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Novel Lunge Biomechanics in Modern Sabre Fencing

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Abstract

Sabre is one of the three disciplines in the sport of fencing, characterised by the use of a lightweight cutting weapon to score hits on an opponent while maneuvering for position with rapid and dynamic footwork. One of the main techniques is the lunge: an explosive extension of the fencer's body propelled by the non-dominant (ND) leg in which the dominant (D) leg is kicked forward. The lunge provides both power and range (up to 3m) to the fencer and helps accelerate the sword for a rapid strike. Classical fencing lunges differ in style but share a common mechanism: a forward leap originating in the ND leg that powers rotation in a highly mobile thoracic cage. A new generation of fencers has begun to deviate from the classical lunge mechanism in recent years with a ND leg adopting a rigid momentum-conserving structure. This constant ND knee extension yields a constant rotational acceleration of the pelvis toward the dominant side and emphases scapular rotation to transfer power to the sword arm compared to thoracic rotation in classical lunges. We hypothesized that the new lunge mechanism delivers greater power, efficiency, range, and acceleration than the classical lunge. We measured the range, speed and acceleration of ten lunges at maximal exertion following a forward step using video capture from each of twenty-one (21) amateur subjects, aged between 10 to 55 years and in experience from 1 to 15 years. We assessed the performance of each subjects' lunge on five measures of alignment from both frontal and lateral videos, then used linear regression to identify correlations between significant markers of alignment and performance. These videos were also compared to competition videos of four (4) current fencers on the international competition circuit (Fédération Internationale d'Escrime, FIE) to verify our analyses with professional athletes.

Results across both cohorts of fencers showed a clear correlation between the ability to maintain lumbosacral neutrality during the lunge and performance as measured by lunge acceleration and speed. Other factors characteristic of the new lunge (achieving lumbosacral neutrality, extent of ND knee extension during transition, ND knee extension during lunge completion, and iliac crest alignment) were not well correlated to lunge performance. Maintenance of lumbosacral neutrality during the new lunge delivers three main advantages to the fencer: 1) greater acceleration; 2) increased range for given flight time; and 3) more efficient power transfer from the preceding step to the lunge. These advantages potentially give a fencer more tactical options and optimizing lumbosacral neutrality.

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Keywords: Sabre; Fencing; Biomechanics

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1. Introduction

Sabre is one of the three disciplines in the sport of fencing, characterised by the use of a lightweight cutting weapon to score hits on an opponent while maneuvering for position with rapid and dynamic footwork. One of the main techniques is the lunge: an explosive extension of the fencer's body propelled by the non-dominant (ND) leg in which the dominant (D) leg is kicked forward. The lunge provides both power and range (up to 3m) to the fencer and helps accelerate the sword for a rapid strike. Classical fencing lunges, as taught to generations of fencers over the past century, differ in style but share a common mechanism: a forward leap originating in the ND leg that powers rotation in a highly mobile thoracic cage [1][2].

A new generation of fencers predominantly from Asian and other non-European nations have begun to deviate from the classical lunge mechanism in recent years. In this new technique, the fencer advances in with greater emphasis on accelerating ND knee extension. The ND leg adopts a rigid momentum-conserving structure which replaces the gait-like behaviour of the ND leg in the classical lunge. This constant ND knee extension yields a constant rotational acceleration of the pelvis toward the dominant side. The fencer's thoracic cage resists the acceleration of the pelvis in this action, transferring power through the transverse, elastic tissues of the trunk [3] to the D scapula, which accelerates dramatically in upward rotation. This emphasis on scapular rotation in the lunge is in stark contrast to the focus on thoracic extension in classical lunges.

