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KINEMATIC CHARACTERISATION OF THE LUNGE AND THE FLECHE IN EPEE FENCING: TWO CASE STUDIES

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Abstract

Introduction. The aim of this study was to characterise the whole body dynamics and upper and lower joint kinematics during two common fencing steps: the lunge and the fleche. ***Material and methods.*** Two male competitive epee fencers were studied. Kinematics data were collected at 120 Hz (BTS Smart system) and ground reaction forces were measured at 120 Hz (Kistler platform). The resultant centre of gravity and end segment velocities were calculated. Temporal events were referenced to the horizontal ground reaction force. Time domain linear joint velocities were extracted. ***Results***. At the whole-body level, the resultant centre of gravity velocity was higher during the fleche (2.64 and 2.89 m/s) than during the lunge (1.94 and 2.21 m/s). At the joint level, the wrist and elbow attained their peak velocities earlier than the proximal joint for both the lunge and the fleche for both athletes. ***Conclusions***. The sequence of peak segmental velocities followed a distal to proximal sequence for both fencing steps.

Key words: lunge, fleche, sports technique, fencing

Introduction

The basic elements of sports technique are thoroughly described by researchers. When the effectiveness of these elements is evaluated, specific criteria are defined. One such criterion is the summation of speed principle first described by Bunn [1]. This criterion is based on the distal body segment attaining its velocity building on the velocity attained by the proximal segment. This principle applies to the javelin throw and also to kicking, walking, and running motions [2, 3, 4]. Another criterion, verified by Mulloy [5], is the one of proximal to distal sequencing as an optimal solution to generating maximum propulsion. The current study aimed to identify whether this kinematic chain is used in the fencing attack lunge. Hochmuth [6], on the other hand, formulated two criteria for achieving efficient technique during take-off from a solid surface: the first one is attaining maximum velocity while performing a movement, and the other one is reaching a target in the shortest possible time.

The fencing lunge is an attacking movement that can be described using biomechanical methods. Research conducted by Adrian and Klinger [7] illustrated the relationship between a fencer's en garde position and the velocity of the tip of the weapon. What they observed was an inverse relationship between the weapon's velocity and the vertical component of the ground reaction force. At the same time, they found a positive correlation between the velocity of the weapon and the horizontal component of the ground reaction force. In their research, Klinger and Adrian [8] concluded that a fit fencer is able to perform the movement with the armed hand before the leg performing the lunge finishes moving. This means that the movement of the weapon precedes the movement of the front leg. Moreover, the correlation occurring between the weapon's velocity and the kinematic parameters of the lunge was researched by Bottoms et al. [9]. They concluded that the values of such parameters as the angle of the knee joint, maximum flexion in the hip joint of the back leg, and flexion in the hip joint of the leading leg are good predictors of weapon velocity. They inferred that a fencer in the en garde position should stand relatively low in order to produce a large force while performing the lunge. The view that fencers in the en garde position should stand low by flexing their hip and knees corresponds with the thesis that time is a significant factor in performing the lunge.

Researchers who focus on the efficient performance of the lunge seek to identify its determinants, even though they use different efficiency criteria. Cronin et al. [10] examined the correlation occurring between the maximum velocity during the forward and return phases of the lunge and strength qualities. The results indicated that the ability to produce peak force earlier in the concentric phase was the best predictor of lunge performance. They also pointed out that, in order to determine the predictors of lunge performance, one should take into account such factors as body mass, flexibility, and leg length. In many of his publications, Cronin supports the idea that the most effective lunge is produced with explosive power [10]. On the other hand, Gresham-Fiegel et al. [11] examined the relationship between an efficient fencing lunge and foot placement. Assuming that foot placement may affect the efficient use of the leg muscles and influence the power produced, they sought a relationship between the placement of the non-leading foot and power and velocity. They concluded that perpendicular foot placement with the front foot pointing forward is the optimum position for achieving peak power and velocity of the body during a lunge. Other researchers have discussed the significance of the timing parameters of the reaction response time (RRT) in the fencer's efficiency [4, 12, 13]. They found that the relationship between the RRT and the kinematic parameters of a lunge depends on target change [15]. Also interesting is the observation that when the target changes, the temporal sequence of the movement pattern does not change appreciably [15]. Another approach to finding the determinants of an efficient lunge technique was related to comparing the kinematic parameters of fencers representing different levels of skill [5, 8, 12, 16, 17]. Klinger and Adrian [8] concluded that skilled fencers initiate a lunge by extending the arm rather than by moving the foot, and they hit the target before the leading foot strikes the floor. Williams and Walmsley [17] compared response timing and muscular coordination between elite and novice fencers. Elite fencers were found to attain a more consistent pattern of muscular coordination than novice fencers. On the basis of peak joint angular velocity ranking, Mulloy et al. [5] demonstrated that elite fencers used kinematic sequencing to a greater extent than novice fencers. Elite fencers presented greater horizontal sword velocity and lunge distance in comparison to novice fencers. Moreover, no significant difference in elbow extension and extension velocity were found between the two groups of fencers.

