doi:10.20944/preprints202009.0665.v1

Anthropometric and Kinematics determinants of lunge velocity and amplitude in young foil fencers.

Lunge kinematics in young fencers.

Antonio Cicchella PhD, and Alessio Mocco M.Sc.

University of Bologna, Department for Quality of Life Studies, Bologna , Italy.

Abstract.

The teaching of the lunge technique in fencing is critical in the developmental age. The relations of anthropometrics with kinematics of lunge was studied only in adult fencers, and no study exist in young considering the different level of experience. Our aims were to assess, in young fencers, which factors, between the anthropometric and the kinematics, were mostly connected with lunge performance (speed and excursion) in different genders and expertise levels. Fifteen young fencers participated in this study. Lunge kinematics, anthropometric characteristics and force expressed in vertical jump tests were collected. Maximal lunge velocity resulted mainly correlated with the posterior knee's extension ((r=0.56, p=0.031). The lunge distance and mean hip velocity were mostly correlated with fencers' height (r=0.85, p=0.000 and r=0.76, p=0.001) and FFM (r=0.8, p=0.000 and r=0.73, p=0.002). Experts and non-experts show significant differences in fat free mass, area of upper arm, and of thighs (Effect Size = 1,27 – 1,33, p= 0,021-0,035). From our results it emerges that, in this age range, the analysed aspects of lunge performance are mainly correlated with participant's anthropometry. Moreover, it is already possible in this age span, to find technical differences linked to the experience.

Keywords: fencing kinematics, lunge velocity, technique development.

Introduction

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

In literature only a few studies investigated the biomechanics of fencing, that remains poorly investigated in sport biomechanics (see Chen et. al 2017 for a review). There is also paucity of data about fencer's anthropometry and its correlation with the performance in the developmental age. Further, genders differences in the mechanics of the lunge in young fencers are poorly addressed. They have less developed motor skills and may not employ the same motor patterning as their older counterparts. In addition, there is discrepancy in the technique suggested by teaching manuals and actual pattern of movements observed in biomechanical studies. Hassan e Klauck (1998) studied 4 fencers (16-17 years old, having 5-9 years of fencing experience) using a 16 markers model of the body to describe the velocity patterns of upper and lower limbs. They measured peak and mean horizontal and vertical velocity of the weapon (foil) and of the hip during the lunge and at the *touche and* movement's timing. They identified two different temporal patterns of movement: upper limb drive, which started the movement, as suggested in the fencing manuals (Arpino & Gulinelli 2012; Gaugler 1997), and lower limb drive, with the lower limb moving first. These different behaviors were observed later also by other authors (Gholipour et al. 2008), who differentiated between experienced fencers (EF), who are lower limb drivers of the armed side, and non-expert fencers (NE), who use a upper limb drive of armed limb. Gholipour et al. (Gholipour et al. 2008) considered two groups, one of 4 novices (age 21.5±1.3 years; high 179.3±1.1 cm; weight 70.3±6.8 kg) and the other of 4 expert fencers (age 24.0±2.5 years, height 181.5±4.8 cm; weight 74.0±4.5 kg). They showed that experienced fencers performed a longer lunge and tilted the trunk more forward at the end of this movement. This behavior allowed an anterior shift of the CG, that permitted a better push coming from the rear leg. They also observed a lower horizontal velocity in the EF (0.68 m/s vs. 0,76 m/s). The tendency of EF to start the attack with the lower limb was observed also in another study (Frère J. et al., 2011) on the flèche, a different offensive technique. This strategy was ascribed to the skills of EF to mask their attack, finishing the lunge with the upper limb later than NE.

In the first third of the movement NE showed a greater angular excursion of the anterior leg's knee (Gholipour et al. 2008). After this first flexion, the EF extended more the forward knee. In the last third of the lunge, EF showed a more flexed hip and knee of the armed side, having a lower body position. They hypothesized this was caused by greater strength and flexibility.

Another aspect investigated in literature is the proximal-to-distal activation of legs muscles.

