DOI 10.2478/afepuc-2022-0013.

TENSIOMYOGRAPHY OF SELECTED UPPER-LIMB MUSCLES IN CROSSMINTON PLAYERS

Rút Lenková, Tamara Lukáčová

University of Prešov, Faculty of Sports, Slovakia

Summary. Background: Crossminton is characterized by the repetition of specific one-side movements that is the determining factor of the development of muscle asymmetry and damage to the musculoskeletal system. **Aim:** The purpose of the study was to identify the lateral symmetry between the dominant and nondominant upper limb of crossminton players and to compare the muscle profile of the players with the recommendation values of tennis players. **Methods:** Four elite crossminton players with world ranking position in top 10 participated in our study. We used a tensiomyography to measure the occurrence of functional disorders of the upper limb muscles. Tensiomyography measures were obtained for 8 muscles: m. deltoideus posterior, m. deltoideus anterior, m. pectoralis major, m. biceps brachii, m. triceps brachii, m. brachioradialis, m. flexor digitorum, m. extensor digitorum. We represented the parameters of overall lateral symmetry, maximal displacement (Dm) and contraction time (Tc) for each player individually. **Results:** Individual TMG-derived parameters such as Tc, Dm and lateral symmetry were different between the dominant and non-dominant upper limb. The major finding of this study was that in each crossminton player was found a significantly overall lateral asymmetry of m. triceps brachii. Interestingly, Tc and Dm values were higher in the non-dominant limb in m. triceps brachii compared to the dominant limb for all the crossminton players. **Conclusions:** According to the results of this study, finding the occurrence of muscle asymmetry between the upper limbs, we recommend carry out regular diagnostics of the musculoskeletal system and the inclusion of compensatory exercises, which would prevent or reduce the occurrence of muscle imbalance.

Key words: racquet sport, assymetry, skeletal muscle, TMG.

Introduction

To detail the factors related to the injury in racquet sports is necessary to increase epidemiological description of musculoskeletal injuries (Abrams, Renstrom & Safran 2012). Crossminton is relatively young racquet sport which combines elements of tennis, badminton and squash. The popularity of this sport has increased in recent years.

Crossminton is a sport in which the player uses the whole body from a kinesiological point of view. Although each player has their own individual technique, the muscle involvement in each stroke is the same and may vary only slightly. According to Vágner (2016), the muscles of the lower limbs, spine extensors, abdominal muscles, muscles of the shoulder joint and forearm are most involved in tennis.

Crossminton is characterized by the repetition of specific one-side movements that is the determining factor of the development of muscle asymmetry and damage to the musculoskeletal system, especially the upper limbs (Sánchez-Alcaraz et al. 2021; Courel-Ibáñez & Herrera-Gálvez 2020; Kozel et al. 2019; Sanchis-Moysi et al. 2013; Abrams, Renstrom & Safran 2012).

Especially the incidence of overuse symptoms in adolescent athletes is increasing (Brenner 2007). For this reason, it´s important to identify youth at risk of overuse (Quarrie et al. 2016; Soligard et al. 2016; Halson 2014). A key component of injury prevention is a regular screening of the player health and neuromuscular function (Hughes et al. 2018). In this context, an effective tool for detecting the bilateral differences of upper limb muscles is tensiomyography (TMG).

TMG is based on the radial deformation of the isolated muscle belly and the time it takes for this action to occur during an isometric twitch contraction evoked by electrical stimul (Simola et al. 2016). The key parameters obtained from TMG are muscle displacement, which is representative of muscle tone and contractile force, and the time of the response, which is related to the speed of force generation (Hunter et al. 2012).

Given the absence of knowledge about functional disorders related to crossminton and the current increase of it among the players, the purpose of the study was to identify the lateral symmetry between the dominant and nondominant upper limb of crossminton players and to compare the muscle profile of the players with the recommendation values of tennis players.