To our knowledge, the lunge has been the subject of many publications, while there is a lack of articles discussing the fleche technique. The only publication that we have had access to described the kinetic parameters of the fleche. Its authors investigated the lunge and the fleche to determine the movement and power of the joints of the lower extremities (hip, knee, and ankle) in the two techniques [18].

The primary aim of this study was to characterise the whole body dynamics and upper and lower extremity segment kinematics during the lunge and the fleche, which are two common epee fencing steps. The secondary aim which had to do with interpreting the results and building hypotheses was to determine the direction of the sequence of motion, that is proximal to distal or distal to proximal, and establish how it was related to the end goal of the task.

Material and methods

Participants

The research was based on the analysis of 2 male epee fencers. The body mass and height of the first fencer (referred to as A) were 83 kg and 174 cm, respectively. The body mass of the second fencer (B) was 96 kg, and his height was 193 cm. Both fencers were members of the Polish National Fencing Team (one of them was a silver Olympic medallist). At the time when the research was conducted, they were both active competitors. They did not report any health issues while the research was being carried out. Prior to the research, the fencers were informed about its aims and procedure, and they expressed written consent to participate in the study.

Experimental set-up

Kinematic measurements were taken with the BTS Smart system, while kinetic parameters were assessed using a piezoelctric Kistler 9286A platform. The BTS system was comprised of 6 calibrated video cameras attached to a computer with the necessary software. Movement was registered at 120 frames per second. Passive markers reflecting infrared light were attached to the fencers' bodies. These were placed in accordance with Davis's model [19], which was also used to mark and label the points for analysis (fig. 1). Additionally, the markers were attached to the armed hand and placed on the medial epicondyle of the humerus and styloid process of the ulna.

The following parameters (computed for the lunge and the fleche for each fencer) were measured for the ankle (F), knee (K), hip (H), shoulder (S), elbow (E), and wrist (W):

- V_{max} [m/s] – maximum velocity,
- V_p [m/s] – first peak of the velocity curve,
- tV_{max}, tV_p [s] – time of attaining V_{max} and V_p,
- F*, K* – first V_{max}.

Furthermore, we determined the centre of gravity (CoG) of the fencers and computed the velocity of the centre of gravity (V_{CoG}) [m/s] and the angle of the velocity vector CoG [°], referred to as the take-off angle (α).

Data gathered from the Kistler plates were used to compute the following:

- t_t [s] – time measured from the beginning of the horizontal ground reaction force during take-off to its end,
- hGRF [N] – horizontal component of the ground reaction force.

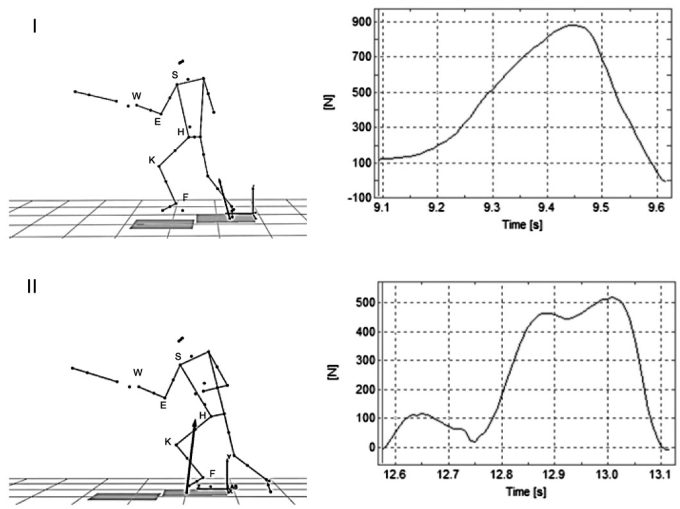


Figure 1. Left: en garde position with the back leg on the platform during the performance of the lunge (above) and en garde position with the front leg on the platform during the performance of the fleche (below). The vector of the ground reaction force drawn on the Kistler plate. Right: sample curve of the horizontal component of the ground reaction force (hGRF); the vertical line indicates the beginning of the take-off phase

Procedures

Prior to the measurements, each subject performed an individual warm-up session. The fencers performed a standing lunge and fleche in the en garde position. The subjects were asked to carry out the task in the shortest possible time, imitating an attack during a duel. They were instructed to point the tip of the epee at the height of an imaginary opponent's chest. All the trials were conducted three times. The lunge was performed from the en garde position with the feet apart and the back leg supported on the Kistler plate. Pushing the front foot forward, the fencer shifted their body weight backward to the back leg (fig. 1). The fleche was also performed from the en garde position with the front leg on the platform (fig. 1). The research was conducted in the Laboratory of Biomechanical Analysis, ISO Quality Certificate no 1374-b/3/2009, PN-EN ISO9001:2009.

