Anatomic and Functional Characteristics of Lower Extremities in Elite and Sub-Elite Fencers

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ABSTRACT

The aim of this study was to investigate possible differences in selected anthropometric and performance parameters between dominant and non dominant limbs, in elite and sub-elite fencers of both genders. In total, 13 female and 15 male fencers all members of the Greek National Fencing team (age 19.9 ± 3.5 years, height 175.6 ± 7.6 cm, weight 64.4 ± 9.5 kg) were examined. Anthropometric parameters included weight, height, mid-thigh skin fold and thigh circumference, while mid-thigh muscle cross sectional area on the dominant and non dominant side was calculated from an anthropometric formula incorporating limb circumference and skin folds. Jumping performance (counter movement jumps) in the dominant and non dominant side was measured using a Chronojump mat, and flexibility of the hamstrings muscles was measured bilaterally using a Lafayette goniometer. Fencers were classified as elite or sub-elite according to their international results. Significant differences were observed between dominant and non dominant limbs in muscle cross sectional area (11.9%, p<0.05) and jumping performance (15.9%, p<0.05). Additionally, significant differences were observed between elite and sub-elite fencers in muscle cross-sectional area of the dominant side (6.8%, p<0.05), flex-

Key Words: Limb differences, power, flexibility, fencing.
ibility of the dominant side (18.9%, p<0.05) and flexibility of the non-dominant side (18.3%, p<0.05). Moreover, significant differences were also found between male and female fencers in countermovement jump performance of the dominant side (24.5%, p<0.05). In conclusion, the observed anatomical and functional differences due to potential specific training adaptations may be used to discriminate elite from sub elite fencers.

INTRODUCTION

The assessment of anthropometric and physiological characteristics is vital to explain sport excellence (1). Many of these anthropometric traits and physiological abilities seem to be essential for successful performance. Therefore, specific sports assessments of the lower extremity functions are necessary before and/or during training season and after an injury rehabilitation process, in order to effectively assess and monitor the progress of the athlete (2, 3). Furthermore, physical parameters can discriminate athletes of different skills, specialization and performance levels in many sports such as in soccer (4), handball (5), hockey (6), volleyball (3) surfing (7) and fencing (8).

The examination and identification of side-to-side bilateral differences or dominant and non-dominant muscle imbalances have been addressed by several authors (9). Specifically, some of the studies have reported non-significant differences in preadolescent children (10), adolescents (11), and sedentary men and women (12), whereas in other studies significant lateral dominance differences were observed (13). In athletes, the lower extremity side-to-side differences are not obvious in symmetric sports such as swimming or running (10). On the other hand, the constant training overload on the preferred leg in unilateral sports (jumping, fencing etc.) may develop significant strength differences in the lower extremities (14). However, previous studies comparing bilateral strength parameters and the association with lateral dominance have yielded conflicting results. Functional asymmetries have been identified in the lower limbs of athletes of different skills (15, 16, 8). These lower-extremity functional differences have been shown to be related to factors that include side-to-side differences in strength, neural control (17, 18), and flexibility (19). In contrast, other studies in various sports failed to report significant asymmetries between the dominant and non-dominant limbs of the participants (18-22).

Fencing is considered a unilateral sport requiring excessive neuromuscular function of the lower limbs to implement specific and accurate kinetic patterns which are crucial in fencing success. The repeated fast and powerful contraction of the extensor muscles of the dominant and non-dominant limbs characterize
fencing performance and can cause asymmetric muscular adaptations (23). Tsolakis et al (24) observed significant muscle cross-sectional area asymmetries between the dominant and non dominant limbs in a large group of both males and females fencers. These differences were evident from the early age and increased from the younger to the older group. However, only a small part of the variation in the observed asymmetry was explained by the variation in years of training and consequently it could be concluded that in technical sports such as fencing the magnitude of muscle cross-sectional area asymmetries may be independent of the training experience (25).

Previous studies in functional asymmetries in fencing are conflicting, reporting that the front lower extremity is usually stronger than the rear as a result of the excessive force put on that extremity during the competitive fencing patterns (26, 27). On the other hand, Poulis et al (28) observed a lack of asymmetry in isokinetic knee extensors strength between dominant and non-dominant limbs. Recently Gulheim et al (29), showed that although the front knee extensor and plantar flexor muscles were stronger compared to the rear, mainly due to the produced eccentric contraction to decelerate the fencers’ body, EMG activity of the rear lower extremity was satisfactory correlated to the average velocity of the propulsive phase.

