelter (Burckhardt 1843a; Psczolla 1979). These snuggeries where gradually combined with more ambitious care in terms of reasonable activity and education, e.g. learning a foreign language (French), reading and writing, natural sciences and knitting. The latter is the reason why they were called “Strickstuben” (French: “poeles à tricoter”) or “knitting snuggeries”. Furthermore, Oberlin attached great importance to PA by playing physical games. On the one hand his aim was to strengthen the children’s organism and health, on the other to improve social behaviour by PA (Pelser 2002). Altogether this very early form of Kindergarten already included the most important so called developmental areas or educational fields of modern German ECE-curriculums such as language, nature, cognition, body and health, motor and social development and ethical/religious questions (MKJS 2011; BSASFF 2012).

Beside this public-clerical approach supporting ECE, the private-economic engagement of Robert Owen (1771–1858) heavily influenced an additional type of German Kindergarten, so called “Betriebskindergarten” or “company-run childcare/daycare facility” (Höltershinken 2003). Established in 1816 at the Scottish New Lanark during the Industrialization, his “Infant Schools” should relieve the hard working mothers from nursing their children, giving the former the opportunity to attend regular work throughout the day and the latter ones to read, write, knit and play physical games especially outdoors in light and fresh air (Owen 1841). Similar to Oberlin’s Strickstuben the Infant Schools not only took the important role of PA for the overall development of children into account but also Kindergarten as the fundament of a new, meaning better society (Owen 1813; Owen 1840).

Almost 50 Years later a second important historical step was taken with the “Kinderbewahranstalten”. These daycare centres were ECE-facilities for all children in the rapidly growing cities, were poverty, disease, crime and neglect were widespread. In terms of education, it is reported that there was (a) a sheer non-education by the mothers due to absence, going to work, (b) a bad education by surrogate mothers, neighbours or others, (c) a bad education by the mother herself as she had no time or expertise nor patience (Chimani 1832; Bönig 2012). At that time the concept by Johann Georg Wirth (1807-1851) on the one hand focused on the unpretentious care of the neglected children. On the other hand Kinderbewahranstalten not only supported the mothers and families by setting the parents free for work but to teach the 2–6-year-old in handcraft, singing, praying and religion, memory tasks, writing, reading, speaking clearly, arithmetic and: physical activity. Again, beside nutrition and clothing PA was considered to be the most important tool for generating health and a strong organism in ECE. Furthermore, cognitive stimulation and the training of social behaviour were serious goals of this type of Kindergarten. The PA-curriculum consisted of stretching, walking (sometimes military marching), running, jumping and bouncing around. Wirth especially accentuated the social, motor and health profits of playing outdoors on the facility’s own playground. Some years later the “Kleinkindschulen”, e.g. by Johannes Fölsing (1816–1882), were based on the same previous content but with a new emphasis highlighting the preparation for real school by extending and deepening learning exercise. That comprised a disciplined type of learning and more earnest, functionalized play. This type of Kindergarten, more school than an appropriate ECE-centre, used PA (“Leibeserziehung”) as a compensation for the more intellectual and cognitive challenging instruction based learning (Fölsing 1846, 1848). In the course of this major milestone
along the historical pathway of German Kindergarten Friedrich Wilhelm August Fröbel (1782-1852) introduced the technical term “Kindergarten” in the context of a institutionalized setting of ECE:

Human as a child, like a flower, a blossom on a tree: that's how children relate to human mankind, a recurrent appearance of a new mankind (1874: 470).

In the line of other pedagogical reformers Fröbel defined Kindergarten as the breeding ground of a new and better society. And nothing less but the specific goals, content and methods of this Kindergarten was the conceptual framework of the socially redesign on a nationwide scale. Interestingly enough play, the right play material (“Spielgaben”) and physical activity was supposed to be a major fundamental educational tool therein.

To draw a first conclusion of this historical root, the answer to the opening question what a very good Kindergarten is made of, can be easily given for the 18th and middle of the 19th century: First, much is about the satisfaction of basic needs of children, wherein PA plays a dominant role. Second, high quality is derived from the success Kindergarten can prepare children for the requirements of the subsequent learning school. Still the quality discussion of that time stays at a very early stage of whether or not some of the little amount of quality criteria is existent on a nominal or ordinal scale at maximum (yes vs. no, more vs. less). Giving consideration to the objective empirical effects of a distinguished pedagogical measure, method, process or arrangement the standard of discussion remained on a very low scale at that time.

This changed when the Prussian government took over the educational system between around 1850 till 1918. They realized that the main idea of forming a new society by institutionalized ECE was somehow dangerous for their own political enterprise (Nacke 1853; Stiehl 1858). Concurrently or just because of this the Prussian government tried to use the recognizable if not measurable effects of Kindergarten themselves. The children were trained with high discipline for new goals e.g. strong patriotism, loyalty to the German emperor and preparation for future wars. Practically the boys were motivated by playing war games (Figure 1) and exercising in marching and troop games (Figure 2), building trenches in the sandpit or tinkering military equipment. High PA-quality in Kindergarten was then derived from the success the education prepared well for serving the Prussian government.

Figure 1. War game “Artilla” as a means of hand motor education for boys – Academy of Arts Dresden, picture print of the original advert in 1916. By courtesy of Karl-Heinz Stamm, Glauchau
Gradually new pedagogical ideas tried to resist the educational suppression by reinventing the perspective on childhood as such. Initiated by a former Kindergarten teacher of Fröbel, Henriette Schrader-Breymann (1827–1899), quality in Kindergarten was less measured according to neither the preparation success for school nor the repression of developmental fields in order to form dutiful soldiers (1894/1962). Instead, by the end of the 19th century, the so called “Reformpädagogik” (Engl.: “reformist pedagogy” or “progressive education”) gave back the principles of individualization, total developmental support for children, co-operative relationship with the teacher, self-determined leisure time activities and the experience of nature and freedom. Especially Maria Montessori (1870–1952) heavily influenced the ECE-system with a new picture portraying children being active, creative, constructive and competent draftsmen of themselves (Ital.: “construttore”) (Montessori 1965, 1972). The German “Montessori-Kindergarten” in 1919 by Clara Grunwald (1877–1943) was consequently designed as a virtual PA-Kindergarten, where children learned and grew up locomotively autonomous and self-reliant using specially designed materials and learning environments (Grunwald 1920, 1995). So far, physical education has never been so important.

Ironically, the predominant role of PA in ECE not only persisted till 1933, when Reformpädagogik ideas were displaced by National Socialismus. On the contrary, the Nazis even strengthened PA education (PAE) to the utmost conceivable state. The leading ECE principles of this new “Leibeserziehung” then were: selection of the strongest children to further support them and filtering the weak ones, body hygiene and racial health, discipline and absolute obedience to the “Führer” and the willingness to sacrifice oneself for one’s own country (Rauschning 1940; Vorländer 1988). These political goals were transformed into concrete exercises and PA-units as there were athletics with running, throwing (as a preparation for using the hand grenade) and jumping, outdoor gymnastics (fresh air and light hypothesis; Benzing 1942) or competition games with winners and losers in terms of the selection quality feature (Ivers 1935). For the first time, the quality outcome and effects of PAE-efforts were empirically measured e.g. with motor diagnostic in athletics. In addition, three scientific institutes were founded to explore the deeper origin of race psychology and development to give the Kindergarten teachers precise information about how
to execute high quality PA-didactics (PAD) in terms of National Socialism ideology. Overall, PAE was the key to a total quality management in ECE with a new Aryan race as the target group.

After the Second World War the ECE-system was completely devastated. The need for a reliable, innocuous PAD led the pedagogues back to the ideas of the Reformpädagogik, were PA was the fundament of physically exploring nature and culture. The facilities were still called Kindergarten and were again given a strong part in the educational system of the new Federal Republic of Germany (western part) by law. Even more, in the 1970s the powerful German Education Council officially referred to the term “quality” for the very first time by using scientifically generated data on an empirical-objective basis. In the course of this scientifically grounded ECE the introduction of what we currently know the “Bewegungskindergarten” or Physical Activity Kindergarten (PAK) took place.

The first type of PAK called “Sportkindergarten” was founded in 1972 at Freiburg i.Br. by a local gymnastics club (Zimmer 1993; Schaffner, 2005). The quintessence of modern PAK in contrast to the mere additive way of using PA as an educational medium was to define PA as the inner core of the pedagogic concept of an ECE-facility. However, this integrated and transversal strategy at that time was designed to prepare mainly for the sports culture, meaning a strong focus on training principles and motor skill acquisition rather than a broad and self-directed experience of whatever learning situation in a variable motor developmental perspective. The first aspect mentioned became known as the education for sport in the sense of simply teaching an already existing sport culture with its corresponding techniques. The second aspect, education through sport/physical activity, underlined the wide range of motor situations not necessarily dependent on cultural guidelines. It refers to a free and open motor development using human motor behavior not only as a means of transporting other developmental fields such as cognition, language, social behavior or health – just as Oberlin did 200 years ago (Prohl 1999). But also as a means for itself, meaning PA without any deeper pedagogical requirements but just for fun and as a human basic need. Especially Zimmer appears to be a prominent pioneer of this new scientific understanding of sport pedagogy in Kindergarten called “Bewegungserziehung” (1993, 2006) which is currently pursued by Schwarz (2014a) on an even more empirical basis. Today we exactly find 1759 PAKs in Germany, licensed by the specific OSA of each federal state in Germany of which 16 exist (status: 31.12.2014, Schwarz 2015). That’s 3.25% of all ECE-facilities (Destatis 2014) with a monthly growth rate of 17 PAKs all over Germany. The crucial question within the current quality debate is whether these modern PAKs can really keep the promise they pretend, due to an overall positive effect on relevant developmental fields.

**General and specific empirical evidence**

Until now not a single empirical study on a reliable, objective or valid level has been published in Germany to examine the sustainable effects of a modern OSA-licensed PAK on distinguished developmental fields except one to come (Schwarz 2015, in prep.). The only thing we know is a collection of all the quality criteria PAKs consist of, five to eleven in number: (1) co-operation with sports clubs or other health and sports related institutions, (2) a high qualification of the PE Kindergarten teachers in special courses, (3) a designated pedagogical concept with PA and motor development at its heart, (4) offering an appropriate time to move and being physically active indoors and outdoors, (5) special activity rooms (“Bewegungsräume”) both indoors and outdoors, (6) the right material, (7) family partnership (work and act together with the parents), (8) public relations and networking, (9) documentation of all quality measures, (10) mobility of parents bringing their children to Kindergarten and finally (11) the motor safety of...
the facility. But can a maximum amount of eleven criteria encompass the entire PA-quality of a complex ECE-centre, even more if the general NQI suggests 69 features? Apart from empirical evidence this rhetorical question can be critically answered by a simple theoretical argumentation. Taking the feature number five “special activity rooms” into account very often the PAK concepts speak of “enough”, “appropriate”, “stimulating” or “childlike” space. Still, when is “enough” enough? The only satisfactory answer obviously is a quantitative one, because it helps to precisely differ a good from a bad activity space. No one can say – using for example a binary logistic regression – whether the Odds Ratio (OR) of more or less 10m² outdoor space makes the significant difference with a high power in a certain dimension of developmental promotion. Thus even the little amount of motor quality criteria of PAKs tends to have weaknesses in its construction of validity within as they lack of accurate cutoffs. Furthermore, the PAK criteria are predominantly of a structural character neglecting the vital processes. As the pioneer of defining “quality” as such in the medical and health area, Avedis Donabedian (1966, 1980), differentiates between three quality dimensions, namely structure (a. input, b. organization), process (a. content, b. configuration) and outcome (a. end point, b. impact) it is quite obvious, that most of the PAK criteria can be placed singularly in the structural dimension. Table 2 shows the transformation of the Donabedian model on an ECE-facility in general and PAKs specifically.