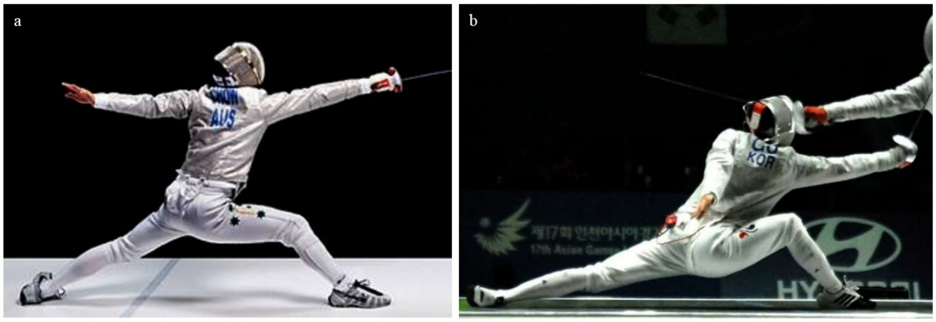

Fig. 1. (a) Classical fencing lunge (b) Modern lunge as demonstrated by a Korean professional fencer

We identified five measures of body alignment characteristic of the new lunge: 1) lumbosacral neutrality achieved; 2) lumbosacral neutrality maintained; 3) extent of ND knee extension during transition; 4) ND knee extension during lunge completion, and 5) iliac crest alignment immediately preceding the lunge. We hypothesized that the new lunge mechanism delivers greater power, efficiency, range, and acceleration than the classical lunge, and that one or more of these identified alignment measures was responsible for increased performance.

To test this hypothesis, we measured the range, speed and acceleration of lunges at maximal exertion following a forward step using video capture from amateur fencers ranging in age from 10 to 55 years and in experience from beginner to amateur international-grade. We assessed the similarity of each subjects' lunge to an 'ideal' new-style lunge as defined by the five measures of alignment from frontal and lateral videos, then used linear regression to identify correlations between significant markers of alignment and performance. These videos were also compared to competition videos of four (4) current fencers on the international competition circuit (Fédération Internationale d'Escrime, FIE) to verify our analyses with professional athletes.

Nomenclature

ND	Non-dominant
D	Dominant

2. Methods

2.1. Study participants

There were 21 subjects in the study. They ranged in age from 10 to 55, both male and female. Fencing experience ranged from 5 weeks to 15 years. The videos taken of the subjects were also compared to competition footage of four male competitive fencers all currently in the top 20 in the world: Gu Bongil, Alexey Yakimenko, Daryl Homer and Kamil Ibragimov.

2.2. Biomechanics analysis

Subjects were instructed to perform 10 trials of the advance lunge and were filmed doing so from two angles: dominant side view and rear view. Each trial was then subjected to a visual assessment and scored using a binary scoring system (1 for yes, 0 for no) on five factors related to biomechanics. The same assessment was performed for footage of the current competitive fencers, with the limitation that this footage was available from side view only.

Table 1. Biomechanics scoring criteria

Visual cue assessed	Score 0	Score 1
Was the rear knee extending on the transition between advance and lunge?		
On advance, after the rear foot had touched the floor and the weight of the body was on the rear foot, preparing to lunge, was the non-dominant-side iliac crest positioned level or higher than the dominant iliac crest?	No: Dominant-side iliac crest higher (Fig 2a)	Yes: Non-dominant iliac crest level or higher (Fig 2b)
In the first moments of the lunge, while the front foot was off the ground and traveling forward, did the rear knee continue to flex?	Yes, continued flexion.	No, no continued flexion.
Was rear knee extension completed? Rear knee reached full extension (180 degrees) before the front foot made contact with the ground at the end of the lunge. For the purposes of this experiment, the visual guide presented in Figure 2c. was used to estimate. [4]	No, full extension not reached	Yes, full extension reached
Was lumbosacral neutral achieved?		
Upon initiation of the lunge, did the lumbar spine exhibit coronal-plane symmetry? Upon initiation of the lunge, was the spinal axis parallel with the direction of momentum of the center of mass?	No: lack of coronal-plane symmetry (Fig. 2e), and spinal axis not aligned with direction of momentum. (Fig. 2g)	Yes: Coronal plane symmetry displayed (Fig. 2d) and spinal axis aligned with direction of momentum (Fig. 2f)
Was lumbosacral neutral maintained when the front foot makes contact with the floor?	No: between the lunge and initial contact, transverse-plane force conductivity was likely interrupted and lumbosacral neutrality compromised. (Fig. 2i and 2j)	Yes: spinal axis and the two posterior superior iliac spines will describe a roughly perpendicular relationship (see Fig. 2h)

