Acta of Bioengineering and Biomechanics
Vol. 20, No. 4, 2018

Original paper
DOI: 10.5277/ABB-01182-2018-02

Determination of loading in the lower limb joints during step-forward lunge in fencing

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Purpose: Sabre is one of the three disciplines in fencing, characterised by the use of a lightweight cutting weapon to score hits on an opponent while maneuvering for position with dynamic footwork. The aim of this study is concerned with the estimation of the load applied to the lower extremities during a step-forward lunge. *Methods*: The study group comprised sixteen subjects from ASA club. Examinations of kinetic parameters of analyzed movement were carried out using Vicon system, Kistler plates and the equipment designed to measure joint torques in isometric conditions. *Results*: Maximal value of the vertical component of the ground-reaction-force generated by the lead leg is significantly higher than the one recorded in the rear leg. The maximal value of hip flexion torque of lead leg in dynamic conditions significantly exceeds the value for this joint recorded in isometric conditions. The maximal value of knee flexion of rear leg in dynamic conditions significantly exceeds the value obtained in the isometric conditions. In general, the sequence of the joint loading from the highest to the lowest is as follows: hip, knee, ankle. *Conclusions*: The comparative analysis of the torques generated by the muscles in isometric and dynamic conditions provides an adequate tool for the assessment of the characteristics of the muscle effort. Therefore, it defines the structure of movement patterns in saber, from the kinetics' point of view, in the process of improving fencing footwork.

Key words: *sabre, kinetics, joint torque, isometric contraction, inverse dynamics*

1. Introduction

The transformations in fencing in recent years, due to changes in the referees rules, have significantly influenced the importance of fencing footwork [5]. Among many other modification, fencing underwent changes that have resulted in the decrease of the length of fencing piste to 14 meters. The, so-called, 2-meter portion of the strip is abandoned, which resulted in a penalty point after a fencer leaves the rear limit. The limitation of the time intervals in the programming of the referees electronics has also become an important factor determining the footwork. As a result, in saber, the timing has dropped from 250 to 125 ms in the conditions of an actual dual. It means that a successful attack needs to be executed in a short moment of time, i.e., within a maximum interval of 125 ms ahead of a successful riposte from the opponent. If a counter hit is completed within this interval, a lamp is lit to demonstrate that a point is scored [21].

Today's fencing footwork, especially in saber, which is a conventional weapon, is characterized by extreme dynamics and requires high neuromuscular coordination and capacity of both lower limbs as well as the hand holding the fencing weapon. The basic fencing steps according to leg work are: lunge, flèche and step-forward lunge. The latter element is most often used as part of the fencing tactic associated with an increased distance between fighting sabers and is characterized by exceptional effectiveness, due to the effect of surprise. A step-forward lunge is formed by a kind of combined forward step and lunge. In training, three phases of acquiring movement techniques are

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Received: August 5th, 2018
Accepted for publication: September 17th, 2018

applied: a step forward to the heel of the lead leg, bringing rear foot to the same level as the lead one, and performing lunge. We can emphasize that saber and foil as conventional weapons (characterized with a priority of attack over defense) require the adoption of a slightly different technique of maneuvering when it comes to coordination of footwork, than in the case of épée [1]. In the initial phase of action, coordinated movements of the lower limbs appear to take on a more important role, while the arm is bent at the elbow at this time. The arm is being fully extended in the final stage of the outbreak lunge before touching the ground with the heel of the front leg [7], [11]. The research problem discussed in this work is associated with the assessment of loads applied to joints throughout the step-forward lunge as it forms the basic element of footwork in terms of the kinetic parameters of the fencing technique. An experiment was applied for this purpose, which involved measurements of the torques in the knee and ankle joints in isometric conditions during extension and flexion movement based on the patterns followed in fencing. The obtained data was used for comparative analysis in dynamic conditions recorded by a motion capture system. In addition, the movement pattern of the step-forward lunge was assessed in the aspect of injury prevention to the lower extremities of sabers (girls and boys), who follow a specialized training course.