A case study (Morris N. et al., 2011) showed that the power necessary to perform the lunge was produced mainly by the rear leg with the activation of the joints happening simultaneously for the ankle and knee joints, excluding a pattern of proximal to distal activation. In this study, most of the power produced by the rear leg derived by the ankle joint's plantar flexion, followed by the knee extension of the same leg. Mulloy (Mulloy F. et al., 2015) studied 6 sword NE male fencers (age 22 ± 10 years; height 178 ± 8 cm, weight 74.6 ± 16.2 kg) were compared with 4 EF (age 24 ± 14, height 181 ± 5 cm, weight 72.0 ± 15.3 kg). They found that the EF employed a sequential kinetic chain from the armed elbow joint's extension to the plantar flexion of the rear leg's ankle joint. Mulloy et al. (2015) found a greater lunge distance covered by the experts, but in contrast with Gholipour et al. study (2008), they found a higher mean speed of movement. Velocities of the armed elbow and rear hip were not different between EF and NE even if EF showed a higher peak angular velocity of the rear ankle's extension. These findings agree with another study (Bottoms et al. 2013) which showed that the peak velocity of the sword is largely determined by the rear lower limb in a group of 14 sword right handed fencers (9 males, 5 females; age 26,2 ± 1,3 years; height 175,7 ± 6,2 cm; weight 75,6 ± 8,2 kg).

 doi:10.20944/preprints202009.0665.v1

From multiple regression it emerged that the main predictors of the sword speed were the lower rear knee ROM and the hips' peak flexion. In this study the upper limb was not considered. Guan et al. (2018) showed that the EF achieved a significant higher horizontal peak velocity of the CG in the lunge. The EF in comparison to the NE showed a greater rear knee and hip ROM and a significant lower peak horizontal velocity of the anterior knee. Both groups flexed the anterior knee before the extension, thus loading the joint. The time to extend the anterior knee was higher in the EF. The same authors found that the peak horizontal velocity in the lunge was significantly correlated with the rear knee's extension ROM.

Gender differences were addressed in a study (Sinclair J. et al., 2013), which observed that females presented a greater knee adduction/abduction angle, a greater hip adduction and a greater ankle eversion angle in the anterior leg at the end of the lunge, according to female anthropometry.

Anthropometric differences in fencers have been observed between male and female only during and after puberty (Tsolakis et al. 2006), observing that the major predictors of the lunge velocity were the drop jump and the cross-sectional area of the dominant leg. The normalized data for body weight showed that the CMJ was the only predictor of lunge velocity.

Our aims were to identify which factor, between the anthropometric and the technical ones, was mostly connected with performance parameters; to identify if there were differences linked to gender or experience level in this technical gesture and to compare our sample and the adult fencers examined in scientific literature, in order to identify critical technical parameters. Another hypothesis we investigated, is that technical differences linked to experience and differences in body composition associated to growth could be already found at this age. In addition, we hypothesized that athletes in

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

this age range still do not have acquired a proper technique, so the analysed performance factors could be mainly linked to the anthropometric ones.

Methods

Fifteen right-handed foil fencers (8 females and 7 males; age 12.9 ±2.7 years, height 157.4 ±15.1 cm, weight 49.7 ±11.7 kg) with different level of experience were tested. Cutoff between the Experts (ES) and Non-Experts (NE) was 5 years of practice. We received from each participant parents a written informed consent form. This research was approved by the Ethics Committee of the University of Bologna.