Methods

Participants

Four elite crossminton players with international ICO (International Crossminton Organisation) ranking position in top 10 participated in our study. Two women representing the club TJ Slávia PU Prešov in category Women and two men representing the club SbK Lipany in category Boys Under 18. All the subjects had a minimum of 5 and maximum of 10 years of crossminton professional activity. In the Table 1 we present the characteristics of each of the players. Players who attend regular training and their average training volume is 5.23±2 hours/week took part in the research. All these players have a dominant right upper limb and have had no serious upper limb injuries so far. Participants were informed of the procedures and risks associated with the study and provided written informed consent before participating.

Table 1
Characteristics of 4 crossminton players

	T.L.	***K.D.***	***J.Š.***	***V.K.***
Gender	Woman	Woman	Man	Man
Body height (cm)	159	169	171	184
Body weight (kg)	50	63	69	73
Decimal age (years)	24	19	15	16
Sport age (years)	10	8	5	5
Category	Women Singles	Women Singles	U18 Male Singles	U18 Male Singles
Position in world ranking	1.	1. (U18 Women Singles)	1.	3.

TMG measuring protocol

We used a tensiomyography to measure the occurrence of functional disorders of the upper limb muscles. Tensiomyography is non-invasive assessment, that measures the specific muscle contraction properties. A displacement-measuring sensor recorded the radial displacement had occurred in the muscle belly when a contraction was produced in response to an electrical stimulus (Valencic & Knez 1997).

We performed the measurement on the dominant and non-dominant upper limb. Tensiomyography measures were obtained for 8 muscles: m. deltoideus posterior (DP), m. deltoideus anterior (DA), m. pectoralis major (PM), m. biceps brachii (BB), m. triceps brachii (TB), m. brachioradialis (BR), m. flexor digitorum (FD), m. extensor digitorum (ED). Measurements were performed under static conditions, with the subject in the sitting and supine position. A digital displacement transducer Dc-Dc Trans-Tek ® (GK 40, Panoptik d.o.o., Ljubljana, Slovenia), which incorporates a spring of 0.17 $N.mm^{-1}$, was set perpendicular to the muscle belly to acquire muscle radial displacement. Sensor location was determined anatomically according to Delagi et al. (1975) and both electrodes (5x5 cm) are placed symmetric to sensor, 5 cm away from the sensor. Individual maximal electrical stimulation was found by progressively increasing the electric current by 20 mA until no further displacement of the muscle belly could be produced. Intervals of 10 s were interspersed between each stimulation to minimize the effects of fatigue and potentiation (Krizaj, Simunic & Zagar 2008;

Simola et al. 2016). Electrical stimulation was made with a TMG-S1 electrostimulator (Furlan Co., & Ltd., Ljubljana, Slovenia)

The TMG displacement–time curve recordings allow muscle contractile properties to be assessed, obtain different parameters, which can inform about muscle stiffness (Pisot et al. 2008). The TMG measures included parameters such as maximum muscle belly radial deformation (Dm) which is representative of muscle tone and contractile force. Contraction time (Tc) is time between 10 and 90 % Dm. Delay time (Td), also known as reaction time, is the taken by the muscle structure analysed to reach 10 % of the total displacement observed. Sustained time (Ts) is the time that contraction is maintained, and is calculated by determining the time period in which muscle response remain greater than 50 % Dm. Half-relaxation time (Tr) r is the time in which muscle response decreases from 90 % to 50 % Dm.

Results are presented individually for each player. We represented the parameters of overall lateral symmetry, maximal displacement and contraction time in figures. Tc and Dm for each muscle were compared between the dominant and nondominant upper limb.

