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Original Article

Comparing lunge techniques depending on the weapon used: Differences between foil and epee fencers

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Abstract:
Purpose: Despite different priority rules in epee and foil competitions, both weapons are trained using similar technical practices. This study aims to investigate whether these rule differences affect the coordination patterns observed in the lunge, a fundamental skill shared by both foil and epee fencers. Thus, we analyzed interlimb coordination between the leg and the arm on the fencers' armed side, as well as intergirdle coordination. **Method:** Sixteen epee and sixteen foil fencers participated in the study. The kinematics of the knee, hip and shoulder and the distances between the weapon and both the knee and the shoulder were computed. The relative phase between the motion of the scapular and pelvic girdles was calculated and the temporal pattern of muscle activity was determined from the EMG recording on the leg and on the arm of the participant's armed side and on the participant's non-armed side. **Results**: Differences in the knee-shoulder coordination and in the inter-girdle coordination were observed between foil and epee fencers. Two strategies were also identified from the temporal pattern of muscular activity. **Conclusion:** The specific constraints of foil and epee practice in a competitive context entail a profoundly different behaviour in terms of interlimb coordination. Although the technique is learned in the same way, rules specific to each weapon implicit in the performance of a simple skill such as lunge and affect the underlying coordination dynamics. These results open up new perspectives on fencing training based on differentiated approach.

Key Words*: intergirdle coordination, skill specialisation, EMG, motor learning*

Introduction

Fencing is an open-skill combat sport practiced with three different weapons, each contested with different rules. Foil and epee are thrust weapons: a hit is done with the point of the blade. An epee fencer can hit his opponent or can be hit all over the body and an attack can be initiated whenever the fencer decides. A foilsman, in contrast, needs to respect rules that limit the valid surface to the chest and establish an attack priority: S/he can hit an opponent only after gaining priority, and at this time, s/he cannot be hit; The opponent needs to accomplish a defensive action before being allowed to attack (Fédération Internationale d'Escrime, 2013).

Gaining attack priority offers the foilsman the possibility to move closer to its opponent thanks to the rule without risk to be hit. On the contrary, epee fencer always needs to be protected by the blade in order to avoid an attack from the opponent whether in an offensive or defensive action.

For a long time, foil has been considered to be a learning weapon for epee fencers in order to perfect their technical skills. It became a specific sport in the beginning of the 20th century. Still, a majority of fencers considers that basic techniques are common to epee and foil weapons (Barth & Beck, 2007).

To produce an adapted sport skill, the many components of the human body need to be coordinated in space and time. Since there is a huge number of components at different levels of the musculo-skeletal systems to bring together to achieve a coordinated movement, the control task for the CNS must simplified through the formation synergies or coordinative structures (Turvey, 1990). These structures or synergies bolster optimal performance by defining primarily an appropriate timing or pattern for the ensemble of the components to be put into motion (Herzog, 2000).

A common view is that a new motor skill is acquired though an internal, oftentimes representational process that makes changes in behaviour relatively permanent (Schmidt & Wrisberg, 2004). In contrast, Dynamic Pattern Theory (Schöner & Kelso, 1988) supposes that coordinated motor pattern emerges through the interaction of the components, by virtue of their mutual coupling and in response to the global constraints arising from the task, the body and the environment, without explicit mechanisms controlling the mobilized joints and body segments. How these elements are coordinated and how coordinative modes spontaneously arise without reference to underlying mechanisms and structures within the human body can be captured by collective

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variables (Haken et al., 1985). In his seminal work, Kelso (1984) identified relative phase as a relevant collective variable, adept to apprehend and distinguish different patterns of coordination. Relative phase variability, typically assessed by its standard deviation, provides a measure of the stability of the coordination between two interacting segments brought about through their coupling. Relative phase proves to be a pertinent variable to capture coordination in discrete movements too (Temprado et al., 1997).

This approach to coordination has been fruitful in the study of sports skills. Several studies show how various body segments are coordinated in volleyball serve (Temprado et al., 1997) or in cross-country skiing (Cignetti et al., 2009), but also how the displacements of the players themselves are coupled in time, particularly in badminton (McGarry et al., 2002) or in tennis (Palut & Zanone, 2005). Moreover, the notions and tools of a dynamical approach also describe how learning or expertise modify intralimb coordination in sports skills (Dedieu et al., 2020; Dedieu & Zanone, 2013). All these findings suggest that the relative motion of the moving elements, whether within a limb, between limbs or between individuals, exhibits similar patterns of coordination, resulting from the same underlying process of synchronization. As the human body is admittedly a complex system (i.e., composed of innumerable components), it is able to exploit its redundancy in order to install a coordinative pattern that is appropriate in a given context.

Dynamic Pattern Theory has also established how learning a new coordinated behaviour (e.g., a new motor skill) emerges from the interplay between the intrinsic dynamics, that is, the existing spontaneous limb spatiotemporal organisation, and extraneous constraints, more or less specific to the task to be performed, such as techniques, goals or associated rules. Thus, learning a motor skill means achieving a compromise through the competition between intrinsic and extrinsic constraints (Zanone & Kelso, 1997).

In fencing, learning is based on individual drill with a coach. Fencers are only focused on technical performance, in principle devoid of any competitive context. Thus, foilsmen are not concerned by priority rules, typical of competition, so that fencing is basically learned in the same way irrespective of the weapon. However, because they are not submitted with any rules in competition, epee fencers are usually trained within a competitive context. They acquire technical skills in conditions identical to those of competition, that is, without priority rules: the first hits, the first wins. On the contrary, foil fencers acquire technical skills in conditions where the priority rules applied in competition are used.

Despite their strong historical filiation and an identical technical practice while learning, performing epee and foil in competition involves specific rules, in particular priority rules, that distinguish both activities (Meyer et al., 2017). Our basic assumption is that these rule differences must somehow affect the dynamics of interlimb coordination exhibited in technical skills. Therefore, our study aims to identify what such differences are in a basic skill common to foil and epee weapon, namely, lunge. Viewed in isolation, lunge seems at first blush to be learned and trained in the same manner during individual lessons for both foil and epee fencers. Yet, epee fencers practice lunge in the same way, that is, without priority rules, during training assaults or during competition. On the contrary, foil fencers practice lunge with priority rules, alike in competition. This differences in the learning situation could induce an implicit and specific learning resulting in two distinct patterns to perform lunge depending on the weapon. The fencing lunge is considered the most basic move for attack. It is characterized by an initial elbow-shoulder extension towards the opponent, followed by the forward displacement of the armed-side leg (Cronin et al., 2003). It requires a specific coordination between the mobilised limbs to achieve both speed and accuracy in a highly-skilled movement (Roi & Bianchedi, 2008).