2. Material and methods

2.1. Participants

Sixteen competitors (10 male and 6 female) with a mean age of 18.69 ± 2.82 years, body mass of 68.5 ± 9.49 kg and a height of 178.69 ± 5.51 cm were evaluated during the study. The participants of the study were members of the Academic Sports Association in Warsaw from the fencing section, with a specialty in saber, with training experience of no less than 5 years and no more than 16 years. Thirteen of them belonged to the national team. The other three were trying to enter the national team. The subjects provided a written consent to participate in the experimental procedures approved by the Senate Committee for Ethics in Scientific Research of the Józef Piłsudski University of Physical Education in Warsaw.

2.2. Measures and data analysis

The experiment was carried out in an indoor hall adapted to conduct biomechanical fencing tests. Prior to the experiment, anthropometric measurements were taken for all the subjects. Next, the subjects performed the measurement of maximum flexion and extension torques in static condition in ankle, knee and hip of both limbs. Each test was performed three times. The highest values were taken for the analysis. After this part, thirty-four spherical markers were placed at anatomical landmarks according to the biomechanical model which followed the PlugInGait standards available in the motion capture system (Vicon Motion Systems Ltd, UK). Two force plates (Kistler Holding AG, CH) embedded into the floor were used to measure ground reaction force (GRF) data at a sampling rate of 1000 Hz. The motion capture system consisting of nine infrared cameras was employed to collect kinematics data at a sampling rate of 100 Hz. The force plates were synchronized with the motion capture system. Before the trials were conducted, both systems were calibrated according to the manufacturers' recommendations. Each subject performed three trials of a step-forward lunge, so that after the second

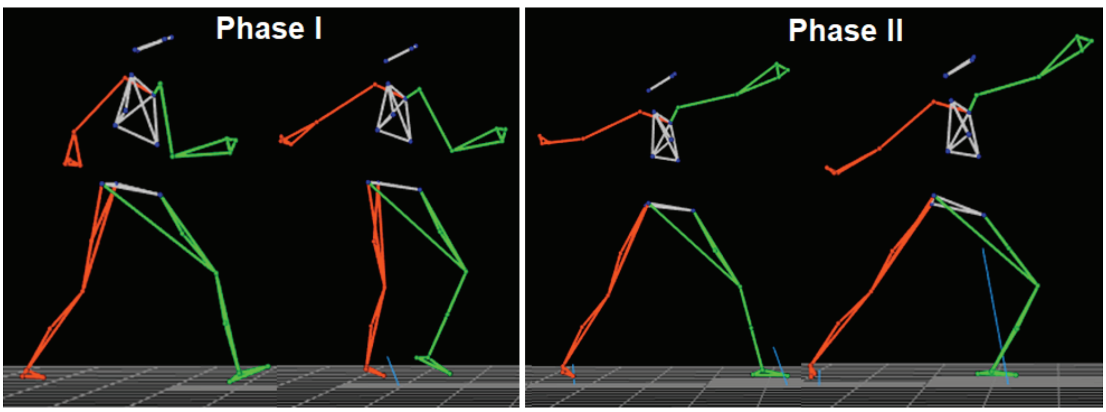

Fig. 1. Phases of step forward-lunge

phase – lunge, each foot was on a different platform (Fig. 1). The analysis was performed based on the trials without any random mistakes, with the individual performing the task naturally and the trial evaluated by the coach as good.

Two phases were identified in the step-forward lunge (Fig. 1). Phase I – step-forward – from the first contact with the ground of lead leg until the first contact with the ground of rear limb. Phase II – lunge – from the contact with the ground of rear limb to maximal knee flexion of lead limb. Therefore, the lunge is performed propelling forward by fully extending the rear leg from the "en garde" position (feet shoulder width apart, legs in perpendicular planes, with the lead leg facing forward), and landing on the lead leg.

The following parameters were taken into account for the analysis: distance between heels of lead and rear legs during step-forward lunge, duration of each phase, maximal values of vertical ground reaction force for both legs, and also maximal values of torques for the lead and rear legs during first and second phase of step-forward lunge and in static conditions.