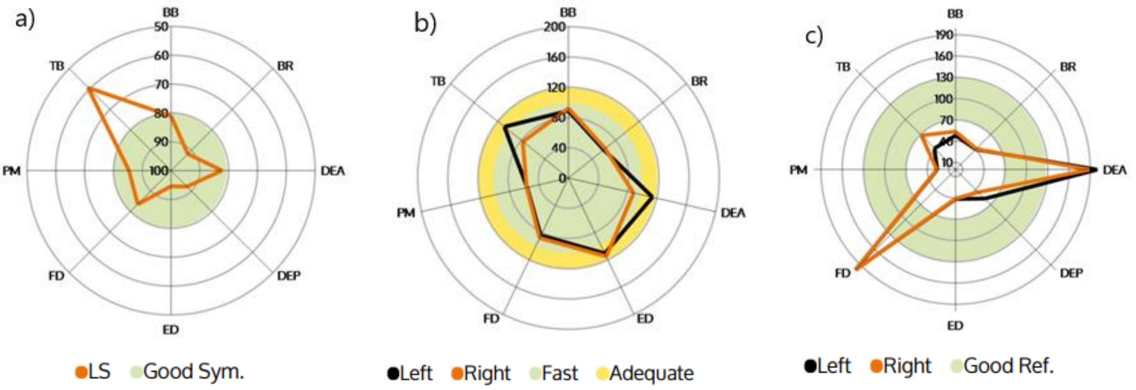
Results

Player no. 1 -T.L.

Player no.1 is a woman with decimal age 24 years and sport age 10 years. The first important parameter that interested us was the lateral symmetry of the muscles of the upper limbs. The overall lateral symmetry of m. triceps brachii was significantly lower than is recommended for the tennis players (59 %). But in m. biceps brachii, m. deltoideus anterior, m. flexor digitorum and m. pectorals major was the overall lateral symmetry compared to the recommendation for the tennis players sufficiently high. Very high overall lateral symmetry was found out in m. brachioradialis, m. deltoideus posterior and m. extensor digitorum (Figure 1a).

Fig. 1b) shows contraction time (Tc) of each muscle and it´s references for the tennis players in %. Player no 1. had a significantly faster m. biceps brachii (right and left upper limb), m. brachioradialis (right and left upper limb) and m. triceps brachii (right upper limb). On the other side, significantly slower than tennis average were m. deltoideus anterior (left upper limb) and m. flexor digitorum (right and left upper limb). Tc values were highest at m. pectoralis major on the right (34.44 $m.s^{-1}$) and on the left side (29.85 $m.s^{-1}$), m. flexor digitorum on the right side (23.90 $m.s^{-1}$) and m. biceps brachii on the left side (23.31 $m.s^{-1}$). The highest differences between the values of dominant and non-dominant limb in Tc were in m. triceps brachii (difference 10.15 $m.s^{-1}$), m. pectoralis major (4.59 $m.s^{-1}$), m. flexor digitorum (3.79 $m.s^{-1}$) and m. biceps brachii (3.67 $m.s^{-1}$).

The last Fig. 1c) shows the maximal displacement (Dm) of muscles and it´s references for the tennis players in %. Significantly lower values of displacement than tennis average had player no 1. in m. biceps brachii, m. brachioradialis, m. deltoideus posterior, m. extensor digitorum, m. pectoralis major and m. triceps brachii. On the other hand, m. deltoideus anterior and m. flexor digitorum had a significantly higher values of displacement than tennis average. We can state, that vast majority of the muscles had a significantly lower values of displacement than average and these muscles need to be stretched. The highest differences between the values of dominant and non-dominant limb in Dm were in m. deltoideus anterior (2.42 $m.m^{-1}$) and m. triceps brachii (1.92 $m.m^{-1}$).



Abbreviations*: m. deltoideus posterior (DP), m. deltoideus anterior (DA), m. pectoralis major (PM), m. biceps brachii (BB), m. triceps brachii (TB), m. brachioradialis (BR), m. flexor digitorum (FD), m. extensor digitorum (ED).*

Figure 1

Player no. 1- Lateral symmetry [%], Tc/References [%], Dm/ References [%]

Player no. 2 – K.D.

Woman with sport age 10 years also demonstrates the occurrence of lateral symmetry of upper limbs muscles. We found out, that significantly lower values of overall symmetry than is recommended for tennis players had m. triceps brachii. Slightly lower values that is recommended were detected in m. brachioradialis, m. deltoideus anterior and m. flexor digitorum (Figure 2a).

In the parameter contraction time (Tc) we found out that only m. triceps brachii of left upper limb is significantly slower than tennis average. On the other side, m. biceps brachii (right and left upper limb), m. brachioradialis (right upper limb) and m. flexor digitorum (left upper limb) were significantly faster than tennis average. Tc values were highest at m. triceps brachii on the left side (36.00 m.s^{-1}), m. pectoralis major on the right side (29.44 m.s^{-1}) and on the left side (27.12 m.s^{-1}). The highest differences between the values of dominant and non-dominant limb in Tc were in m. triceps brachii (11.35 m.s^{-1}) and m. brachioradialis (5.52 m.s^{-1}) (Figure 2b).

