Original Article

Relationship between the armed arm's motor response and muscle activation time during the lunge in fencers of varied ability

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ABSTRACT

The present work studied potential differences in activation times of selected muscles associated with the motor responses of the armed arm and differences in selected muscle pairs activation during the fencing lunge. Twenty-eight fencers (epée fencers, aged 23.1 ± 5.4 years) grouped into elite and beginning skill levels, participated in this study. Surface electromyography was used to determine muscle activation time (time period measured from visual stimulus occurrence to the moment of muscle activation threshold detection). For motor response, we measured the time between visual stimulus occurrence and armed arm movement. A significant difference was found between elite and beginning fencers in the motor response of the armed arm. Detection of armed arm's motor response was significantly later in beginners. Greater time disparities between arm's motor response and muscle activation time of the m. rectus femoris on the front/lunge side was also found in beginners. Lastly, difference was detected between elite and beginning fencers regarding the muscle activation time of selected muscle pairs. Future studies and trainers can use these results to further explore key areas of motor control and biomechanics for improving of fencing performance. **Key words:** SURFACE ELECTROMYOGRAPHY, MOTOR CONTROL, BIOMECHANICS, SPORT PERFORMANCE, REACTION TIME.

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INTRODUCTION

Fast reaction, suitable and timely executed movements during the match (Allerdissen et al., 2017; Borysiuk & Waskiewicz, 2008) in optimal distance from an opponent, technical and tactical skills (Kriventsova et al., 2017), optimal psychological mood, physical fitness (Chan et al., 2011) represent elementary determinants necessary for the overall performance of a fencer. Other authors mention the importance of lunge velocity and change of direction speed for overall fencing performance during fencing competitions (Turner et al., 2016). During a match, both opponents utilize distance and timing to spring an attack. The lunge is the most common method of attack in fencing (Bottoms et al., 2013; Cheris, 2002). Similarly, Roi and Bianchedi (2008) suggest that lunge is one of the most frequently used attacking mechanism during fencing competition. The lunge is usually practiced during the introductory phase of training, where the priority is to improve the function of the armed arm before concentrating on other parts of the body (e.g., lower extremities). The main precondition and requirement for successful completion of an attack is to realize the movement quickly. This situation can occur when both opponents perform the lunge at the same time. The speed of each opponent can shorten the time needed to perform this action. Related to this argument, the prior programmed movement pattern is being recalled, and this motion cannot be altered. This means that it is more efficient to use previous experience of programmed movements than to use time-consuming conscious movement correction during fast action sequences in fencing. Optimal reaction (Gutiérrez-Cruz et al., 2016), muscle coordination during the lunge can have a large impact on the successful completion of the action (hitting the target). The reaction time (motor response of the armed arm) in fencing seems very important component of the fencing performance. In this context arise studies focused on the possibilities of its influencing (Doyle et al., 2016).

Many authors have focused their studies on the kinematic profile of the movements in fencing (Bober et al., 2017; Bottoms et al., 2013; Geil, 2002; Gholipour et al., 2008; Sillero et al., 2008; Sinclair & Bottoms, 2013a, 2013b; Stewart & Kopetka, 2005). The summarizing review of the studies focused on fencing movements was done by Chen et al. (2017). Based on previous studies it is still necessary to search variables for fencing performance improvement with respect to quality of performed movement and health ensuring (injury). Appropriate method for the identification of muscle time activation interactions among varying levels of athletes can be used by surface electromyography. This method can provide important information about the speed of information processing or motor control (Enoka, 2008). The muscular coordination in fencing lunge was previously observed by Williams and Walmsley (2000a, 2000b). Authors confirmed the differences in time muscle activation among varying performance level groups of fencers. Based on these and similar findings, differences in motor control and the quality of performed movement can be assumed between elite athletes and beginners (Schmidt & Wrisberg, 2008). With this overwhelming amount of evidence, we can conclude that optimal muscle coordination is directly associated with a success of fencing lunge action.