Although many studies have investigated coordination and control in fencing, particularly muscular coordination (Frère et al., 2011; Pierson, 1956; Williams & Walmsley, 2000) and relationship between the armed arm's motor response and muscle activation time during the lunge in épée fencers (Balkó et al., 2018), comparison between the two thrust weapons remains to be drawn in order to assess the consequences of priority rules on the coordination dynamics. Therefore, our study aims to explore the interlimb coordination in fencing during lunge and to compare possible differences involved by specific rules constraints in this skill, even though it has been practiced in the same way during learning.

Material & methods

This study was carried out in accordance with the Helsinki Declaration and had been approved by the local ethics committee.

Participants

A previous experimentation with twelve fencers (6 foils men and 6 epee fencers) was carried out with the same procedure as the present one. Mean value of CRP between knee and shoulder was used to estimate the sample size needed for the current study. The statistical power to be achieved was 95 % in this pilot study.

Thirty-two fencers participated in the present study (Table 1). Sixteen were epee fencers and sixteen were foil fencers. They had been fencing for over five years. They were specialized in their weapon and were all regularly competing in French national level competitions. Weapon specialization appears early after a common learning stage with foil and depends on the wishes of fencers. Table 1 indicates the duration of specialization. When the choice is done, they do not practice the other weapon during training and competitive events. The trainers are also weapon specialists. So, participants were aware of grouping affiliations.

Participants volunteered to participate in the study.

Procedure

After an individual warming-up, participants performed ten trials in which lunges were studied. Each trial for each participant started in the on-guard position in the movement analysis lab. The participant was asked to perform a "marche-marche-fente" assault (step-step-lunge) which is a combination of basic forward displacements in fencing. The participant came back the initial starting position by two retreat steps, which are also basic backward displacements. Each participant performed ten successive trials.

There were no target and no opponent in front of them.

Data collection

The 3D coordinates of reflective markers placed on body landmarks were recorded at 200 Hz using a ten-camera Vicon system (Oxford Metrics Ltd., Oxford, England). Markers were placed in accordance with Plug-in-Gait Marker Placement on both sides of the lower limbs and on the anterior-superior iliac spines, on upper limbs and atop of the guard of the weapon.

Muscular activity was recorded through a surface EMG system (Bagnoli-8 system; Delsys, Boston, MA) at 1000 Hz. Following an appropriate skin preparation (Hermens et al., 2000), electrodes were placed on the participant's armed side over the bellies of tibialis anterior, soleus, rectus femoris, deltoidus anterior and triceps brachii and on the participant's non-armed side over the bellies of tibialis anterior and soleus in accordance with SENIAM recommendations for sensor locations.

Data processing

Data recording started at take-off of the armed side foot and finished after contact of the armed side foot when the value of armed side hip flexion was maximal. Every lunge was divided in two phases: from take-off to contact of the armed side foot (progression phase) and from contact of the armed side foot to the maximum of hip flexion (stabilisation phase).

The raw 3D coordinates were smoothed with a two-way Butterworth low-pass filter with a cutoff at 6 Hz (Winter, 2009). From the 3D coordinates, the kinematics of the armed side knee, hip and shoulder were calculated following the usual ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion (Marin et al., 1999; Wu et al., 2002; Wu et al., 2005). There were time normalized, so that each gait cycle lasted 100 samples (Kurz & Stergiou, 2002).

The angle formed by the scapular and pelvic girdles in the horizontal plane was computed between the line that connected the two markers of the shoulders and the one that connected the two anterior–superior iliac spines (Dedieu & Zanone, 2012).

The relative phases value between the motion of the scapular and pelvic girdles and between the knee and shoulder joints were assessed by a Continuous Relative Phase (CRP) algorithm, using a Hilbert transform within the range of $-180° \leq \text{CRP} \leq 180°$ (Pikovsky et al., 2001).

This method consists in linearly transforming a time series of real numbers by convolution into a series of complex numbers. It has the advantage of being less sensitive to amplitude and frequency variations. Near 0 °, it indicates an in-phase coordination of these segments, a synchronous movement in the same direction. Close to ± 180 °, it indicates an anti-phase coordination, a movement of the synchronous segments in opposite direction. With a value between 0 ° and ± 180 °, it indicates a time lag between the two considered elements.

A positive value indicates a temporal advance of the distal segment on the proximal segment, and vice versa. This procedure is now mainstream in movement studies assessing synchronization between periodic movements.

The EMG signal was band-pass filtered between 10 and 400 Hz. The linear envelope was obtained by low-pass filtering of the rectified signals at 6 Hz (Winter, 2009). Each linear envelope was normalized in time on 100 samples and in magnitude in reference to the highest peak of each gait cycle. A muscle was considered to be active when the signal magnitude was above two standard deviations computed during relaxed upright standing (Chang et al., 2007). The start and duration of muscular activity were expressed as a percentage of the lunge duration.

Statistical analysis

The independent variables were foil and epee groups. The dependent variables were the duration of the lunge, the normalised distance between shoulder and weapon, the normalised distance between knee and weapon, the mean value of shoulder flexion, the mean value of knee flexion, the mean value of hip flexion, the mean value of CRP between knee and shoulder and the mean value of intergirdle CRP.

Trials were analysed by comparing sample by sample the entire lunge through a one-way ANOVA (foil vs epee).

The temporal similarity of the data about joint angular displacement was measured by a Pearson product-moment correlation (Derrick et al., 1994). Data were analysed sample by sample along the entire lunge through a one-way ANOVA (foil vs epee). The mean values for lunge were averaged and contrasted using a t-test (foil vs epee). Start time and activity duration of every muscle were compared between foil and epee conditions using a t-test (foil vs epee).

For all analyses, the significance level was set at $P < 0.05$.

Results

Individual parameters (Table 1)

The individual data did not show any significant difference between fencers of the foil and epee groups.

Table 1: Individual parameters

	Foil	Epée
N	16	16
Age (year)	22.38 (4.76)	25.32 (9.61)
Weight (kg)	68.57 (8.41)	73.31 (11.44)
Height (cm)	177.74 (5.66)	177.86 (4.23)
Experience in fencing (year)	12.87 (8.54)	13.43 (7.37)

Note: Mean data are presented with standard deviation in parentheses.

Relative phase and evolution of CRP between knee and shoulder (Table 2 and Figure 1)

The mean value of relative phase between knee and shoulder measures their synchronization of armed side during lunge. Our results indicate that foilsmen present a significant lead of the lower limb, as compared to epee fencers whose knee and shoulder progress more synchronously (P = 0.02). Synchronisation between knee and shoulder during the lunge nonetheless indicates significant differences particularly after start of the lunge. Whereas the knee leads the shoulder at the beginning of the lunge for both fencers, two behaviours follow rapidly: The lead of knee increases sharply in the foil group before the foot is in contact with the ground. On the contrary, shoulder leads knee rapidly in the epee group. It clearly appears that knee of foilsmen lead the lunge establishing primacy of lower limb from the beginning of the lunge whereas lower and upper limbs move forward more simultaneously for epee fencers. Foilsmen launch their body forward when epee fencers launch their weapon first. This difference allows foilsmen to delay their hand strategy relative to the reaction of the opponent.

