A DESCRIPTIVE PROFILE OF ISOMETRIC MUSCLE STRENGTH AND MUSCLE STRENGTH IMBALANCE IN YOUNG TENNIS PLAYERS

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ABSTRACT

Background. Tennis is assumed as asymmetric sport, prolonged training practice could affect muscle strength imbalance. Muscle strength functional ratio imbalance could be a reason for poor posture, physical weakness and increased risk of injury. The purpose of the research was to evaluate young tennis players' main muscle group strength topography and to investigate the level of different muscles groups' bi-lateral and contra-lateral imbalance.

Methods. The participants of the study were six young right handed competitive tennis players (girls, age 11.4 ± 0.5 years, tennis experience 4.7 ± 0.6 years). Examination of main muscles groups was performed with an isokinetic dynamometer.

Results. Young tennis players have pronounced bi-lateral imbalance between shoulder joint extensors and flexors (25%), internal and external rotators (36%), left elbow flexors and extensors (58%), wrist pronator and supinator (the right hand 17%, left 48%), hip flexors and extensors (35%); knee joint flexors and extensors (60%); ankle dorsal flexors and plantar flexors (59%); spine and abdominal muscles (48%). It was detected that young tennis players have pronounced contra-lateral imbalance between right and left internal rotators of the shoulder joint (27%) and external rotators (26%), wrist joint supinators (41%).

Conclusions. To avoid the increase in muscle bi-lateral imbalance it is highly recommended to pay more attention to shoulder adductors and shoulder external rotators, elbow flexors and extensors, wrist supinators and extensors, knee extensors, ankle plantar flexors and spine flexors. For contra-lateral imbalance prevention in addition to train non-dominant upper extremity muscles: shoulder internal and external rotators, wrist supinators.

Keywords: bi-lateral imbalance, contra-lateral imbalance, maximal isometric torque, muscle functional ratio, asymmetry.

INTRODUCTION

Muscle strength plays an important role in sports where maximum power should be applied in transitional and fast movements, which are *throwing-like* movements (Bartonietz, 1994; Clements, Ginn, & Henley, 2000; Hay, 1992; Henry, 1960; Kopsic Segal, 2002). Tennis player performs about 380 strokes on average during one hour of play. Minimal time spent in trainings is two hours a day, tennis game in competition may last from one to five hours (Girard & Millet, 2008; Kovacs, 2006). To clarify the winner they have to play at least 48 matches in a game of three sets and 72 matches in a game of five sets (Christmass, Richmond, Cable, & Arthur, 1998; Mendez-Villanueva, Fernandez-Fernandez, Bishop, Fernandez-Garcia, & Terrados, 2007). Minimum number of stokes per game may fluctuate from 130 to 220 for which they need as many contractions of *working* muscles as possible. An ability to withstand great pressure depends on enormous muscle strength and endurance during the whole game, were we can observe a fatigue-resistance phenomenon (Stephenson, Lamb, & Stephenson, 1998). The more powerful stroke is produced, the greater muscle effort is made. Not only wrist, elbow and shoulder joint muscles take part in the stroke generation, but also great input is produced by body core and lower limb muscles (Reid & Schneiker, 2008). The demands of tennis can lead to characteristic injury patterns and musculoskeletal system adaptation (Ellenbecker, Pluim, Vivier, & Sniteman, 2009).

The evaluation of young tennis players' muscle strength condition is important because of several points of view. First of all, muscle strength testing helps coaches control proper and harmonic muscle system evaluation and assess physical fitness of an athlete for strength training improvement (Andrade et al., 2013; Reid & Schneiker, 2008; Ulbricht, Fernandez-Fernandez, & Ferrauti, 2013; Zuša, 2013). Secondly, knowledge about muscle strength condition and functional ratio between agonist-antagonist (*bi-lateral imbalance*), dominant and non-dominant body side (*contra-lateral imbalance*) is vital for reducing and predicting the risk of injury because muscle strength imbalance could effect this (Alizadehkhaiyat, Fisher, Kemp, & Frostick, 2007; Andrade et al., 2013; Ellenbecker, Roetert, Sueyoshi, & Riewald, 2007; Hayot et al., 2014; Kovacs, 2006; Nagel & Avram, 2013; Saccol et al., 2010). In spite of common traumas and complains on different joint, back pain in sport, subject of muscle strength imbalance in different age athletes still has been not sufficiently studied (Everett, Strutton, & McGregor, 2008; Saccol et al., 2010).

