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THE INFLUENCE OF TRAINING ON NEUROMUSCULAR FACTORS IN ELITE AND NON ELITE FENCERS

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Abstract The aim of this study was to investigate the influence of training on neuromuscular factors related to the speed of basic kinetic fencing patterns. 10 elite and 10 non-elite fencers underwent: a) anthropometric measurements and leg cross sectional area estimation (leg CSA), b) determination of jumping ability and the time needed to perform a lunge attack, using 7 tests on a jumping mat (Ergojump system): squat jump (SJ), counter-movement jump (CMJ), counter-movement jump on the dominant and non-dominant leg (CMJD-ND), counter-movement jump using the hands (CMJH), drop jump (DJ), and lunge. Elite fencers were significantly stronger in CMJD and CMJND (23-16%, $p<0.01-0.000$) than non-elite fencers. Significant differences in leg CSA and explosive strength (10-15%, $p<0.005-0.000$) were observed between the dominant and non-dominant limp of fencers. Smaller significant differences (8%, $p<0.000$) were observed in leg CSA of non-elite fencers. There was no relationship between muscular and strength asymmetries. The time needed to perform a lunge attack was similar among the elite and non-elite fencers and was negatively related to muscle elasticity of elite fencers (0.71, $p<0.05$). Fencing training produces significant muscular and strength asymmetries, which are not related to each other, and the fencers' muscle elasticity seems to be an important factor in neuromuscular performance among fencers of different technical level.

Key words: jumping ability, lunge, elasticity, asymmetries, fencing

INTRODUCTION

The fencing lunge is considered the most basic kinetic dexterity of the fighting process. It requires speed and precision and is characterized by an initial elbow-shoulder extension towards the opponent, which is followed (supported) by the vigorous straightening of the backward leg [15]. This results in a possibly more rapid acceleration of the center of weight after a relaxed but immediate extension of the forward knee [39, 40].

The asymmetric specific patterns of the lower extremities in unilateral sports like fencing are characterized by the continuous, repeated and intensive extensional movements, demanding excessive muscular force, speed and neuromuscular coordination [26]. The repeated and different motor patterns of the dominant and non–dominant legs of the fencers, aiming at the application of the desirable techniques and tactics, result in development of anatomical and functional asymmetries [5, 24, 27].

The muscular force developed during the proper execution of a lunge is of particular importance [7]. Therefore, it would be useful to determine the sport-specific adaptations of the lower-extremity muscular functions that are associated with the explosive strength and muscle elasticity required in the actual fencing competitive conditions [3, 11].

Although a number of interrelated morphological and functional factors seem to determine the success in fencing [26, 34], the complexity of the posturomotor, locomotor and operant activities that involve the lower activities are difficult to measure in real fight conditions [39]. Besides, the results of relevant experimental studies can differentiate the exercise-related adaptations between non-elite and elite fencers in competitive kinetic technical and tactical tests [15, 40].

The aim of this study was to examine the influence of the systematic fencing training to neuromuscular parameters that are related to the speed and power of basic motor patterns, comparing two groups of fencers of different competitive levels.

MATERIALS AND METHODS

SAMPLES AND TESTING PROCEDURE

During their pre-competitive training period, 10 elite male fencers, members of the Greek national team and 10 non-elite fencers from the local Athens club were informed about the purpose of this study and volunteered to undergo:

a) anthropometric measurements (height, weight, quadriceps' skinfolds and girth). Subjects' height and body mass were measured to the nearest 0.1 cm and 0.1 kg, respectively, while skinfolds were taken using a Harpenden skin fold caliper. Leg lean cross sectional areas (CSA) were calculated from an anthropometric formula incorporating limb circumference and skin folds, as proposed by Gurney and Jelliffe, [13] and Heymsfield et al, [17]; and,

b) determination of the jumping ability and the time needed to perform a lunge attack, using a contact mat of the Ergojump system as described by Bosco, [3]. Subjects performed the subsequent tests: squat jump, counter-movement jump, counter-movement jump of the dominant and the non-dominant leg, counter-movement jump using the hands, drop jump from 40 cm height and a fencing lunge. The time needed to perform a lunge attack was estimated from the flight time of the dominant leg. Each subject performed two trials for each jump type with 30 sec rest between jumps.

The highest score was recorded for further analysis. The subjects performed the exercise tests following a standardized warm-up, which included 10 min of jogging, static stretching and 1 – 2 preliminary trials for each test (ICC = 0.91-0.93, $p<0.01$). Muscle elasticity was indirectly determined from the difference between the squat and counter-movement jump [4].