Results

Lunge

Take-off time computed on the basis of the horizontal ground reaction force (hGRF) was approximately 0.5 s. In that time, the centre of gravity (CoG) reached the velocity of approximately 2 m/s or more. The fencers differed in terms of their V_{CoG} and take-off angle (α). It was observed that the higher the V_{CoG} was, the smaller the take-off angle (α) was (fig. 2).

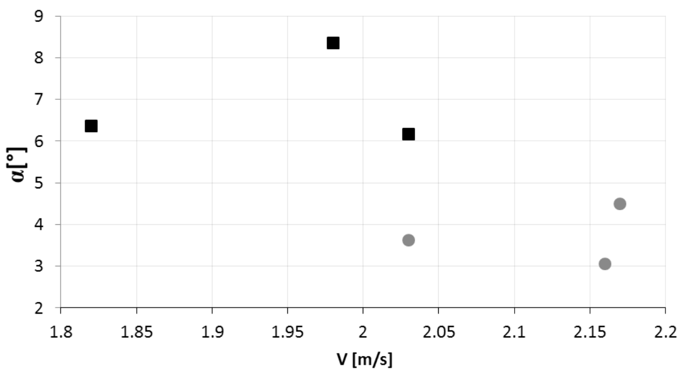
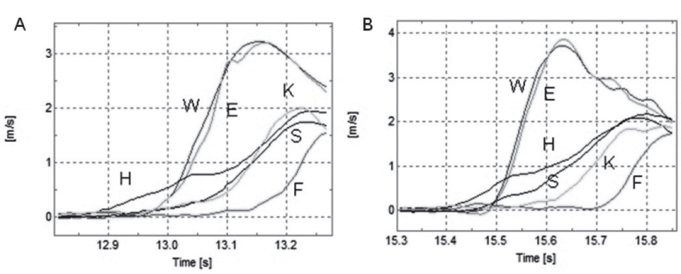


Figure 2. Centre of gravity velocity (V_{CoG}) and take-off angle (α) during the lunge performed by fencers A (square) and B (circle)

Figure 3 presents the sequence of the movements of fencers A and B during the performance of the lunge.

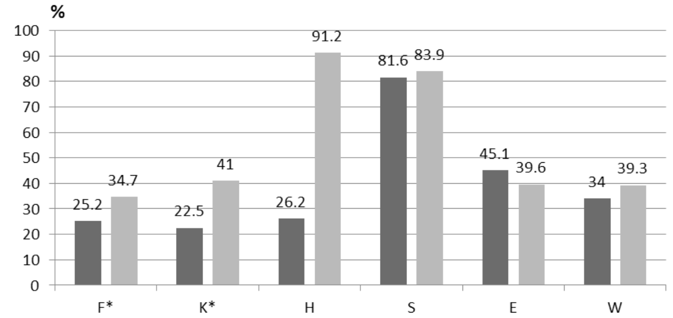
In the case of these two subjects, the lunge was characterised by a similar sequence of reaching V_{max} in the selected segments of the body. The curves representing the velocity of the points of the armed hand are also characteristic (fig. 3). In both cases, there was an initial delay in the increase of the velocity with significant acceleration after approximately 0.2 s. Hence, it can be concluded that the armed extremity needs a minimum amount of time to perform a movement, even if terminal velocity is low.



F – ankle, K – knee, H – hip, S – shoulder, E – elbow, W – wrist.

Figure 3. Characteristics of the velocity (V_{max}) of the selected body segments of fencers A and B during the lunge. Trial number one

Figure 4 presents the relative time values required for the points analysed to obtain V_{max}. Fencer A reached V_{max} the most quickly for the wrist (W), and then the elbow (E) and shoulder (S), while fencer B attained V_{max} for the selected points in the following order: elbow (E), wrist (W), and shoulder (S).



F – ankle, K – knee, H – hip, S – shoulder, E – elbow, W – wrist. Black – fencer B, grey – fencer A.