The aim of the research was to evaluate young tennis players' main muscle group strength topography and to assess the level of bi-lateral and contra-lateral imbalance. We hypothesized that young tennis players have pronounced muscle strength bi-lateral imbalance between shoulder adductors and abductors, internal and external rotators, wrist supinators and pronators, and contra-lateral imbalance between dominant and non-dominant upper extremities shoulder adductors and internal rotators, wrist flexion, extension and supination muscles strength.

METHODS

Participants. The participants of the experiment were six healthy and competitive tennis players (girls, age 11.4 ± 0.5 years, mass 42.6 ± 4.6 kg, height 157.8 ± 5.2 cm, tennis experience 4.7 ± 0.6 years, weekly training 10 ± 2 h). All tennis players were right handed. The research was accepted by Latvian Academy of Sport Education local Ethics Commission (Resolution No. 11-D1).

Testing procedure. An isokinetic device (Rev-9000, Italy) was used for the determination of the maximum isometric torque in selected joint positions in the major muscle groups of young tennis players. The testing procedure was originated based on the recommendations of Davies, Ellenbecker and Brinks (2000). Before testing each participant was encouraged to perform a general 8–10 min warm-up. Maximal muscle strength testing procedure consisted of specific joint warm up of 60 s, followed by 6 x 3 s isometric muscle work (fixed joint angular position, with resistance 600 N·m and fixed speed at 0°/s) with 20 s passive rest and then 60 s cool down continuous passive motions.

Shoulder joint muscle strength testing. Shoulder joint flexion and extension testing was performed in supine position, upper extremity straight, 10° flexing in elbow joint is acceptable, 90° angle in shoulder joint. Shoulder joint adduction and abduction was performed in supine position, upper extremity straight, 10° flexing in elbow joint is acceptable, 60° angle in shoulder joint. Shoulder joint internal and external rotation testing was carried out in sitting position, elbow joint in 90° flexion and 60–75° abduction, 25° angle in shoulder joint.

Elbow joint testing. Elbow joint flexion and extension was tested in sitting position with 90° in elbow joint, wrist was in supination position during flexion and in pronation position during extension exercise.

Wrist joint testing. Wrist flexion and extension was performed in sitting position with 60–70° flexion in elbow joint and 50° in wrist joint. Forearm pronation and supination performed in sitting position, a rotation axis was parallel to forearm, testing angle – 90°.

Hip joint testing. Hip flexion and extension were performed in supine position, testing angle – 80°. Hip adduction and abduction testing position was lying on one side with testing angle in hip joint of 45°.

Knee joint testing. Knee flexion and extension were performed in a sitting position, testing angle was 90°.

Ankle joint testing. Ankle joint dorsal flexion and plantar flexion were performed in supine position with knee flexed at 120°, testing angle in joint 15°. Ankle inversion and eversion was measured lying on one side, knee slightly bended, testing angle of 45°.

*Spine and abdominal muscle testing***.** Spine flexion and extension exercise was performed in a sitting position, testing angle – 50°.

Verbal and visual feedback was used to increase the motivation of the young tennis players. For data analysis we chose the best result for current player, an exception was the first repetition – if the best record was during the first repetition, we did not take it for the following data analysis – this is based on recommendation of Davies et al. (2000).

RESULTS

Young tennis players of the same age and qualification that were training in the same group took part in the research. Regardless of these circumstances, indicators of muscle group strength and their mutual relations were different for each participant.