The anthropometric characteristics of the subjects are presented in Table 1.

STATISTICAL ANALYSIS

For the statistical analysis of the data the SPSS 11 was used. Mean differences between groups were examined using an unpaired t-test. The asymmetries between dominant and non-dominant legs were analyzed using a paired t-test. Relationships between variables were examined by Pearson's correlation coefficient (r). For each analysis statistical significance was set at the $\alpha = 0.05$ probability level.

RESULTS

ELITE / NON-ELITE FENCERS

The results of the present study are presented in Table 2. Significant differences were observed among elite and non-elite fencers in counter-movement jump for the dominant (23%, $p<0.001$) and the non-dominant leg (16.8%, $p<0.01$). The mean differences (dominant – non-dominant leg) of the functional and anatomical asymmetries in elite fencers were significantly greater than those of non-elite fencers by 77%, $p< 0.05$ and 46%, $p<0.01$ respectively.

Squat jump, muscle elasticity, drop jump, the time needed to perform a lunge attack and the CSA of both the dominant and non-dominant legs were similar among elite and non-elite fencers, although elite fencers were subjected to a greater number of trainings per week by 30%, $p<0.05$ than their non-elite counterparts.

ASYMMETRIES

Significant differences in leg CSA (12%, $p<0.004$) were observed between the dominant and the non-dominant leg for the total of subjects, while no functional asymmetries were observed. More specifically, elite fencers developed both significant functional (dominant – non-dominant: 10.3%, $p<0.005$, Table 2) and anatomical asymmetries (15%, $p<0.000$). Smaller significant differences (8%, $p<0.000$) were observed in leg CSA of non-elite fencers (Table 1).

Table 1. Anthropometric and training characteristics of elite (n:10) and non-elite fencers (n:10), ($\bar{X}$ ± SD)

	Elite fencers	**Non-elite fencers**
Age (Years)	20.1±2.84	22.6±6.15
Height (cm)	180.2±7.11	179.9±5.91
Weight (kg)	70.50±8.19	77.1±6.85
CSAD (cm2)	245.83±39.72†	240.67±22.45†
CSAND (cm2)	208.54±31.67	220.67±22.45
Trainings/week	5.6±0.69*	3.9±1.52
Years of training	9.5±3.5	8.7±2.4

CSAD: Dominant leg lean cross sectional area (CSA), **CSAND**: Non-dominant leg lean cross sectional area †(Dominant vs non-dominant, $p<0.000$) * (elite vs non-elite $p<0.005$)

Table 2. Explosive strength parameters and the time needed to perform a lunge attack calculated from the Ergojump system for the elite (n:10) and the non-elite fencers (n:10), ($\bar{X}$ ± SD)

	Elite fencers	**Non-elite fencers**
SJ (cm)	33.14±3.89	32.005±7.68
CMJ (cm)	39.87±3.71	36.35±7.73
CMJD (cm)	23.64±3.13 *** †	18.2±2.71
CMJND (cm)	21.21±2.56 **	17.66±2.86
CMJD - CMJND (cm)	2.33±1.96 *	0.53±1.65
CMJH (cm)	45.76±4.44	41.82±8.18
Elasticity(cm)	6.75±5.14	4.39±1.93
CTDJ 40 (msec)	263.33±64.47	263.33±84.41
TL (msec)	387.7±103.92	419.25±89.63

SJ: Squat jump, **CMJ**: Counter movement jump, **CMJD**: Counter movement jump for the dominant leg, **CMJND**: Counter movement jump for the non-dominant leg, **CMJH**: counter movement jump using hands, **CTDJ 40**: Contact time drop jump from 40 cm height, **TL**: the time needed to perform a lunge attack, (elite vs non-elite fencers, *$p<0.05$, **$p<0.01$, ***$p<0.005$), (dominant vs non-dominant †$p<0.005$)

CORRELATIONS

No relationship was found between leg CSA and counter-movement jump for both the dominant and the non dominant leg in elite and non-elite fencers. On the contrary, the mean differences of the non-elite fencers functional asymmetries (counter-movement jump of dominant – non-dominant leg) were negatively associated with a) the leg CSA of the dominant ($r = -0.69$, $p<0.01$), and b) the leg CSA of the non-dominant leg ($r = -0.73$, $p<0.01$) respectively.