Table 2: Duration of lunge and its different phases, distance between shoulder and weapon and between knee and weapon, kinematic data and coordination data by weapon along the lunge and by phases (significant difference: * *P*<0.05)

	Foil (n=16)	Epée (n=16)
Mean duration of the lunge (s)	0.40 (0.08)	0.45 (0.02)
Progression phase (% of lunge)	85.82 (4.68)	87.09 (3.28)
Stabilisation phase (% of lunge)	14.18 (6.85)	12.91 (2.83)
Mean normalised distance between shoulder and weapon*	2.70 (0.77)	4.05 (0.76)
Progression phase (cm)	2.65 (0.76)	4.01(0.85)
Stabilisation phase (cm)	2.90 (0.80)	4.03 (0.71)
Mean normalised distance between knee and weapon*	1.48 (0.71)	2.54 (0.33)
Progression phase* (cm)	1.51 (0.71)	2.55 (0.39)
Stabilisation phase (cm)	1.67 (0.99)	2.64 (0.25)
Mean value of shoulder flexion (°)	34.29 (30.36)	60.34 (16.57)
Progression phase (°)	31.35 (28.66)	58.83 (17.52)
Stabilisation phase (°)	47.06 (27.52)	64.57 (23.53)
Mean value of knee flexion (°)	93.72 (23.96)	112.29 (23.21)
Progression phase (°)	97.86 (27.21)	115.61 (19.93)
Stabilisation phase (°)	70.87 (21.08)	89.73 (23.64)
Mean value of hip flexion (°) *	48.59 (13.04)	40.91 (14.61)
Progression phase (°)	45.77 (14.81)	38.26 (13.62)
Stabilisation phase (°)	59.857 (8.52)	51.90 (19.58)
Mean value of CRP between knee and shoulder (°) *	90.86 (34.52)	3.13 (35.96)
Progression phase (°) *	89.80 (36.51)	-1.38 (35.04)
Stabilisation phase (°) *	96.87 (19.62)	33.33 (26.92)
Mean value of intergirdle CRP (°) *	-0.05 (1.29)	-0.74 (0.59)
Progression phase (°) *	0.33 (1.15)	-0.82 (0.58)
Stabilisation phase (°) *	-1.57 (0.49)	-0.18 (0.12)

Note: Mean data are presented with standard deviation in parentheses.

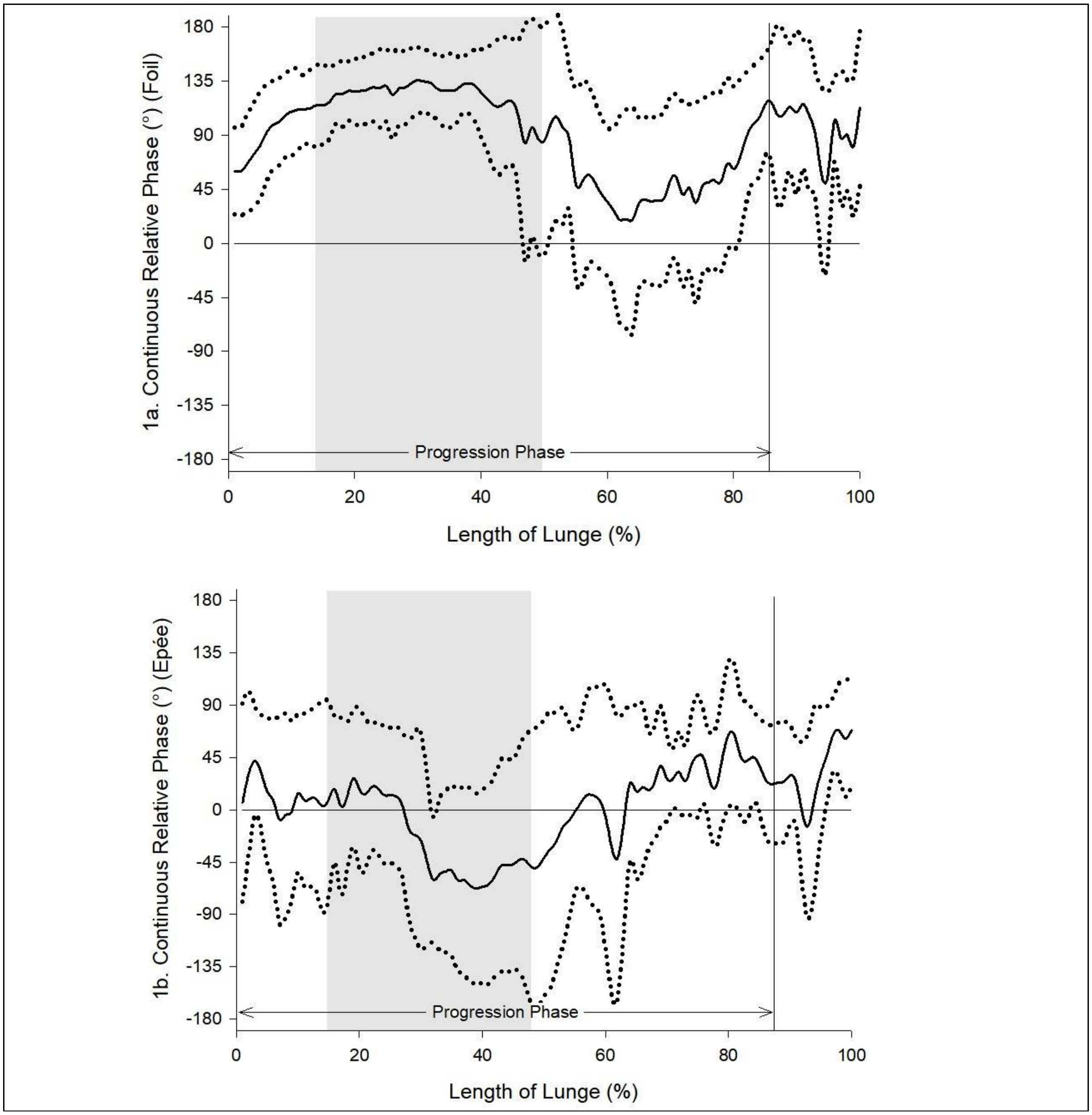

Figure 1: Evolution of Continuous Relative Phase (°) (solid line) and SD (dashed line) between knee and shoulder along the lunge for foil (1a) and epee (1b) (shaded area denotes the portion of the time series that differs significantly between foil and epee)

Intergirdle coordination (Table 2 and Figure 2)

Intergirdle coordination reflects independence of movement of lower and upper body. When the value of relative phase is close to in-phase (0°), the lower and upper body move synchronously in the same direction. When the value is far to in-phase (0°), the lower and upper body move with temporal and/or directional shift.