The subjects were instructed to perform the lunge at the maximal speed possible. Anthropometry was collected following the ISAK manual recommendations (Marfell-Jones et al. 2012). Height was measured with a Seca wall mounted stadiometer and weight with an electronic scale (Tanita BC-418 MA, Tanita Corporation, Tokyo, Japan). The followings lengths were measured with a Harpenden anthropometer: hand, forearm and upper arm of the dominant upper limb; thigh, tibia and lateral tibial height of both legs and bi-epicondylar width. These measures were combined to obtain the following lengths: upper limb, lower limb and trunk. Circumferences of upper arm and upper third of the thigh were taken with an anthropometric tape. The biceps, triceps and thighs skinfolds were assessed with an Harpenden caliber. Absolute and % fat mass (FM) and fat free mass (FFM) were assessed by bioelectrical impedance (Maltron BF906, Rayleigh, GB) as well as the body mass index. Cross sectional area (CSA) of dominant upper arm and of thighs were calculated respectively with Martine et al. (1997) and Knapik et al. (1996) formulas. For kinematics measurements, a ten-camera system was employed (BTS SMART DX 7000, BTS Bioengineering, Milan, Italy) with a sampling frequency of 250

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

Hz. We employed a modified Plug-in Gait (McGinley et al. 2009; Vicon, Oxford Metrics, UK, 2016) model composed of 35 markers (Fig. 1).

Fig. 1. Biomechanical model. The model is a modified Plug-In-Gait models.

Virtual markers (midpoint between the ASIS, midpoint of ankle, knee, elbow and wrist, midpoint between the 1st and the 5th metatarsophalangeal joints) were computed post acquisition. A customized model was built because currently no validated model for fencing exist. Markers labeling, linking and tracking were performed with SMART Tracker software (BTS Bioengineering, Milan, Italy). Volume reference points were set accordingly to ISB norms (Wu et al. 2002). 3D points were filtered with a Butterworth low pass filter of 4th order set at 20Hz. The followings angles and ROM were measured (Fig. 2) using the software SMART Analyzer (BTS Bioengineering, Milan, Italy): "on guard" position: elbow, anterior and posterior knees and ankles. Final lunge position: elbow, knees and ankles. For the elbow, the maximum extension angle was obtained.

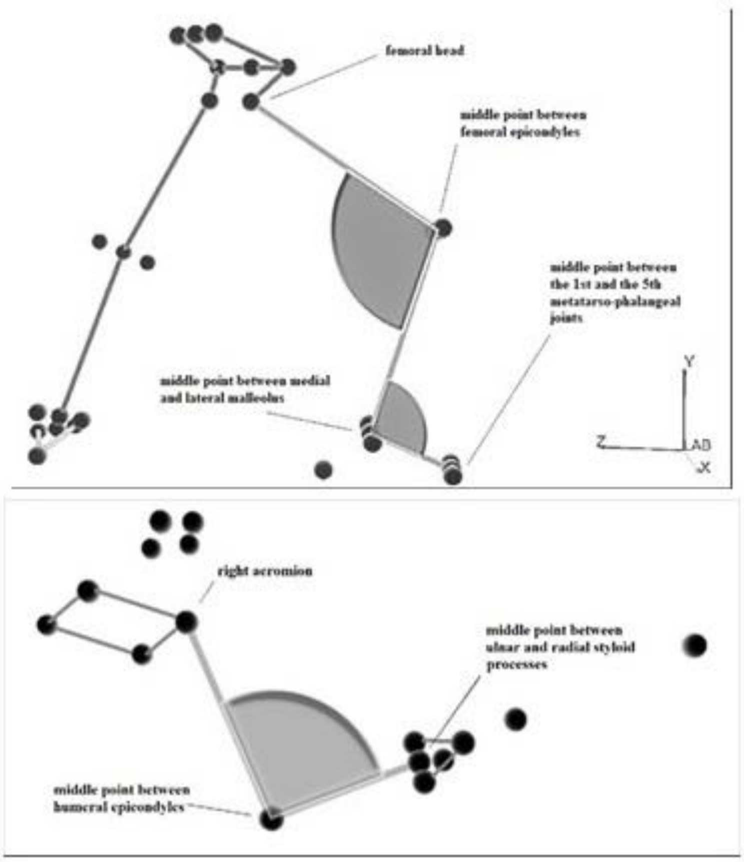

Fig. 2. Angles and ranges of motions.

During the lunge, the anterior knee performs three different movements: a first flexion, followed by an extension, and a second flexion that brings the lunge to a conclusion (Fig. 3).