Table 2. Fundamental model of quality dimensions transferred to ECE facilities and PAKs according to Donabedian (1966, 1980)

<table>
<thead>
<tr>
<th>Structure: Basic meaning:</th>
<th>Process: Basic meaning:</th>
<th>Outcome: Basic meaning:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defines the relatively stable framework for the activities of people in an organization and the results of their actions. The spatial, time, financial, personal and material resources belong to this dimension.</td>
<td>Total of all observable activities and services that produce an outcome in type and number Examples in PAK: – Familiarization and admission of children – Interaction with children (e.g. responsivity) – Direct co-operation with parents</td>
<td>The observable results and effects on the target group that evidently can be derived from the overall input (input-outcome-difference) Examples in PAK: – Well-being of children – Satisfaction of parents – Developmental progress of the children in the educational fields of cognition, language, body and health, physical activity, sensual development, social behaviour, religion, etc. – Prosperity of society (overall effects of ECE on later outcomes e.g. higher net-incomes, lower crime rate, etc.)</td>
</tr>
<tr>
<td>Examples in PAK: – Size of facility (m²) – teacher-children-ratio – Size of children groups (units) – Grade of staff qualification – Type of working material and toys – Network and co-operation agreement and treaties – Safety requirements and hygiene – Education curriculum and concept – Number and content of further job training</td>
<td>Examples in PAK: – Involvement of parents into the day-care and total quality management (e.g. workshops conducted by parents) – Interaction between day-care manager and municipality – Visibility of content, goals and results of the everyday work (e.g. pictures pinned on the information board, data documentation, etc.)</td>
<td>Examples in PAK: – Means of scaffolding e.g. in the gymnasium</td>
</tr>
</tbody>
</table>

Tietze (1998) and Tietze et al. (2005) examined the influence of the structural and the process dimensions on the outcome as measured by the developmental progress in selected fields of ECE. Accordingly it seems evident that – the structural input considerably influences the pedagogical process quality ($R^2 = 0.48**$; blockwise-hierarchical regression) i.e. nearly half of the statistical differences correlating to process quality may be explained by variables of structural quality. That especially applies for the job experience of Kindergarten teachers, the teacher-children-relation (e.g. 1 : 8), the duration of opening hours and the space offered (m²).
Second, the quality of pedagogical processes preferentially in families and subordinately in ECE-facilities significantly correlate with the social \( R^2 \approx 0.20 \), linguistic \( R^2 \approx 0.32 \) and the outcome of life competence \( R^2 \approx 0.31 \).

Dohmen (2005) summarizes the empirical effects of structural and process quality on the outcome with respect to their sustainability in general (Table 3).

### Table 3. Short-, medium- and long-term effects of a better structural and process quality on the children’s outcome (developmental fields)

<table>
<thead>
<tr>
<th>Short-term</th>
<th>Medium-term</th>
<th>Long-term</th>
</tr>
</thead>
<tbody>
<tr>
<td>– higher IQ</td>
<td>– earlier school enrolment</td>
<td>– derive one’s income earlier</td>
</tr>
<tr>
<td>– more pro-social behaviour</td>
<td>– leaving school earlier</td>
<td>– higher net-income</td>
</tr>
<tr>
<td>– better nutrition</td>
<td>– higher probability of attending</td>
<td>– lower risk of unemployment</td>
</tr>
<tr>
<td></td>
<td>higher education e.g. university</td>
<td></td>
</tr>
<tr>
<td>– better overall health and well-being</td>
<td></td>
<td>– higher job productivity</td>
</tr>
<tr>
<td>– higher self-esteem</td>
<td>– more pro-social behaviour</td>
<td>– lower crime rate, more pro-social</td>
</tr>
<tr>
<td>– improved parent-child-interaction</td>
<td></td>
<td>behaviour</td>
</tr>
<tr>
<td>– higher self-contentment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Schwarz (2014b) collects all data existing in particular about high quality programs designed for ECE-Physical Activity interventions in Germany. This latest review comprises all systematically, controlled longitudinal studies ever conducted in Germany from 1980–2013 examining effects on children’s outcome (motor development, cognition, social-emotional development and physical health). Other inclusion criteria were duration of intervention \( \geq 6 \) months, a minimum of two measure points, age between three and eight years, at least two dependent variables (motor development plus x) and a sample size of \( N \geq 25 \). The result: 14 studies comply with the methodical requirements (Table 4).

### Table 4. Review of controlled longitudinal studies in Germany (1980–2013) on the effects of systematically designed PA intervention programmes in ECE-facilities, \( N = 14 \)

<table>
<thead>
<tr>
<th>Target variable</th>
<th>Outcome – Effects on dependant variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor development</strong></td>
<td>PA intervention programmes (Motor behaviour as influencing variable) have a positive effect almost every time they are applied on motor development. Ten out of 14 studies show significant results. Main outcome: the weaker the children (retarded), the earlier they get more physically active (very early PAE) and the more often they get intervened (daily intervention) the stronger the effects (max. ( \eta^2 = 0.33 ); MANOVA over time).</td>
</tr>
<tr>
<td><strong>Cognition</strong></td>
<td>Six studies deliver findings on cognition, mainly dealing with IQ-tests, sometimes concentration and very rarely to memory. Correlations range from 0.22** to 0.46*** at the IQ and between 0.31** to 0.46*** at the concentration findings. Memory results are very heterogeneous.</td>
</tr>
<tr>
<td><strong>Social-emotional development</strong></td>
<td>Inconsistent findings: very positive results face totally absent effects on the contrary. This can be explained by a different understanding of how to define social-emotional development. There is not a single study using interference statistics.</td>
</tr>
<tr>
<td><strong>Physical health</strong></td>
<td>Studies ( N = 6 ) on this target variable are mainly of medical and public health character. The findings show low blood pressure ( p &lt; 0.001 ), increase of abdominal muscle strength ( \alpha = 0.002 ), decrease of subcutaneous adipose tissue ( p = 0.13 ), deeper and more regular sleep. There are no psychosomatic effects examined at all in the long run.</td>
</tr>
</tbody>
</table>
From a qualitative perspective these systematic PA interventions may be of some reasonable effect on the outcome. But concerning the structural or process input there are only confuse notions about what really works. These imprecise intervention variables are (1) intensive qualification of Kindergarten teachers, (2) variable application of material and PA toys, (3) motivating (childlike) PA content, (4) better timing of PA units and didactically structuring them, (5) integration of the parents as a role model (PA at home), (6) re-designing of rooms indoor and outdoor (more space) and finally (7) using a handbook of documentation and manual of reliable quality standards. However, there is little known about the exact empirical effects of these rather ‘variables of tendency’.

Therefore, the author is in the line with the theoretical claims of Leu (2005) and Tietze and Förster (2005) that licensed Kindergartens should fulfill several meta-requirements. Without them, a further, mere quantitative expansion of OSA-licensed PAKs would be at least questionable:

– A consensual quality definition has to be found. Only if there is a mutual understanding the generalization of appropriate criteria is successful.
– This general validity implies an intensified empirical objective research, separating the sheep from the goats.
– To do this one clearly needs operationalized and therefore measurable indicators for the quality standards to describe, analyze and interpret Kindergarten quality.
– Such sort of evaluation is not for laypersons but for experts and scientific staff, meaning that a high quality certification, like the announced PAKs, needs high quality evaluators that ought to be neutral.

Conclusion

Since the installation of Kindergarten in Germany PAE has always been playing a vital role in the ECE-curriculums. On a very plain level it seemed subjectively obvious for former pedagogues that motor intervention is a fundamental key to satisfy basic needs of children. The main function of PAE till the middle of the 19th century was compensating the health dangers in the wake of growing cities or the neglect by the working mothers. A high quality Kindergarten in this sense helped to keep children alive and somehow engaged. Later on PAE became a medium of preparation for school and forming the children as a good serving member for society and soldiers at war times. High quality in Kindergarten saved the outcome as a somehow ‘social investment’. It wasn’t until the end of the 19th century when a new perspective arouse wherein children were considered to be active and creative by nature with fundamental rights for autonomy and self-determination. Forty years after the Second World War this attitude became the leading principle not only in ECE in general but also in PAE.

The “Bewegungskindergarten” (PAK) of Germany’s organized sports associations (OSA) picked up the traditionally high expectations considering the effects of PAE and installed a minimum quality management by designing some criteria as a matter of quality assurance. However, only some general findings of high quality effects can be reported as well as PA specific results from a recent review on systematically designed PAE programmes. Despite this fact, Germany’s OSA are still expanding Physical Activity Kindergarten (PAK) believing in their overall positive developmental effect. Subsequently a very popular license originated without having evidence for its positive outcome. A randomized, controlled longitudinal study is still to come.
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INFLUENCE OF PLANTAR FASCIAL TAPING ON PRESSURE PAIN SENSITIVITY CHANGES IN LOWER EXTREMITY POSTERIOR LINE MUSCLES IN FUTSAL PLAYERS

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Abstract. The aim of the study was to evaluate the threshold of muscle pain sensitivity at the posterior line of the futsal player’s lower extremity muscles under the influence of the stimulation of the foot arch with a nonelastic tape application.

The study included 25 futsal players representing university club AZS AWF Wrocław. During the experiment, a nonelastic tape was applied on the plantar foot surface, basing on the standards of low-Dye taping. The test program consisted of a 3-day cycle, during which the pressure pain threshold (PPT) was measured: 1) before application of the tape, 2) 24 hours and 3) 72 hours after application. The PPT was measured using the Somedic Algometer type 2.

Analysis of the results was performed using analysis of variance for repeated measures and post hoc Bonferroni’s test. Long-term stimulation of plantar surface significantly affects the increase in the PPT in the lower extremity posterior line muscles.

In motor control trainings, especially in match-starter terms, new physiotherapeutic measures and therapeutic techniques should be used.

Key words: Low-Dye Taping, prevention, sport injuries, overtraining, futsal

Introduction

Futsal is a discipline classified as a team game. It is played on a standard handball court, in the sports hall. Furthermore, high dynamism, a lot of take-offs, short distance sprints and changes of running directions constitute futsal and contribute to its spectacularity and popularity (Barbero-Alvarez et al. 2009).

The nascence of muscle overloading in the osteoarticular system constitutes a characteristic movements sequence (e.g. outbursts, feints, running with ball, passing and shots), of the games played on hard surfaces, and depends on the individual predispositions of the player. During the match players engage multiple muscle groups...
that perform mostly a series of eccentric contractions, causing micro-injuries of muscle fibers (Andersen et al. 2006). Intense muscle performance causes muscle soreness, that may be evaluated on the basis of pressure pain threshold (PPT). Muscle soreness may be experienced randomly after the exertion. The individual may be exposed to it during the training session, as well as immediately after it because of the uncontrollable muscle spasms (Nosaka et al. 1991). All of the micro-injuries of the muscle lead to muscle swelling and muscle inflammation. It is manifested by the delayed onset muscle soreness (DOMS), with symptoms such as increased pressure sensitivity (hyperalgesia), rest pain and changes in movement control within the muscle (Woods et al. 2004). Algometry is a method, which allows for the investigation of the muscle sensitivity during squeezing session – one of the main symptoms of DOMS (Jönhagen et al. 2009).

Soreness, strains (including those of in lower extremity posterior line muscles) are one of the most common consequences of the muscle overloading in futsal players. Hamstrings muscle, popliteal muscle and gastrocnemius muscle (including the Achilles tendon) are the most susceptible to injuries. Tension disintegration in the muscles of the lower extremity posterior line may be directly linked to the discordant configuration of the foot insteps, abnormal distribution of the compressive force placed on the plantar foot surface, as well as the inflammation of the plantar fascia. The imbalance between the anterior and posterior muscle groups may be the consequence of those changes (Myers 1997).

All of the harmful effects emerging from the dysfunctions located within the musculoskeletal system may pose a danger in enhancing the skill level of a given player. This constitutes a great challenge for coaches and physiotherapists in the planning of the trainings that are oriented not only towards the development of motor and technical skills, but also on reducing the risk of injuries (Kirkendall and Dvorak 2010).

Futsal is a relatively new team game therefore, it is necessary to deepen the knowledge on the issues related to the prevention of injuries. Further studies will provide the trainers and physiotherapists with an access to a more profound understanding of the issue, which undoubtedly will be reflected in the sport results.