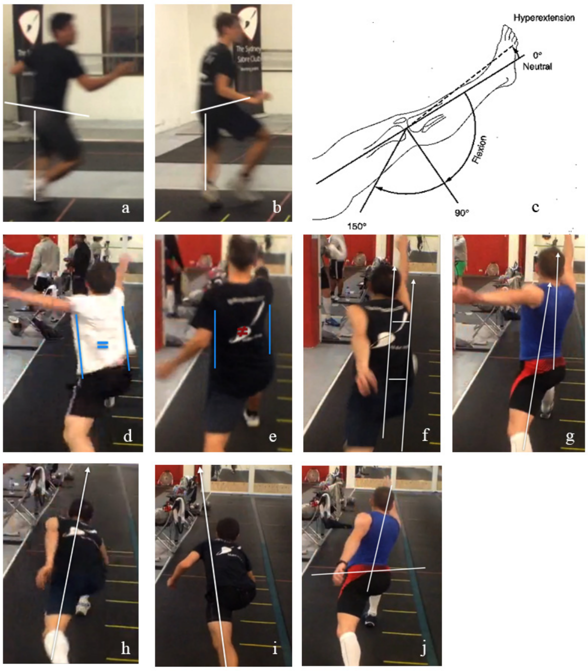

Fig. 2. (a) Successful knee extension on transition (b) Unsuccessful knee extension on transition (c) Visual guide used to estimate degree of knee extension (d) Successful coronal plane symmetry (e) Unsuccessful coronal plane symmetry (f) Successful alignment of spinal axis with direction of momentum of centre of mass (g) Failure to align spinal axis with direction of momentum of centre of mass (h) Successful maintenance of lumboosacral neutrality in respect to the ND femur (i) Unsuccessful maintenance of lumbosacral neutrality, as indicated by the longitudinal axis of the ND femur (j) Unsuccessful maintenance of lumbosacral neutrality

2.3. Distance and time analysis

Five criteria for performance were measured from video capture, from video timestamps and calibrated markings on the piste surface used by the subjects for this experiment, listed in Table 2.

Table 2. Distance and time measurements

Parameter	Initial Measurement	Final Measurement
Distance and time of advance	Front foot at the start of the advance	Back foot at the end of the advance
Distance of entire action	Front foot at the start of the advance	Front foot at the landing of the lunge
Distance of lunge	Back foot at the end of the advance	Front foot at landing of lunge
Time of entire action	Front foot at the start of the advance	Maximum extension of the front hand
Time of lunge	Back foot at the end of the advance	Maximum extension of the front hand

2.4. Statistical analysis

Values for the parameters listed in s2.3 and each measure of alignment listed in s2.2 were averaged over the 10 trials for each subject and analysed for correlation pairs by multiple linear regression in Microsoft Excel 2013. Two lunge performance metrics were identified: speed (distance of lunge/time of lunge) and acceleration (([speed of lunge]-[speed of advance])/[time of lunge]).

3. Results

We identified a clear correlation between lunge performance in terms of both speed and acceleration versus the aggregate measures of body alignment (Figure 3), with R^2 values of 0.33 and 0.30 respectively. However, there was sufficient variation in the performance scores in this correlation with the top performer in the second lowest alignment score (0.1) having similar performance (acceleration = 0.5 ms^{-2}) to the subject with the second highest alignment score (3.0, and acceleration = 0.7 ms^{-2}).

