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GAIT PATTERN OF PROFESSIONAL FENCERS

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Abstract. *This study used a comprehensive approach including kinematic and EMG data analysis to determine how normal gait patterns may change as a result of professional non-cyclical sport activity and to determine the electromyographical pattern of m. adductor longus. The study was performed on 37 professional fencers and 68 healthy non-professional subjects as the control group. Gait analysis was performed using the zebris three-dimensional ultrasound-based system with surface electromyography (zebris). Kinematic data (spatial-temporal parameters, knee joint kinematics and relative ligament-movement parameter) were recorded for the lower limb. The muscles examined include vastus lateralis and medialis, biceps femoris and adductor longus. Analysis of the values of professional and non-professional subjects shows that the influence of well - proportioned muscles is not due to a reduction of muscle activity during all-day motion, but rather a more complex neuromuscular mechanism, which brings about effectiveness in gait and a joint stability. The EMG traces of m. adductor longus show an adductor longus avoidance gait for a small part of subjects, which does not depend on gender, age, and sport activity level. The results suggest that the reduced rotation of thigh could result in a reduced rise in adductor longus EMG activity during preswing.*

Key words: *gait analysis, 3D kinematics, electromyograph*

1. INTRODUCTION

The gait pattern of healthy subjects has been assessed in a number of studies all using different techniques. The previous investigations examined muscles vastus medialis, lateralis, rectus femoris, semimembranosus, biceps femoris, tibialis anterior, and gastrocnemius. However, few studies have evaluated the changes of m. adductor longus during the gait.

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The development of adductor longus avoidance gait pattern has been described as a patient's tendency to reduce or avoid contraction of the adductor longus muscle during the preswing phase.

Bechtol (1975) examined EMG patterns for 28 of the major muscles in the lower extremities during a gait cycle. The study was performed on 10 male and 10 female subjects. Bechtol (1975) found that the m. adductor longus produced activation during the early stance, preswing and late swing phases. Ciccotti et al. (1994) analyzed EMG patterns during gait in 22 normal healthy subjects. Muscle adductor longus produced activation just at the early stance and late swing phases at 6 subjects out of twenty-two. In our earlier investigation (Kiss and Knoll, 2002), evidence of an adductor longus avoidance pattern was observed at 22% of investigated subjects. We found that the reduced rotation of the thigh and pelvis as measured during pre-swing could be interpreted as the cause of adductor longus avoidance gait (Kiss and Knoll, 2002). The behaviour was compensated by an increase in pelvic obligation (Kiss and Knoll, 2002). Future studies investigating EMG patterns in adductor magnus in professional and non-professional athletes may shed more light on this topic.

No previous studies investigated the comparison of biomechanical parameters between non-professional and professional athletes, nor the way the activity level influences the gait pattern.

This study used a comprehensive approach including kinematic and EMG data analysis to determine how normal gait patterns may change as a result of professional non-cyclical sport activity and to determine the electromyographical pattern of m. adductor longus.

2. METHOD

2.1. Subjects

The study was carried out with a group of 27 professional fencers and a control group of 68 non-professional athletes.

The population of the control group consisted of forty-five males and twenty-three females. The group of professional athletes consisted of 11 males and 16 females. 11 males and 16 females were tested before the training season, four males and six females during the training season. The data of the different groups are summarized in Table 1.

Table 1. Mean (SD) of age, height, and mass for the investigated groups

	Mass [kg]	Height [cm]	Age [years]
non-professional male athletes (n=45)	77.89 (11.88)	178.42 (7.20)	28.17 (7.69)
non-professional female athletes (n=23)	59.86 (6.38)	168.07 (5.70)	25.09 (4.21)
professional male fencers before the training season (n=11)	79.09 (9.13)	186.18 (4.19)	26.16 (3.05)
professional female fencers before the training season (n=16)	63.70 (8.51)	172.20 (6.37)	23.37 (4.08)
professional male fencers during the training season (n=4)	73.60 (5.18)	188.60 (6.73)	24.52 (3.72)
professional female fencers during the training season (n=6)	62.31 (6.94)	168.00 (7.95)	26.46 (7.72)

For inclusion, subjects were not to have any pathology that would affect gait and had to be unfamiliar with treadmill walking. Each subject provided informed consent before participation and signed a consent form approved by the Hungarian Human Subjects Compliance Committee.

2.2. Procedures and instrumentation

The subjects walked on a motorized treadmill (Bonte Zwolle B.V, Austria), the walking area of the treadmill belt was 330 mm × 1430 mm. Each subject was asked to perform, after six minutes familiarization time (Alton et al., 1998; Matsas et al., 2000), at least 10 minutes of walking at a three km/h speed (Knoll et al., 2003).

The analysis of gait features was performed using an ultrasound-based zebris CMS-HS system (ZEBRIS, Medizintechnik GmbH, Germany) consisting of the following: (a) measuring head and 5 ultrasound triplets for recording kinematic data; (b) EMG system equipment with surface electrodes for recording neuromuscular activity. EMG signals were acquired at a sampling rate of 1000 Hz, whereas the ultrasound measuring system worked at a sampling rate of 100 Hz. Further elaboration of all the variables was carried out by computer.