Statistical analysis was conducted using the Statistica software (StatSoft, USA). A significant *p*-value was set at 0.05 for all analyses. The normality of the distributions of all parameters was verified using the Shapiro–Wilk test. Next, the non-parametric Wilcoxon test was used to identify difference in the following study aspects: distance, duration of each phase, ground reaction forces and torques.

3. Results

3.1. Distance and ground reaction force

In Figure 2A a distance change graph between heels of lead and rear leg during a step-forward lunge is shown. Statistically significant differences ($p = 0.0001$) were found between the maximum (1.26 ± 0.13 m) and minimum (0.26 ± 0.06 m) values of the distance between the heels and for the duration of phase I (0.34 ± 0.07 s) and phase II (0.58 ± 0.12 s) of the step-forward lunge.

Such fast motor activity accompanying a step-forward lunge generates large peaks recorded in terms of ground reaction forces (Fig. 2B), for which mean maximal value of vertical component in phase I was: 9.52 ± 1.57 N/kg for lead leg and in phase II: 17.90 ± 1.91 N/kg for lead leg and 13.36 ± 1.47 N/kg for rear leg. All combinations of values were statistically significant ($p \leq 0.05$).

3.2. Torques

Analysis of joint torques may be conducted at three levels: relationship between static and dynamic conditions, comparison of the same joints between the limbs under dynamic conditions and comparison of all joints within one limb separately.

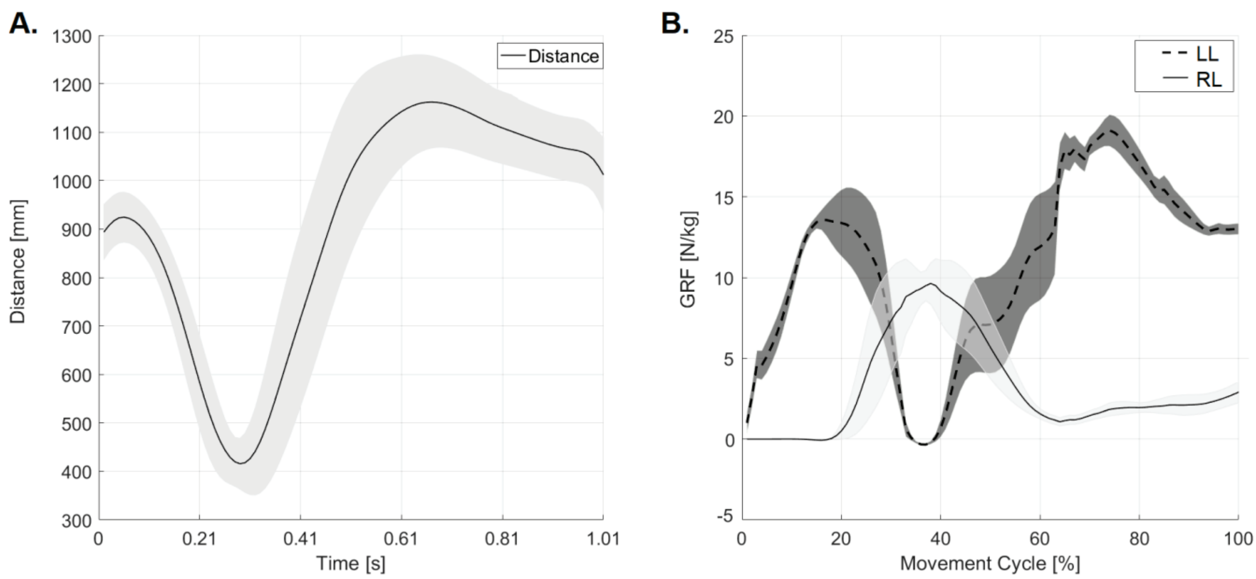

Fig. 2. Mean and standard deviation of: A. distance between heels during step-forward lunge, B. vertical component of ground reaction force during step-forward lunge; LL – lead leg, RL – rear leg