The focus of our study is to find out whether differences exist between various groups of fencers concerning muscle activation time (MAT) of the selected muscle pairs, as well as the relationship between the motor response (MR) of the armed arm and selected muscles while executing a fencing lunge. We believe that tracking the time differences between the activation of selected muscles and also differences between MAT of the selected muscles and the motor response of the arm can be very important for sports practice. From the point of view of the possibility of modifying the movement patterns of partial movements in fencing, the time interval between the activation of the armed arm's motor response and the sequence in the activation of the selected muscles is very important for streamlining of the training process. Possible differences between these variables can be considered as an important aspect of fencing performance during the epée fencing lunge which is one of the most common attacks during the match.

MATERIAL AND METHODS

Participants

The research sample consisted of 28 epée fencers, aged 23.1 ± 5.4 years. The fencers were divided into two specific groups based on their current performance levels. The first group, labeled E, consisted of 14 elite fencers (25.9 ± 6.2 years; 14.8 ± 5.9 active in fencing; height 184.9 ± 6.3 cm; weight 77.7 ± 10.1 kg). These fencers are active athletes participating in various international championships, World Cups, and Olympic Games. Lastly, group B consisted of 14 beginners (21.3 ± 5.7 years; 1.6 ± 0.7 active in fencing; height 179.4 ± 5.7 cm; weight 73.1 ± 8.8 kg). These fencers have not participated in any tournaments or competitions. All test subjects were introduced to the measuring system, analysis, and research methods before the research started. The study was approved by the Ethics Committee in accordance with the ethical standards of the Helsinki Declaration. Signed consent declaring their voluntary agreement to participate in this study was given by all athletes.

Procedures

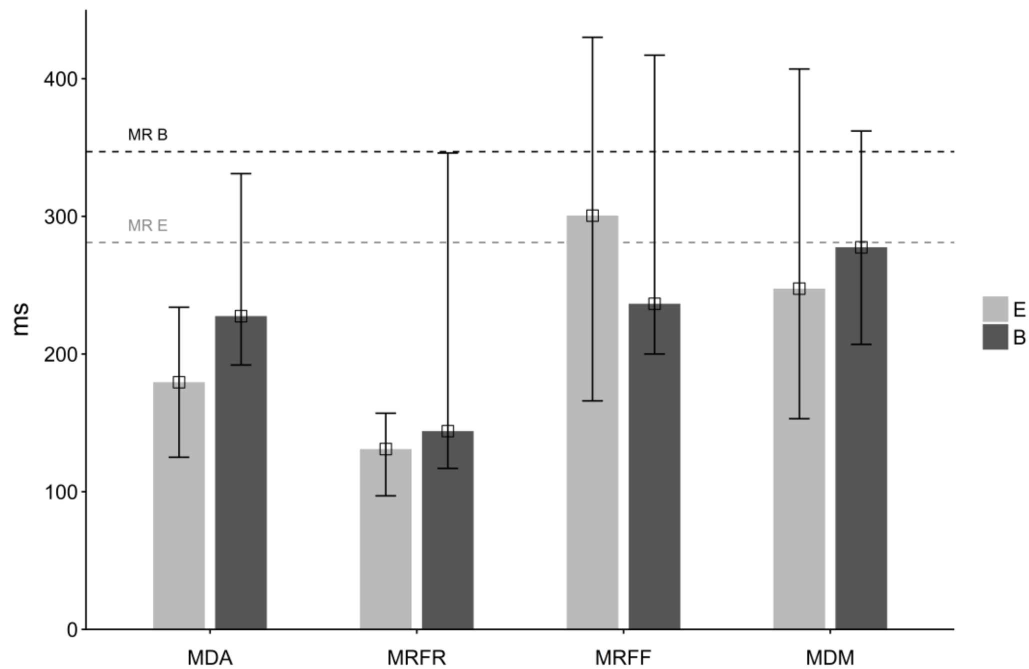