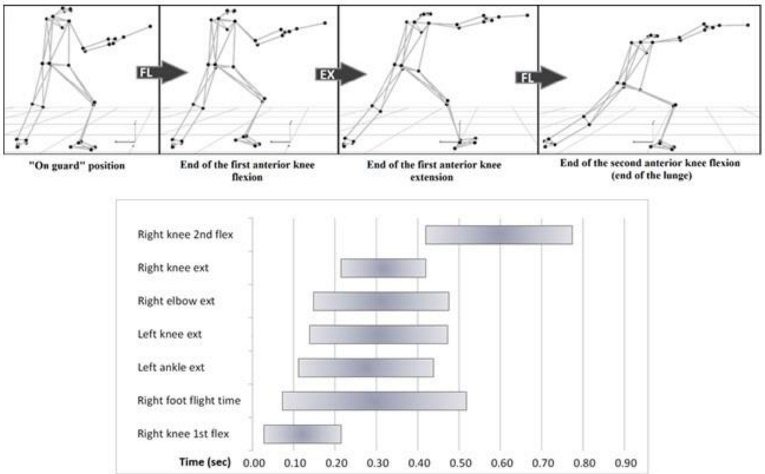

Fig. 3. Phases of the anterior knee during lunge and time chart of the lunge (mean values on 15 subjects). (FL = flexion; EX = extension). The arrows indicate the movement performed by the anterior knee between frames.

We calculated the extension ROM of the armed elbow, the rear ankle and knee, and the ROM of the three phases of the anterior knee. For each ROM it was also calculated the respective mean angular velocity.

Start, end and duration of each event were computed. The lunge distance was defined as the horizontal difference between the posterior heel in the guard position and the anterior heel in the final lunge position. Mean and peak horizontal velocities of ASISm (the middle point between the two ASIS) and of the 3rd metacarpal head marker (3mtc) were also computed.

 doi:10.20944/preprints202009.0665.v1

Data normality was assessed with Kolomogorov-Smirnov test. All data appeared to be normally distributed. Then descriptive statistics, bivariate correlation, t-test and simple regression were performed (IBM SPSS v.25.0. Armonk, New York). Significance level was set at $P \leq 0.05$. Cutoff to discriminate between expert and non-expert fencers was set at 5 years of practice. Effect size was calculated using Cohen's d, which resulted >0.8 for each variable that presented a difference between groups (Cohen, 1988).

Results

Anthropometric measures are reported in Tab. 1. Height, body weight and BMI were very near to the 50th percentiles of Italian population (Cacciari et al. 2006).

	M	±SD
BMI	19.9	2.4
FM (Kg)	9.8	3.6
FM %	20	7.2
FFM (kg)	39.9	10.9
FFM %	80	7.2
Lenghts (cm)		
Upper limb	67.5	7.4
Lower limb	79.2	8.1
Trunk	78.2	7.5
R thigh	38.4	4
L thigh	38.4	3.9
R biep	8.3	0.6
L biep	8.3	0.6
Circumferences (cm)		
Cr upper arm	23.2	2.8
Cr R thigh	51	5.3
Cr L thigh	50	5.2
Sk bicep	0.9	0.4
Sk tricep	1.4	0.5
Sk R thigh	2.1	0.8
Sk L thigh	2.1	0.8
CSA upper arm	27	7.3
CSA R thigh (cm^2)	126.4	28.2
CSA L thigh (cm^2)	120.7	25.1

Tab 1. BMI, Fat Mass and Fat Free Mass, Circumference, Cross-Sectional Area (R= right; L= left).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

All subjects were right-handed, so they stayed in guard position taking forward their right side. Any significant differences were found between left and right side in body segments length and CSA contrary to adults were a greater CSA of the dominant leg was found (Tsolakis et al. 2006). Fig. 3 reports the timing of the different actions composing the lunge. Kinematics data are shown in Tab. 2.