Representative of muscle tone and contractile force is maximum displacement (Dm). Muscles, that have significantly lower displacement that tennis average need to be strengthened. For the player no. 2 it is these muscles: m. brachioradialis (right upper limb), m. deltoideus posterior (left upper limb), m. triceps brachii (left upper limb). On the contrary, significantly higher displacement we found out in muscles: m. brachioradialis (left upper limb), m. deltoideus anterior (right upper limb), m. flexor digitorum (right upper limb) and m. triceps brachii (right upper limb). In m. brachioradialis and m. triceps brachii was lateral symmetry of displacement significantly lower than is recommended. The highest differences between the values of dominant and non-dominant limb in Dm were in m. triceps brachii (5.53 m.m^{-1}) and m. brachioradialis (3.26 m.m^{-1}) (Figure 2c).

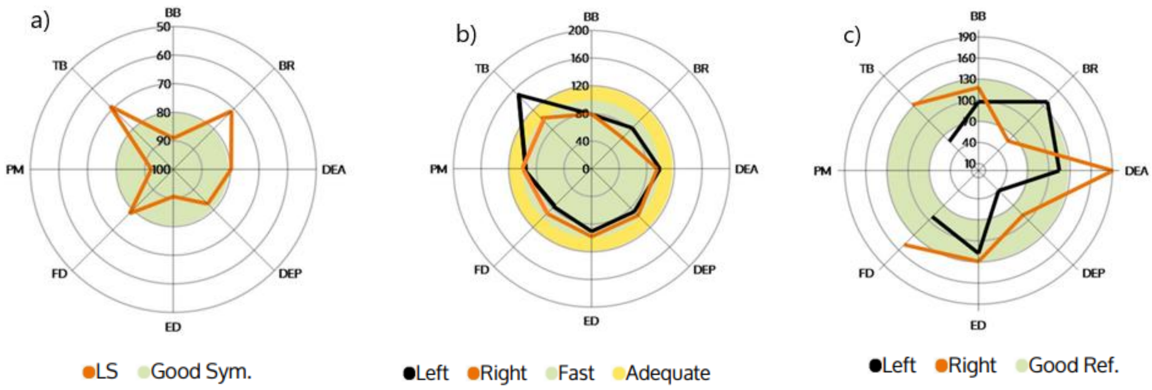


Figure 2
Player no. 2- Lateral symmetry [%], Tc/References [%], Dm/ References [%]

Player no. 3 – J. Š.

For the player no. 3 we found out significantly lower the overall lateral symmetry of m. triceps brachii. Slightly lower the overall lateral symmetry that is recommended for tennis players were in m. deltoideus posterior and m. flexor digitorum (Figure 3a).

In the Fig. 3b) we can see the contraction time of each muscle. M. extensor digitorum (right upper limb), m. pectoralis major (right and left) and m. triceps brachii (left upper limb) were significantly slower than tennis average. We also noticed that lateral symmetry of contraction time of m. triceps brachii was significantly lower than recommended. Tc values were highest as with the previous two players at m. pectoralis major on the right side (40.66

m.s-1) and on the left side (37.65 m.s-1), m. biceps brachii on the left side (32.77 m.s-1) and on the right side (27.50 m.s-1). The highest differences between the values of dominant and non-dominant limb in Tc were in m. triceps brachii (11.52 m.s-1), m. biceps brachii (5.27 m.s-1) and m. extensor digitorum (5.04 m.s-1).

The last parameter is maximum displacement of each muscle (Dm). M. flexor digitorum (right and left upper limb), m. pectoralis major (right and left) and m. triceps brachii (right upper limb) had displacement significantly lower than the tennis average. On the contrary, m. brachioradialis (right upper limb) had a significantly higher displacement than recommended. As for lateral symmetry of displacement, we noticed significantly lower values at m. deltoideus anterior, m. flexor digitorum, m. pectoralis major and m. triceps brachii. The highest differences between the values of dominant and non-dominant limb in Dm were in m. triceps brachii (4.49 m.m-1) and m. biceps brachii (3.66 m.m-1) (Figure 3c).