Shoulder joint muscle strength. The measurements show that all participants of the experiment had more powerful shoulder extensors than flexors: right shoulder extensors 39.5 ± 9.9 N·m and left 40.6 ± 9.1 N·m, right shoulder flexors 29.9 ± 4.5 N·m and left 25.4 ± 3.0 N·m. The average result of right shoulder adductors was 24.15 ± 2.8 N·m, for abductors 23.15 ± 4.25 N·m, but for left shoulder adductors 26.22 ± 7.2 N·m and abductors 22.91 ± 5.07 N·m. Muscular pronounced bi-lateral imbalance was observed in shoulder joint internal and external rotators, averages for right shoulder internal rotators 25.91 ± 3.61 N·m and external rotators 16.31 ± 6.34 N·m, for left shoulder internal rotators 20.45 ± 5.88 N·m and external rotators 13.02 ± 4.39 N·m.

Elbow joint muscle strength. The average group indicator for right elbow joint flexors was 25.34 ± 3.96 N·m, for extensors 23.90 ± 6.99 N·m and for left elbow joint flexors was 21.58 ± 5.82 N·m, for extensors 26.10 ± 8.56 N·m.

Wrist joint muscle strength. The average group indicator of right wrist flexors was 5.33 ± 2.20 N·m and extensors 5.14 ± 1.52 N·m, for left wrist flexors 8.34 ± 1.34 N·m and extensors 4.01 ± 1.50 N·m. The analysis of wrist pronators and supinators testing results showed that right wrist pronator strength was 5.56 ± 1.47 N·m and for supinators 4.52 ± 0.48 N·m; for left wrist pronators it was 5.96 ± 1.97 N·m and for supinators it was 4.02 ± 2.37 N·m.

Hip joint muscles strength. The testing results of hip joint flexors and extensors maximum torque showed that flexors dominated over extensors, the average group torque indicator of right hip flexors was 116.63 ± 20.69 N·m and for extensors it was 73.32 ± 14.39 N·m, for left hip flexors 128.64 ± 25.86 N·m and for extensors 81.22 ± 11.49 N·m. Adductors of hip joint muscles were more powerful than abductors, right hip adductors torque average indicator was 77.46 ± 15.09 N·m, for abductors 66.39 ± 7.62 N·m and for left hip adductors 76. 63 ± 14.15 N·m, for abductors 65.41 ± 10.14 N·m.

Knee joint muscles strength. Right knee flexors torque was 131.58 ± 26.67 N·m, extensors 50.74 ± 6.04 N·m and for left knee joint muscles respectively flexors 130.00 ± 28.00 N·m and extensors 54.65 ± 12.67 N·m.

Ankle joint strength. The average indicators of the group for right ankle dorsal flexors was 80.02 ± 30.52 N·m, plantar flexors 33.04 ± 6.97 N·m and for left ankle dorsal flexors 83.40 ± 19.60 N·m, planar flexors 30.64 ± 8.00 N·m. The average torque of group right ankle invertors was 18.52 ± 4.05 N·m, evertors 15.66 ± 2.97 N·m and left foot respectively invertors 19.42 ± 4.38 Nm and evertors 14.23 ± 2.57 N·m.

Spine and abdominal muscle strength. There was the same tendency for all young tennis players – domination of spine extensors back muscles. The average indicators of maximum torque of abdominal muscles spine flexors were 94.47 ± 12.30 N·m and of extensors 185.40 ± 34.35 N·m respectively.

DISCUSSION

The main idea for investigating muscle strength topography is to understand the muscle strength condition of tennis specific and non-specific muscles, to find out critical level of muscle strength ratio and imbalance. The present study focused on the 11-year-old competitive tennis players – girls. Muscle strength topography of young tennis player reflects the functional state of different muscles at 11 years of age and the influence of tennis specific training. To be able to acquire and to perform stroke technique, it is important to have a specific muscle strength development level (Saccol et al., 2010) and this is the reason why during the training of young tennis players a particular attention (60–70% of all training time) needs to be paid to musculoskeletal system strengthening (Schönborn, 1998; Zuša,

2013) and promotion of all muscle group strength development.