The task of each test subject was to perform the lunge action from the guard position when the target was illuminated with a red light. A physiotherapist applied the electrodes on selected muscles. For clarity, two basic sides were used to describe and analyze various aspects: lunge/front and rear/bounce side of the body. The analyzed muscles on the rear/bounce side were the *m. rectus femoris* and the *m. deltoideus pars medialis.* On the lunge/front side were analyzed the *m. rectus femoris* and *m. deltoideus pars anterior*. Activation of these four selected muscles was registered with surface electromyography (SEMG) by ME6000 measurement system (MEGA Electronics, Ltd., Finland, with MegaWin software, 16 channels). The Fitrosword recording device (Fitronic, s.r.o., Bratislava, Slovak Republic, with SWORD software) was used for identification of motor response of the armed arm. The experiment included 20 attempts (lunges) with a rest interval of at least 15-20 seconds between each pair of attempts. The attempts were recorded successfully with both measuring devices (ME6000 and Fitrosword, both set on the same frequency, 1000 Hz). To set the time activation, a method of setting the EMG threshold was used during the observed phase. This method was previously suggested by Špulák et al. (2012). Subsequently, the gained signal was converted to the absolute value and then smoothed via filtering, creating the EMG cover. The threshold value in this measurement was the level related to the maximum EMG cover value. This digital signal was then transformed (converted into absolute values). The time muscle activation was measured with the use of scripts in Matlab software (version R 2012b). Before the lunge, test subjects were in the guard position. This position allowed for the fencers to have active muscles during the measurement. An artificial baseline of each muscle was established based on the muscular activity in guard position. This line is related to the average value of the EMG signal (550 ms) before the lunge performing. When the amplitude of the signal reached 20% of the local maximum of the artificial line, the muscle was regarded as activated. The movement distance was measured from the location of the target to baseline placed in the distance calculated by multiplying of the height in cm of each participant by the coefficient 1.5. Lastly, the middle of the target was positioned at the height of the test subject's xiphisternum. Based on the occurrence of the stimulus, the test subjects had to perform the lunge as fast as they could from a movement distance. The motor response was measured based on the period from the illumination of the LED bulb to the movement of the goblet on the weapon upon making contact with the sensitive horizontal obstacle where the goblet was placed.