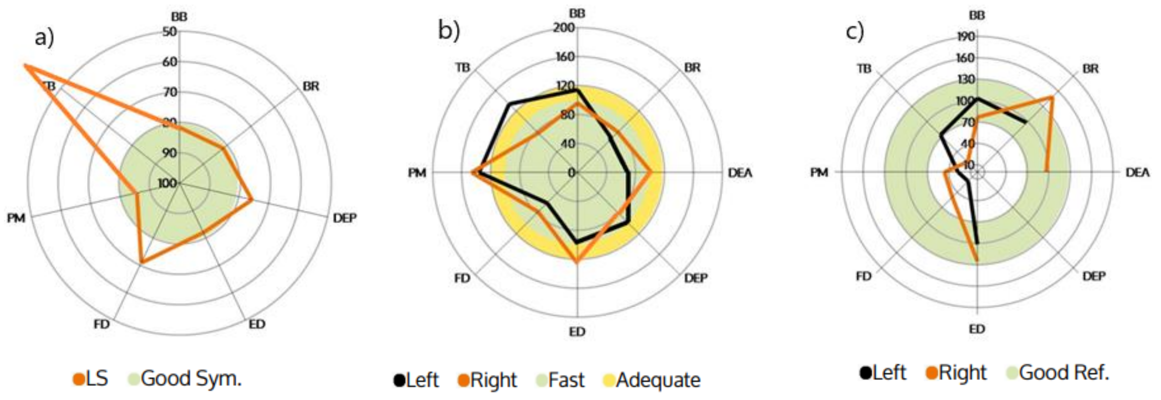


Figure 3
Player no. 3- Lateral symmetry [%], Tc/References [%], Dm/ References [%]

Player no. 4 – V.K.

Player no 4.with sport age of 6 years and decimal age of 17 years also proved like three another players´ occurence of lateral asymmetry of upper limbs. The largest overall lateral assymetry was found out in m. triceps brachii. This player showed the lowest incidence of overall lateral assymetry among all 4 diagnosed players. We only found out that m. triceps brachii and m. deltoideus posterior have slightly lower values of overall lateral symmetry than recommended (Figure 4a).

When we look on contraction time of each muscle and what muscles need to be activated. In player no. 4 we found out, that only three muscles (m. brachioradialis, m. pectoralis major, m. triceps brachii) were significantly faster than tennis average. All remaining muscles meet the recommendation of contraction time of muscles for tennis players. Slightly lower values of lateral symmetry of contraction time had m. triceps brachii, m. deltoideus anterior and m. brachioradialis. Tc values were highest at m. biceps brachii on the right side (26.54 $m.s^{-1}$) and on the left side (25.63 $m.s^{-1}$) and m. triceps brachii on the left side (21.86 $m.s^{-1}$). The highest differences between the values of dominant and non-dominant limb in Tc were in m. triceps brachii (6,35 $m.s^{-1}$), m. deltoideus anterior (4.39 $m.s^{-1}$) and m. deltoideus posterior (3,23 $m.s^{-1}$) (Figure 4b).

In the last parameter, maximum displacement (Dm), had a player no. 4 slightly worse results. M. pectoralis major showed a significantly lower values of displacement that the tennis average. On the contrary, m. brachioradialis (right upper limb) and m. extensor digitorum (right upper limb) had a significantly higher displacement that is recommended. The highest differences between the values of dominant and non-dominant limb in Dm were in m. biceps brachii (3.17 $m.m^{-1}$) and m. triceps brachii (3.11 $m.m^{-1}$) (Figure 4c).