On average, our results indicate that scapular and pelvic girdle move synchronously for both foilsmen and epee fencers. However, the study of the evolution of intergirdle coordination along the lunge shows significant difference between foilsmen and epee fencers just before contact of the armed side foot. For the first one, pelvic girdle is ahead, confirming the prevalence of the lower limbs.

On the contrary, scapular girdle is ahead for the latter, confirming the lead of the upper armed limb when the fencer is close to his opponent. These results confirm that position of epee fencers is more sideway than that of foilsmen to reduce the surface of body directed to the opponent. Moreover, dissociation between pelvic and scapular girdle is larger for foilsmen than for epee fencers.

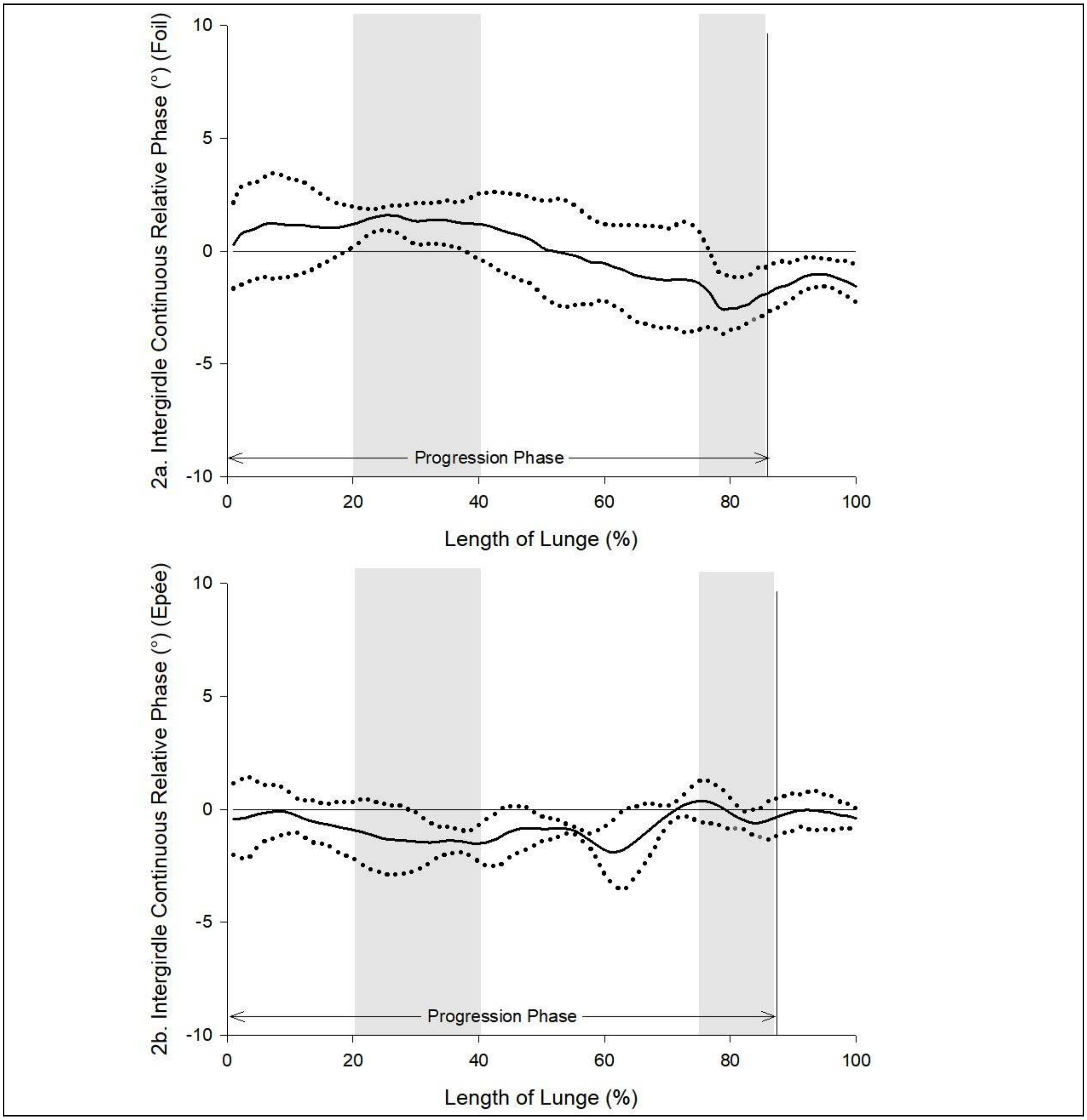

Figure 2: Evolution of Continuous Relative Phase (°) (solid line) and SD (dashed line) between pelvic and scapular girdle along the lunge for foil (2a) and epee (2b) (shaded area denotes the portion of the time series that differs significantly between foil and epee)

The temporal similarity of joints data

The correlation coefficient ρ quantifies the degree of relationship between kinematic data of knee and shoulder of the armed side for each participant and by group. For the entire lunge, the mean value of ρ = - 0.92 (P = 0.03) for foilsmen and ρ = -0.78 (P = 0.03) for epee fencers indicate strong correlation between both knee and shoulder kinematics.

For the progression phase, the mean value of ρ = -0.87 (P = 0.02) for foilsmen and ρ = 0.17 (P = 0.11) for epee fencers indicates a strong correlation between the knee and shoulder kinematics for foilsmen and an absence of correlation between the knee and shoulder kinematics for epee fencers. However, in accordance with Derrick et al. (1994), this low value does not imply a lack of temporal similarity. For the stabilisation phase, the mean value of ρ = -0.91 (P = 0.03) for foilsmen and ρ = - 0.88 (P = 0.04) for epee fencers indicate strong correlation between both knee and shoulder kinematics whatever the weapon.

Kinematics of shoulder, knee and hip (Table 2 and Figure 3)

At the beginning of the lunge, the armed shoulder of foilsmen is more flexed than that of epee fencers. This position allows possibility to extend arm progressively and to delay time when blade thrust becomes close to opponent.

Results do not show differences on kinematics of knee and hip, confirming similarity of initial position of lower limbs despite the weapon.