A. *The relationship between static and dynamic conditions*

The maximal value of hip flexion torque of lead leg in dynamic conditions in phase II significantly exceeds (by 79%) the value that was recorded for this joint in isometric conditions ($p = 0.0037$) (Fig. 3A). On the other hand, the values obtained for rear leg are significantly higher for extension in isometric conditions ($p = 0.0016$). In the knee joint, statistically significant higher values in dynamic conditions were observed only in the first phase for the rear limb ($p = 0.0013$). For the ankle joint, the values obtained under isometric conditions for all phases of movement were significantly higher ($p \leq 0.05$) compared to those in dynamic condition. Summarizing, in the hip and knee joints achieved are values of torques that significantly exceed those achieved in isometric conditions are achieved.

B. Comparison of same joints in the limbs in dynamic conditions

In hip joint, the lead leg is significantly more loaded ($p = 0.0004$) at phase II, compared to phase I in the rear leg. In knee joint, significantly more loaded is rear leg in phase I, compared to other values for leading leg. However, in ankle joint of leading leg in phase I has significantly higher values, compared with rear leg (Fig. 3).

C. *Comparison of all joints in one limb separately*

In phase I, in lead limb, the most loaded joint is ankle (1.3 ± 0.2 Nm/kg) with values by 12% higher than those achieved for hip joint (1.16 ± 0.44 Nm/kg). The lowest values are achieved in knee joint (0.94 ± 0.39 Nm/kg), while in phase II, the sequence of loading from the highest to the lowest values is as follows: hip (3.63 ± 0.75 Nm.kg), knee (1.71 ± 0.64 Nm/kg) and ankle joint (1.28 ± 0.15 Nm/kg).

During phase I, the highest flexion values are achieved in the rear leg in the following sequence: hip (2.27 ± 1.3 Nm/kg), knee (1.9 ± 0.8 Nm/kg) and ankle (1.01 ± 0.11 Nm/kg). In phase II, the sequence of loading is the same, but the values achieved are in average by 70% lower than in phase I and in all joints are in extension position (Fig. 3).

4. Discussion

The current investigation aimed to determine loading in the lower limb joints during the step-forward lunge in fencing. Lunge performance is one of the most fundamental movements of fencing and also rocket sports. It has been demonstrated that the correct and fast execution of a lunge and its subsequent patterns has a crucial role in the success in competing [10]. Fencing is a highly asymmetric sport, with the armed side of the body executing movement over a substantial duration of a competitive bout, and during training. Moreover, the upper and lower extremities present distinctive motion patterns, and a considerable load is applied on the neuromuscular system, including effects of dominance on kinematics and kinetics [17].