Data analysis

The results were processed in software Statistica (StatSoft Inc, 2016). The Shapiro-Wilks test confirmed that the data were not normally distributed. Based on this finding nonparametric tests were used. The Mann-Whitney test was used to find the differences among groups (E vs. B). Statistically significant differences were defined as those for which $p < 0.05$. Confidence intervals for effect size (d) were determined (0.2 - small effect, 0.5 - middle effect, 0.8 big effect). The correct attempt was not shorter than 100 ms (anticipatory) and longer than 1000 ms (incorrect attempts) in the case of motor response. Only first 15 “correct” attempts were processed from total number of 20 measured attempts (lunges).

RESULTS

This part of the study focuses on the detected difference between the activation of observed muscles and the motor response of the armed arm among both groups of fencers.

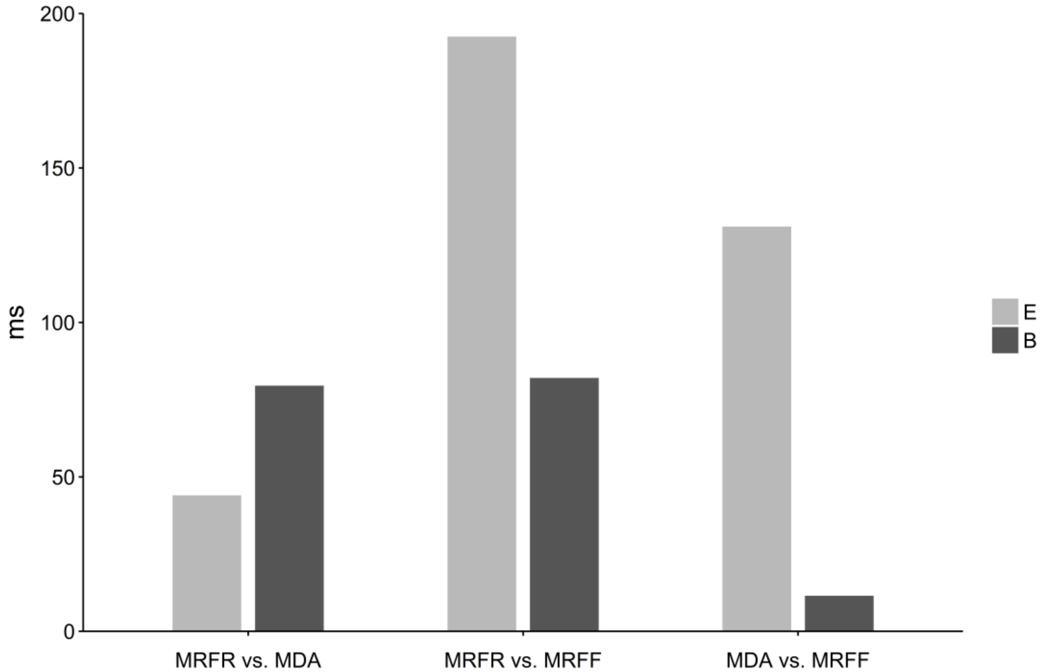


MR E = motor response in elite fencers; MR B = motor response in beginners; E = elite fencers, B = beginners; MDA, MRFR, MRFF, MDM = observed muscles.

Figure 1. Relationship between muscle activation time of muscles and arm’s motor response.

Figure 1 describes the relationship between the observed muscles and motor responses among both groups of fencers. The MR occurred significantly later than the identification of the *m. deltoideus pars anterior* activation in both groups. After the visual stimulation, *m. rectus femoris* on the rear/bounce side activated first in both groups. There was only a minimal difference in the MAT of the *m. rectus femoris* on the rear/bounce side among observed groups of fencers. Interestingly, elite fencers activated the *m. rectus femoris* on the front/lunge side after the identification of the MR. In beginners, the all observed muscles were activated before the MR. Significant difference in the MR between the elite fencers and the beginning fencers was found ($p = 0.0067$, d = 0.51).

The next part of the study presents the results of differences between selected muscle pairs. Figure 2 shows that differences were detected between observed groups in the case of all monitored relationships.



E = elite fencers; B = beginners; MRFR vs. MDA, MRFR vs. MRFF, MDA vs. MRFF = relationship between muscle pairs.

Figure 2. Differences in activation of selected muscle pairs.

Table 1. Motor response vs. MAT of selected muscles and relationship in muscle pairs activation.

Muscle	*p*	d	Muscle pairs	*p*	d
MDA	0.9634	0.01			
MRFR	0.3827	0.16	MRFR vs. MDA	0.0661	0.35
MRFF	0.0101	0.49	MRFR vs. MRFF	0.0044	0.54
			MDA vs. MRFF	0.0021	0.58
MDM	0.6133	0.09			

MDA = m. deltoideus pars anterior; MRFR = m. rectus femoris on the front/lunge side; MRFF = m. rectus femoris on the front/lunge side; MDM = m. deltoideus pars medialis.

Important distinctions regarding the MR and MAT of the *m. rectus femoris* on the front/lunge side were found between elite fencers and beginners. Other differences between both groups of fencers in relationships of selected muscles (MDA, MRFR, MDM) and armed arm's motor response were not significant (table 1). Table 1 and Figure 2 further show that elite fencers and beginners had significantly different MATs in muscle pairs, for relationship between *m. rectus femoris* on the rear/bounce side vs. *m. rectus femoris* on the front/lunge side and for relationship between *m. deltoideus pars anterior* on the front/lunge side vs. *m. rectus femoris* on the front/lunge side.