Velocities (m/sec)	M	±SD
V_m $ASIS_m$	0.86	0.13
V_m 3mtc	1.28	0.18
V_{max} $ASIS_m$	1.66	0.25
V_{max} 3mtc	2.45	0.34
Lunge distance (m)	1.12	0.2
Lunge duration (sec)	0.77	0.11
Angles (deg)		
On Guard		
Elbow	96	16
R knee	120	10
L knee	121	10
R ankle	98	6
L ankle	83	5
During lunge		
Elbow maximal ext	151	5
End of R knee 1st flex	103	11
Endo of R knee ext	151	5
Final lunge position		
Elbow	150	5
R knee (end of 2nd flex)	90	9
L knee	170	4
R ankle	103	6
L ankle	116	5
Rom (deg)		
Elbow ext	55	17
R knee 1st flex	17	7
R knee ext	47	11
R knee 2nd flex	59	8
L knee ext	48	11
L ankle plantar flex	32	6
Angular Velocities (deg/sec)		
Elbow ext	180.4	56.3
R knee 1st flex	87.8	20.4
R knee ext	242.1	61.3
R knee 2nd flex	179.5	26.8
L knee ext	160.9	46.9
L ankle plantar flex	108.6	26.6

Tab 2. Velocities, distance, duration. Vm= mean; Vmax= peak velocity; ASISm= anterior superior iliac spine midpoint; 3 mtct= 3rd metacarpal head. Angles, ROM and angular velocities (R= right; L= left; ext= extension; flex= flexion).

Linear regression results are reported in Tab. 3 with FFM (kg) as independent variable.

	B	SE	β	p
V_m $ASIS_m$	0.516	0.091		0.000
	0.009	0.002	0.733	0.002
Lunge distance	0.531	0.129		0.001
	0.015	0.003	0.797	0.000

Tab. 3. Linear Regression for FFM (kg) as independent variable.

Anthropometric differences found between males and females are reported in Tab. 4,

	M (N=7)		F (N=8)			
	M	±DS	M	±DS	Effect size	p
FM %	15.14	6.28	24.24	5.18	1.58	0.011
FFM %	84.86	6.28	75.76	5.18	1.58	0.011
R thigh skinfold (cm)	1.54	0.64	2.66	0.4	2.1	0.003
L thigh skinfold (cm)	1.53	0.64	2.66	0.38	2.17	0.002

Tab 4. Anthropometric differences between male and female. R= right; L= left.

while differences between expert fencers (EF) and non-expert ones (NE) are in Tab. 5.

	NE (N=8)		EF (N=7)			
	M	±DS	M	±DS	Effect size	p
Age (years)	11.5	2.4	14.4	2.2	1.27	0.029
FFM (kg)	34.05	8.5	46.6	9.7	1.38	0.021
CSA upper arm (cm^2)	23.1	5.5	31.3	6.8	1.33	0.026
CSA R thigh	112.3	23.2	142.5	25.7	1.23	0.035
CSA L thight	107.6	19.9	135.8	22.6	1.33	0.025
Angles and Rom (deg)						
R knee guard ANG	126	9	111	5	1.98	0.002
L knee guard ANG	126	10	115	6	1.37	0.02
R knee 1st flex ANG	109	12	96	5	1.49	0.015
R knee ext ROM	41	12	55	3	1.69	0.01
R knee 2nd flex ROM	55	8	64	5	1.23	0.032
L knee ext ROM	42	12	54	6	1.26	0.031

 doi:10.20944/preprints202009.0665.v1

Tab. 5. Differences between experts (EF) and non-expert (NE) fencers. Cut of was set at 5 years of practice. R= right; L= left; flex= flexion; ext= extension.

Peak hand velocity (Vmax 3mtc) was observed during the elbow extension and showed an increase of 1,17 m/sec above the mean hand velocity (Vm 3mtc) in the whole lunge. The anterior superior iliac spine midpoint (ASISm), which can be assumed as the body center of gravity (CG), showed a peak of 0,80 m/sec above the mean velocity of the whole lunge.