There are limited resources on the subject of young tennis player muscle strength measuring. Strength deficits or muscle imbalance is assumed as one of several injury risk factors in sport (Alizadehkhaiyat et al., 2007; Almekinders & Temple, 1998). It has been suggested that the incidence of various types of overuse injuries may be reduced by performance of sport and motor-specific resistance training, potentially after measuring agonist and antagonist strength imbalances to identify any predisposition for injury (Alizadehkhaiyat et al., 2007; Ellenbecker, Roetert & Riewald, 2006; Fleck & Falkel, 1986), especially in young tennis players – injuries can involve virtually all anatomical regions of the body (Ellenbecker, 2014). It has been verified that during a period of 11–12 years children's physiological features do not show much muscle strength increase (Burnie, 1987; Degache, Richard, Edouard, Oullion, & Calmes, 2010; Gur, Akova, Punduk, & Kucucoglu, 1999; Sunnegardh, Bratteby, Nordesjo, & Nordgren, 1998). This fact allows us to assume that increase of the muscle strength could be connected with performing a regular physical exercise and tennis practice influence (Chandler, Kibler, Stracener, Zeigler, & Pace, 1992; Saccol et al., 2010; Zuša, Lanka, & Čupriks, 2012).

Upper extremity muscle strength, level of bi-lateral and contra-lateral imbalance. The role of upper extremity (shoulder, elbow and wrist joint) muscles during forehand stroke production has been studied by Bahamonde and Knudson (2003). Over-training, repetitive movements (Ellenbecker et al., 2006), training errors, poor and faulty stroke technique, inappropriate equipment or the level of expertise (Hayot et al., 2014), flexibility problems, poor circulation, strength deficit or muscle imbalance (Almekinders, & Temple, 1998) could progress such injury as swimmers' shoulder, lateral epicondylitis, lateral tendinosis, lateral epicondylopathy, tennis elbow, radial epicondylalgia, extensor tendinopathy and row elbow pain (Alizadehkhaiyat et al., 2007). A shoulder-elbow-wrist segment cooperation is very significant in tennis stroke production, a weak muscle of one joint will affect next segment, for example, a weakness of shoulder muscles will provide elbow muscle overuse because of compensation action, etc.

There are several studies (Chandler et al,, 1992; Ellenbecker, 1992; Julienne, Gauthier, Moussay, & Davenne, 2007; Yildiz, Aydin, Kirapl, Hazneci, & Kalyon, 2006;) which showed that competitive tennis players had upper extremity contra-lateral imbalance – dominant arm muscles are better developed in a comparison with non-dominant arm muscles. **Shoulder** internal / external rotators and adductors/abductors are often studied in tennis players, because these muscles are assumed as tennis specific – they play an important role in racquet acceleration in all tennis strokes (Bahamonde & Knudson, 2003; Julienne, Gauthier, & Davenne, 2012; Ryu, McCormick, Jobe, Moynes, & Antonelli, 1988; Saccol et al., 2010). All studies have similar results – tennis players have a significant contra-lateral imbalance in shoulder internal rotators (Chandler et al., 1992; Ellenbecker & Roetert, 2003; Ellenbecker, 1992; Nagel & Avram, 2013), this is assumed to be related with the tennis training demands and it is considered as an adaptation to the serving motion. The ratio values recommended to provide muscular balance are between 66–75%, such that shoulder external rotators are at least 2/3 the strength of the shoulder internal rotators in the concentric mode (Saccol et al., 2010), a conventional strength ratio of 2:3–3:4 (0.66–0.75) to prevent shoulder injuries (Ellenbecker, & Davies, 2000). The results of our study approved previous study trends – young tennis players have contra-lateral imbalance in shoulder internal rotators, which varied between 22–42% (only for one participant bi-lateral imbalance level was only 12%). In shoulder external rotators for 3 participants the level of contra-lateral imbalance was not higher than 11% and for other 3 – it varied between 44–52%. Contra-lateral imbalance in shoulder adductors was found for 3 participants (22–36%) and in flexors for 1 participant (36%). Level of bi-lateral imbalance highly varied between all participants: difference in internal and external rotators for right shoulder was 10–75%, for left shoulder 15–56%; in adductors and abductors for right shoulder 0–28%, for left shoulder 0–25%; in shoulder extensors and flexors for right 11–38% and for left 23–50%. Including a specific strength training program in tennis practice to avoid shoulder muscle strength imbalance proved a positive effect (Julienne et al., 2012; Niederbracht, Shim, Sloniger, Paternostro-Bayles, & Short, 2008).