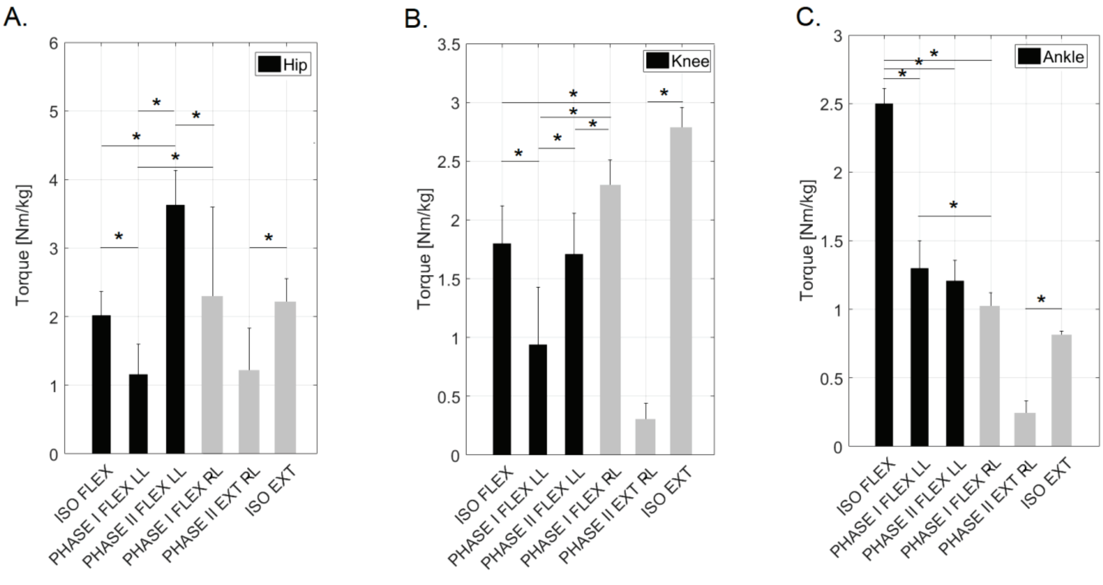

Fig. 3. Mean and standard deviation of torques measured during step-forward (phase I), lunge (phase II) and during isometric condition (ISO) for: A. Hip, B. Knee, C. Ankle, where: FLEX – flexion, EXT – extension, LL – lead leg, RL – rear leg, * – statistically significant differences

The advance, retreat, flèche and lunge movements, commonly used in fencing, have been evaluated using motion capture, demonstrating the greater joint motion and force output required to perform the flèche and lunge movements [9], [18].

The results reported in this paper demonstrate that in terms of the time and dynamic aspects, the movement patterns followed during a step-forward lunge, i.e., a complex element of an offensive activity in fencing, correspond to the structure that has been described in the literature [8], [18]. The mean duration of a complex activity took, on average, 0.92 ± 0.19 s, whereas lunge length was 1.26 ± 0.13 m, which confirms the result reported in [14]. We can stress that the minimum value in the results (Fig. 2A) recorded for fencing footwork is similar to chassé step, during which feet never pass one another. In fencing and gymnastics, chassé steps are often followed in preparation of the lunge steps, as they provide acceleration to the entire movement pattern [4]. Such dynamic footwork pattern during step-forward lunge and an explosive extension of the fencer's body, in which acceleration provided by the rear leg in which the lead leg is kicked forward, provides both power and range to the fencer and helps to accelerate the weapon for a rapid strike. Unfortunately, this action leads to considerable loads applied to the athlete's locomotive system. The simplest assessment of musculoskeletal system loads can be made using ground reaction forces and by comparison of the values of joint torques in static and dynamic conditions.

In terms of the vertical component of the ground reaction forces, a sequence of two peaks generated by the lead leg at a level of 9.52 ± 1.57 N/kg and 17.90 ± 1.91 N/kg is clearly visible. Another characteristic element is associated with the value of the ground reaction force in the rear leg at a level of 13.36 ± 1.47 N/kg recorded over 40% of the duration of the entire movement pattern. Comparing these values to the results recorded during gait (12 N/kg) [3], we find out that the values are greater during the step-forward lunge by 49 and 11%, respectively.