Figure 4. Mean values of the relative time needed to achieve V_p or V_{max} (*V_p for points F and K; V_{max} for the remaining points)

Fleche

Similarly as in the lunge, in the fleche, the take-off angle (α) recorded in the take-off phase differed between the two subjects. It was observed that, as was the case in the lunge, the higher the V_{CoG} was, the smaller the take-off angle (α) was (fig. 5).

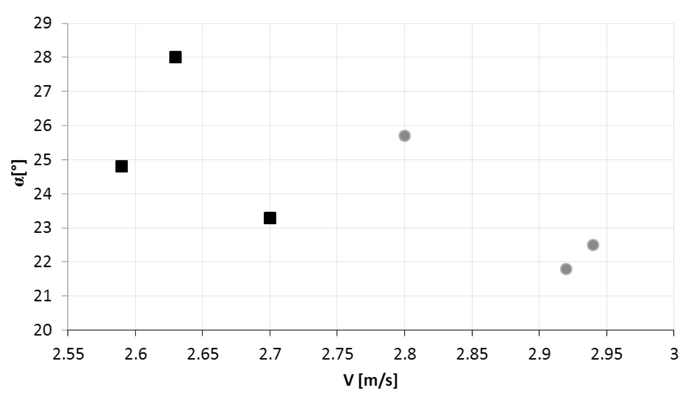
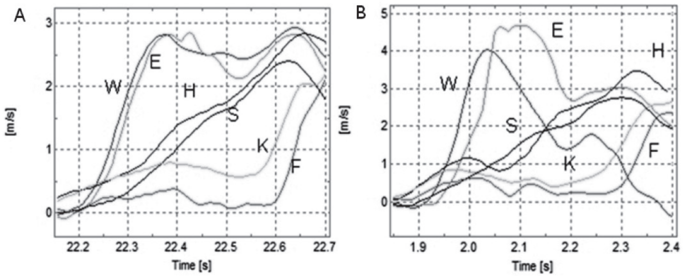


Figure 5. Centre of gravity velocity (V_{CoG}) and take-off angle (a) during the fleche performed by fencers A (square) and B (circle). Trial number one

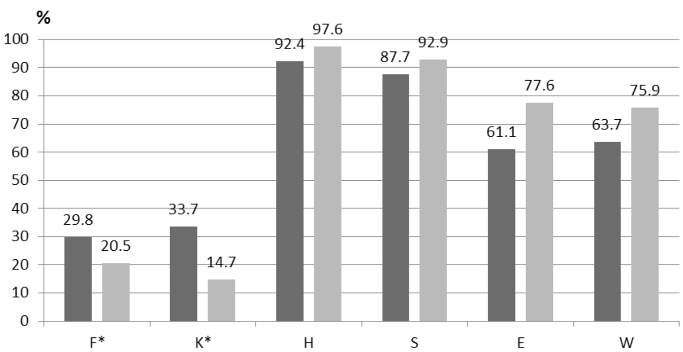
The parameters analysed revealed that the fencers performed the fleche differently. This was already visible in the curve representing the velocity of particular points of their bodies and their velocity observed for the first fleche (fig. 6). The V_{max} of the armed extremity was attained quickly: in ≈ 2.85 m/s in the case of the first fencer (A) and almost 5 m/s in the case of the second one (B). The fact that the values of V_{max} for the wrist (W) were higher than those for the elbow (E) requires specific interpretation; this situation did not result from the shoulder-elbow (S-E) sequence, as V_{max} was not attained in this order.



F – ankle, K – knee, H – hip, S – shoulder, E – elbow, W – wrist.

Figure 6. Characteristics of the velocity of the selected body segments of fencers A and B during the fleche. Trial number one

Figure 7 presents the relative time values needed by the points analysed to obtain V_{max} during the performance of the fleche. An analysis of time needed to attain V_{max} led to the conclusion that both fencers (A and B) reached their highest values earlier for the wrist (W) and later for the hip (H) and the shoulder (S). However, fencer B reached V_{max} for the hip (H) before obtaining peak velocity at the upper extremity points.



F – ankle, K – knee, H – hip, S – shoulder, E – elbow, W – wrist. Black – fencer B, grey – fencer A.

Figure 7. Mean values of the relative time needed to achieve V_p or V_{max} (*V_p for points F and K; V_{max} for the remaining points)

Discussion

The physical demands of fencing competitions are high; they involve aerobic and anaerobic metabolism and are also affected by age and tactical and technical models used in relation to the adversary [3]. Since technique has a significant influence on the results achieved by athletes, the authors have decided to focus on identifying the criteria of efficiency in fencing. The analysis of fencing technique was deliberately conducted on two highly experienced fencers whose morphological parameters differed remarkably. Research has shown that body height has an influence on the technique of performing the fleche [8], and the training experience and results achieved by the two fencers guaranteed that their technique for both the lunge and the fleche, described using biomechanical parameters, would involve certain movement habits.