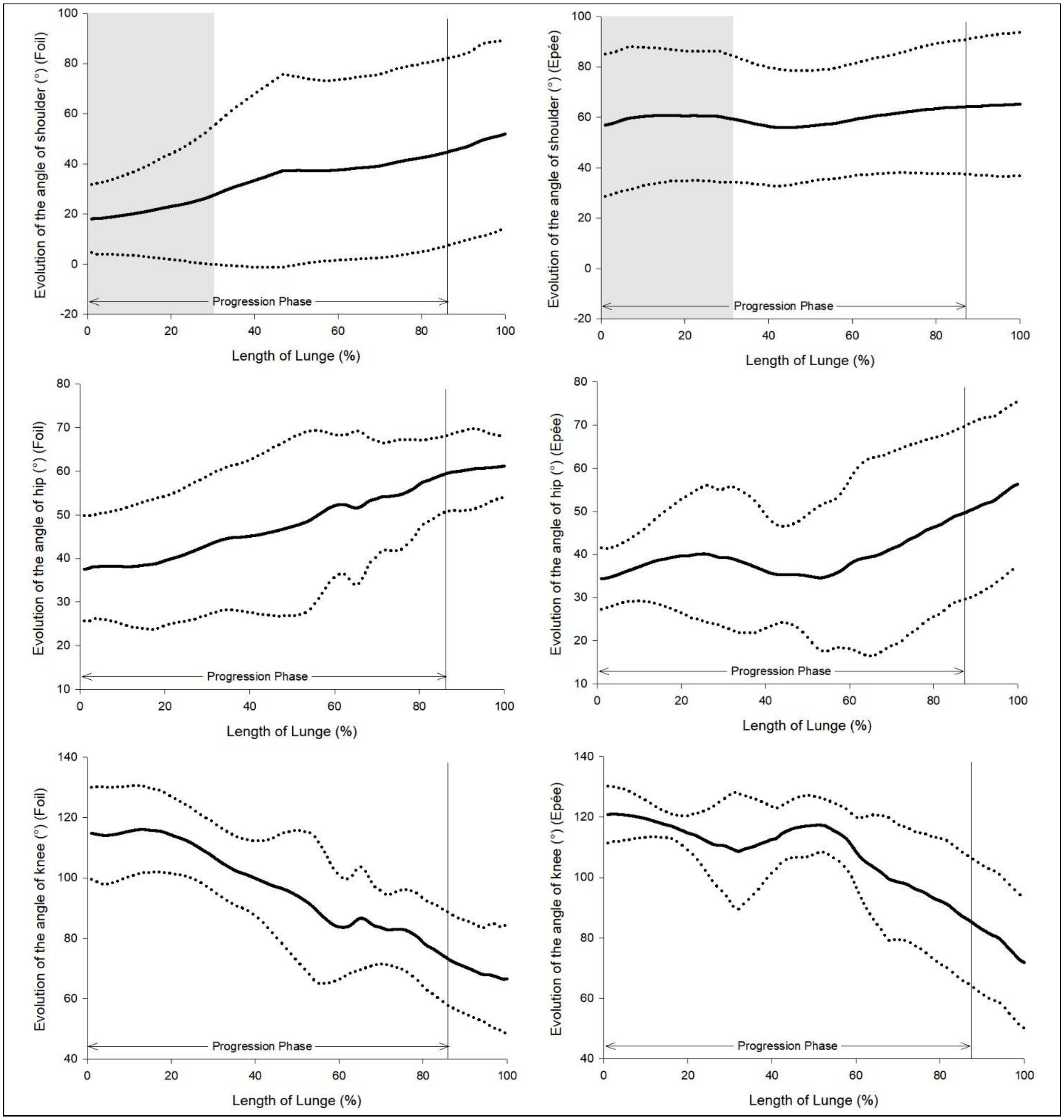

Figure 3: Evolution of the angle (°) (solid line) and SD (dashed line) of shoulder, hip and knee along the lunge for foil (left plots) and epee (right plots) (shaded area denotes the portion of the time series that differs significantly between foil and epee)

Normalised distance between foil/epee and knee and shoulder (Table 2 and Figure 4)

The mean distance between shoulder and weapon is an average indicator of the protective position of weapon relative to the upper body. The farther it is, the more protective it is by its menacing position for opponent. This distance is lower for foilsmen than for epee fencers (P = 0.04). Moreover, the mean distance between knee and weapon is an average indicator of the protective position of weapon relative to lower limbs. This distance is lower for foilsmen than for epee fencers (P = 0.03).

Observed differences do not depend on posture adopted by fencers. The mean values of shoulder flexion, of knee flexion and of hip flexion do not indicate differences between foilsmen and epee fencers. This lack of differences indicates an identical global posture of foilsmen and epee fencers.

Differences are from weapon deducted from the movement in sagittal plane of the marker placed atop of the guard of the weapon. So that, foil, unlike epee, is not directed to the opponent. This first main difference has to be compared with theoretical guard position which indicates that weapon should be directed at opponent.