A comparative analysis of the torques generated during muscular activity in isometric and dynamic conditions provides an assessment of the characteristics of the load and muscle activity during concentric and eccentric conditions of muscle contractions [2]. Skeletal muscles contract either by shortening or lengthening (concentrically or eccentrically, respectively), however, the two contractions substantially differ from one another in terms of mechanisms of force generation, maximum force production and energy expenditure. It is generally known that eccentric actions generate greater force than isometric and concentric contractions and at lower metabolic cost. Hence, by virtue of the greater mechanical loading involved in active lengthening, eccentric resistance training is assumed to produce greater hypertrophy than concentric resistance training [13]. It can be noted that the recorded values of the torques generated by the muscles are directly proportional to the forces generated by the muscles attached to a given joint, under the assumption that the lever arm of the muscle force assumes a constant value. For this reason, the criterion applied to determine a considerable level of a load applied to a joint adopted in the present paper was associated with the value of the torque of the muscle force acting in the dynamic conditions (for a step-forward lunge) that exceed the torque of the muscle forces generated in the ankle, knee and hip joint, respectively in isometric conditions. The analysis of the results collected during the study demonstrated that the hip is the joint with the greatest load. The maximal value of torque, corresponding to the hip flexion of the lead leg after the completion of the lunge exceeds the value recorded for this joint during isometric flexion by 79%. The knee forms the second joint in terms of the generated load. The maximal value of knee flexion of rear leg in the dynamic conditions exceeds the value registered in the conditions of isometric flexion by 33%. In ankle joint, all values obtained in dynamic conditions were lower, compared to the conditions of isometric flexion or extension. This analysis shows that the hip and knee joints are the most vulnerable to injuries during step-forward lunge. This statement may be further confirmed by comparison with the results for the gait analysis. We found that during the second phase of the movement (lunge), the following order of the highest to lowest values of the load applied to the joints was recorded in: hip (3.63 ± 0.75 Nm/kg), knee (1.71 ± 0.64 Nm/kg) and ankle joint (1.28 ± 0.15 Nm/kg). Comparing these values to those obtained during gait, we learn that the values of torques during lunge are by 626 and 280% higher than during gait in the hip and knee joints, respectively (0.5 Nm/kg). At the same time, the maximum value recorded in the ankle joint during gait was 1.5 Nm/kg [2], which is by 13% greater than in the analyzed movement pattern. In addition, comparing the maximum values recorded for the joints in the lead and rear legs during the lunge, we can see that the loads are greater for the lead leg, which was also confirmed in other studies [6], [12], [15], [19], [20]. We can also add that the approach followed in this study work has also a physioprophylactic aspect. A comparative analysis of muscle torque in isometric and dynamic conditions offers the assessment of the characteristics of internal load and muscular effort in concentric and eccentric conditions. This can form a source of information during prevention against chronic injuries and injuries in beginning and advanced fencers [16]. At this point it is necessary to present some limitation of this study. Fencing is a sport with unique patterns of asymmetrical movements and biomechanics. A unique feature of fencing is the metal carpet piste and the poor shock-absorbing characteristics of the fencing shoes, which increase the magnitude of impact forces and the risk of foot/ankle and knee injuries [9]. Foremost, due to differences in the characteristics of different weapons and, therefore, movement requirements, findings of this paper are not transferable across weapon type. Moreover, fencing contest regularly lasts for more than an hour, during which fencers experience rapid alternation between resting and intensive activity. Therefore, muscle fatigue and psychophysical exhaustion would influence performance measures and results. Future studies are necessary to evaluate effects of fatigue on fencing performance.

5. Conclusions

The results obtained in this paper highlight the size of joint loading during performance of step-forward lunge. Fencing requires high muscular strength even during the early years of training. The results of the present study may help in specifying strength capacity and training specificity, and in preventing injury in good fencers. These findings may be also useful in designing of training and rehabilitation programs for this population, considering that training methods should mainly influence the muscles of hip joint.

References

[1] BALKÓ Š., BORYSIUK Z., BALKÓ I., ŠPULAK D., *The influence of different performance level of fencers on muscular coordination and reaction time during the fencing lunge*, Archives of Budo., 2016, 12, 49–59.

[2] BŁAŻKIEWICZ M., SUNDAR L., HEALY A., RAMACHANDRAN A., CHOCKALINGAM N., NAEMI R., *Assessment of lower leg muscle force distribution during isometric ankle dorsi and plantar flexion in patients with diabetes: a preliminary study*, J. Diabetes Complications, 2015, 29, 282–287, 10.1016/j.jdiacomp.2014.10.007.

[3] BŁAŻKIEWICZ M., WISZOMIRSKA I., KACZMARCZYK K., BRZUSZKIEWICZ-KUZMICKA G., WIT A., *Mechanisms of compensation in the gait of patients with drop foot*, Clin. Biomech., Bristol, Avon, 2017, 42, 14–19, 10.1016/j.clinbiomech.2016.12.014.

[4] BOBO-ARCE M., RIAL B., *Determinants of competitive performance in rhythmic gymnastics. A review*, 2013.

[5] BORYSIUK Z., *Modern Saber Fencing. Island*, SKA Swordplay Books, N.Y. 2009.