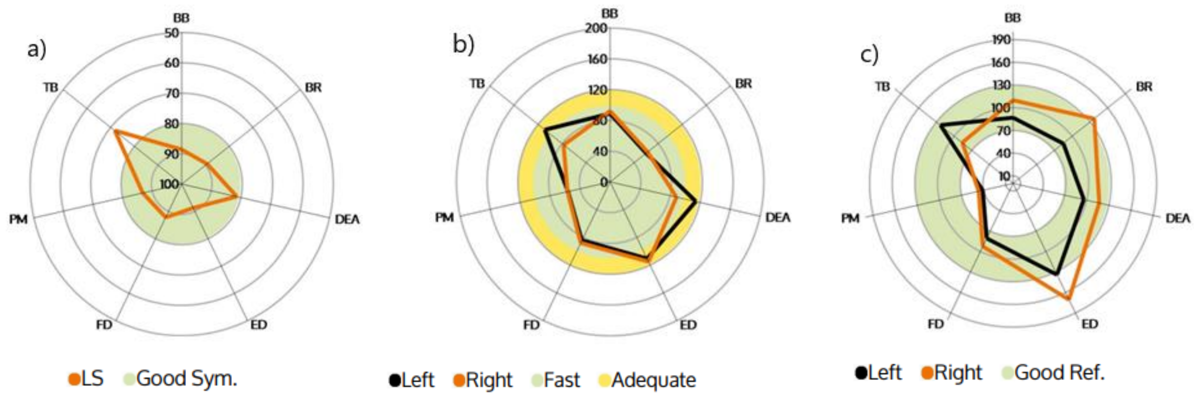


Figure 4
Player no. 4- Lateral symmetry [%], Tc/References [%], Dm/ References [%]

Discussion

To the author´s knowledge, this is the first study that examined tensiomyographic markers of muscle fatigue in elite crossminton players. The present study examined the values of muscle contractile properties in 4 crossminton players. We found significant differences between limbs for the vast majority of variables and muscles examined. Individual TMG-derived parameters such as Tc, Dm and lateral symmetry were different between the dominant and non-dominant upper limb.

The overall lateral symmetry of m. triceps brachii for all the players was significantly lower than it is recommended for tennis players, from 47 to 71 %. Two players had also the overall lateral symmetry significantly lower than it is recommended in muscles m. deltoideus posterior (75-79 %) and m. flexor digitorum (70 - 78 %). Player no. 2 demonstrated the significantly lower values of the overall lateral symmetry of m. deltoideus anterior and m. brachioradialis (Figure 5). In tennis players, the dominant upper limb displays greater mass than nondominant one (Noffal 1999). This asymmetry between the upper limbs volumes is explained by an increase in bone mass (Kannus et al. 1995) and muscle hypertrophy in the dominant upper limb (Buskirk, Andersen & Brozek 1956; Colak et al. 2004).