DISCUSSION

The present work studied potential differences in activation times of selected muscles associated with the motor responses of the armed arm and also differences in selected muscle pairs activation during the fencing lunge in fencers of varied ability. The selected muscles were observed on the basis of recommendation from previous studies (Williams & Walmsley, 2000a, 2000b). It can be assumed that due to a sufficiently long and quality training process athletes will automate the movement patterns that affect the quality and efficiency of the movement. For this reason, we were wondering if the differences between the observed variables in different performance groups of fencers would be found. It is obvious that in top-level athletes are both coordination (Carboch et al., 2014; Wąsik & Góra, 2016) and speed of the movement (Wąsik, 2015) very important factor for sport performance, especially in sport with high requirements for technical abilities (fencing, karate, judo, taekwon-do, gymnastics etc.). In fencing this coordination has to be solved in time (maximum time of match) and in fencing ground limitations. The importance of muscle coordination during the lunge in fencing, which is the subject of our research, was previously discussed by Czajkowski (2005) and Gutierrez-Davila et al. (2013).

The present study observed and analyzed the motor response of the armed arm during the lunge. It is important to note that activation of the *m. deltoideus pars anterior* of armed arm close to the identification of motor response during a lunge can be considered as a key moment for successful lunge performance in epée fencing. In our study, the motor response of the armed arm was identified among elite fencers as equal to the moment of activation of *m. deltoideus pars medialis* on the front/lunge side. Further, the difference between the motor response and the *m. rectus femoris* on the front/lunge side was significant between elite fencers and beginners. Interestingly, elite fencers activated the *m. rectus femoris* on the front/lunge side after the motor response identification. This may be caused by the intention of the elite fencers to perform the extension in the knee joint at the end of the lunge. In context with study of Williams and Walmsley (2000a, 2000b) we can confirm some similarities in order of muscle activation. They concluded that while performing the lunge, *m. rectus femoris* on the rear leg was activated before *m. deltoideus pars anterior* on the front side (arm with the weapon, closer to the target). The activation of *m. rectus femoris* on the front (lunge) leg in their study were detected significantly later. These authors also found differences in muscle activation among elite fencers and beginners. Findings of Williams and Walmsley (2000a, 2000b) correlate with the conclusions of Adrian and Klinger (1976) and Szilagyi (1993), who reported that the activity of muscles in the lower rear (bounce) leg begins the lunge. Similar findings have also been confirmed by Harmenberg et al. (1991), stating that more experienced fencers initiate the lunge by activation of their muscles on the rear (beat) side arm before activating muscles on the front (lunge) side lower limb. Finally, the muscle activation time of the *m. rectus femoris* on the front/lunge side must be the final sequence. This finding seems logical from the perspective of performing a successful lunge because the activity of the lunge/front lower limb can be easily considered as the intention of the opponent to attack during the epée fencing match. The initiation of the activity of the lunging lower limb before the activity of the arm movement can be considered as an incentive to the attack of the opponent during match. This script is well known to fencers, who try to recognize it during the training process. Early and correct observation of an opponent's "mistake" is regarded as one of the most difficult skills acquired by a fencer. The relationship between the muscle pairs was tested and analyzed based on the general suggestion that lunging must be initiated (based on the stimulus occurrence) by the activity of the armed arm, followed by the activity of other muscles. The interaction between these muscles is essential for the initiation of the movement. The muscle pairs were also chosen to determine muscle activation characteristics during a lunge that could possibly influence the observed movement.

A surprising result was discovered in the difference in the muscle activation time between selected muscle pairs. The significant difference was found in relationship of *m. rectus femoris* on the rear/bounce side vs. the *m. rectus femoris* on the front/lunge side. Elite fencers showed greater time disparities differences between activation times for relationship of *m. rectus femoris* on the rear/bounce side vs. *m. rectus femoris* on the front/lunge side than beginners. Smaller time disparities between *m. rectus femoris* on the rear/bounce side and *m. deltoideus pars anterior* on the front/lunge side were observed in elite fencers than in beginners but this difference was not detected as statistically significant. However, we believe that the shorter muscle activation time between *m. rectus femoris* on the rear/bounce side and *m. deltoideus pars anterior* on the front/lunge side activation can be considered as essential for desired movement. With regard to the isolated muscle activation times, it is necessary to mention that significant difference was found between muscle activation time of *m. deltoideus pars anterior* on the front/lunge side between observed groups of fencers. This muscle was activated earlier in elite fencers.