To our knowledge, no study has in detail examined lower extremity asymmetries in fencers. Therefore, the aim of this study was to investigate possible differences in selected anthropometric and physiological parameters between dominant and non dominant limbs in elite and sub-elite fencers of both genders. The results of this study can inform trainers and physiotherapists about potential muscle and function imbalances in fencing, and may facilitate the design of appropriate strength training programs to develop fencing performance.

MATERIALS AND METHODS

Subjects

The subjects consisted of the 27 members of the Greek National Fencing Team (age 19.9 ± 3.5 years, height 175.6 ± 7.6 cm, weight 64.4 ± 9.5 kg) (Table 1). They all volunteered to participate in the study after invitation and by signing an informed consent. In total, 13 female and 14 male fencers were classified as elite or sub-elite according to their international results, during the time at testing. Three athletes had experience from Olympic Games, ten from Juniors’ World Championships and the remaining only participated in national level competitions. The elite group consisted of five female and five male fencers, while in the sub-elite group there were seven females and ten males. Subjects met the following inclusion criteria :
(i) older than 14 years, (ii) healthy with no reported musculoskeletal dysfunction, (iii) had more than four years of systematic training, and (iv) had more than two years of competition experience.

**Testing Procedure**

The anthropometric characteristics were assessed before the performance tests: bilateral countermovement jumps (CMJs) and a hamstring flexibility test. Subjects were instructed to warm up 10 minutes by jogging at their own pace and perform dynamic stretching program afterwards. The testing procedures were performed at the same time of the day for each participant, an hour prior their regular training time. A day before participating in the study the subjects did not engage in any strenuous activity regarding specific sport related activities. Finally, each subject was instructed and verbally encouraged during each test to perform to their maximum results at each trial.

**Table 1.**

*Subjects’ descriptive characteristics. Values are mean ± standard deviations.*

<table>
<thead>
<tr>
<th></th>
<th>Elite fencers</th>
<th>Sub-elite fencers</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.8 ± 3.4</td>
<td>18.7 ± 3.2</td>
<td>19.3 ± 3.7</td>
<td>20.4 ± 3.9</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.77 ± 8.4</td>
<td>1.65 ± 6.8</td>
<td>1.80 ± 7.9</td>
<td>1.67 ± 6.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>69.5 ± 12.5</td>
<td>63.7 ± 11.4</td>
<td>70.14 ± 12.0</td>
<td>58.0 ± 7.1</td>
</tr>
</tbody>
</table>

**Anthropometric measurements**

The anthropometric measurements included: height, weight, quadriceps’ thigh girths, and quadriceps’ mid thigh skin fold. All measurements were taken twice on the dominant (fencing leg) and on the non dominant side of each subject. The quadriceps’ girths and skin folds were also obtained by measuring both sides. The test-retest reproducibility (ICCs) of the measurements was estimated to 0.98, (p<0.05). Subjects’ height and body mass were measured to the nearest 0.1 cm and 0.1 kg, respectively. Measuring equipment included a Lafayette Gullick anthropometric tape (Model J00305) and a Harpenden skin fold caliper. Percent (%) body fat was estimated according to Durnin and Rahaman (30). Body Mass
Index (BMI) was calculated as body mass per (height)$^2$ in kg/m$^2$. Mid-thigh cross sectional areas (CSA) were calculated by an anthropometric formula which incorporates limb circumference and quadriceps’ skin folds, as proposed by Defreitas et al. (31).

**Functional tests**

*Jumping performance*

Jumping performance was determined using a Chronojump platform (http://www.chronojump.org) as described by Bosco, Luhtanen, and Komi (32). Subjects were tested on their standing reach height with their arms at their sides. They performed countermovement jumps with a 30 second rest between jumps on the dominant (CMJ-D) and non dominant (CMJ-ND) leg. Moreover, subjects were instructed to initially flex the knee of the limb tested in order to activate the stretch-shortening cycle, and then leave the platform with the knee and ankle extended and land in an upright position. Two trials were performed to each side with the mean of the two recorded as the jumping score. The test-retest reproducibility (ICCs) between trials for the dominant side (CMJ-D) and for the non dominant side (CMJ-ND), was estimated to 0.91 and 0.90 (p< 0.05).