Being the most common attack with all three fencing weapons, a powerful lunge is fundamental to successful performance [11, 20]. Papers describing lunge technique mention the fact that the foot moves forward prior to the armed hand performing the movement [7, 8]. The analysis focused mainly on the role of the back leg because the front leg performs a forward movement while being supported by the back leg. The back leg is active, which was represented by the positive values of the horizontal ground reaction force (hGRF). It can be assumed that the body stops being propelled forward when the lunge ends, and this defines the end of the take-off phase. Interesting is the fact that V_{max} for the shoulder (S), which is in a kinematic chain between the trunk and upper extremity, was attained at the end of the take-off phase (≈ 90% t_t). The above data prove that the movement of the armed hand was not synchronised with the movement of the hip and the shoulder. This was confirmed by the V_{max} values of the armed extremity which were attained faster than those of the hip (H) and the shoulder (S). Based on V_{CoG} and the take-off angle (α), it was assumed that the difference existing between the fencers lay in the strategy applied: attaining a higher velocity, which meant a smaller take-off angle (α), or the reverse strategy. These differences in technique may result from the differences in the body height of the fencers examined.

The lunge and the fleche differed in terms if their kinematic parameters, but they also displayed relevant similarities. Take-off time (t_t) was similar in both techniques and oscillated around 0.5 s. A significant difference, however, was observed in V_{CoG} in the lunge, for which V_{max} oscillated between 1.8 and 2.3 m/s. Similar results (1.36-2.08 m/s) were obtained for the direct-thrust attack by Gutierrez-Davila et al. [12, 13]. On the other hand, the values of the fleche velocity were in the range between 2.6 and 2.9 m/s. The values of the take-off angle (velocity vector angle) for the lunge ranged from 3 to 8° and those for the fleche ranged from 22 to 28°. Both in the lunge and the fleche, the greater the centre of gravity velocity (V_{CoG}) was, the smaller the velocity vector angle was. The range of V_{CoG} and the take-off angle (α) proved that there were differences between the fencers.

For both techniques, the researchers observed a slight primary movement of the foot and knee of the back leg performed approximately 30% of the time in the take-off phase. These values refer to the velocity first described as primary (V_p), which first fluctuated and fell and then increased and reached the maximum (V_{max}). The fleche may be performed with a movement of the hip, but it may also be a feature observed in an individual fencer, and not observed in other fencers. Additionally, except for this single case, both the H (hip) and the shoulder (S) reached their maximum velocity in the lunge and the fleche at the end of the take-off phase (> 80% t_t). However, before they achieved their peak velocity, the maximum velocity was attained by the points of the armed extremity at the elbow (E) and wrist (W). This occurred earlier in the fleche (≈ 40% t_t) than in the lunge (≈ 60% for fencer B and ≈ 75% for fencer A).

The analysis of the kinematics and kinetics enabled the researchers to answer questions about the technique efficiency criteria formulated for different motor techniques and their application in fencing. The principle of speed summation presented in the works of various authors [4, 5, 21] was not confirmed by this research. This conclusion is supported by the fact that the wrist (W) and the elbow (E) attained V_{max} at the same time, prior to the shoulder (S) reaching its V_{max}. This shows that a fencer has attempted to reach their target in the shortest possible time, which is consistent with one of Hochmuth's criteria [6]. This would mean that the movement of the armed arm is the most significant element in fencing, and it needs to be performed in the shortest possible time. Attaining maximum terminal velocity is of secondary importance. Thus, there is no velocity transfer from the proximal segment (shoulder) to a distal point (elbow, hand). Similar conclusions were drawn by Stewart and Kopetka [22]. These authors sought to answer the question which kinematic variables in the performance of the fencing lunge have the greatest effect on its overall speed. They concluded that the overall speed of the lunge is dependent not on how fast the maximum angular velocities of the sword arm, elbow and knees are, but on how soon they can be reached.

Conclusions

Take-off time was similar in both epee steps; however, the resultant centre of gravity velocity and the resultant velocity vector were higher in the fleche than in the lunge. In the two fencing steps that were analysed, the lunge and the fleche, higher velocity was accompanied by a lower resultant velocity vector. During both the fleche and the lunge, the peak velocity was first observed at the wrist. This observation is in contrast to the proximal to distal sequence of peak velocities reported for throwing tasks. Furthermore, the time-domain velocity curves in the lunge and the fleche suggest that the fencer attempts to shorten the task time rather than attain a high final velocity of the armed hand.

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