In the "on guard" position knees were semi-flexed, and lower leg were nearly perpendicular to the ground. The elbow reached its maximal extension before the final lunge position: between these two events, its angle stayed almost unchanged. In the final lunge position the left (rear) knee was almost totally extended, while the anterior knee was flexed. The higher angular velocity was observed during the right knee extension, which is the movement that brings the anterior foot forward after its take-off.

Discussion and Implications.

We hypothesized that young fencers would have showed a different technique compared to the one reported in manuals, namely that they would have started the lunge with the lower limbs' movement. Our findings disagree with the action's sequence recommended in technical manuals currently used, which recommend starting the lunge with the elbow extension (Arpino e Gulinelli, 2012, Gaugler 1997). Our results are in accord with what observed in other studies where the athletes started the movement with the lower limbs instead than with the elbow (Hassan e Klauck, 1998; Gholipour et al., 2008). This way of performing the lunge is supported by the study of Witowski et al. (2018) in which it is

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

reported the tendency of fencers to focus the gaze on the opponent's torso and armed upper limb. Given this tendency, we believe that a lunge starting with the lower limbs' movement is more unpredictable. Frère et al. (2011) made a similar observation, even though they were considering the flèche, and confirmed that expert fencers started the lunge with the lower limbs to mask their intention to attack.

Anterior knee's first flexion and the following extension were like those reported by Gholipour et al. (2008) for élite athletes (respectively 20±12 and 51±9). Posterior knee extension was similar found by Guan et al. (2018) in intermediate-level athletes (50.4±9.6°) while angular velocities we found are lower in our sample. This suggests that fencers in developmental age still do not have a mature technique and that it would be appropriate to pay attention to the correct learning of the gesture so that they do not consolidate a wrong technique. To better understand this subject, a longitudinal study would be necessary about technique's evolution during the different phases of development.

We considered the significant correlations of the variables quantifying the lunge performance (velocity, distance, and time) with the anthropometric and kinematic ones. We found a significant correlation between V_{max} $ASIS_m$ and the ROM of the rear knee extension ($r=0.56$, $p=0.031$), as in a previous study (Guan et al. 2018) conducted on adult fencers. In agreement with these authors, we think that this correlation is in turn linked to the guard position. Fencers are taught that in the lunge execution the rear knee's angle must reach its maximal extension. This angle is very similar in all subjects, as its little SD shows. So, we hypothesize that the ROM of the rear knee extension is influenced by knees' angles in guard position, as underlined by its correlation with these variables ($r = -0.94$ and $r = -0.85$ respectively with Left and Right knee angle in guard position; $p < 0.001$). Thus, the more the knees are flexed in guard position, the wider the extension of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

the posterior knee will be. Previous studies (Bottoms et al. 2013, Guan et al. 2018) assert that the lower guard position seems to allow a pre-tensioning which facilitates the higher lunge velocity expression. Moreover, more flexed knees in guard position allow a greater extension of the rear knee during the lunge. So, our explanation for the influence of the guard position on the lunge velocity is supported by the mentioned studies.

As we hypothesized, the variables representing the lunge performance were mostly correlated with the anthropometric variables rather than the kinematic ones. The lunge distance and V_m $ASIS_m$ were mostly correlated with fencers' height (r=0.85, p=0.000 and r=0.76, p=0.001) and FFM (r=0.8, p=0.000 and r=0.73, p=0.002). As previously said, we suppose that this happen because fencers in developmental age still did not have a mature technique, so anthropometric characteristics compensated for the lack of proper technique.

FFM was selected as independent variable for the linear regression because it was the trainable factor mostly correlated with variables representing the lunge performance. It was the best predictor of hips mean horizontal velocity and lunge distance

Similar relations of lunge's speed and distance with anthropometric characteristics were observed in the work of Turner et al. (2016).

Considering the whole sample, significant differences in anthropometry were found between males and females for FM %, FFM %, and thigh skinfolds. Females showed greater FM % and thigh skinfolds thickness. Any significant differences were found in kinematics between males and females.