Lastly, the relationship between the *m. deltoideus pars anterior* on the front/lunge side and the *m. rectus femoris* on the front/lunge side was analyzed. Unlike the group of beginners, the group of elite fencers activated the *m. rectus femoris* on the front/lunge side significantly later than the *m. deltoideus pars anterior* on the front/lunge side. These results are consistent with the study of Harmenberg et al. (1991), which showed that experienced fencers activate the muscles in the armed arm first, followed by activation of the muscles on the lower limb on the lunge/front side of the body. In our study, all fencers activated the observed muscles in this pattern and sequence.

Based on the claim that elite fencers are equipped with better movement skills, we may conclude that the results of elite fencers can be regarded as "optimal". The fact that this study only examined the activity of the observed muscles during movement initiation means that there may be changes in muscle activity duration. However, it is possible to predict that muscle activation during the beginning of the movement can act as an influencing factor for the following lunge and result in a successful movement. This is also true in cases in which a fencer involuntarily re-evaluates their intention to hit the target while lunging. This usually occurs when the opponent counteracts. It is also possible that a fencer might need to shorten or lengthen the movement based on the opponent's movement. From the previously mentioned results concerning the activation time of the observed muscles, we can also conclude that fast activation of the *m. deltoideus pars anterior* on the front/lunge side activation and a fast motor response of the armed arm is an important factor for success in epée fencing lunge. In other fencing disciplines (foil, saber), the muscular coordination during the attack (lunge) could be different in connection with the rules. Similar results were reported by Bottoms et al. (2013), suggesting a connection between the speeds of the defined armed hand segment and the cooperating activity of other bodily segments. Frère et al. (2011) observed activation of the armed arm muscles during the flèche attack. It would be interesting to look differences or similarities in muscular coordination between various types of attacks in fencing (lunge vs. flèche).

An important limiting factor of the study was the use of the cable system that is part of the device used for surface electromyography. In other similarly focused studies, it would be worthwhile to use a cordless system for free range of movement and individual unlimited feeling by participants. Another recommendation is to use a microswitch or accelerometer to identify a motor response placed on the armed arm instead of using the horizontal obstacle used in our study. This would reduce the number of incorrect attempt that arose by shifting of the goblet over this obstacle before visual stimulation. The realistic combat situations in fencing can provide fencing robot mentioned in the article of Weichenberger et al. (2015). Using of this robot for visual stimulus generation seems to be better than lighting of the LED light on the target for movement (lunge) initiation. In this context, it can be mentioned that visual perception and preferences of fencers during computer monitor simulated attack were observed in the study of Hagemann et al. (2010). It should be taken into account that besides of muscular coordination fencing performance is influenced by many other factors. The differences in measurable variables not evaluated in this work could possibly be measured and verified within a larger research sample in a future study.

CONCLUSIONS

The results of the study showed that there are differences in the activation of selected muscles in relation to the motor response of the arm and also difference between muscle pairs activation between the various performance level groups of fencers. This fact is most likely related to the experience and effectiveness of the movement represented by elite athletes. It is probable that the use of such a model among groups of lower-performance fencers might positively manifest itself by an increase in their efficiency and overall sport performance. It would be very interesting to observe if the difference in bioelectric muscle tension between these groups of fencers would be detected before visual stimulation. Differences in bioelectric tension could be related to the efficiency and economy of movement represented by elite athletes. These results can be used in the future for finding the key areas of fencing performance, and they can help to support the significance of the motor control in sport practice.

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