Plantar fascial taping should be used in reducing the plantar fascia tension and arch support, thereby increase of pain sensitivity in muscle groups. In professional sport it is necessary in optimization of overloads. The use of nonelastic tapes on plantar foot surface has been assessed only in a number of studies (Radfort et al. 2006; Russo and Chipehase 2001; Vicenzino et al. 2007). Therefore, the aim of the study was to evaluate the threshold of muscle pain sensitivity at the posterior line of the futsal player’s lower extremity muscles under the influence of the stimulation of the foot arch with a nonelastic tape application.

## Material and methods

### Participants

25 male futsal players (age 23.03 ±1.15 years, body height 179.30 ±3.56 cm, body weight 76.10 ±6.67 kg, BMI 23.40 ±2.76 kg/m²) participated in the study. The players were university club AZS AWF Wroclaw members. Training experience of the whole group was on average 14 years. The shortest experience was 8, and the longest – 17 years of training. The players are the medallists of the Polish Academic Championships in futsal. None of the respondents within the past six weeks has suffered from an injury, none has complained of pain. All subjects were informed about the purpose and the research protocol assumptions.
Research protocol

During the experiment, a nonelastic tape was applied on the plantar foot surface, basing on the standards of low-Dye taping. To perform this technique, a nonelastic cotton tape of 4 cm × 5 m was used. The application was carried out in a supine position with the lower extremity bent at an angle of 90° in the knee joint. The person applying the tape degreased plantar and dorsal surface of the foot, as well as the medial and lateral edge and, afterwards, the adhesive spray was applied.

Tape application method consisted of 4 stages: 1) bonding the base at a height of 1st to 5th metatarsal head; 2) placing the tape on the medial and lateral edge (start and end of the application at the height of the base); 3) parallel and overlapping application of the tape towards the base (from the base to the calcaneus), and 4) re-application of the tape at the medial and lateral edge, as well as at the height of metatarsal heads (base) (Figure 1).

Figure 1. Low-Dye taping technique

The experiment protocol consisted of a 3-day cycle, during which the PPT was measured: 1) before application of the tape, 2), 24 hours and 3) 72 hours after application. PPTs markings were made within the posterior line of the lower extremity muscles. The overall research model assumes that the smaller the value of the PPT, the higher the muscle tenderness.

Research method

Somedic Algometer type 2 was used to measure the PPTs. The diameter of the tip of the device used for the compression of specific points on the muscle was 10 mm and covered with 2 mm of rubber. The pressure on point and its rate was standardized (30 kPa/s). The value of the pain threshold equals the value of the pressure at which the examined person reported that the pressure exerted on a certain point causes pain (Kawczyński et al. 2013).
PPT measurements were made on the posterior line of the lower extremity muscles in 13 reference points, i.e. (Figure 2): semitendinosus and semimembranosus muscle (points 1–4); biceps femoris muscle (points 5-8); lateral head of the gastrocnemius muscle (points 9, 11); medial head of the gastrocnemius muscle (points 10, 12); and soleus muscle (section 13). Points 1–8 belongs to the posterior thigh muscles (hamstrings muscle), while 9–13 to the posterior shin muscles (gastrocnemius) (Kawczyński et al. 2013).

Figure 2. Reference points for PPT assessment

Statistical analysis

Analysis of the results was performed using the analysis of variance for repeated measures (RMANOVA) and post hoc Bonferroni’s test. Before the examination, two tests were conducted to verify the assumptions, namely 1) the normality of distribution – the Shapiro-Wilk test and 2) the homogeneity of variance – Levene’s test. Intraclass Correlation Coefficient (ICC) was also assessed in the study and it was $R^2 = 0.912$. Calculations were made using the Statistica 10 PL software. While assessing the differences, it was assumed that they were significant at $p \leq 0.001$. 
Results

Table 1 shows the complete results of PPT values for all muscle groups, belonging to the lower extremity muscles. Furthermore, the results include reference points of PPT measure (i.e.: 1–8 and 9–13) for futsal players.

Table 1. Mean values of the PPT and significances before, 24 and 72 hours after the low-Dye Tape application

<table>
<thead>
<tr>
<th>Muscle</th>
<th>reference point</th>
<th>before</th>
<th>24 h after</th>
<th>72 h after</th>
<th>before</th>
<th>24 h after</th>
<th>72 h after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semitendinous</td>
<td>5</td>
<td>951.38</td>
<td>1125.32</td>
<td>1403.29</td>
<td>973.15</td>
<td>1153.74</td>
<td>1475.35</td>
</tr>
<tr>
<td>Semimembranosus Muscles</td>
<td>6</td>
<td>945.76</td>
<td>1115.61</td>
<td>1448.95</td>
<td>934.71</td>
<td>1105.63</td>
<td>1410.52</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>942.33</td>
<td>1115.37</td>
<td>1418.48</td>
<td>943.26</td>
<td>1117.03</td>
<td>1431.44</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>918.38</td>
<td>1114.11</td>
<td>1411.52</td>
<td>946.81</td>
<td>1129.45</td>
<td>1443.29</td>
</tr>
<tr>
<td>Biceps femoris muscle</td>
<td>1</td>
<td>909.14</td>
<td>1106.45</td>
<td>1450.71</td>
<td>952.74</td>
<td>1150.00</td>
<td>1453.50</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>955.24</td>
<td>1146.05</td>
<td>1443.71</td>
<td>915.14</td>
<td>1108.23</td>
<td>1407.86</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>958.38</td>
<td>1152.80</td>
<td>1435.71</td>
<td>936.53</td>
<td>1118.48</td>
<td>1458.65</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>978.90</td>
<td>1155.06</td>
<td>1444.38</td>
<td>956.62</td>
<td>1142.65</td>
<td>1460.81</td>
</tr>
<tr>
<td>Lateral head of the gastrocnemius muscle</td>
<td>9</td>
<td>940.33</td>
<td>1152.25</td>
<td>1452.62</td>
<td>952.00</td>
<td>1153.79</td>
<td>1458.29</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>948.29</td>
<td>1121.68</td>
<td>1413.24</td>
<td>955.88</td>
<td>1130.00</td>
<td>1436.00</td>
</tr>
<tr>
<td>Medial head of the gastrocnemius muscle</td>
<td>10</td>
<td>943.90</td>
<td>1123.40</td>
<td>1450.71</td>
<td>955.19</td>
<td>1131.75</td>
<td>1462.38</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>958.57</td>
<td>1173.00</td>
<td>1474.29</td>
<td>962.59</td>
<td>1165.71</td>
<td>1466.24</td>
</tr>
<tr>
<td>Soleus muscle</td>
<td>13</td>
<td>950.48</td>
<td>1134.58</td>
<td>1432.57</td>
<td>960.86</td>
<td>1132.20</td>
<td>1436.95</td>
</tr>
</tbody>
</table>

Figure 3. PPT values of thigh muscles before, 24 and 72 hours after taping in futsal players.

The average PPT for posterior thigh muscles in the right lower extremity has significantly changed after 24 and 72 hours after the application (respectively 1135.85 ±41.63 kPa; α = 0.0001; 1462.10 ±56.13 kPa; α = 0.0002; p ≤ 0.001). However, in the initial trial the value was 954.94 ±31.63 kPa. In comparison with the study before tape application (924.87 ±48.53 kPa) (Figure 3), a significant increase of PPT was also found in the left lower extremity (respectively 1118.15 ±48.50 kPa; α = 0.0001; 1440.68 ±55.64 kPa, α = 0.0001; p ≤ 0.001) (Figure 3).
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Figure 4. PPT values of shin muscles before, 24 and 72 hours after taping in futsal players

The PPT value within right lower extremity posterior shin muscles has increased significantly after 24 and 72 hours after the application (respectively 1084.98 ±38.84 kPa; α = 0.0003; 1344.69 ±62.87 kPa; α = 0.0002; p ≤ 0.001), in comparison with the initial measure (902.31 ±42.68 kPa). While in left lower extremity muscles significant changes after 24 and 72 hours after the application were also observed (respectively 936.69 ±44.32 kPa; α = 0.001; 1151.97 ±47.08 kPa; α = 0.0001; p ≤ 0.001). In the first measurement the value equaled 876.30 ±37.46 kPa (Figure 4).

Discussion

The analysis of the most popular databases of scientific journals proved a limited number of publications relating to futsal. As one of the varieties of football, it is characterized by many interesting aspects, including biomechanical model of postural control, different ergonomics of the game, as well as brand new sets of the factors posing a risk for injuries. Therefore, an attempt to analyse the factors posing a risk for injuries and to verify one of the methods preventing the posterior line of lower extremity muscles has been made.

Epidemiological data relevant to the frequency and the types of the injuries experienced by the futsal players is scarce. This fact can be directly linked to the low popularity of this discipline, as opposed to football (Baroni et al. 2008). A study conducted by Ribeiro et al. (2003), as well as Ribeiro and Pena Costa Ribeiro (2006) proves, that the lower extremities are the segments of the human body, that are the most vulnerable to injuries (constituting about 70% at whole). The main cause of the injuries of the lower extremity muscles is linked to the reduced mobility (Lentell et al. 1995), muscle flexibility (mainly hamstrings muscle) and the imbalance occurring between the agonistic and antagonistic muscle groups (Knapik et al. 2001; Nasiri and Salehian 2011).

A series of functional changes may be observed in the bodies of futsal players. The impact, that abnormal forces have on the foot, peripheral joins and the higher segments is the main reason behind the occurrence of those functional changes (Ribeiro et al. 2003). The main factor that encourages the emergence of those changes, is the ground, on which the training sessions and matches take place. The most common surface is of hard quality,
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which alters abnormal distribution of pressure on the plantar surface of the foot and overloading located within the ligamental-muscular system (Junge and Dvorak 2010). As a result, the pain formation emerges, which consequently conditions the inflammation, a decrease in flexibility and an increase in the stiffness and muscle tension (Cain et al. 2007). It may be assumed that the overloading and muscle injuries, especially those located in the posterior line of the lower extremity muscles, are caused by the distance covered during the match (Balbero-Alvarez et al. 2008; de Oliveira Bueno et al. 2014), the kinematics of the ball kicks (Barbieri et al. 2010; Ismail et al. 2014), sharp braking and frequent changes of the running direction (Dogramaci et al. 2011).

The results, that have been observed during the study determine a new direction of the research on the reduction of the injury risk. Furthermore, the new therapeutic solutions to the process of physiotherapy are being introduced. The emphasis should be placed on the innovation and novelty that this research provides to the scientific world since there is a scarce and extremely limited number of the studies that engage with the usage of nonelastic taping on the football players in order to prevent the excessive pronation of the foot (Fumich et al. 1981; Sandrey 1996).

The analysis of the data gathered, proved that under the influence of low-Dye taping on the foot, a significant increase in the average value of the PPT may be observed. The PPT value within the hamstrings muscle has increased by 20% (right) after 24 hours, and by 54% (right) after 72 hours. Moreover, in the left foot the PPT value within the hamstrings muscle has increased by 21% after 24 hours, and by 56% after 72 hours. On the contrary, the increase of the PPT value within the gastrosoleus after 24 hours reached 20% (right), whereas after 24 hours it indicated 49% (right). In the left foot an increase of 7% and 31% was observed after 24 and 72 hours.

The therapeutic efficiency of the application of low-Dye taping has been confirmed by the examination conducted on the kinematic (Radfort et al. 2006) and electromyographic (Radfort et al. 2006) dynamometric platform (Russo and Chipchase 2001; Vicenzino et al. 2007). However, the studies are engaged with the parts of the body that are located above the foot and ankle. The analysis of the PPT value within the hamstrings muscle and gastrocnemius provides a more profound assessment of the risks of DOMS and injuries (Andersen et al. 2006). The stimulation of the plantar foot surface results in an increase in the stimulus of the plantar fascia, which reduces the excessive tension within the aforementioned structure and the upper segments (Kogler et al. 1999).