*Flexibility test*

A straight-leg-test (SLT) was performed to examine the flexibility and tightness of the hamstring muscles. The subjects were positioned supine on a flat bench and were instructed to relax as much as possible. Two testers performed the test. The tester placed one hand slightly below the knee and the other hand on the heel, and then raised the subject’s straight leg to the point in the range when the onset of pelvic tilt was detected. At this point, the investigator measured the angle of displacement of the leg from the horizontal line. The landmarks of the goniometer (Lafayette Instrum. Inc., Model 01135) were the distances from the greater trochanter to the lateral epicondyle and from the greater trochanter and horizontally. Two separate trials were performed with the mean of the two recorded as the criterion score. The procedure was repeated for both legs. The test-retest reproducibility for this test (ICC) was estimated to 0.98 (p< 0.05).

**Statistical Analyses**

All calculations were performed using the SPSS 22.0 Software for Windows (SPSS Inc., Chicago, Ill., USA). The study was an observational cross sectional
study. Mean differences between dominant and non dominant limbs, elite and sub-elite fencers and male and female fencers were examined. Dependent t-test (paired samples t-test) was used to identify differences between dominant and non dominant sides; independent t-tests were used for comparing elite and sub-elite level fencers and male versus female fencers. All variables were tested for their conformity to the assumption of distributional normality using Kolmogorov-Smirnov test. All dependent variables were normally distributed, and the use of parametric tests was therefore considered appropriate. The test retest reproducibility for each test was estimated by intraclass correlation coefficients (ICCs). All tests were two-sided and the level of significance was set at \( p < 0.05 \).

**RESULTS**

The results of the t-tests used to identify differences between the groups in this study are presented in Tables 2-4.

* Differences between dominant (DOM) and non dominant (NON-DOM) sides.

Significant differences were observed between dominant and non-dominant limbs in muscle cross sectional area (CSA) (11.9%, \( p < 0.05 \)) and countermovement jump performance (CMJ), (15.9%, \( p < 0.05 \), respectively (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>DOM</th>
<th>NON-DOM</th>
<th>% Difference</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA (cm(^2))</td>
<td>242.08 ± 14.0</td>
<td>217.5 ± 5.0</td>
<td>11.9</td>
<td>0.023</td>
</tr>
<tr>
<td>FLEX (degrees)</td>
<td>101.4 ± 26.1</td>
<td>100.9 ± 24.1</td>
<td>0.6</td>
<td>0.599</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>12.86 ± 5.1</td>
<td>10.1 ± 2.9</td>
<td>15.9</td>
<td>0.033</td>
</tr>
</tbody>
</table>

CSA= mid thigh muscle cross sectional area, FLEX= flexibility, CMJ= counter movement jump
Differences between elite and sub-elite fencers

Significant differences were observed between elite and sub-elite fencers for muscle cross sectional area of the dominant side (CSA-D) (6.8%, p<0.05), flexibility of the dominant side (FLEX-D) (18.9%, p<0.05) and flexibility of the non-dominant side (FLEX-ND) (18.3%, p<0.05) (Table 3).

<table>
<thead>
<tr>
<th></th>
<th>ELITE</th>
<th>SUB-ELITE</th>
<th>% Difference</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSAD (cm²)</td>
<td>252.3 ± 6.8</td>
<td>235.1 ± 14.3</td>
<td>6.8</td>
<td>0.012</td>
</tr>
<tr>
<td>CSAND (cm²)</td>
<td>230.2 ± 11.6</td>
<td>221.9 ± 16.9</td>
<td>3.6</td>
<td>0.183</td>
</tr>
<tr>
<td>FLEXD (degrees)</td>
<td>114.7 ± 13.8</td>
<td>93.0 ± 28.1</td>
<td>18.9</td>
<td>0.032</td>
</tr>
<tr>
<td>FLEXND (degrees)</td>
<td>115.1 ± 12.0</td>
<td>94.05 ± 27.6</td>
<td>18.3</td>
<td>0.030</td>
</tr>
<tr>
<td>CMJD (cm)</td>
<td>14.41 ± 5.1</td>
<td>12.5 ± 3.5</td>
<td>13.2</td>
<td>0.287</td>
</tr>
<tr>
<td>CMJND (cm)</td>
<td>11.73 ± 2.9</td>
<td>10.6 ± 3.1</td>
<td>9.2</td>
<td>0.408</td>
</tr>
</tbody>
</table>

CSAD = mid thigh muscle cross sectional area of the dominant leg, CSAND = mid thigh muscle cross sectional area of the non-dominant leg, FLEXD = flexibility of the dominant leg, FLEXND = flexibility of the non-dominant leg, CMJD = counter movement jump performance of the non-dominant leg, CMJND = counter movement jump performance of the non-dominant leg.