Lack of **elbow joint** muscle strength or muscle strength imbalance could affect racquet orientation during stroke production (this will affect accuracy and efficiency of the stroke) and could be an injury predisposition (Bazzucchi, Riccio, & Felici, 2008; Elliott, 2003). Greater dominant arm strength in elbow extensors was found in junior elite tennis players (Ellenbecker, & Roetert, 2002). The results of our study showed that the trend of imbalance between elbow flexors and extensors was different for all participants, 2 participants had bi-lateral imbalance 21 and 31% of flexors dominance for right elbow joint; and 2 participants had bi-lateral imbalance 15, 27% of flexors dominance and 3 had 13, 32, 56% of extensors dominance for left joint. Level of contra-lateral imbalance varied between 13–64% for elbow flexors and between 9–74% for extensors. The data of the testing young tennis players differed from other similar studies (Bazzucchi et al., 2008; Howatson, & Someren, 2005) – indicators of young tennis players elbow flexors and extensors maximal torque are significantly lower and it could be explained with age differences of the participants.

Wrist is distal segment in tennis stroke upper extremity kinematic chain, tennis specialists named wrist as *weakest* part, because very often wrist muscle strength training stays behind physical condition training. During prolonged practice, repetitive high level of finger/wrist extensor muscle solicitations in all tennis strokes could provoke the overuse of these muscles and affect the tendinous tissue of their origins in the most extreme cases (Hayot et al., 2014). In similar study Salonikidis et al. (2009) measured WrF strength in adult high level tennis players (n = 6), handball players (n = 4) and University students (n = 10). Salonikidis et al. (2009) concluded that there was a high level of individual variation in the groups and maximal difference between groups muscle strength torque wasn't significant ($p > .05$). This proves that regular practice of tennis and handball doe not influence on wrist flexors strength development and to improve muscle strength it is necessary to perform specific exercises. Alizadehkhaiyat et al. (2007) and Hayot et al. (2014) found that wrist flexors were stronger than wrist extensors in healthy adults. Significantly greater dominant arm wrist flexors and extensors, as well as forearm pronation strength was found in highly skilled adult tennis players by Ellenbecker (1991). In our study the results of maximal torque in wrist flexors/extensors and pronators/supinators were low (in comparison with adult participants in other studies) and similar between each other. Significant trend for all participants was that wrist pronators were stronger than supinators: bi-lateral imbalance for right wrist joint varied between 8–29% and for left wrist joint – 25–73%. This fact could be explained with groundstroke, smash and serve stroke technique biomechanics – in finish part of *ball follow-through* phase the input of wrist pronators are essential. We found contra-lateral imbalance in wrist flexors, extensors, pronators and supinators – dominant arm muscles were stronger, this fact confirms previous researches data (Ellenbecker et al., 2006).

Low extremity muscle strength, level of bi-lateral and contra-lateral imbalance. There are certain opinions (Chow, Park, & Tilman, 2009; Ellenbecker & Roetert, 1995) that lower body part development in tennis players is as important as upper part physical development. The proper *foot work* provides enough quick stars, competent speed during running and start/stop movements (Ellenbecker et al., 2009). From biomechanical point of view strength of the muscles of the low body parts plays an important role in powerful stroke production (Elliott, 2006; Kopsic Segal, 2003; Zusa, 2013). All movements in tennis are initiated by the feet pushing against the ground, and a force and momentum transfer via the kinetic chain segments of the lower extremities to the trunk, upper extremities and, finally, the racquet. Tennis requires repetitive multidirectional movement patterns that can lead to lower extremity injury (Ellenbecker et al., 2007).

Young tennis players' **hip** joint muscle strength results showed, that level of extensors/flexors bi-lateral imbalance for right joint was between 19–45% and for left between 21–51% hip extensors dominance; contra-lateral imbalance for 4 participants was between 10–24% (left hip joint extensor and flexor muscles dominate on right hip joint muscle). For 3 participants, hip adductors were stronger than abductors – level of bi-lateral imbalance 16–36% for right side and between 14–36% for left side muscles, contra-lateral imbalance was not significant for hip adductors and abductors.