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The Myers’ theory proves, that all structures (muscles, ligaments, and fascia) included in the posterior line are connected with each other. Accordingly, it may be assumed that the alignment/reduction of the excessive tension located within the plantar fascia affects the Achilles tendon, gastrocnemius, and hamstrings muscle (Mayers 1997). This further encourages the occurrence of the new stimuli. Under the influence of the stimulation, the additional stimulation of the skin sensory receptors and proprioceptive sensation occurs, which results in the improvement of the postural control, stability, and balance. The increase in the proprioceptive sensation results in the additional response of the peripheral nervous system, which aims at changing the configuration of a given segment of the motion system and/or equalisation of the motion pattern (Layne et al. 2002).

The aforementioned functional and morphological changes occurring in the control of human movement are the consequence of the reduction of the excessive stiffness, the standardization of tension, increase in the muscle flexibility and changes in the motor unit recruitment strategies (Fromy et al. 2008).

In conclusion, the studies constitute a new path in the discipline of the physiotherapy and the motor preparation of the players. The issue of crucial importance is the continuation of broadening the research by introducing another devices. The studies prepare an interesting ground for further analysis. They may serve in programming and
monitoring of the trainings throughout the training cycle, as well as, in the monitoring of the regenerative training (e.g. post-match biological regeneration). It should constitute the basic tool in the physiotherapy. What should be highlighted, is the validity of the usage of the aforementioned results in the treatment of the injuries and pain afflictions stemming from the overloading of the musculoskeletal system during the trainings characterised by high intensity and the frequent changes of the surface.

Conclusions

1. Long-term stimulation of plantar surface significantly affects the increase in the PPT in the lower extremity posterior line muscles.

2. In motor control trainings, especially in match-starter terms new physiotherapeutic measures and therapeutic techniques should be used.

References


Pressure Pain Sensitivity in Lower Extremity Muscles in Futsal Players


INFLUENCE OF SIMULATED MICROGRAVITY ON MECHANICAL PROPERTIES IN THE HUMAN TRICEPS SURAE MUSCLE *IN VIVO*

II. Effect of 120-days of bed rest with physical training on human muscle contractile properties and musculo-tendinous stiffness in young women

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Abstract. Purpose. The aim of the study was to investigate the effects of a simulated microgravity on the mechanical properties of the human triceps surae (TS) and to assess the effectiveness of physical training (PT) in preventing detrimental effects. Methods. Eight women (aged 26–36 years) underwent 120-d of Bed rest (BR): four underwent Bed rest only (BR group) and four performed PT during this period (BRPT group). The training sessions were conducted for 60 min each day for 6 days a week for 14 weeks, and 30–40 min twice a day for 2 weeks under the experiment conditions. PT was performed over a 4-d cycle: 3-d of training and 1-d of rest. The maximal voluntary contraction (MVC), and isometric twitch contraction ($P_t$), and electrically evoked tetanic tension at 150 impulses × s⁻¹ ($P_o$), time-to-peak tension (TPT) of the twitch were determined. The difference between $P_o$ and MVC expressed as a percentage of $P_o$ and referred to a force deficiency ($P_d$). The MTS was determined according to the electromechanical delay (EMD) value during the explosive voluntary contraction. Surface electrodes sensed electromyographic (EMG) activity in the soleus muscle. Electromechanical delay (EMD) was the time interval between the change in EMG and movement muscle force production. Results. In the BR group, $P_t$, MVC, and $P_o$ had decreased by 12, 36, 24%, respectively, but $P_d$ had increased by 39%. TPT of the twitch had increased by 14%. The rate of increase of voluntary contractions reduced, but in the electrically evoked contraction no changes were observed. The EMD had increased by 27%. In the BReX group, MVC, $P_t$, and $P_o$ decreased by 3%, and 14%, and 9%, respectively. TPT had decreased by 4%. The $P_d$ had decreased significantly by 10%. The rate of rise increase of electrically evoked tetanic did not change significantly, but the rate of rise in isometric voluntary tension development was increased. The EMD had decreased by 12%. Conclusion. Unloading decreased function and EMD muscle and, although the PT did attenuate these effects, they did not completely prevent them. It is suggested that the total loading volume (mainly its intensity) was not sufficient to completely prevent alterations in tendon mechanical properties.

Key words: bed rest, triceps surae muscle, training, electromechanical delay, musculo-tendinous stiffness, contractile properties
Introduction

It is well known that the unloading of the musculoskeletal system by actual or simulated microgravity causes numerous changes in the musculoskeletal system, such as muscular atrophy and decreased contraction strength, both after relatively short-term (10–17 days) (Grigor’eva et al. 1987; Narici et al. 2003; Gopalakrishnan et al. 2010; Koryak 2008, 2011a, b) and long-term (>5 weeks) periods of unloading (LeBlanc et al. 2000; Kubo et al. 2000; Lambertz et al. 2001; Koryak 2007, 2011a, b). The deterioration of musculoskeletal function causes no direct health hazards and does not affect the capacity for work during short-term space missions. However, during long-term missions, serious problems can arise after returning back to Earth, unless the negative effects of microgravity are mitigated. Therefore, measures to prevent the complete adaptation of the human body to microgravity conditions are vital, as well as supporting the effective functioning of all body systems which have adapted to life in the terrestrial gravitational field through phylogensis and ontogenesis.

Physical training (PT) has been proposed as a potential countermeasure to microgravity-induced effects on the size (mass) and function of skeletal muscles (Nicogossian 1982; Koryak 1998). High-resistance physical exercises are known to be effective in increasing the size/cross-sectional area or contractile force of muscles (Tesch 1991; Koryak 1993; Norrbrand et al. 2008; Fernandez-Gonzalo et al. 2014). Therefore, high-intensity resistance training may be successfully applied during unloading in order to counteract the deterioration of the contractile functions of the muscle.

Surface electromyogram data show the electrical activity of muscle and have been used in the analysis of human movement. The electromechanical delay (EMD) is traditionally defined as the time lag between the onset of muscle electrical activation and the onset of force production (Cavanagh and Komi 1979). Muscle force is registered only when the contractile elements of the muscle shorten, thus stretching the series elastic components (SEC), which participates in the transmission of force to tendons and joints (Hill 1938; Norman and Komi 1979; Cavanagh and Komi 1979; Hof and van den Berg 1981; Winter and Brookes 1991). The time required to stretch the SEC of the musculo-articular system is the prevailing EMD component and thus a measure of the series elastic stiffness. Changes in any of the previously listed events could potentially induce EMD alterations (Viitasalo and Komi 1981; Granata et al. 2000; Muraoka et al. 2004; Yavuz et al. 2010; Esposito et al. 2011; Cè et al. 2013; Lacourpaille et al. 2013).

The EMD changes can be attributed, first of all, to changes in muscle SEC stiffness. Muscle stiffness is described as the ratio between the force and length of stretching. A mechanically stiff muscle will transmit more force if the SEC stretches a small amount and, on the contrary, mechanically “gentle” (or “slack”) tissue requires a significantly stronger muscle contraction in order to stretch the SEC and produce measurable force. “Slack” tissues require more time from the moment of activation to the start of force generation, i.e. their EMD is longer and it is shortened when muscle stiffness is increased before muscle tension (Norman and Komi 1979; Vos et al. 1991; Zhou et al. 1995; Orizio et al. 1999, 2003). Therefore, the EMD may become a criterion for the differences in stiffness of the musculo-tendinous complex (MTC) under different conditions.

Unloading leads not only to the loss of muscle mass and muscle dysfunction (which seems to be clinically relevant), but also affects other functionally important structures of the musculoskeletal system, which undergo changes under the influence of microgravity (in particular, the tendon serially connected to the muscle). It is already known that the tendon not only provides structural connections between a muscle and a bone, but also plays the main role in the transmission of force produced by contractile muscle elements to the skeleton. Therefore, the
tendon can change the length, and, therefore, the force of the contractile elements connected serially depends on the degree of variation of tensile strength (Zajac 1989; Reeves et al. 2004). The degree to which a tendon deforms in response to a muscle contraction depends on the mechanical properties of the tendon (Magnusson at al. 2001; Maganaris 2002; Maganaris and Paul 2002), since the tendon is not an inert structure and like a muscle it can change with the physical load level. The mechanical properties of the tendon may be adapted to changes in load level (Woo et al. 1980, 1982; Buchanan and Marsh 2001; Hansen et al. 2003; Reeves et al. 2003). For example, a higher load is associated with tendon hypertrophy (Woo et al 1980, 1982). Therefore, if unloading causes a decrease in musculo-tendinous stiffness (MTS), then it is vital to understand whether load (PT) can prevent the potentially harmful effect of unloading. The MTS is known to increase after strength training (Buchanan and Marsh 2001; Kubo et al. 2000, 2001; Grosset et al., 2009), and it may therefore be expected that the EMD would be shorter in those subjects who practiced PT in microgravity conditions, compared to those who were not subject to PT (Koryak 2012).

Firstly, the objective of this study is to evaluate the effect of PT on the contractile properties of the human triceps surae muscle (TS) in a group of young women in order to reduce the negative effects of mechanical unloading caused by long-term bed rest, and secondly, to assess the degree of EMD changes in the subjects of the study undergoing a strict bed rest regimen but also engaging in PT. We suppose that if the decreased MTC stiffness is caused by unloading, then PT during bed rest may prevent the detraining of skeletal muscles and reduce the negative effect of unloading.

Materials and methods

The study was approved by the Human Ethics Committee at the Institute of Biomedical Problems and had been performed in accordance with the principles of the 1975 Declaration of Helsinki on the use of human subjects in experiments.

Participants

Subject selection was based on a screening evaluation consisting of a detailed medical history, complete blood count, urinalysis, resting electrocardiogram, and a selection of blood chemistry analyses, which included the estimation of concentrations of fasting blood glucose, blood urea nitrogen, creatinine, lactic dehydrogenase, serum transaminase bilirubin, uric acid, and cholesterol, as well as an evaluation of their physical state using a bicycle ergometer stress-test. All subjects were recreationally active, but not involved in sporting activities at a competitive level. At the time of the study, no participant was taking any medication, and all were non-smokers. Eight women between 26 and 36 yr. of age gave their written, informed consent to participate in the study after they had been informed of all of the procedures and possible risks. The volunteers were allocated to two experimental groups: a group [n = 4; age: 31.5 (SEM 1.7) yr.; body mass: 55.0 (SEM 1.8) kg; height: 162.3 (SEM 1.9) cm] that underwent Bed rest only (BR) and a group [n = 4; age: 28.0 (SEM 1.1) yr.; body mass: 59.9 (SEM 2.3) kg; height: 162.3 (SEM 4.2) cm] that underwent Bed rest while performing PT (BRPT). During preliminary visits to the laboratory, the subjects were informed of the objectives and methods of the study and were introduced to all the procedures for evaluating

1 Continuous, gradually increasing work in the bicycle ergometer at a constant pedaling rate of 60 rpm over 3 min with initial load of 50 W was specified; the load of subsequent “steps” was increased by 25 W; achievement of submaximal heart rate was the criterion for work termination.
voluntary muscle contractions and those induced by electricity. After that, each subject signed an Informed Consent Form for participating in the experiment. Each subject served as her own control.

**Bed rest**

Bed rest during 120-days in an anti-orthostatic position (5° HDT) of the body was used as a model of the long-term hypokinesia/hypodynamia effect of spaceflight. The HDT position was chosen since various physiological alterations induced by actual spaceflight have been shown to be similar to those reported in ground-based studies using this model (Sandler and Vernikos 1986). During this 120-day experiment, the subjects were housed 24 h a day in the Human Research Facility of the Health Ministry Institute of Biomedical Problems. During bed rest, the subjects remained in the HDT position continuously for all activities including excretory functions, showering, eating and PT.

**Exercise regimens**

Details of the training program and performance tests have been provided elsewhere (Eremin et al. 1970; Stepanstov et al. 1972). Briefly, subjects were accustomed to training using bilateral supine leg press and arm press. The PT consisted of three regimes: on the first day a force-velocity regime was carried out (70% of the training was force-velocity exercise, and 15% a velocity and force requiring exercise); on the second day a velocity regime (70% of the training was velocity required exercise, while 15% was force, and force-velocity requiring exercise), and on third day a force regime (70% was force exercise, and 15% velocity and force-velocity requiring exercise).