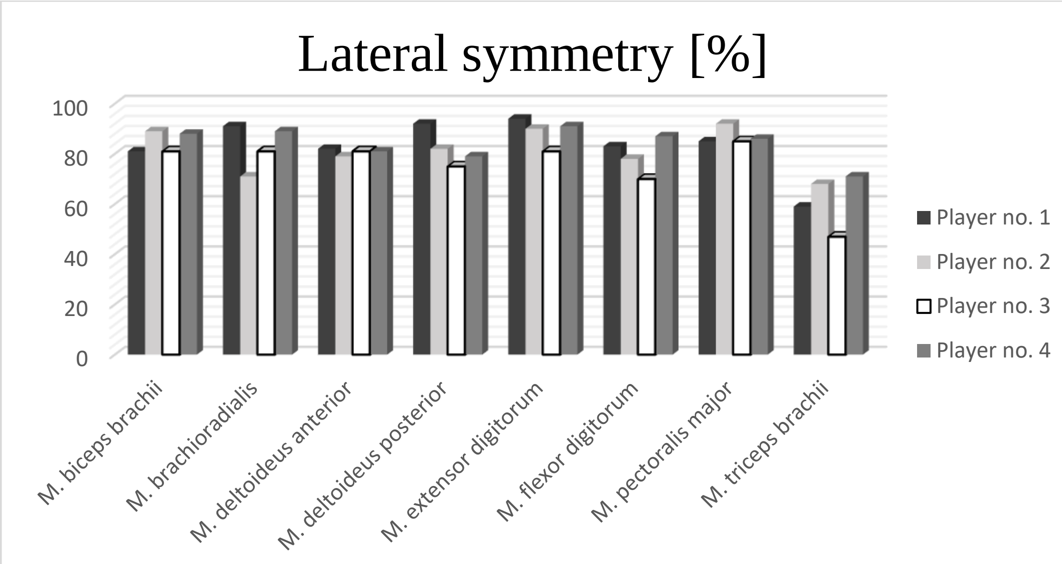


Figure 5
Overall lateral symmetry of all players

The most reliable (Šimunič 2012; Paravlić, Zubac & Šimunič 2017; Tous-Fajardo et al. 2010) and clinically relevant (Pišot et al. 2008; Paravlić, Pisot & Šimunič 2020; Šimunič, Degens & Rittweger 2011) parameter of muscle contraction derivered from TMG are Tc and Dm. Shorter Tc values provide an information about muscles with predominance of fast-twitch muscle fibres (Valenčič & Knez 1997; Dahmane et al. 2005) and Dm values indicate muscle structure. Increased values of Dm indicate decreased muscle stiffness (Pisot et al. 2008). Interestingly, Tc values were higher in the nondominant upper limb in m. triceps brachii compared to the dominant upper limb for all the crossminton players. It means, that m. triceps brachii of the dominant upper limb has predominance of fast-twitch muscle fibres which can be caused by constant repetition of quick swinging movements of dominant upper limb when performing each crossminton stroke.

These findings suggested that functional asymmetries induced by repetitive movements patterns in crossminton players seem to occur in different sports ages. A limitation of this study is the small sample (n = 4). However, it was found that due to the nature of the crossminton, the muscle imbalance occurs regardless of the decimal and sports age.

Conclusions

The number of youth athletes participating in organized racquet sports activities is increasing. On the contrary, one-side specific movements of upper limbs that are repeating in a very short period of time represent a risk of causing injury. The major finding of this study was that in each crossminton player, was found a significantly overall lateral asymmetry of m. triceps brachii. Interestingly, Tc and Dm values were higher in the non-dominant limb in m. triceps brachii compared to the dominant limb for all the crossminton players. Except for m. triceps brachii, we found out the biggest asymmetry in Tc and Dm values of each crossminton player in at least one other muscle. Finding such as adaptations already in adolescent crossminton players points out the importance of carrying out regular diagnostics of the musculoskeletal system and the inclusion of compensatory exercises, which would prevent or reduce the occurrence of muscle imbalance.

Acknowledgment

The TMG S2 tensiomyographic divice was used in the study thanks to the project "Physical activity-related injuries prevention in adolescents (PARIPRE)" co-funded by the research grant 622594-EPP-1-2020-1-SK-SPO-SCP from the Education, Audiovisual and Culture Executive Agency (EACEA) ERASMUS+ Sport Collaborative Partnerships Program.

References

1. ABRAMS, G.D., P.A. RENSTROM & M.R. SAFRAN, 2012. Epidemiology of musculoskeletal injury in the tennis player. In: *British Journal of Sports Medicine*. **46**(7), 492-498.
2. BRENNER, J. S., 2007. Overuse injuries, overtraining, and burnout in child and adolescent athletes. In: *Pediatrics*. **119**, 1242–1245.
3. BUSKIRK, E. R., K. L. ANDERSEN & J. BROZEK, 1956. Unilateral activity and bone and muscle development in the forearm. In: *Research Quarterly*. **27**(2), 127-131.
4. COLAK, T. et al., 2004. Nerve conduction studies of upper extremities in tennis players. In: *British Journal of Sports Medicine*. 38(5), 632–635.
5. COUREL-IBÁÑEZ, J. & HERRERA-GÁLVEZ, J. J., 2020. Fitness testing in padel: Performance differences according to players' competitive level. In: *Science & Sports*. **35**(1), 11-19.