CSA of the dominant and the non-dominant leg of the non-elite fencers were correlated with the number of training/week ($r = 0.76 – 0.67$, $p<0.05$), while the mean anatomical differences (leg CSA dominant – non-dominant) of the fencers in total (n: 20) and the elite and non-elite fencers were also significantly correlated with the years of training, ($r = 0.66 – 0.75$).

The time needed to perform a lunge attack was related to the counter-movement jump of the dominant and the non-dominant leg of non-elite fencers ($r = 0.65 – 0.72$, $p< 0.05$) and was negatively related to: a) the muscle elasticity of the fencers in total (n: 20), ($r = -0.55$, $p<0.05$), b) the muscle elasticity of the elite fencers ($r = -0.71$, $p<0.05$).

Table 3. Pearson r correlations between selected variables for the total (n = 20), elite (n =10) and non-elite fencers (n =10)

		CSAND	**CMJD**	**CMJND**	**DCMJ**	**DCSA**	**TL**	**ELAS**	**TW**	**YT**
CSAD	Total	0.88**	0.04	0.15	-0.22	0.58*	0.16	-0.31	0.37	0.38
	Elite	0.93**	0.04	0.06	-0.11	0.72*	0.02	-0.36	0.18	0.51
	Non	0.90**	-0.16	0.24	-0.69**	-0.40	0.53	-0.29	0.76*	0.02
CSAND	Total	***xxxx***	-0.16	-0.01	-0.36	0.13	0.17	-0.40	0.13	0.13
	Elite	***xxxx***	0.01	-0.02	-0.05	0.47	-0.07	-0.34	0.03	0.40
	Non	***xxxx***	-0.03	0.39	-0.73*	-0.04	0.50	-0.42	0.67*	-0.33
CMJD	Total		***xxxx***	0.86**	0.57**	0.30	0.04	0.25	0.41	-0.08
	Elite		***xxxx***	0.75*	0.51	-0.11	-0.10	0.10	0.51	-0.16
	Non		***xxxx***	0.82**	0.21	-0.30	0.65*	-0.04	-0.29	-0.43
CMJND	Total			***xxxx***	0.06	0.31	0.20	0.17	0.36	-0.19
	Elite			***xxxx***	-0.18	0.11	0.02	0.02	0.55	-0.16
	Non			***xxxx***	-0.38	-0.27	0.72*	-0.08	-0.18	-0.59
DCMJ	Total				***xxxx***	-0.22	0.23	0.24	0.22	0.13
	Elite				***xxxx***	-0.33	-0.16	0.14	0.07	0.06
	Non				***xxxx***	-0.03	0.18	0.06	-0.17	0.30
DCSA	Total					***xxxx***	0.07	0.06	0.54*	0.66*
	Elite					***xxxx***	0.24	-0.22	0.42	0.71*
	Non					***xxxx***	0.15	0.20	0.33	0.75*
TL	Total						***xxxx***	-0.55*	0.13	0.22
	Elite						***xxxx***	-0.71*	0.34	0.46
	Non						***xxxx***	-0.30	0.31	-0.12
ELAS	Total							***xxxx***	0.10	-0.05
	Elite							***xxxx***	0.07	-0.23
	Non							***xxxx***	-0.45	-0.40
WT	Total								***xxxx***	0.40
	Elite								***xxxx***	0.59
	Non								***xxxx***	0.23

CSAD: Dominant leg cross section area, **CSAND**: Non-Dominant leg cross section area, **DCSA**: Dominant – non-dominant cross sectional area difference, **CMJD**: Counter movement jump on the dominant leg, **CMJND**: Counter movement jump on the non-dominant leg, **DCMJ**: Dominant – non-dominant counter movement jump, **TL**: The time needed to perform a lunge attack, **ELAS**: Elasticity, **WT**: numbers of training/week, **YT**: training experience. *<0.05,**<0.01

DISCUSSION AND CONCLUSIONS

The most important results of the present study are summarized as follows:

The observed significant functional and anatomical asymmetries in the lower extremities of the elite fencers were not correlated. The magnitude of the anatomic asymmetries was correlated with the number of trainings per week as well as with the training experience of the subjects. The non-elite fencers were considerably weaker in the explosive strength for both the dominant and non-dominant leg in comparison to the elite fencers. On the contrary, there were no differences observed between the two groups concerning the proposed by Bosco parameters of the explosive strength (SJ, CMJ) and the time needed to perform a lunge attack. The time needed to perform a lunge attack was associated with the elasticity in elite fencers and with the explosive strength of each leg separately in the non-elite fencers respectively.