The PT was scheduled over a 4-day cycle: 3 days of training and 1 day of rest. PT used during long-term spaceflights in the Russian space station “MIR” included a warm-up (walking on a treadmill for 5 min), and low (2 min), moderate (2 min) and maximum (1 min) intensity running. The training sessions were conducted for 60 min each day for 6 days a week for 14 weeks, and 30–40 min twice a day for 2 weeks under the experiment conditions. The recommended workload and intensities of exercises on treadmill varied from 3100 to 4400 m, performed with an average rate of 117–135 m (Kozlovskaya and Grigoriev 2004). It is known that intensity of loads set up by the subject’s level of work load, durations of high intensity intervals and subsequent pauses give a fairly correct notion about working abilities. In addition, taking into consideration the anatomical and physiological specificities of a woman’s body, the total physical load was reduced to 70% of that usually exposed to by men, and when the expanders were used for muscle-strengthening exercises, the load was reduced by 25–30%.

**Experimental protocol and measurements**

*Experimental set-up.* The subjects were carefully familiarized with the test procedures of voluntary force production during several warm-up contractions preceding the actual maximal contractions and were allowed to habituate to the electrical stimulation procedures during preliminary visits to the laboratory before definitive control measurements were taken. To ensure standardization of position and fixation of the limb during assessment, a special set-up, previously shown by Koryak (1985), was used (Figure 1). The dynamometer and recording system used to measure the forces produced by electrical and voluntary contractions of the TS have previously been described in detail (Koryak, 1985). In brief, the subject was seated comfortably on a special chair in a standard position (at a knee joint angle between the tibia and the sole of the foot of 90°). The position of the seat was adjusted to the individual and then firmly secured. A rigid leg fixation ensured isometric conditions for the muscle contraction. The dynamometer was a steel
ring with a saddle-shaped block attached to fit the Achilles tendon. The resting pressure between the sensor and the tendon was constant for all the subjects and was set at 5 kg. The contractile properties of the TS were tested twice: 10-8 days before the beginning of the Bed rest and after it ended. The test protocol was identical for both preBed rest and postBed rest tests.

**Figure 1.** A. Examples of isometric twitch contraction curve (left) and electrically evoked tetanic tension and voluntary muscle tension development (right) showing how the parameters of the mechanical responses of muscle contraction were subsequently calculated. TCT, time-to-peak tension; 1/2 RT, half-relaxation time; TCT, total contraction time; Pt, twitch force. B. Schematic presentation of a sample showing total reaction time (TRT) with its premotor (PMT) and motor time (MT) or electromechanical delay (EMD) and electromyogram (EMG) of the soleus (Sol) muscle.
**Electrical stimulation.** A single, square-wave, supramaximal transcutaneous electrical stimulus of 1 ms duration was delivered to the tibial nerve. Transcutaneous electrical stimuli were delivered to the tibial nerve using a high-voltage (maximal voltage = 400 V), constant current stimulator (model “ESU-1”, USSR). The cathode (active electrode) was a metal probe (Ø 1 cm) with the tip covered in a saline-soaked sponge, which was pressed over the tibial nerve in the popliteal fossa which is the place of the lowest resistance. The anode (passive electrode) was a 6 × 4 cm rectangular self-adhesive electrode that was positioned between the tibial tuberosity and the patella. The large grounding electrode (7.5 cm × 6.5 cm) was located in the proximal portion of the leg between the peak-up and stimulating electrodes.

Single stimuli were administered to the tibial nerve at a low current (amperage = 20 mA) to determine the optimal probe location based on the visual inspection of the compound muscle action potential (M-wave) and H-reflex of the soleus muscle that were monitored on an storage oscilloscope. A single stimulus was given every 30 s. Once the location was determined and marked, the maximal M-wave was achieved with incremental (5 mA) amperage increases until a plateau in the peak-to-peak M-wave was observed after three successive amperage increases. To assure a supramaximal stimulus, 120% of the stimulus that elicited the maximal M-wave was used during the evoked twitch procedures.

The isometric tetanic contractions of the TS were induced by electrical stimulation of the tibial nerve using supramaximal rectangular pulses with a frequency of 150 impulses × s⁻¹ (Koryak 1995). All the recordings were made in a room at constant temperature (~22 ± 1 C).

**Electromyography recording.** Bipolar surface electrodes (standard Ag/AgCl electrodes, 8 mm in diameter, spaced 25 mm centre-to-centre) were placed 6 cm below the insertion of the gastrocnemii on the Achilles tendon for the soleus. The large grounding electrode (7.5 cm × 6.5 cm in size) was located on the proximal portion of the leg between the upper recording electrode and the stimulating electrodes. The skin was rubbed with an abrasive paste and cleaned with alcohol to reduce the inter-electrode impedance to around 5 kΩ. Electrode gel was used with all surface electrodes.

**Procedure.** Contractile properties of the TS estimated on mechanical parameters voluntary and electrical (involuntary) contractions. The experimental protocol consisted of four parts.

1. Maximal voluntary contraction (MVC) was estimated according to the tendogram of isometric voluntary contraction performed on the instruction condition to exert maximal contraction. From 2–3 maximal contractions were usually recorded from each subject until maximal force contractions was obtained. There was a 1–2 min rest between the sets. The MVC was determined as the highest value of voluntary force recorded during the entire contraction. The force was recorded on magnetic tape.
   The subjects were also carefully instructed to respond to an auditory signal by exerting MVC as rapidly as possible, and to maintain it as long as the signal was audible (~1.5–2.0 s). In the force-time curves, the times taken to increase the force to 25, 50, 75, and 90% of MVC were calculated (Koryak 1985).

   Involuntary (electrically evoked) isometric contraction (twitch contraction, double and tetanic) of the human TS caused electrical stimulated tibial nerve, using a neuromuscular stimulator.

   The isometric twitch and tetanic contractions of the TS were induced by electrical stimulation of the tibial nerve using supramaximal rectangular pulses of 1 ms duration. Maximal isometric twitch force (P₁) was estimated according to the tendogram of the TS isometric twitch response to a single electrical stimulus applied to the tibial nerve (Figure 1, A, left panel). The maximal force (Pₒ) was estimated by the tendogram from the evoked contraction in
response to an electrical tetanic stimulation of the nerve, innervating the TS, with a frequency of 150 impulses × s⁻¹ (Figure 1, A, right panel). The difference between $P_0$ and MVC expressed as a percentage of the $P_0$ value and referred to as force deficiency ($P_d$) as has been calculated before (Koryak 1985).

After an appropriate rest of 4–5 min the motor nerve was stimulated at various intervals. Supramaximal twin stimuli at 330, 250, 200, 100, 50, and 20 impulses × s⁻¹ were applied (Koryak, 1985). The maximal strength (amplitude) of the muscle contraction was determined and expressed as a percentage of the twitch contraction.

Tetanic index (TI) was expressed as the relation of $P_o/P_t$ (Close 1972; Koryak 1985).

2. The time from the moment of stimulation to peak twitch (TPT), the time from contraction peak to half-relaxation (1/2 RT) were calculated by the tendogram of isometric twitch (Figure 1, A, left panel). The accuracy of measurement was 1 ms.

3. The subjects were also carefully instructed to respond to an auditory signal by exerting MVC as rapidly as possible, and to maintain it as long as the signal was audible (~1.5–2.0 s). In the force-time curves, by the time taken to increase the force to 25, 50, 75, and 90% of MVC were calculated (Koryak 1985). Similarly, the rate of rise of evoked contraction in response to electric stimulation of the nerve with a frequency of 150 impulses × s⁻¹ was determined (Koryak 1985) (Figure 1, A, right panel). The accuracy of measurement was 1 ms.

4. On a light signal the subject carried out plantar flexor under condition of «to contract as it is possible quickly and strongly» (Figure 1, bottom panel). Voluntary contraction in response to a visual stimulus (flash lamp) was adopted as a rapid ballistic movement. The signal to movement of «explosive» character was the visual diode – lamp (Ø 7 mm, 1 W) – was placed at eye level 1 m in front of the subject. Lasted signals were 2.5 s and the pause between the signals was random ranging from 1.4 to 5.0 s. The threshold for force was 5 N.

A separate timer was used to record the time interval from the presentation of the light signal to movement. The special timer allowing synchrony with presentation of a light signal to the beginning of movement to record the development of mechanical answer of the human TS, was used.

From the tendogram total reaction time (TRT), defined as the time interval from the application of the light stimulus to movement, was estimated. TPT was divided into pre-motor (PMT), defined as the time interval from the application of the stimulus to the change in electrical activity of the soleus muscle, and motor time (MT or electromechanical delay – EMD), defined as the time interval from the change in electrical activity in the soleus muscle to movement (Weiss 1965). The force thresholds were also taken as relative values of 2% from the maximum isometric force level of each contraction.

Subjects were permitted three practice trials separated by 30 s and in most cases the mean of three readings was used to determine TRT, PMT and EMD.

**Statistical analysis**

Conventional statistical methods were used for the calculation of means and standard errors of the mean. Differences between baseline (background) values of the subject and those post-exposure (bed rest) were tested for significance by Student’s paired t-test. Valued are given as mean ±S.E.M. in the text. Significant differences between means were set at the p < 0.05 level. The percentage changes for pre- and postBed rest were calculated.
Results

There were significant baseline differences between the BR and BREx groups for any of the reported variables.

**BR group**

The mean changes in TS tension under HDT are shown in Figure 2 (top panel) and reveal a significant decrease. Isometric $P_t$ decreased by a mean of 11.5% [pre 105 (SEM 12.8) N compared to post 85.3 (SEM 5.9) N; $p < 0.05$], MVC by a mean of 36.1% [pre 307.1 (SEM 21.6) N compared to post 196.2 (SEM 22.6) N; $p < 0.01$] N and $P_o$ by a mean of 24.4% [pre 503.3 (SEM 55.9) N compared to post 380.6 (SEM 28.4) N; $p < 0.01$]. The $P_d$ increased significantly by a mean of 39.8% [pre 37.6 (SEM 4.7) % compared to post 48.8 (SEM 3.7) %; $p < 0.01$] after HDT (cf. Figure 2, lower panel).

![Figure 2](image-url)

* $p < 0.05$; ** $p < 0.01$.

**Figure 2.** The effect of a 120-day 5° HDT for the BR and BRPT groups on maximal voluntary contraction (MVC), and evoked tetanic tension at 150 Hz ($P_o$), and at maximal twitch tension ($P_t$) (top panel) and at force of deficiency (lower panel) of the triceps surae muscle. Values are means and S.E.M.

The change in mean time of isometric twitch contraction as the opposite value to contraction velocity for the TS after a 120-day HDT effect is given in Figure 3 (left panel). As is seen from the data analysis, exposure to HDT conditions was accompanied by a statistically significant decrease of the muscle contraction and increased relaxation velocity. Thus, TPT increased by a mean of 13.6% [pre 118 (SEM 5) ms compared to post 134 (SEM 5) ms], and 1/2 RT decreased by a mean of 19.2% [pre 123 (SEM 6) ms compared to post 102 (SEM 7) ms; $p < 0.01$], respectively.

TI increased by a mean of 4.2% ($p > 0.05$).

Mean changes in isometric force of the TS under paired stimulation of maximal intensity when twin stimuli were applied at 3, 4, 5, 10, 20, 50 ms separation are presented in Figure 4 (top panel). The greatest force of contraction was observed at intervals of 4–10 ms and decreases or increases of interval from this range was accompanied by considerable decreases ($p < 0.05$) with no change in the general pattern of muscle tension developed. At any given interpulse interval the relative increase in force of contraction after 120-day HDT effect was significantly less compared to the control value ($p < 0.001$).
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**Figure 3.** The effect of a 120-day 5° HDT for the BR and BRPT groups on the isometric twitch time-to-peak tension (TPT), and half-relaxation time (1/2 RT) of the triceps surae muscle. Values are means and S.E.M.