6. DAHMANE, R. et al., 2005. Spatial fiber type distribution in normal human muscle:Histochemical and tensiomyographical evaluation. In: *Journal of Biomechanics*. **38**(12), 2451–2459.
7. DELAGI, E. F. et al., 1975. *Anatomic guide for the electromyographer: the limbs*. Springfield: Charles C. Thomas. ISBN 978-0398075781.
8. HALSON, S. L., 2014. Monitoring training load to understand fatigue in athletes. In: *Sports Medicine*. **44**, 139–147.
9. HUGHES, T. et al., 2018. Periodic Health Examination and Injury Prediction in Professional Football (Soccer):Theoretically, the Prognosis is Good. In: *Sport Medicine*. **48**(11), 2443–2448.
10. HUNTER, A. M., 2012. Assessment of eccentric exercise-induced muscle damage of the elbow flexors by tensiomyography. In: *Journal of Electromyography and Kinesiology*. **22**, 334–341.
11. KANNUS, P. et al., 1995. Effect of starting age of physical activity on bone mass in the dominant arm of tennis and squash players. In: *Annals of Internal Medicine*. **123**(1), 27–31.
12. KOZEL, M. et al., 2019. The influence of active sport on the athlete's posture. In: *European Journal of Clinical and Experimental Medicine.* **23**, 51-51.
13. KRIZAJ, D., B. SIMUNIC & T. ZAGAR, 2008. Short-term repeatability of parameters extracted from radial displacement of muscle belly. In: *Journal of Electromyography and Kinesiology.* **18**, 645–651.
14. NOFFAL, G.J., 1999. Anthropometric upper limb characteristics of the high performance tennis player. In: *Medicine and Science in Tennis*. 4.
15. PARAVLIĆ, A., D. ZUBAC & B. ŠIMUNIČ, 2017. Reliability of the twitch evoked skeletal muscle electromechanical efficiency:A ratio between tensiomyogram and M-wave amplitudes. In: *Journal of Electromyography and Kinesiology.* **37**, 108–116.
16. PARAVLIĆ, A., R. PISOT & B. ŠIMUNIČ, 2020. Muscle-specific changes of lower extremities in the early period after total knee arthroplasty:Insight from tensiomyography. In: *Journal of Musculoskeletal & Neuronal Interactions*. **20**(3), 390–397.
17. PISOT, R. et al., 2008. Whole muscle contractile parameters and thickness loss during 35-day bed rest. In: *European Journal of Applied Physiology.* **104**(2), 409–414.
18. QUARRIE, K. L. et al., 2016. Managing player load in professional rugby union: a review of current knowledge and practices. In. *British Journal of Sports Medicine*. **51**(5), 421–427.

19. SÁNCHEZ-ALCARAZ, B. J. et al., 2021. Ball Impact Position in Recreational Male Padel Players: Implications for Training and Injury Management. In: *International Journal of Enviromental Research and Public Health*. **18**(2), 435.
20. SANCHIS-MOYSI, J. et al., 2013. The hypertrophy of the lateral abdominal wall and quadratus lumborum is sport-specific: An MRI segmental study in professional tennis and soccer players. In: *Sports Biomechanics.* **12**(1), 54-67.
21. SIMOLA, R. et al., 2016. Muscle mechanical properties of strength and endurance athletes and changes after one week of intensive training. In: *Journal of Electromyography and Kinesiology*. **30**, 73–80.
22. SOLIGARD, T. et al., 2016. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. In: *British Journal of Sports Medicine.* **50**, 1030–1041.
23. ŠIMUNIČ, B., 2012. Between-day reliability of a method for non-invasive estimation of muscle composition. In: *Journal of Electromyography and Kinesiology*. **22**(4), 527–530.
24. ŠIMUNIČ, B., H. DEGENS & J. RITTWEGER, 2011. Noninvasive Estimation of Myosin Heavy Chain Composition in Human Skeletal Muscle. In: *Medicine and Science in Sports and Exercise*. **43**(9), 27–30.
25. TOUS-FAJARDO. J. et al., 2010. Inter-rater reliability of muscle contractile property measurements using non-invasive tensiomyography. In: *Journal of Electromyography and Kinesiology*. **20**(4), 761–766.
26. VÁGNER, M., 2016. *Kondiční trénink pro tenis*. 1. vyd. Praha: Grada publishing, a.s. ISBN 978-80-247-5814-5.
27. VALENČIČ, V. & N. KNEZ, 1997. Measuring of skeletal muscles' dynamic properties. In: *Artif Organs*. **21**(3), 240–242.