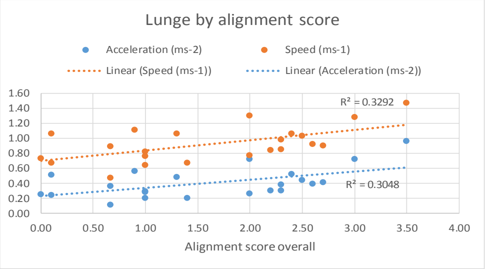

Fig. 3. Lunge speed and acceleration against alignment score over all 5 parameters

We were thus motivated to identify the components of body alignment that contribute most strongly to lunge performance (Figure 4). Contrary to the underlying principle for classical lunges in which the extension of the ND knee and propulsion from the ND leg is the main driver of performance, we found that these measures were not correlated with lunge performance (Figures 4a and 4b). Instead, the ability to achieve (Figure 4c) and maintain (Figure 4d) lumbosacral neutrality, that is, to ensure that force propagation is aligned and maintain along the axis of movement from the ND foot through to the sword arm, were most closely correlated to lunge speed and acceleration.

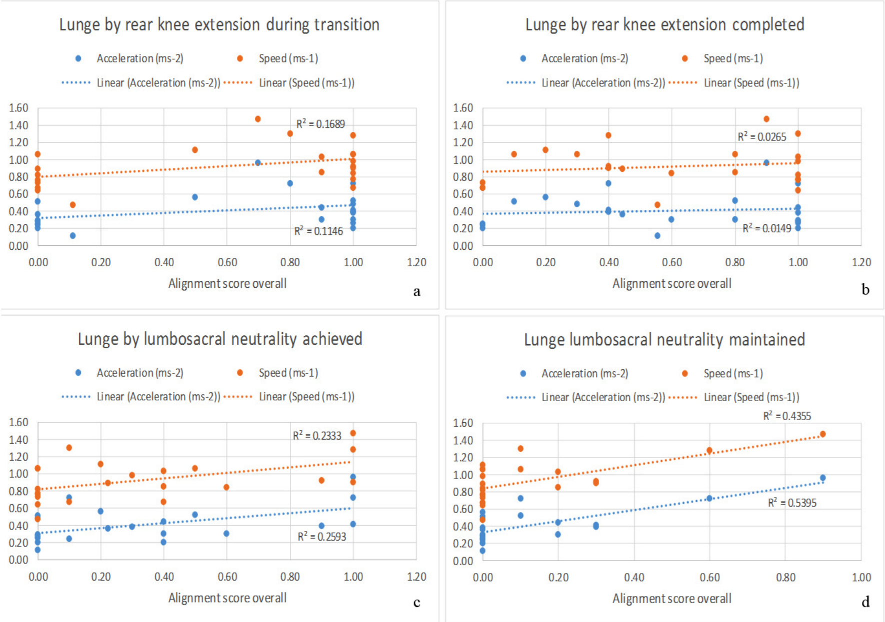

Fig. 4. Lunge speed and acceleration against individual alignment parameters. (a) Extension of rear knee during transition between advance and lunge (b) Completion of rear knee extension during lunge (c) Achievement of lumbosacral neutrality (d) Maintenance of lumbosacral neutrality

We compared our results from the subjects to those obtained from current competitive fencers with broadly similar findings. Notably, one fencer (Gu Bongil) who consistently executes lunges of the new style (average alignment score = 3.9) also had the second highest average lunge acceleration for both the subject and competitive fencer cohorts (0.72 ms^{-2}) and the highest average speed (1.40 ms^{-1}). Given that these metrics were obtained from competition footage where fencers do not typically lunge at full power (due to tactical considerations), we expect that the values would be higher under laboratory conditions.

4. Conclusions

Our results across both cohorts of fencers showed a clear correlation between the ability to maintain lumbosacral neutrality during the lunge and performance as measured by lunge acceleration and speed. Other factors characteristic of the new lunge (achieving lumbosacral neutrality, extent of ND knee extension during transition, ND knee extension during lunge completion, and iliac crest alignment) were not well correlated to lunge performance.

We surmise that this characteristic maintenance of lumbosacral neutrality during the new lunge delivers three main advantages to the fencer: 1) greater acceleration; 2) increased range for given flight time; and 3) more efficient power transfer from the preceding step to the lunge. These advantages potentially give a fencer more tactical options than an otherwise equally-matched opponent, and optimizing lumbosacral neutrality and associated biomechanical mechanisms may deliver significant improvements to athletes in addition to those from physical conditioning alone.

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