The systematic participation in asymmetric activities causes proportional functional adaptations in the relevant muscles [38], while at the same time anatomic asymmetries are developed [6]. On the contrary, kinetic asymmetries in sports characterized by simultaneous or reciprocal movements are difficult to reveal [28, 33, 35, 36]. The anatomical and functional asymmetries may be affected by the characteristics of training [24, 35] and the specific loading of different parts [16].

Significant functional asymmetries were observed between fencers' dominant and non-dominant legs, after concentric and eccentric isokinetic contractions in slow and fast angular velocities [5, 26, 31]. Anatomical asymmetries were also evident in young subjects [34], and in elite fencers as well [27]. The results of the present study concerning leg anatomical asymmetries in elite Greek fencers confirm that participating in a unilateral sport such as fencing makes the lower body become considerably asymmetrical in muscular development [34]. As a result, one leg is usually stronger than the other due to the higher stress and force exerted on that leg during competition [26, 31].

The study of the fencing lunge execution under laboratory conditions can give adequate information concerning biomechanical factors related to the optimal performance and can differentiate world-class from non-elite fencers [40]. Particularly, in the present study significant differences were not observed between athletes of different level with regard to the squat, counter-movement, drop jump and the time needed to perform a lunge attack. These results confirm the observation that the technical characteristics of fencing should be considered as more important factors than anaerobic functional parameters [27], although obvious differences between elite and non-elite fencers need the recording of a more complex test in comparison to a single fencing lunge [15].

On the other hand, elite athletes were considerably stronger in the explosive strength of each leg separately by 16-23%. This could be attributed to the close relation between muscle mass and force [21] and primarily in the specific characteristics of the training stimuli, since a significant relation was observed between the training experience of the fencers and the dominant / non-dominant leg CSA difference.

The exercise-related increase in force depends on the interaction of neural [14, 23, 30] and morphological changes in muscle fibers [12], which are attributed to hormonal, metabolic and mechanical factors [9, 20, 29]. Although strength is proportional to the muscle CSA, poor relation exists between the exercise-related differences in strength and muscle mass [20, 41]. The lack of significant correlations between the anatomical and functional asymmetries in elite fencers of the present study could be due to the close-chain fencing movements requiring specific coordination actions of many lower limb muscles involving the stretch-shortening cyclic neural mechanisms [1].

The explosive strength of the leg extensors as it was determined by Bosco tests [4], although dependent on a large neuromuscular parameters such as the contractile elements, the elastic energy used, the intramuscular coordination [3] and the heredity [19], do not appear to influence the time needed to perform a lunge attack, since the technique and other kinaesthetic factors seem to be responsible for fencing performance [18, 27]. In contrast, the calculation of muscle elasticity (CJ – SJ) is proved a decisive factor of the power performance of the fencers in the present study, confirming its importance in muscle contraction evaluation and, consequently, the time needed to transfer the force generated during the active process through the connective tissue to the skeleton [8].

Moreover, the relationship between the differences of the dominant and non-dominant functional asymmetries and the relative muscle CSA were stronger for the non-dominant leg ($r = -0.73$) in comparison to that of the dominant leg ($r = -0.69$). Additionally, the time needed to perform a lunge attack in non-elite fencers was also more strongly correlated to the counter-movement jump ability of the non-dominant leg ($r = 0.72$), than of the dominant leg ($r = 0.65$) respectively. It is well known that in fencing the legs contract following different kinetic patterns [10], highlighting the importance of the participation of the non-dominant leg in developing the speed and power of the lunge [2, 22, 39]. This information is very important in fencing, confirming the significant role of the flexors and extensors during the lunge, which consists of a fast movement execution from the initial guard posture, as well as during the backward movement called retreat which follows after the balance - maintaining posture of the fencer [32].

In conclusion, the present study showed that the systematic fencing training causes muscular and functional asymmetries that are not interrelated. Muscle elasticity seems to be a decisive factor in lunge performance which determines the neuromuscular differences between elite and non - elite fencers.

PRACTICAL APPLICATION

The results of the present study may provide useful help to fencing coaches in: a) determining leg-strength capacity using the appropriate neuromuscular tests, and b) effectively designing the strength-training program variables, related to the sport-specific requirements for an optimal fencing performance. It is obvious that numerous questions remain to be answered regarding: a) the selected neuromuscular performance during different training periods, and b) the practical application of the mean squat jump differences (dominant – non-dominant leg) concerning muscle elasticity in this specific population.

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