**Figure 4.** The effect of a 120-day 5° HDT for the BR and BRPT groups on the maximal force contraction of triceps surae muscle in response to supramaximal twin stimuli at 3, 4, 5, 10, 20, and 50 ms. Values are means and S.E.M.
Mean changes in the rate of development of isometric tension of the TS are given in Figure 5 (top panel). The analysis of the data gives evidence of a decrease (p < 0.01–0.001) in the rate of rise in isometric voluntary tension development of the TS (top panel). This may be seen as a decrease in the convexity of the force-time curve estimated according to a relative scale. However, in the assessment of the force-velocity muscle properties, no substantial changes were observed on the effect of 120-day HDT on isometric electrically evoked tetanic development (below panel).

![Figure 5](image.png)

* * p < 0.05; ** p < 0.01; *** p < 0.001.

**Figure 5.** The effect of a 120-day 5° HDT for the BR and BRPT groups on the maximal rates of electrically evoked tetanus (top panel) and of development of voluntary isometric force (below panel). Values are means and S.E.M.

The mean changes in TS EMD after a 120-day HDT effect is given in Figure 6 (left panel). The EMD increased significantly, by 27.4 ±1.3% after HDT (mean post HDT value 57.7 ±3.4 ms compared to post mean pre HDT value 45.3 ±2.1 ms; p < 0.01). The PMT decreased significantly by a mean of 21.4% [pre 167.4 (SEM 10.1) ms compared to post 131.6 (SEM 16.2) ms; p < 0.01], and TRT decreased by a mean of 13.7% [pre 157.3 (SEM 15.2) ms compared to post 135.8 (SEM 13.5) ms; p < 0.05] after HDT.
**BRPT group**

Mean changes in TS tension under the HDT effect are shown in Figure 2 (right panel), indicating a decrease in tension. Thus, isometric $P_t$ decreased by 13.6% [pre 101.0 (SEM 17.6) N compared to post 87.3 (SEM 6.8) N; $p < 0.05$], MVC by 3.1% [pre 352.2 (SEM 55.9) N compared to post 341.4 (SEM 25.5) N] and $P_o$ by 9.4% [pre 594.5 (SEM 66.7) N compared to post 538.6 (SEM 25.5) N]. The $P_d$ decreased by 10.0% [pre 40.2 (SEM 8.2)% compared to post 36.2 (SEM 5.5)%].

The change of mean time of isometric twitch contraction for the TS after the 120-day HDT effect with PT is given in Figure 3 (right panel). As it is seen the analysis of the data, exposure to HDT conditions was accompanied by a statistically significant increased muscle contraction and increased relaxation velocity. Thus, TPT decreased by 3.5% [pre 135.5 (SEM 11.7) ms compared to post 130.8 (SEM 6.0) ms], 1/2 RT decreased by 7.4% [pre 101.5 (SEM 10.0) ms compared to post 94.0 (SEM 10.2) ms; $p < 0.05$].

TI was reduced by 15.8% ($p < 0.05$).

Mean changes in isometric force of the TS during paired stimulation of maximal intensity at interpulse intervals of 3, 4, 5, 10, 20, and 50 ms can be seen in Figure 4 (low panel). As may be seen the greatest force of contraction was observed at intervals of 4−10 ms and decreases or increases outside this range was accompanied by considerable decreases ($p < 0.05$) but with similar trends of tension developed by the muscle. There were differences in the curve at identical interpulse intervals the relative increase in force of contraction after 120-day HDT with PT being significantly greater by comparison with the initial values ($p < 0.001$).

Changes in the rate of development of isometric tension in the TS are shown in Figure 5 (lower panel). Analysis of the data provides evidence of an increase in the rate of rise of development of isometric voluntary tension in the TS ($p < 0.05$). This may be seen as an increase in convexity of the force-time curve estimated according to a relative
scale. However, no substantial changes were observed in the electrically evoked isometric tetanic development (below panel).

The analysis of the maximum normalized ratio $dP_o/dt$ revealed a not significantly decrease by a mean of 8.4% [pre 0.83%/ms compared to post 0.78%/ms]. The analysis of the development of electrically evoked contractions demonstrated not significantly differences throughout the whole period of the development of isometric tension, but at the same time, a minor (by a mean of 14.5%) increase of the maximum $dP_o/dt$, compared to the initial one [pre 1.17%/ms compared to post 1.34%/ms; $p < 0.001$].

The EMD was significantly less in response to the light signal (by a mean of 12.2%) after 120-day HDT with PT compared to the baseline value [pre 44.9 (SEM 2.0 ms) compared to post 39.4 (SEM 3.1) ms; $p < 0.05$] (Figure 6, right panel). After 120-day HDT, the PMT decreased by 5.3% (pre 131.8 ±6.4 ms compared to post 124.8 ±7.1 ms; $p < 0.05$) and the TRT decreased by a mean of 7.3% [176.2 (SEM 6.7) ms compared to post 163.4 (SEM 8.3) ms; $p < 0.05$].

Discussion

The present study aimed to elucidate the effects of chronic unloading on the mechanical properties of human TS and to examine the potential preventive effects of PT performed during the period of unloading (of strict the 120-day HDT) on mechanical properties of the muscle. The TS was the muscle tested in the study, since it has been demonstrated that foot extensors were the muscles most affected by unloading, compared to other extensors of the lower limbs (Fitts et al 2000).

This study considers the program of physical exercises carried out by the study subjects during 120-day of strict HDT, while the International Space Station team members carry out a similar program over 6 months. We studied the advantages of this program in order to protect various contractile elements of the skeletal muscle. This study may be considered unique due to the duration of the unloading period (120-day) with the use of women as study subjects and the examination of the physical adaptation of the muscular system to longer periods of unloading.

The most significant finding of the present investigation was the absence of changes in the contractile properties, and contraction time, as well as in the rate of development of voluntary tension contraction of the TS after the 120-days of bed rest when an attempt was made to preserve muscle condition. For instance, the MVC after the 120-day HDT with PT decreased by 3%, the TCT decreased by 4%, and the rising curve of isometric voluntary contraction underwent fewer changes, which, in general, confirms the importance of PT in the preservation of muscle function, especially under conditions of mechanical unloading. However, the PT program applied, as well as the regimen of exercises carried out, did not completely prevent the negative effect of unloading on TS function.

The training programme applied in the present study had an effect on contractile properties in the TS. A significant decrease in MVC was observed after 120-day bed rest (Koryak 1995) and it was concluded, therefore, that the small decrease (3%) in MVC after 120-day bed rest with PT reflected a neural adaptation. The decrease in $P_a$ (cf. Figure 3, right panel) would suggest an increase in central drive in the control of voluntary muscle by the motor nerve system. These findings taken together with the reported increase in motor unit synchronization (Milner-Brown et al. 1975) and motor unit activation (Komi et al. 1978; Moritani and DeVries 1979) would suggest that neural adaptation may also have contributed to the increase in voluntary strength that occurred with training under conditions of 120-day bed rest. It was anticipated that the changes in $P_a$ and $P_o$ would correspond to these in voluntary
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force, namely, with increases in training (see Koryak 1993) and decrease with bed rest without countermeasures (Koryak 1995). In contrast, it was observed that there were nonsignificant changes in the twitch tension after 120-day HDT with PT (Koryak 1995). These unexpected experimental findings are not unique. Edgerton (1976) has found a nonsignificant 15% decrease in the gastrocnemius muscles twitch tension in the bushbaby. These changes are quite similar to those observed in our study.

PT counteracts the muscle mass loss related to inactivity and prevents changes in the composition of muscle fibers caused by disuse (MacDougall et al. 1980). This agrees with the previous suggestion of Alway et al. (1988) that contractile adaptation to training can occur independently of the changes in percentage fibre type. Since we were not able quantitatively to assess the intensity of the exercises performed and the device applied had certain limitations, this could have led to the study subjects performing a greater volume of exercises, but with less intensity. Data on the use of high resistance exercises with high intensity confirms their importance in the protection of muscle function from atrophy. Thus, balanced PT consisting of high resistance and intense exercises (2–3 days/week) and aerobic exercises (~4 days/week) is more effective in the preservation of muscle function during prolonged bed rest (Trappe et al. 2007, 2008, 2009). Moreover, training with highly intensive resistance exercises lasting for ~7 min/week during the bed rest period was more effective when compared to exercises lasting for more than 60 min/week under actual zero gravity conditions (Trappe et al. 2009).

It was anticipated that the changes in $P_t$ and $P_o$ would correspond to these in voluntary force, namely, with increases in training (Koryak 1998) and decrease with bed rest without countermeasures (Koryak 1998). In contrast, in the present study, $P_o$ even slightly decreased (~9%) after PT, which led to a tendency toward a decrease in the $P_t/P_o$ after the 120-day HDT with PT. Changes in the $P_t/P_o$ may reflect the degree of changes in the muscle tensile strength. The literature indicates that disuse induced an increase in muscle and joint stiffness and a decrease in the range of motion (Lambertz et al. 2003; Grosset et al. 2010). Decreased muscle tensile strength permits the body to transmit the tension developed by sarcomeres of the contractile tissue more effectively and thus the $P_t/P_o$ increases. On the contrary, increased muscle tensile strength during PT may result in a decreased $P_t/P_o$ (Less et al. 1977). We suppose that in our experiment PT during the HDT contributed to the increased muscle tensile strength to a certain extent. Training may lead to a decreased $P_t$ by causing an increase in the muscle tensile strength, which is described in this work.

The PT applied in the present study was performed every third day, which only allowed the subjects to carry out two sessions a week. Furthermore, taking into consideration the fact that physical training was performed twice a week by the end of the study but total physical load was reduced down to 70% of that usually applied to men (see the Methods), then it seems that the total volume and, especially, the intensity of exercises, was insufficient to support the mechanical properties of the TS tendon. Furthermore, PT significantly reduced the level of decrease in MTC stiffness when compared to unloading without training (Koryak 2012). It should be noted that the tendon is not an inert structure, and a skeletal muscle also changes with the level of physical load; in other words, the mechanical properties of the tendon may adapt to load changes.

During gravity loading (0 G), the human TS tendon is exposed to very high rhythmic load due to constant muscle use and the transmission of muscle force related to heel activity (heel-and-toe movements), which require stabilization and movement of the body during movement (walking and running) (Fukunaga et al. 2001). Therefore, during unloading the full volume of exercises (load level, frequency and duration) should exceed the threshold level in order to prevent changes to the mechanical properties of the tendon completely. The walking load produced by
the Achilles tendon is ~210 kg/cm² (Finni. et al 1998), i.e. for a person weighing 70 kg, the lifting and dropping of body weight in 1g would lead to the development of tension in the Achilles tendon equal to ~200 kg/cm². Therefore, if we suppose that ordinary walking is a stimulus sufficient to maintain the mechanical properties of the tendon under normal gravity conditions, then the threshold PT level required for the prevention of any deterioration during unloading should be more than or equal to the body weight. Hence, it may be supposed that although the load level applied in this study has been sufficient, the training regimen followed during unloading has been significantly lower than the load frequency during ordinary walking. Therefore, the required load frequency should obviously be higher in order to exceed the threshold volume. The latter is confirmed by a study when during 20 days of bed rest, PT was not only performed every day (16 out of 20 days), but also with load/weights approaching the subjects body weight (Akima et al. 2003). Moreover, the analysis of exercises used in the training process within the frames of this study revealed a lack of exercise for training the foot extensors. And if we take into consideration the fact that the total PT load was reduced (see the “Methods”), it may be the main (or even principal) cause of incomplete preservation of muscle function during unloading.

PT and disuse have often been associated with muscle hypertrophy and atrophy, respectively (MacDougall et al. 1980). In the present experiment no direct measurement of the TS mass muscle was made; however, the peak-to-peak amplitude of the maximal M-wave is an indirect measurement of the excitable muscle mass. The M-wave amplitude did not change significantly with either PT or HDT [10.4 (SEM 0.9) mV compared to post 11.0 (SEM 1.0) mV], suggesting that little alteration in muscle mass occurred.