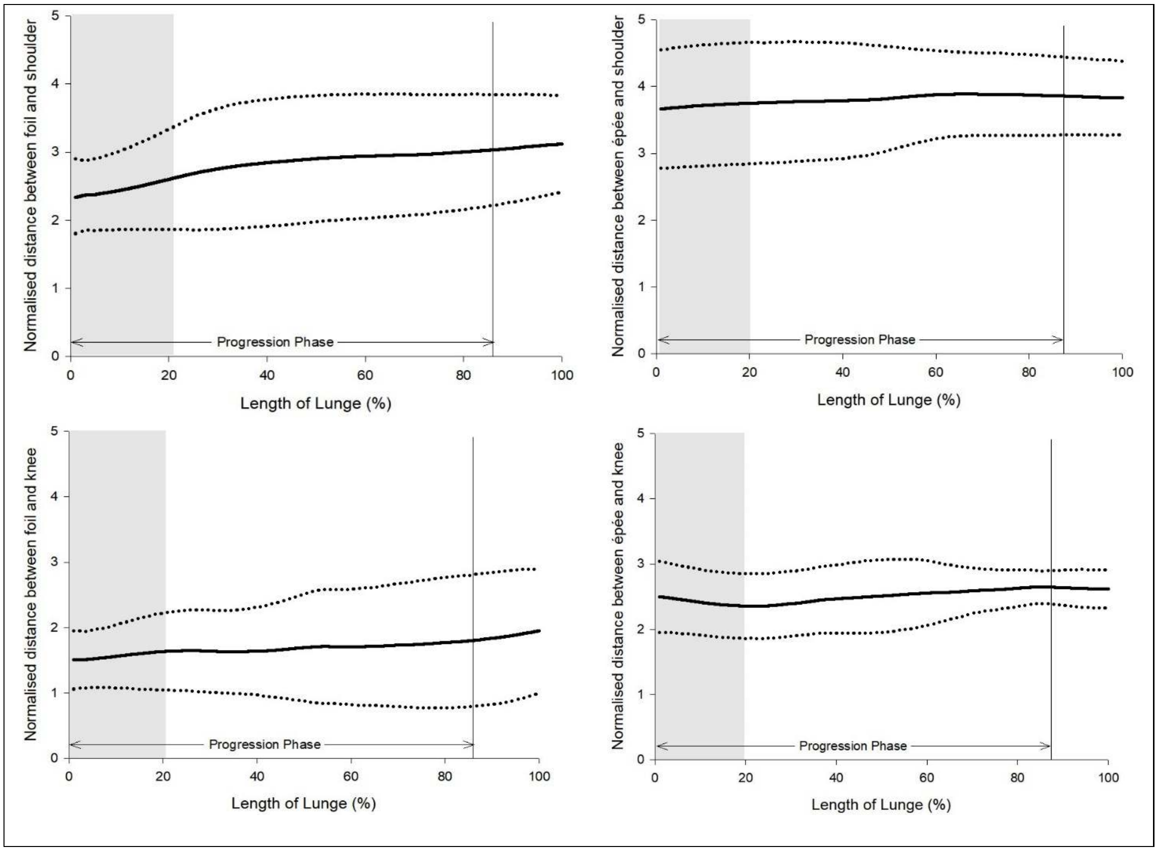

Figure 4: Evolution of the distance between foil/epee and knee and shoulder along the lunge normalised in relation to the height of each participant for foil (left plots) and epee (right plots) (solid line) and SD (dashed line) (shaded area and * denote the portion of the time series that differs significantly between foil and epee)

Muscular pattern (Figure 5)

On the armed side, soleus was active at the start of the lunge and about foot contact for both foil and epee. In this second part, it was activated earlier (P = 0.04) and its duration activity was significantly longer in the epee fencers group (P = 0.04).

Rectus femoris was active at the start of the lunge and around foot contact in both conditions. However, it was activated earlier (P = 0.03) and its duration activity was significantly longer in the epee fencers group (P = 0.04). Deltoidus anterior was active at the start of the lunge and after foot contact in both conditions.

In the first part of the lunge, its duration activity was longer significantly longer in the epee fencers group (P = 0.03). In the second part, it was activated earlier (P = 0.04) and its duration activity was significantly longer in the epee fencers group (P = 0.04).

No differences were observed on start and duration of tibialis anterior and triceps brachii on the participants' armed side and of tibialis anterior and soleus on the participants' non-armed side.

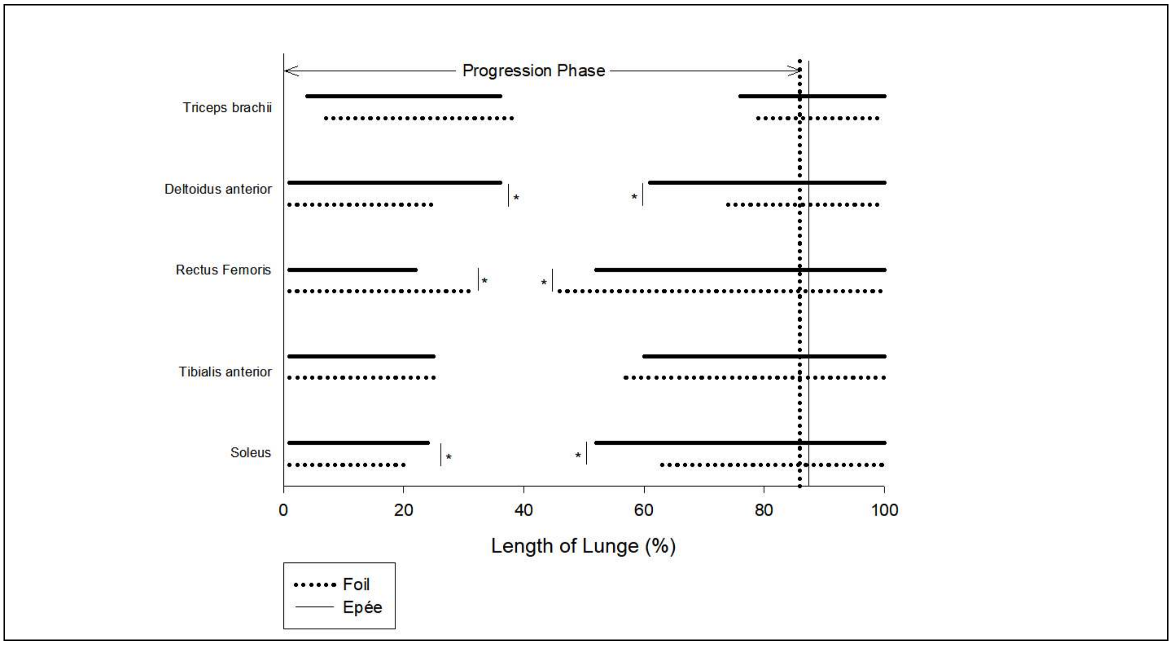

Figure 5: Pattern of muscular activity of *Tibialis Anterior*, *Soleus*, *Rectus Femoris*, *deltoidus anterior* and *Triceps Brachii* of armed side (ArS) and *Tibialis Anterior* and *Soleus* on the non-armed side (NArS) along the lunge (duration significantly different between foil and epee : *)

Discussion

The aim of this study was to explore the interlimb coordination adopted in fencing during lunge in order to determine differences involved by specific rules implicit to each weapon, even if the technique itself is common and actually learnt in the same way.

In fencing, the distance between the opponents is very short as a fencer must come close to his/her opponent to minimize the risk to be hit. Moreover, a crucial problem is to catch the opponent off-guard in order to score. Fencers need thus to cope with specific rules and with the opponent's feint to switch quickly from an intended action to another, more appropriate one (Di Russo et al., 2006). Therefore a proper lunge is quite instrumental in managing longitudinal displacement, a movement skill that requires a fine coordination between the lower and the upper limbs.

Our results reveal significant differences in the knee-shoulder coordination between epee and foil fencers during lunge. For epee fencers in the progression phase, the upper armed limb is ahead of the lunging leg (also on the armed side). This dissociation suggests that fencers use the weapon in a protective goal, independent of the forward movement induced by the lower limbs: The objective to hit opponent or to be protected from the opponent is a priority. On the contrary, the lower and upper limbs of foilsmen move forward with a strong correlation. Movement context and rules constraints could explain the differences observed on coordination of knee and shoulder during lunge. Even though angles of shoulder and elbow are similar for foil and epee fencers, the underlying coordination strategies or muscles recruitment are different, particularly during the progression phase. They suggest that a same skill context can lead to different coordination between the system controlling posture and that controlling movement depending on the weapon used.

The results of the present study also reveal different intergirdle coordination as a function of the weapon. Because fencing is an asymmetrical sport, coordination between the lower and upper body allows forward (or backward) progression while paying attention to avoid the opponent's attack. Such coordination may depend on the coupling brought about by the neuronal circuits controlling their respective muscles (Dietz, 2002). The coordination between girdles also pertains to the specific motion of the arms and the legs, particularly during locomotion (Dedieu & Zanone, 2012).