Differences between Male – Female fencers

Significant differences were observed between male and female fencers for countermovement jump performance of the dominant side (CMJD) (24.5%, p<0.05) (Table 4).
Table 4.

Differences between male (N=14) and female (N=13) fencers in anthropometric measures and functional tests.

<table>
<thead>
<tr>
<th></th>
<th>MALE</th>
<th>FEMALE</th>
<th>% Difference</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSAD (cm²)</td>
<td>244.8 ± 15.5</td>
<td>238.2 ± 13.2</td>
<td>2.7</td>
<td>0.263</td>
</tr>
<tr>
<td>CSAND (cm²)</td>
<td>227.6 ± 12.7</td>
<td>222.2 ± 18.2</td>
<td>2.4</td>
<td>0.183</td>
</tr>
<tr>
<td>FLEXD (degrees)</td>
<td>101.1 ± 12.3</td>
<td>101.00 ± 35.8</td>
<td>2.7</td>
<td>0.994</td>
</tr>
<tr>
<td>FLEXND (degrees)</td>
<td>102.2 ± 15.0</td>
<td>101.5 ± 33.5</td>
<td>0.7</td>
<td>0.946</td>
</tr>
<tr>
<td>CMJD (cm)</td>
<td>15.06 ± 4.4</td>
<td>11.4 ± 3.1</td>
<td>24.5</td>
<td>0.045</td>
</tr>
<tr>
<td>CMJND (cm)</td>
<td>11.9 ± 2.8</td>
<td>10.2 ± 3.0</td>
<td>14</td>
<td>0.183</td>
</tr>
</tbody>
</table>

CSAD = mid thigh muscle cross sectional area of the dominant leg, CSAND = mid thigh muscle cross sectional area of the non-dominant leg, FLEXD = flexibility of the dominant leg, FLEXND = flexibility of the non-dominant leg, CMJD = counter movement jump performance of the non-dominant leg, CMJND = counter movement jump performance of the non-dominant leg.

DISCUSSION

The results of this study revealed significant muscle cross-sectional area (CSA) and countermovement jump (CMJ) performance differences between the two limbs in favor of the dominant side in elite and sub-elite fencers. Moreover, elite fencers had a higher muscle cross-sectional area on the dominant limb, while they also had higher flexibility (FLEX) in both lower limbs, compared to sub-elite fencers. The comparison between male and female fencers showed that men performed better than women in CMJ performance of the dominant side.

Dominance in fencing is determined by the weapon handle and this may cause significant increases in the muscle mass and strength of the upper and lower dominant limbs (8). The clearly defined bilateral myodynamic differences of this study established by the higher muscle activation of the dominant limb are of significant importance to explain laterality adaptations in fencing. Fencers’ quadriceps muscles are responsible for the fast kinetic patterns of the dominant side in comparison to hamstring muscles, characteristics which are mostly responsible for the body stabilization after the end of the lunge (28). Recently, Gulheim et al (29) investigated the kinetic patterns of the fencing lunge and showed that the dominant limbs’ repeated concentric contraction of the quadriceps muscles (propulsive phase), and the following eccentric contraction of the same muscle groups (braking phase), may explain the excessive asymmetries that are observed.
in fencers. Although the rear lower extremity activity is related to the velocity of
a lunge during the propulsive phase, the dominant limb of the fencers produce
higher forces and consequently develop anatomical and functional asymmetries.