Differences between expert fencers (EF) and non-expert fencers (NE) were also studied. EF revealed significant higher values for all the variables considered, showing a more pronounced muscular development. Anthropometric differences were due to the older age of the EF.

 doi:10.20944/preprints202009.0665.v1

Experts showed more flexed knees in the guard position and greater ROM in some of the movements composing the lunge. Our results are in line with those of other authors (Gholipour et al. 2008, Bottoms et al. 2013, Guan et al. 2018) in which EF kept a lower guard position and performed greater anterior and posterior knee extension and 2nd flexion.

As already observed, the posterior knee's extension is correlated with peak horizontal velocity of the hips. This relation explains the higher, but not significantly different, V_{max} $ASIS_m$ in the EF (1.75 ±0.27 m/s vs ME 1.58 ±0.21 m/s, p=0.2).

Regarding all the observed differences, our findings confirm our hypothesis, that, between the selected groups, there already were technical differences linked to experience and anthropometric differences related to growth. From the differences between EF and NE it emerges that the more experienced ones adopted strategies closer to those of adult athletes to improve lunge performance.

Conclusion

Studies about fencing are still few in sport science's literature. There is a paucity of studies which consider the technique and there is none about it exclusively in developmental age.

Fencing environment is very traditional, and technique is often referred to classical manuals, which teach the technique in a way more oriented to the form rather than the competition requirements. For example, is taught to begin the lunge with the armed upper limb. In our study we observed that the lunge starts by the legs and the elbow extension is activated only later. The procedure reported in manuals is less effective because it is more predictable by the opponent. From the correlation's analysis, in this age range, lunge performance resulted to be linked to anthropometrics.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 September 2020 doi:10.20944/preprints202009.0665.v1

Young fencers show few similarities with adult fencers' lunge kinematics, but we noted that, compared to NE, EF adopted strategies which allow the improvement of the lunge physical performance, closer to those observed in adult fencers. As in previous studies, we observed that experienced fencers showed a different behavior compared to the non-experienced ones. The EF performed wider and faster movements. In contrast with previous findings (Sinclair et. al 2013), we did not find any difference between males and females in all the technical variables. In agreement with Tsolakis et al. (2006), we think that the differences in technique we found were due to the normal growth process.

A limitation of our study is that we tested one subject at a time and not in competition circumstances, e.g. with an opponent.

Moreover, we are aware that a determinant variable for the outcome of the lunge is precision, but in our study, we did not use a target because we consider it could have influenced fencers in choosing the lunge distance. An improvement of our study could be to examine the subjects when they are fencing against an opponent, to have a more realistic environment, closer to the competition setting. Furthermore, it would be necessary to study the influence of a target on the lunge kinematic to understand if it is an essential element.

Acknowledgments

This paper was realized with Funds for Fundamental Research of the University of Bologna.

Delaration of interests statement.

The author has no conflict of interests.

References

Arpino, M., & Gulinelli, M. (2012) Quaderni della Scuola dello Sport. Quaderni di scherma: il fioretto, la sciabola, la storia della scherma [Notebooks of Scuola dello Sport. Notebooks of fencing: the foil, the sabre, the history of fencing]. *SDS*.

Bottoms, L., Greenhalgh, A., Sinclair, J., (2013) Kinematic determinants of weapon velocity during the fencing lunge in experienced épée fencers. *Acta of Bioengineering and Biomechanics*, 15(4):109–113.

Cacciari, E., Milani, S., Balsamo, A., Spada, E., Bona, G., Cavallo, L., Cerutti, F., Gargantini, L., Greggio, N., Tonini, G., Cicognani, A. (2006) Italian cross-sectional growth charts for height, weight and BMI (2-20y). *Journal of Endocrinological Investigation*, 29(7):581–593.