In fencing, our results indicate that the pelvic and scapular girdles are close to an in-phase coordination: Girdles move synchronously in the same direction. However, differences along the lunge observed between epee and foil fencers are tentatively due to the rule of attack priority, inducing a protective state. The postural requirements of the fencing movements need a coupling of the lower limb muscles and the initiation of the movement of the weapon arm (Williams & Walmsley, 2000). In order to be protected from an opponent's attack, epee fencers must maintain the pelvic in-phase with the scapular girdle. Thus, they adopt a half-turned position to limit the body surface exposed to the opponent's hit and to increase the possibility to be closer to opponent by stretching the armed-side upper limb. In contrast, foilsmen, as they are protected by the priority rule, can adopt a more usual position, with the pelvic girdle slightly turned toward the opponent. Such a position allows an easy forward-leaning of the fencer's body while the hand is pointing at the target. Thus, foilsmen can come closer to the opponent and delay their attack according to the opponent's reaction. Thus, differences observed in the intergirdle coordination as a function of the weapon adopted follow from the specific rules implied by each speciality.

Interestingly, these specificities are never learned explicitly (Barth & Beck, 2007) and tend emerge from practice

Touya and Leclerc (2007) stated that an exclusive learning of technical fencing skills may give the illusion that the fencer masters the activity. They suggested that a skill, learned in an isolated way, outside the competition context, is meaningless. Viewed from the perspective of coordination dynamics (Kostrubiec, Zanone, Fuchs, & Kelso, 2012), practice involves the transition from an initial to a new coordination pattern. Applied here, learning is about the passage from a skill learned outside any competitive context to a new coordination pattern performed in a competitive context, thereby confronting the fencer with priority rules. Frère et al. (2011) claimed that the kinematics of the upper limb in fencing implies a relationship between kinematic strategies, muscular activations and fencing performance. Moreover, fencing performance is also dependent on the competitive context, including rules constraints and metabolic demands (Dedieu, 2015). Thus, the skill should be considered as it is performed in its context moreso than an isolated performance.

Beyond the difference between foil and epee fencers, the observed shift in relative phase between knee and shoulder is a sign of the participants' expertise and their skill specialization. According to Baldissera et al. (Baldissera et al., 1991), coordination between limbs of the same side is preferentially in-phase. In our study, the persistent time shifts between the limbs observed along the lunge reflects the mastering the skill. Particularly, the opposite direction of the shift as a function of the weapon indicates an integration of the specific rules into the activity, particularly priority rules. The shoulder of epee fencers is ahead of the knee, in a protective attitude, whereas the knee of foilsmen is ahead, in a forward attitude that is made possible by virtue of the priority rule. In terms of learning, this result corroborates the fact that with practice, a freeing of degrees of freedom occurs, so that the more body segments tend to function as a multisegmental unit, a so-called synergy (Bernstein, 1937/1967).

These findings are in line with a recent study by Chan et al. (2011) indicating that expertise in fencing fosters limb independence. It also expresses the capability to control action which could be spontaneously done, facilitating the fencer's ability to delay an ongoing action while progressing forward. In our findings, the observed lead of one limb relative of the other tends to break a tendency for the limbs to progress simultaneously. It reinforces a displacement adapted to the specific rules implied by each speciality. Although the rule mentioning that attack is made by extending the arm and continuously threatening the opponent is the same for foil and epee fencers, the results of the present study reveal differences in the temporal pattern of muscular activation. Two strategies are identified. Duration of activation of deltoidus anterior and triceps brachii is longer for epee fencers than for foilsmen. This indicates a more extended position of the epee fencer's upper limb. On the other hand, the duration of the activation of rectus femoris along the progression phase is longer for foilsmen than for epee fencers.

This attests to a larger knee extension, typical of a forward strategy. A recent study analysing EMG patterns of the lower limb muscles of the rear and front leg shows a forward strategy of the lower limbs in sabre fencers (Guilhem et al., 2014). As priority rules exist for both foil and sabre, this finding indicates that priority rules which avoid the risk to be hit favours the same forward strategy in lunge.

Following Do and You (1999) who examined the link between the maximal speed of the foil and anticipatory postural adjustments, this forward projection of the body intends to reduce risk of opponent parry and, consequently, a loss of priority. On the contrary, the activation of rectus femoris before lunge foot contact for epee fencers indicates a process of preparation for the future foot contact. This anticipating behaviour is in accordance with Williams and Walmsley (2000) who describe a continuous preparation of muscular activity for the arrival phase. Moreover, this behaviour represents an anticipatory strategy in the event of a retreat if the hit is not successful. Whereas a foilsman gets a non-valid hit and, therefore, the fencing sequence is stopped, an epee fencer faces the possibility of a riposte, hence, a risk of being hit.

Conclusion

A new motor skill, namely lasting behavior change, are emerging with repetitions (see for example, Reuchlin, 2000). While lunge is learned in the same way for foil and epee fencers, the rule constraints entail a profoundly different behaviour in terms of intersegmental and intergirdle coordination. Fencers who participated in our study have long integrated the proper constraints of foil and epee practice in a competitive context.

Our results thus question the custom of learning in an isolated, non-competitive environment. It can be assumed that an early specialisation of beginners would address the proper logic of foil and epee practice in better conditions. Finally, the emergence of a specific motor skill for foil and epee performance, captured by a specific underlying neuromuscular organisation, reflects a successful adaptation of foil and epee fencers to the constraints inherent to their competitive practice in such a common skill as lunge.

Conflicts of interest Every author does not have commercial relationships which may lead to a conflict of interests.

In memoriam Bertrand Dedieu (1997-2020)

References:

Baldissera, F., Cavallari, P., Marini, G., & Tassone, G. (1991). Differential control of in-phase and anti-phase coupling of rhythmic movements of ipsilateral hand and foot. *Experimental Brain Research*, *83*(2), 375-380. https://doi.org/10.1007/BF00231161

Balkó, Š., Heidler, J., & Jelínek, M. (2018). Relationship between the armed arm's motor response and muscle activation time during the lunge in fencers of varied ability. *Journal of Human Sport and Exercise*, *13*(1), 50-59. https://doi.org/10.14198/jhse.2018.131.06

Barth, B., & Beck, E. (2007). *The complete guide to fencing*. Meyer & Meyer Sport Ltd.

Bernstein, N. S. (1937/1967). *The co-ordination and regulation of movements*. Pergamon Press.