Previous studies in fencing have reported that one limb is usually stronger than
the other as a result of the higher stress and force put on that dominant limb during
the competitive kinetic patterns (33). The observed bilateral asymmetries in this
study are in accordance with a study by Margonato et al. (25) who also found
significant differences in muscle cross sectional area and maximal force between
dominant and non dominant side in fencers compared to a control group. These
observations were also confirmed by Tsolakis and Vagenas (8), who reported
that muscle development of the lower body in fencing can become grossly
asymmetrical from the early age. In contrast, Poulis et al. (28) who examined the
force produced in flexion and extension of the knee between the dominant and
non dominant sides during concentric isokinetic contraction at slow (30–60°/sec.)
and fast (240°/sec.) angular velocities in elite fencers, observed a lack of limb
asymmetry, which was attributed to the nature of isokinetic assessment that does
not reflect the closed-chain movements and coordinated actions of lower limb
muscles involved in stretch-shortening cycle movements of fencing.

Concerning flexibility, the results of Rahnama et al (34) are in line with the results
of this study and reported similar knee joint flexibility measures between the preferred
and the non-preferred limb in a group of elite and non-elite football players. The
mean flexibility values of the present study (approximately 100-102°) are greater
than the previous reported values (34) in football players and showing that flexibility
characteristics of this group of fencers cannot impair the kinetic patterns specific to the
particular sport while the predisposition of muscle injury is restricted significantly (35).

The anthropometric profile and jumping performance measures of athletes
can distinguish elite from sub elite level in many individual or team sports (36,
37). However, some other factors such as, age, gender, level of competition and
discipline potentially influence power performance (38). To our knowledge, there
are no fencing studies comparing the anthropometric traits between elite and
sub-elite fencers. On the other hand, a small number of studies investigated the
physiological (8) and neuromuscular differences (29, 39, 40) of elite fencers in
comparison to sub-elite fencers.

In the present study, the comparison between elite and sub-elite fencers,
revealed significant differences in dominant muscle cross sectional area and
flexibility, while a non significant difference in jumping performance showed that
elite fencers were more powerful in both limbs in jumping performance. This
finding could reflect a trend of higher training volumes and intensity level that
possibly could affect jumping performance output. Therefore, these competitive
related adaptations confirm special abilities and may discriminate elite from sub-
elite fencers (8).
Anthropometric, morphological and functional performance is different between genders (41). Women have less muscle mass and strength compared with men. Knapik et al. (42) reported that the observed differences in strength between men and women vary from 40-80% depending on the measurement method. In addition, adequate information exists regarding the determination of muscle-cross sectional area and its relation to strength-power and performance parameters, between men and women (43). Only one study investigated in fencing the gender anthropometric asymmetries in a large group of male and female fencers. Arm muscle cross-sectional area was higher in males compared with females in all age groups, except for the 10-13 years old group. However, an important finding was that leg muscle cross-sectional area was similar in male and female fencers across all age groups examined. The results of the present study also showed similarity between genders’ muscle cross-sectional area confirming earlier results. To our knowledge, there is a lack of information concerning between gender physiological asymmetries in fencing. The results of this study showed that male fencers demonstrated significant higher CMJ performance in the dominant limb compared with female fencers, which could potentially be attributed to higher force full contractions, observed in men during training and competition (43).

CONCLUSIONS

In conclusion, this study confirmed anthropometric and performance parameters differences between the two limbs in fencers. Also, the assessment of elite and sub-elite fencers shows that elite fencers are superior in the selected performance tests compared with their sub-elite counterparts. With a few exceptions, elite fencers are very similar to sub-elite in most of the anthropometric traits, which may indicate that other factors such as muscle coordination and technique may contribute in elite fencing performance. Regarding gender influence, the observations show a lack of differences in between comparison, except for jumping performance. Further studies are needed to identify relationships between selected anthropometric, strength-power qualities and fencing-specific skills in order to provide additional evidence regarding the incorporation of certain training methodologies into designing effective development programs in fencing.

PRACTICAL APPLICATIONS

From a practical perspective, muscle cross-sectional area and jumping performance of the dominant side may be used to differentiate elite from sub-
elite fencers. Muscle cross-sectional area, flexibility of the hamstring muscles and jumping performance are influenced by the specificity of the fencing training programs. These observations confirm different leg quality requisites all of which seem to be important in functional power characteristics of fencing performance, especially in elite fencers. This study investigated differences between elite and sub-elite fencers in Greece. It seems that the greatest limitations of this study, is that due to the relative small sample size and the specificity of the population used, the results may not translate to fencers of other ethnicities, or different level of performance. There are still a lot of knowledge gaps to fill, where future studies and different designs could assist in building new and stronger evidence based science, regarding bilateral asymmetries in fencers.

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