Chen, T.W.-L., Wong, D.W., Wang, Y., Ren, S., Yan, F., Zhang, M. (2017) Biomechanics of fencing sport: a scoping review. *Plos ONE*, 12 (2):e0171578

Cohen, J. (1998) Statistical power analysis for the behavioural sciences (2nd ed.). *Hillsdale, NJ: Lawrence Erlbaum*.

Frère, J., Gopfert, B., Nuesch, C., Huber, C., Fischer, M., Wirz, D., Friederich, N. F. (2011) Kinematical and EMG-classifications of a fencing attack. *International Journal of Sport Medicine*, 32(1): 28-34.

Gaugler, W.M. (1997) The Science of Fencing: A Comprehensive Training Manual for Master and Student: Including Lesson Plans for Foil, Sabre and Épée Instruction. *Laureate Press*.

Gholipour, M., Tabrizi, A., Farahmand, F. (2008) Kinematics analysis of lunge fencing using stereophotogrametry. *World Journal of Sport Sciences*, 1(1): 32-37.

Gresham-Fiegel, C.N., House, P.D., Zupan, M.F. (2013) The effect of nonleading foot placement on power and velocity in the fencing lunge. *Journal of Strength and Conditioning Research*, 27(1): 57-63.

Guan, Y., Guo, L., Wu, N., Zhang, L. (2018) Warburton D.E.R. Biomechanical insights into the determinants of speed in the fencing lunge. *European Journal of Sports Sciences*, 18(2): 201-208.

Hassan, S.E.A., & Klauck J. (1998) Kinematics of lower and upper extremities motions during the fencing lunge: results and training implications. *Proceedings of 16th ISBS Conference*, 1: 170-173.

Knapik, J.J., Staab, J.S., Harman, E.A. (1996) Validity of an anthropometric estimate of thigh muscle cross-sectional area. *Medicine and Science in Sports and Exercise*, 28(12):1523–1530.

Marfell-Jones, M., Olds, T., Stewart, A., Lindsay Carter, L.E. (2012) ISAK manual, International standards for Anthropometric Assessment. *International Society for the Advancement of Kinanthropometry*.

Martine, T., Claessens, A.L., Vlietinck, R., Marchal, G., Beunen, G. (1997) Accuracy of anthropometric estimation of muscle cross-sectional area of the arm in males. *American Journal of Human Biology*, 9(1):73–86.

McGinley, J.L., Baker, R., Wolfe, R., Morris, ME. (2009) The reliability of three-dimensional kinematic gait measurements: a systematic review. *Gait & Posture*, 29(3): 360-9.

Morris, N., Farnsworth, M., Robertson, D.G.E. (2011) Kinetic analyses of two fencing attacks and lunge and fleche. *Portuguese Journal of Sport Sciences*, 11(2): 343-346.

Mulloy, F., Mullineaux, D., Irwin, G. (2015) Use of the kinematic chain in the fencing attacking lunge. *33° International Conference on Biomechanics in Sports, Poitiers*.

Oxford Metric. (2016) Plug-in Gait Reference Guide. Oxford, UK.

Sinclair, J., Bottoms, L. (2013) Gender differences in the kinetics and lower extremity kinematics of the fencing lunge. *International Journal of. Performance Analysis in Sport*, 13(2): 440-451.

Tsolakis, C., Bogdanis, G.C., Vagenas, G. (2006) Anthropometric profile and limb asymmetries in young male and female fencers. *Journal of Human Movement Studies*, 50(3): 201-215.

Turner, A., Bishop, C., Chavda, S., Edwards, M., Brazier, J., Kilduff, L. P. (2016) Physical characteristics underpinning lunging and change of direction speed in fencing. *Journal of Strength and Conditioning Research*, 30(8): 2235–2241.

Witkowski, M., Tomczak, M., Bronikowski, M., Tomczak, E., Marciniak, M., Borysiuk, Z. (2018) Visual perception strategies of foil fencers facing right- versus left-handed opponents. *Perceptual and Motor Skills*, 125(3): 612–625.

Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D'Lima, D.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.

Wu, G., van der Helm, F.C., Veeger, H.E., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B. (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): 981-92.