During many everyday activities, the ability to produce high muscle force per time unit is more important than the ability to generate high force. The rate of force development depends on many factors, in particular, on the duration of the excitation-contraction process, on the force-velocity properties of muscle fibers (even during isometric contraction due to tendon structure deformity) and SEC stiffness. Therefore, decreased MTC stiffness may be the reason for the decreased rate of development of TS contraction after unloading, since SEC stiffness in known to be an important factor determining the rate of muscle force development (Bojsen-Møller et al. 2005). In other words, as indicated in the Introduction, the time of SEC stretching by contractile elements determines the EMD value (Hill 1938). Therefore, changes in MTC (SEC) stiffness after hyperactivity/hypoactivity mainly explain changes in EMD. In addition, all the structures of the SEC, classically composed of an active part (located in myofibrils) and a passive part (mainly aponeurosis and tendon) (Zajac 1989), could contribute differently to EMD. Nordez et al. (2009) used the noninvasive methodology (a real-time ultrasonography) determine the relative contribution of the passive part of the SEC (47.5 ±6.0% of EMD) and each of the two main structures of this component (aponeurosis and tendon, representing 20.3 ±10.7% and 27.6 ±11.4% of EMD, respectively).

This study demonstrated that the rate of isometric voluntary contraction development performed after the instruction to exert the fastest contraction had decreased after unloading, which confirms the theoretical relationship between the decreased muscle MTC stiffness and decreased rate of transmission of the contractile force and therefore the rate of contraction development, but to a significantly less extent when compared to similar conditions without PT (see Figure 4). This data was obtained for the first time and is indicative of the increase of MTC stiffness after PT under conditions of muscular system unloading. Our results in the present study indicate that PT during bed rest results in an increase in MTS (MTC), whereas a lack of training is associated with a decrease of this parameter (Koryak 2012). Therefore, PT decreases the EMD under muscular system unloading conditions.
The changes in elastic properties due to PT have been well documented. Endurance training resulted in an increase in the SEC stiffness in the soleus muscle of rats, associated with an increase in type I fibres (Goubel and Marini 1987). Both jump and endurance training also appear to increase both collagen concentration (Kovanen et al. 1980; Ducomps et al. 2003) and muscle passive stiffness. The soleus rat muscles submitted to plyometric training had more fast twitch fibres and a lower SEC stiffness than controls (Watt et al. 1982; Pousson et al. 1991; Almeida-Silveira et al. 1994). Malisoux et al. (2006) reported that human subjects given 8 weeks of maximal effort stretch-shortening cycle exercise training tended to have an increase in the proportion of type II fibres in their vastus lateralis muscles. Kubo et al. (2000) reported that the MTS is greater in long distance runners than in untrained individuals.

The results obtained correlate well with data on the decreased EMD after isometric training under bed rest conditions (Kubo et al. 2001). The EMD changes during training are mainly attributed to changes in the tendon structure, but it should be noted that tendon stiffness is always increased during any physical activity, both during endurance (Buchanan and Marsh 2001) and isometric training (Kubo et al. 2000, 2001). Furthermore, EMD changes correlate very closely with muscle MTC and especially with the active SEC fraction during training (Pousson et al. 1991; Ducomps et al. 2003, Malisoux et al. 2006).

This study demonstrated that the EMD is sensitive enough and may serve as an indirect marker for measurements of muscle MTC stiffness in order to determine the chronic adaptation of the musculo-tendinous structure of the muscle to the mechanical unloading during PT under real or simulated microgravity conditions. The data obtained demonstrates that a 120-day of simulated microgravity led to decrease the TS mechanical properties and although the adverse effects were reduced thanks to PT, they were not completely prevented by the training program. This permits us to suppose that the volume of exercises and especially the intensity of exercises performed did not exceed the threshold level required for the complete prevention of changes in mechanical properties.

The mechanical muscle responses obtained and the list of physical exercises received from the study subjects, as well as from members of long-term (6-month) space missions confirm the importance of PT in preserving muscle function and the capacity to work during long-term stays under microgravity conditions. Within the framework of this study, the PT program contained mainly low intensity exercises. The inclusion of exercises with higher load and higher intensity into the training process would contribute to a more effective exercise program for the training of skeletal muscles and it would reduce the total training time under zero gravity conditions. In general, PT under microgravity conditions allows subjects to create an increased functional reserve and reduces the effect of unloading observed under real microgravity conditions.

Acknowledgements

The author wishes to express his appreciation to all who contributed to the success of the experiment. He is especially grateful to V. Stepanstov for his guidance as the IBMP representative of the Exercise Countermeasures Project and the exercise testing group, including I. Amelin, N. Kharitonov, and N. Serikov.

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Influence of Simulated Microgravity on Mechanical Properties in the Human Triceps Surae Muscle in vivo


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ANALYSIS OF THE LONGEST DISTANCES RUN BY THE BEST SOCCER PLAYERS AT THE FIFA WORLD CUP IN BRAZIL IN 2014

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A Study Design; B Data Collection; C Statistical Analysis, D Manuscript Preparation; E Funds Collection

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Abstract. The aim of the study was, among other things, to characterise the maximum distance run by the four best teams in the FIFA World Cup in Brazil, including individual tactical formations and players who played for at least 90 minutes in the whole tournament. In total, the highest results of 68 players were established. In the analysis data obtained using Castrol Performance Index method were used.

The mean maximum distance run by players of the tournament semi-finalist teams in the 24 analysed games was 11.63 km. The mean by the analysed defenders was 11.75 km, whereas for midfielders it was 12.02 km, for forwards – 11.02 km, and for goalkeepers – 5.65 km. In group of all 68 respondents soccer players a distance of over 15 km in one game was obtained by Bastian Schweinsteiger, Thomas Müller and Lucas Biglia.

Key words: World Cup, distance run, soccer

Introduction

According to the researchers (Wilmore and Costill 1999) motor preparation of soccer players to competitive matches should be based on good adaptation to long-term work and efforts characterised by intensity corresponding to aerobic energy metabolism (according to the studies aerobic work in soccer accounts for 90% of active play time (Bangsbo et al. 1991)). Thus, it can be classified as a sport characterised by large endurance efforts, that is those where the ability to continue long-term work of specific intensity is required (from 60 to approx. 80–90% of maximum performance capacity), irrespective of the external conditions. One of the pillars of motor preparation of a soccer player is aerobic performance, the maximum level of which should not be below 60 ml/kg⁻¹ (Reilly et al. 2000; Helgerud et al. 2001).
In the 1960s and 1970s a player in a soccer competition would run on average approx. 4,000 to 5,000 m or less during a match. Nowadays, the mean distance (for outfield players) depending on the sports level of a player and a playing position ranges from 8,000 to 12,000 m (Jastrzębski 2005; Barros et al. 2007; Di Salvo et al. 2007). Moreover, this distance can increase to even 13,500–14,000 m in one match (Stølen et al. 2005; Barros et al. 2007).

In a comparison of the results of teams and playing positions it should be noted that Di Salvo et al. (2007) on the basis of the analysis of maximum running distances of players in twenty matches of the Spanish Premier League and ten matches of the UEFA Champions League in 2002/2003 and 2003/2004 seasons established that on average players cover approx. 11,393 m in a match (min. = 5,696; max. = 13,746). The largest distance is covered by central midfielders (approx. 12,027 m), side midfielders (approx. 11,990 m), side defenders (approx. 11,410 m), forwards (approx. 11,254 m) and central defenders (approx. 10,627) (Di Salvo et al. 2007). Bradley et al. (2009) reported results corresponding to a large extent to the above. After the analysis of the activity of 370 players of the English FA Premier League competing in 2005/2006 season they indicated that the “most active” tactical positions in terms of running are side midfielders (covering approx. 11,535), central midfielders (approx. 11,450), side defenders (approx. 10,710 m), forwards (approx. 10,314 m) and central defenders (approx. 9,885). During the 2010 World Cup in South Africa the largest distances in the analysed championship matches were covered by midfielders (from 12.3 to 12.9 km), forwards (from 10.5 to 11.9 km) and defenders (from 10.8 to 12.0 km) (Sang Duk et al. 2011).

In the light of the differences between running distances covered by the players a few decades ago and now, and taking into consideration new analyses of soccer play in championship level events it can be noted what changes have taken place in soccer competition in terms of game specificity and, as a consequence, in terms of demands placed on professional players of 11-a-side soccer. For this reason, the aim of the authors of this study was to characterise mean maximum running distances covered by the top players of the best teams of the 2014 World Cup.

Methodology of Study

The main objective of the study was to analyse maximum running distances covered by the players of the four best teams of the FIFA World Cup in Brazil, i.e. the national teams of Germany, Argentina, the Netherlands and Brazil. An additional objective was to determine the differences in mean maximum results between the four top teams of the tournament, and between the corresponding tactical positions of the teams. The following research questions were posed:

1. What mean maximum running distances were covered by the four top teams of the 2014 World Cup during the tournament?
2. What mean maximum running distances were covered according to playing positions of players of the four best teams at the Brazil World Cup during the tournament?
3. What was the largest running distance covered in one match by a goalkeeper, a defender, a midfielder and a forward playing in the semi-finals of the tournament?
4. Can any significant differences be indicated in terms of mean maximum running distances between the individual teams and between players in the corresponding playing positions of individual teams?

The analysis was carried out on players representing the four best teams of the World Cup in Brazil, that is the finalists of the tournament and the teams playing the third-place play-off. Only players who played for at least 90 minutes in the whole tournament were taken into consideration, that is 68 players in total. During the tournament
which took place from 12 June to 13 July 2014 all analysed teams played seven matches (three in the group stage, round of 16, quarter-finals, semi-finals and the third-place play-off or the final).

The analysis also included statistics obtained during so called “extra time”. In the cup games, which last 120 minutes instead of 90, the playing time is extended and therefore the competing players have to perform longer work. In total maximum results obtained during 24 championship games were determined. The selection of the specific games for this analysis is not accidental, as it is the best teams competing in international competitions that give direction to the changes in tactics and technique, setting trends in the game (O’Donoghue 2005).

The study used statistical data prepared on the basis of the Castrol Performance Index, a kinematic game analysis (source: www.fifa.com/castrolindex; access on 14–20.07.2014), assessing motor activity of the players during games, and enabling real-time match analysis. It is an objective system of game analysis, which was first introduced to evaluate the players during the 2008 UEFA European Championship.

Thanks to an available database the largest running distances covered by each analysed player in each game played by him in the Brazilian tournament were determined. In the analysis only the highest result (value of the indicator) of a player from all games played was used. On this basis mean maximum running distances were specified for:

1. Individual teams (the total of the greatest distances covered in the tournament by all players of a given team was divided by the number of players included in the analysis of the given team).
2. Playing positions (the total of the greatest distances covered in the tournament by players in a given playing position in given team was divided by the number of players included in the analysis of the given team).

Descriptive statistics was used for the mathematical analysis of the data and to indicate the significance of differences between the analysed teams and playing positions – one-way analysis of variance (ANOVA) was used. The calculations were performed in STATISTICA 10.0 PL software, StatSoft Polska.

Results

The analysis of the four best teams of the championship indicated that mean maximum running distance of representatives of Germany, Argentina, the Netherlands and Brazil in the analysed 24 games was 11,628 m (11.63 km). The players of the German team had the mean result of 12,418 m (12.42 km), the Dutch – 11,664 m (11.66 km), the Argentines – 11,462 m (11.46 km) and the Brazilians 11,142 m (11.42 km). The results are presented in Table 1.

Table 1. Mean values of the maximum running distances of the best four teams of the 2014 World Cup

<table>
<thead>
<tr>
<th>No.</th>
<th>Team</th>
<th>Number of players</th>
<th>M distance (metres)</th>
<th>Min. (metres)</th>
<th>Max. (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Germany</td>
<td>14</td>
<td>12,418</td>
<td>6,607</td>
<td>15,338</td>
</tr>
<tr>
<td>2.</td>
<td>Netherlands</td>
<td>15</td>
<td>11,664</td>
<td>6,949</td>
<td>13,906</td>
</tr>
<tr>
<td>3.</td>
<td>Argentina</td>
<td>17</td>
<td>11,462</td>
<td>5,143</td>
<td>15,012</td>
</tr>
<tr>
<td>4.</td>
<td>Brazil</td>
<td>18</td>
<td>11,142</td>
<td>8,481</td>
<td>14,513</td>
</tr>
</tbody>
</table>

Mean for 64 players 11.628

M – mean; Min. – minimum results; Max. – maximum results.
The ANOVA analysis of variance did not indicate any significant differences in the levels of mean largest running distances of the four best teams of the 2014 World Cup (F = 0.868; df = 3.60; p = 0.463).