Chan, J. S. Y., Wong, A. C. N., Liu, Y., Yu, J., & Yan, J. H. (2011). Fencing expertise and physical fitness enhance action inhibition. *Psychology of Sport and Exercise*, *12* 509-514. https://doi.org/10.1016/j.psychsport.2011.04.006

Chang, W. N., Lipton, J. S., Tsirikos, A. I., & Miller, F. (2007). Kinesiological surface electromyography in normal children: range of normal activity and pattern analysis. *Journal of Electromyography and Kinesiology*, *17*, 437-445. https://doi.org/10.1016/j.jelekin.2006.02.003

Cignetti, F., Schena, F., Zanone, P. G., & Rouard, A. (2009). Dynamics of coordination in cross-country skiing. *Human Movement Science*, *28*(2), 204-217. https://doi.org/10.1016/j.humov.2008.11.002

Cronin, J., McNair, P. J., & Marshall, R. N. (2003). Lunge performance and his determinants. *Journal of Sports Sciences*, *21*, 49-57. https://doi.org/10.1080/0264041031000070958

Dedieu, P., & Zanone, P.-G. (2012). Effects of gait pattern and arm swing on intergirdle coordination. *Human Movement Science*, *31*, 660-671. https://doi.org/10.1016/j.humov.2011.07.009

Dedieu, P., & Zanone, P.-G. (2013). Effects of expertise on inter-joint coordination while running (Fr). *Movement & Sport Sciences – Science & Motricité*, *83*, 11-23. https://doi.org/10.1051/sm/2013044

Dedieu, P., Pelaez, M., Poirier, E., & Zanone, P.-G. (2020). Effects of saddle height on muscular pattern and interlimb coordination in cycling. *Journal of Physical Education and Sport*, *20*(1), 222-228. https://doi.org/10.7752/jpes.2020.01029

Derrick, T. R., Bates, B. T., & Dufek, J. S. (1994). Evaluation of time-series data sets using the Pearson product-moment correlation coefficient. *Medicine and Science in Sports and Exercise*, *26*(7), 919-928.

Di Russo, F., Taddei, F., Aprile, T., & Spinelli, D. (2006). Neural correlates of fast stimulus discrimination and response selection in top-level fencers. *Neuroscience Letters*, *408*, 113-118. https://doi.org/10.1016/j.neulet.2006.08.085

Dietz, V. (2002). Do human bipeds use quadrupedal coordinaation ? *Trends in Neurosciences*, *25*(9), 462-467. https://doi.org/10.1016/S0166-2236(02)02229-4

Do, M. C., & You, E. (1999). Do centrally programmed anticipatory postural adjustments in fast stepping affect performance of an associated "touche" movement? *Experimental Brain Research*, *129*(3), 462-466. https://doi.org/10.1007/s002210050914

Fédération Internationale d'Escrime. (2013). Règlement technique.

Frère, J., Göpfert, B., Nüesch, C., Huber, C., Fischer, M., Wirz, D., & Friederich, N. F. (2011). Kinematical and EMG-Classifications of a Fencing Attack. *International Journal of Sports Medicine*, *32*, 28 - 34. https://doi.org/10.1055/s-0030-1267199

Guilhem, G., Giroux, C., Couturier, A., Chollet, D., & Rabita, G. (2014). Mechanical and Muscular Coordination Patterns during a High-Level Fencing Assault. *Medicine and Science in Sports Exercise*, *46*(2), 341-350. https://doi.org/10.1249/MSS.0b013e3182a6401b

Haken, H., Kelso, J. A. S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics* *51*(5), 347-356. https://doi.org/10.1007/BF00336922

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*(5), 361-374. https://doi.org/10.1016/S1050-6411(00)00027-4

Herzog, W. (2000). Muscle properties and coordination during voluntary movement. *Journal of Sports Sciences*, *18*, 141-152. https://doi.org/10.1080/026404100365045

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Physiology: Regulatory, Integrative, and Comparative Physiology*, *15*, R1000-R1004. https://doi.org/10.1152/ajpregu.1984.246.6.R1000

Kurz, M. J., & Stergiou, N. (2002). Effect of normalization and phase angle calculations on continuous relative phase. *Journal of Biomechanics*, *35*(3), 369-374.

Marin, F., Allain, J., Diop, A., Maurel, N., Simondi, M., & Lavaste, F. (1999). On the estimation of knee joint kinematics. *Human Movement Science*, *18*(5), 613-626. https://doi.org/10.1016/S0167-9457(99)00024-X

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. M. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences*, *20*(10), 771 - 781. https://doi.org/10.1080/026404102320675620

Meyer, V., Rosnet, E., Guérin, V., Hornus-Dragne, D., Dedieu, P., & Poussel, M. (2017). L'escrime : « en garde ! Êtes-vous prêts ? Allez ! ». *Science & sports*, *32*, 169-178. https://doi.org/10.1016/j.scispo.2017.04.001

Palut, Y., & Zanone, P.-G. (2005). A dynamical analysis of tennis: Concepts and data. *Journal of Sports Sciences*, *23*(10), 1021-1032. https://doi.org/10.1080/02640410400021682

Pierson, E. R. (1956). Comparison of fencers and non-fencers by psychomotor, space perception and anthropometric measures. *Research Quarterly*, *27*, 90-96.

Pikovsky, A., Rosenblum, M., & Kurths, J. (2001). *Synchronization: a universal concept in nonlinear sciences*. Cambridge University Press.

Reuchlin, M. (2000). *Psychologie* (15th ed.). Presses Universitaires de France.

Roi, G. S., & Bianchedi, D. (2008). The Science of Fencing. Implications for Performance and Injury Prevention. *Sports Medicine*, *38*(6), 465-481. https://doi.org/10.2165/00007256-200838060-00003

Schmidt, R. A., & Wrisberg, C. A. (2004). *Motor learning and performance* (3rd ed.). Human Kinetics.

Schöner, G., & Kelso, J. A. S. (1988). Dynamic pattern generation in behavioral and neural systems. *Science*, *239*(4847), 1513-1520. https://doi.org/10.1126/science.3281253

Temprado, J.-J., Della-Grasta, M., Farrell, M., & Laurent, M. (1997). A novice-expert comparison of (intra-limb) coordination subserving the volleyball serve. *Human Movement Science*, *16*(5), 653-676. https://doi.org/10.1016/S0167-9457(97)00014-6

Turvey, M. T. (1990). Coordination. *American Psychologist*, *45*(8), 938-953. https://doi.org/10.1037/0003-066X.45.8.938

Williams, L. R. T., & Walmsley, A. (2000). Response timing and muscular coordination in fencing: A comparison of elite and novice fencers. *Journal of Science and Medicine in Sport*, *3*(4), 460-475. https://doi.org/10.1016/S1440-2440(00)80011-0

Winter, D. A. (2009). *Biomechanics and Motor Control of Human Movement* (4th ed.). John Wiley & Sons.

Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D D'Lima, D., Cristofolini, L., & Witte, H. (2002). ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics*, *35*(4), 543-548. https://doi.org/10.1016/S0021-9290(01)00222-6

Wu, G., Van der Helm, F. C., Veeger, H. D., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., & Wang, X. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981-992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Zanone, P. G., & Kelso, J. A. S. (1997). Coordination Dynamics of Learning and Transfer: Collective and Component Levels. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(5), 1454-1480. https://doi.org/10.1037/0096-1523.23.5.1454