We found a significant difference in **knee** joint muscle strength indicators. For all participants, knee extensors were stronger than flexors: a level of bilateral imbalance for right leg was 51–65%

and for left leg 50–67%. Level of contra-lateral imbalance in these muscles was not significant – less than 14% for flexors and less than 24% for extensors. This data verifies previous researches – no significant difference exists between the dominant and non-dominant lower extremity for knee extensors and flexors strength in elite junior tennis players (Ellenbecker et al., 2007; Ellenbecker & Roetert, 1995) and adult tennis players (Read & Bellamy, 1990).

Ankle joint is assumed as *weakest* part in low extremity kinematic chain, proper *throw-like* movement production begins from ground reaction forces (Bartonietz, 2000; Lanka, 2000; Elliott, 2006; Ivancevic, Jovanovic, Djukic, & Lukman, 2011; Kopsic Segal, 2003) and ankle joint muscle strength here is vital as much, as during speed on-court movements and from injury prevention point of view. The results of our study showed the same trend for all participants – ankle dorsal flexors strength torque was bigger than plantar flexors, level of bi-lateral imbalance was between 31–66% for right foot and 54–70% for left foot. The results are in a conflict with Morrison & Kaminski's (2007) study – ankle plantar flexors were stronger than dorsal flexors for physical active adults (man n = 8, woman n = 18) and all plantar and dorsal flexors indicators for adults were much higher in comparison with our results, this could be explained with age difference of the participants. Ankle evertor and invertor indicators and level of bi-lateral and contra-lateral imbalance highly varied between all study participants.

Spine and abdominal muscle strength condition in different participants is a well-studied question among the researchers. Once of the motions that can particularly stress the spine in tennis players is the combined movements of extension, lateral flexion and rotation that are inherent in the loading phase of the tennis serve (Ellenbecker et al., 2009). Everett et al. (2008) and Sanchis-Moysi, Idoate, Dorade, Alayon and Calbet (2010) measured spine flexors and extensors in adult tennis players, runners, swimmers and non-athletes. The main conclusion of these two studies (Everett, Strutton, & McGregor, 2008; Sanchis-Moysi et al., 2010) was similar – abdominal muscles were significantly stronger than spine muscles in adult tennis players and spine extensors were stronger in non-athletes (Sanchis-Moysi et al., 2010). Similar results of spine flexors dominance for tennis players showed other specialists (Andersson, Swart, & Thrstensson, 1988; Roetert, McCormick, & Ellenbecker, 1996) who explained this with tennis technique specifics. Our study results are in conflict with previous mentioned – young tennis players' spine extensors were significantly stronger than flexors – the level of bi-lateral imbalance was between 42 and 55% for all participants. Our explanation could be only that, possibly, at the age of 11 the tennis specific topography in accordance of spine and abdominal muscle strength indicators has not developed yet, tennis player specific spine flexors dominance could be a result of the influence of several years training.

The data presented in this research provides descriptive muscle strength topography of 11-year-old tennis players. The main *limitations of the study* were a small number of participants, only girls, not tested body core rotator muscles, which plays an important role in powerful stroke generation.

CONCLUSIONS

1. The study pointed out that, in order to develop tennis specific muscle strength topography, young tennis players should train spine flexors, shoulder adductors, internal rotators and wrist pronators more.
2. To avoid the increase of muscle bi-lateral imbalance it is highly recommended to pay more attention to shoulder abductors and external rotators, elbow flexors and extensors (especially for the right hand), wrist supinators and extensors, knee extensors and ankle joint plantar flexors.
3. For contra-lateral imbalance, prevention in addition to work with non-dominant upper extremity muscles should be considered for shoulder joint internal and external rotators, wrist supinators.
4. It is highly recommended for 11-year-old tennis players to complete tennis practice with muscle strength development exercises and special musculoskeletal system strengthening programs – it could play a key role in injury prevention in young tennis players.

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