The mean of the largest distances covered by the defenders of the best four teams of the tournament was 11,747 m (11.75 km). The analysis of these data showed that the Argentine defenders covered the mean distance of 12,492 m (12.49 km), the Dutch defenders covered 11,851 m (11.85 km), the Germans – 11,630 m (11.63 km) and the Brazilians 11,225 m (11.23 km). The results of the analysis were presented in Table 2.

Table 2. Mean values of maximum running distances during covered by the defence players of the four best teams of the World Cup in Brazil

<table>
<thead>
<tr>
<th>No.</th>
<th>Team</th>
<th>Number of players</th>
<th>M distance (metres)</th>
<th>Min. (metres)</th>
<th>Max. (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Argentina</td>
<td>5</td>
<td>12,492</td>
<td>10,576</td>
<td>14,089</td>
</tr>
<tr>
<td>2.</td>
<td>Netherlands</td>
<td>5</td>
<td>11,851</td>
<td>10,618</td>
<td>12,991</td>
</tr>
<tr>
<td>3.</td>
<td>Germany</td>
<td>5</td>
<td>11,630</td>
<td>6,607</td>
<td>14,115</td>
</tr>
<tr>
<td>4.</td>
<td>Brazil</td>
<td>7</td>
<td>11,225</td>
<td>9,527</td>
<td>13,780</td>
</tr>
</tbody>
</table>

Mean for 22 defenders

M – mean; Min. – minimum results; Max. – maximum results.

The one-way ANOVA showed that there were no statistically significant differences in terms of mean result between the defence formations of Argentina, Netherlands, Germany and Brazil (F = 2.262; df = 3.21; p = 0.111).

The defenders who covered more than 14 kilometres in one game were German, Benedikt Hoewedes – 14,115 m (14.12 km) and Argentine, Marcos Rojo – 14,089 m (14.09 km).

The midfielders of the top four teams of the tournament had mean maximum running distance of 12,021 m (12.02 km). The players of the German team covered the mean distance of 13,758 m (13.76 km), followed by the Dutch with 12,145 m (12.15 km), Argentine with 11,527 m (11.53 km) and the Brazilians with 11,047 m (11.05 km) (Table 3).

Table 3. Mean values of maximum running distances covered by midfield players of the four best teams of the 2014 World Cup

<table>
<thead>
<tr>
<th>No.</th>
<th>Team</th>
<th>Number of players</th>
<th>M distance (metres)</th>
<th>Min. (metres)</th>
<th>Max. (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Germany</td>
<td>5</td>
<td>13,758</td>
<td>11,261</td>
<td>16,338</td>
</tr>
<tr>
<td>2.</td>
<td>Netherlands</td>
<td>5</td>
<td>12,145</td>
<td>10,949</td>
<td>13,906</td>
</tr>
<tr>
<td>3.</td>
<td>Argentina</td>
<td>7</td>
<td>11,527</td>
<td>5,143</td>
<td>15,012</td>
</tr>
<tr>
<td>4.</td>
<td>Brazil</td>
<td>6</td>
<td>11,047</td>
<td>8,481</td>
<td>14,513</td>
</tr>
</tbody>
</table>

Mean for 23 midfielders

M – mean; Min. – minimum results; Max. – maximum results.

The ANOVA analysis of variance carried out on the midfield players of the four best teams of the 2014 World Cup did not indicate any statistically significant differences in the level of mean maximum running distances (F = 2.487; df = 3.22; p = 0.087).
The midfielders of the four top teams of the World Cup who covered distances above 15 kilometres in one game were German, Bastian Schweinsteiger with 15,338 m (15.33 km) and Argentine, Lucas Biglia with 15,012 m (15.01 km).

The mean maximum running distance in the group of forwards was 11,016 m (11.02 km). Among the players in the most offensive playing position of the teams which qualified to the semi-finals, the mean value for the Germans was 11,728 m (11.73 km), for Brazilians it was 11,142 m (11.14 km), for the Dutch 10,995 m (11.00 km), and for the Argentines 10,342 m (10.34 km). The graphic presentation of the mean maximum distances was shown in Table 4.

Table 4. Mean values of maximum running distances covered during the games of the World Cup in Brazil by players in the forward position of the best four teams of the tournament

<table>
<thead>
<tr>
<th>No.</th>
<th>Team</th>
<th>Number of players</th>
<th>M distance (metres)</th>
<th>Min. (metres)</th>
<th>Max. (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Germany</td>
<td>4</td>
<td>11,728</td>
<td>8,942</td>
<td>15,180</td>
</tr>
<tr>
<td>2.</td>
<td>Brazil</td>
<td>5</td>
<td>11,142</td>
<td>9,186</td>
<td>13,581</td>
</tr>
<tr>
<td>3.</td>
<td>Netherlands</td>
<td>5</td>
<td>10,995</td>
<td>6,949</td>
<td>13,855</td>
</tr>
<tr>
<td>4.</td>
<td>Argentina</td>
<td>5</td>
<td>10,342</td>
<td>6,464</td>
<td>13,519</td>
</tr>
<tr>
<td></td>
<td>Mean for 19 forwards</td>
<td></td>
<td>11,016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M – mean; Min. – minimum results; Max. – maximum results.

The ANOVA analysis of variance did not indicate any statistically significant difference in the level of mean maximum running distances of forwards of the four best teams of the championship (F = 1.628; df = 3.18; p = 0.218).

The only forward of the four top teams of the 2014 World Cup who covered a running distance longer than 15 km during one game was German, Thomas Müller – 15,180 m (15.18 km).

The mean maximum running distance covered by goalkeepers was 5,651 m (5.65 km). Among them German, Manuel Neuer covered 6,985 m (6.99 km) in one game, Dutchman Jasper Cillessen 6,277 m (5.11 km), Brazilian Julio Cesar 4,233 m (4.23 km) and Argentine Sergio Romero – 4,233 m (4.23 m).

Discussion

A soccer match is characterised by a long duration, i.e. 90 minutes or 120 minutes or more in case of knockout cup competitions. Therefore, a player’s preparation to sport competition should be based on adaptation to long-term effort (Wilmore and Costill 1999). This is supported by the fact that during a match some players cover in total from approx. 8 to 12 kilometres (Jastrzębski 2005; Barros et al. 2007; Di Salvo et al. 2007) or even more (Stølen et al. 2005; Barros et al. 2007). The running distances of individual players differ depending on the role assigned to the player by the manager or the player’s playing position. For example, Di Salvo et al. (2007) established on the basis of analysis of the top league in Spain and the UEFA Champions League that the largest distances are covered in one game by central midfielders, followed by side midfielders, side defenders, forwards and central defenders. According to Bradley et al. (2009) the most active players in the analysed element of competition are side midfielders, central midfielders, side defenders, forwards and central defenders (a study of the English FA Premier League). Sang Duk et al. (2011), analysing the games of the 2010 World Cup, established that the highest demands in terms of distance covered are placed on midfielders, followed by forwards and defenders.
With the above as the theoretical foundation of our analysis, its aims included determining the maximum running distances by teams, playing positions and players of the four best teams of the World Cup in Brazil, i.e. Germany, Argentina, the Netherlands and Brazil. Only players who played at least 90 minutes in the whole tournament were included in the analysis. The results were collected for 68 players in total using the Castrol Performance Index. The analysis included also game statistics characterising the analysed players in games with "extra time", that is matches which lasted 120 minutes and more. Four research questions were specified in the study.

The analysis of available data showed that in the studied 24 games the German team covered a mean maximum running distance of 12.42 kilometres, the Dutch covered 11.66 km, the Argentines 11.46 km and the Brazilians 11.14 km. The total mean of all above teams was 11.63 km, which answers the first research question.

The analysis of maximum distances by playing positions indicates that the defenders of the four semi-finalist teams covered in the whole tournament mean distance of 11.75 km (the Argentines – 12.49 km, the Dutch – 11.85 km, the Germans – 11.63 km, the Brazilians – 11.23 km), whereas the midfielders covered approx. 12.02 km (the German team – 13.76 km, the Dutch team – 12.15 km, the Argentine team – 11.53, the Brazilian team – 11.05 km). The mean maximum result for 19 analysed forwards was approx. 11.02 km (the Germans – 11.73 km, the Brazilians – 11.14 km, the Dutch – 11.00 km and the Argentines – 10.34 km) and the four goalkeepers who presented their skills in at least semi-finals of the Cup – 5.65 km. Determining the above data answers the second research question. These values of mean maximum distances covered by top players largely correspond to the results obtained by Jastrzębski (2005), Barros et al. (2007) and Di Salvo et al. (2007), who estimated the mean running distance covered by a player during a soccer game at approx. 8–12 km.

To answer the third research question it was noted that among goalkeepers Manuel Neuer (Germany) and Jasper Cillessen (Netherlands) covered at least 6 km in one game. Among defenders German, Benedikt Hoewedes and Argentine, Marcos Rojo covered more than 14 km in one game. In the group of midfielders and forwards Bastian Schweinsteiger (Germany), Lucas Biglia (Argentina) and Thomas Müller ran over 15 km in one game. Maximum locomotion results obtained by the latter, that is the most active running players who exceeded the limit of 15 km per game, confirm the findings of such authors as Stølen et al. (2005) and Barros et al. (2007), which referred to very high demands in terms of endurance abilities that have to be met by the world’s best players during selected championship games. German Bastian Schweinsteiger who covered relatively the largest locomotive distance among all analysed players, ran 15,180 m (15.19 km) in the final with Argentina, played on 13 July 2014 at the Maracanã Stadium in Rio de Janeiro.

The one-way ANOVA analysis of variance did not show any statistically significant difference between the studied teams or between players in corresponding playing positions of the teams in terms of mean maximum running distances. This means that none of the teams and positions showed significantly higher or lower level of the analysed variable. The results of the study could have been influenced by the selection of the studied teams, where only results achieved by the four semi-finalists of the tournament were considered in the analysis.

Conclusions

On the basis of the analysis of mean maximum running distances by teams, playing positions and players of the four best teams of the Brazil World Cup the following conclusions can be formulated:

1. On average in individual games at championship level players cover a maximum distance of approx. 11.63 km (from approx 11.14 to approx. 12.42).
2. In top level soccer games the defenders cover a maximum distance of approx. 11.75 km, midfielders – approx. 12.02 km, forwards – approx. 11.02 km and goalkeepers – approx. 5.65 km.

3. The World Cup in Brazil showed that in sports competition in individual cases a player has to perform higher than average work determined by the running distance of a minimum of 15 km or more per one game.

4. During a championship level tournament there is no statistically significant difference between the best teams and players in the corresponding playing positions in various teams in terms of maximum running distances covered by them.

References

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Illustrations (photographs and line drawings) and tables must not be included in the text file. The table(s) and figure(s) have to be submitted as separated, source file(s). Table(s) files should be prepared as .doc files. Tables, referred to as ‘Table 1’, ‘Table 2’, and so on, must be numbered in the order in which they occur in the text. Illustrations should be prepared referred to as ‘Figure 1’, ‘Figure 2’, and so on, must be numbered in the order in which they occur in the text. Diagrams and drawings should be produced using a computer drawing or graphics package at the appropriate resolution. It is in the Author’s interest to provide the highest quality figure format possible. Colour figures will be reproduced in the on-line edition of the journal free of charge, in the print version all figures will be reproduced in the greyscale. If you wish to have figures in colour online and black and white figures printed, please prepare both versions.

References

References should be cited in the text by author and year of the publication e.g. (Cięszczyk 2009). In case there are more than one author: reference with two authors should be cited as Nowak and Kowalski (2008) or (Nowak and Kowalski 2008); when citing a reference with three authors or more use Nowak et al. (2010) or (Nowak et al. 2010). All references must be alphabetized by surname of first author and numbered at the end of the article.

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