[6] BORYSIUK Z., MARKOWSKA N., CZYŻ S., KONIECZNY M., PAKOSZ P., KRĘCISZ K., *Fencing fleche performed by elite and novice epeeists depending on type of perception*, Archives of Budo., 2018, 14, 18.

[7] BORYSIUK Z., WAŚKIEWICZ Z., *Information processes, stimulation and perceptual training in fencing*, Journal of Human Kinetics, 2008, 19, 63–82.

[8] BOTTOMS L., GREENHALGH A., SINCLAIR J., *Kinematic determinants of weapon velocity during the fencing lunge in experienced epee fencers*, Acta of Bioengineering and Biomechanics, Wrocław University of Technology, 2013, 15, 109–113.

[9] CHEN T.L., WONG D.W., WANG Y., REN S., YAN F., ZHANG M., *Biomechanics of fencing sport: A scoping review*, PLoS One, 2017, 12, e0171578, 10.1371/journal.pone.0171578.

[10] CRONIN J., MCNAIR P.J., MARSHALL R.N., *Lunge performance and its determinants*, J. Sports Sci., 2003, 21, 49–57, 10.1080/0264041031000070958.

[11] DI RUSSO F., TADDEI F., APNILE T., SPINELLI D., *Neural correlates of fast stimulus discrimination and response selection in top-level fencers*, Neurosci. Lett., 2006, 408, 113–118, 10.1016/j.neulet.2006.08.085.

[12] DO M.C., YIOU E., *Do centrally programmed anticipatory postural adjustments in fast stepping affect performance of an associated "touche" movement?*, Experimental Brain Research, 1999, 129, 462–466.

[13] FRANCHI M.V., REEVES N.D., NARICI M.V., *Skeletal Muscle Remodeling in Response to Eccentric vs. Concentric Loading: Morphological, Molecular, and Metabolic Adaptations*, Frontiers in Physiology, 2017, 8, 447, 10.3389/fphys.2017.00447.

[14] GHOLIPOUR M., TABRIZI A., FARAHMAND F., *Kinematics Analysis of Lunge Fencing Using Stereophotogrametry*, World Journal of Sport Sciences, 2008, 1, 32–37.

[15] GUTIERREZ-DAVILA M., ROJAS F.J., ANTONIO R., NAVARRO E., *Response timing in the lunge and target change in elite versus medium-level fencers*, Eur. J. Sport Sci., 2013, 13, 364–371, 10.1080/17461391.2011.635704.

[16] HARMER P.A., *Rate and Characteristics of Time-loss Injuries Do Not Differ Across Age Groups in Competitive Fencing: 1522: Board #69 May 28 3:30 PM – 5:00 PM*, Medicine & Science in Sports & Exercise, 2008, 40, S234, 10.1249/01.mss.0000322502.64076.d1.

[17] KAWAŁEK K., OGURKOWSKA M., *A comparison of selected biomechanical parameters in speed-endurance athletes*, Trends in Sport Sciences, 2014, 21, 21.

[18] ROI G.S., BIANCHEDI D., *The science of fencing: implications for performance and injury prevention*, Sports Med., 2008, 38, 465–481.

[19] TSOLAKIS C., VAGENAS G., *Anthropometric, Physiological and Performance Characteristics of Elite and Sub-Elite Fencers*, Journal of Human Kinetics, 2010, 23, 43–50.

[20] TURNER A., JAMES N., DIMITRIOU L., GREENHALGH A., MOODY J., FULCHER D. et al., *Determinants of olympic fencing performance and implications for strength and conditioning training*, Journal of Strength and Conditioning Research, 2014, 28, 3001–3011, 10.1519/jsc.0000000000000478.

[21] WITKOWSKI M., TOMCZAK M., BRONIKOWSKI M., TOMCZAK E., MARCINIAK M., BORYSIUK Z., *Visual Perception Strategies of Foil Fencers Facing Right- Versus Left-Handed Opponents*, Perceptual and Motor Skills, 2018, 125, 612–625, 10.1177/0031512518767758.