The spatial coordinates to determine kinematic data were collected by the measuring head with three ultrasound transmitters and five ultrasound-based triplets with active markers during walking. The measuring head was positioned behind the subject (Fig.1). Five ultrasound triplets with three active markers on each were placed on the sacrum, left and right thighs, and left and right calves (Fig.1.). The data obtained from the measuring system recording of these active markers allowed the determination of the coordinates of the following anatomical points of the lower limbs: (1) right medial malleolus, (2) right heel, (3) right lateral malleolus, (4) right tibial tubercule, (5) right fibular head, (6) right lateral femoral epicondyle, (7) right medial femoral epicondyle, (8) right greater trochanter, (9) right ASIS, (10) left medial malleolus, (11) left heel, (12) left lateral malleolus, (13) left tibial tubercule, (14) left fibular head, (15) left lateral femoral epicondyle, (16) left medial femoral epicondyle, (17) left greater trochanter, (18) left ASIS, and (19) sacrum. The protocol is defined in (Kocsis, 2002) in detail.

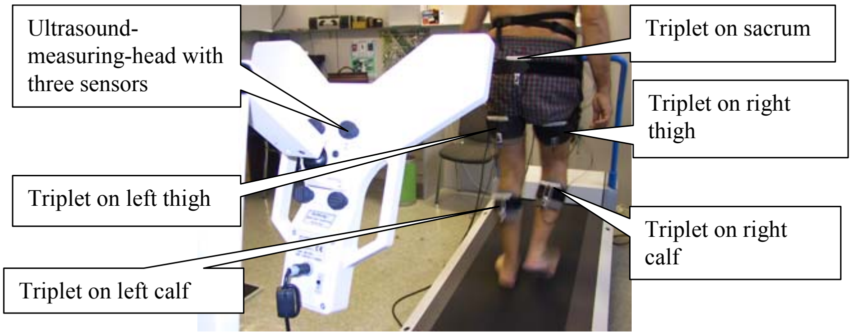

Fig. 1. Arrangement of measurement

Assessment parameters

The kinematic assessment parameters are the following: (a) step-length; (b) walking base; (c) the modified knee angle; (d) relative ligament movement parameters; and (e) thigh rotation.

The knee angle defined as the angle between the spatial vectors joining the lateral malleolus to the fibular head and joining the lateral femoral epicondyle to the greater trochanter. The calculation method is shown in detail by Kocsis (2002).

The motion analysis technique is used to study the motion of the knee into the direction of ligaments during walking, because the medial and lateral anatomical points of the knee are investigated. The tibial translation could be described by the relative ligament-movement parameter, which is the relative maximum displacement between the two characterized points of the knee. The calculation method is summarized by Kocsis (2002) in detail.

The rotational angle of the thigh is determined by calculating the angular velocity vector of the thigh as a rigid body and by the time integration of its longitudinal component about the axes of the segment as described by Kocsis and Beda (2001) and by Kiss and Knoll (2002).

EMG data were collected using bipolar surface electrodes (blue sensor P-00-S, Germany). The electrodes were placed on the skin overlying the muscle belly of the muscles vastus medialis and lateralis, biceps femoris, and adductor longus of both limbs. To achieve an optimal EMG signal and low impedance, three 3 cm^2 areas of skin were sanded and cleaned. Prior to measurement, the electrode positions were tested to control for cross talk between different muscle groups. The raw data were high pass filtered to eliminate frequency components below 10 Hz, then rectified and filtered to eliminate the components of the signals over 500 Hz. The linear envelope EMG curve was determined by the root-mean square method (Vaughan et al., 1999) and normalized to the average of the peak EMG signal values of six gait cycles.

Treadmill-walking allows the determination of the average and the standard deviation of all parameters from six gait cycles for each subject. These data were then calculated and exported to further analysis.

The different groups were defined as (a) control group; (b) professional athletes before the training season; (c) professional athletes during the training season. The average trend for all variables was computed for each group. Student tests were used to determine levels of significance ($\alpha = 0.05$) when comparing the groups.

3. RESULTS

3.1. Spatial-temporal parameters

Table 2 presents a summary of comparisons for professional athletes before and during the training season and for the control group by selected spatial-temporal parameters (step length and walking base). No significant statistical differences were observed between the dominant and non-dominant limbs for the control group and professional athletes before the training season ($p>0.27$). Significant statistical differences were observed between the dominant and non-dominant limbs for professional athletes during the training season ($p<0.0024$). Significant differences were observed between the professional and non-professional group ($p<0.0019$).

3.2. Knee joint kinematics

Table 3 and Table 4 present a summary of comparison for professional athletes before and during the training season and for the control group in terms of knee joint kinematics (knee angle and relative ACL-movement).

Table 2. Mean (SD) spatial-temporal parameters for non-professional athletes and for professional fencers before and during the training season

	Step length [mm]		Walking base [mm]	
	dominant	non-dominant	dominant	non-dominant
non-professional male athletes (n=45)	513.3 (26.6)	510.3 (28.8)	41.9 (8.2)	50.5 (11.5)
non-professional female athletes (n=23)	470.7 (20.1)	466.3 (29.9)	39.0 (9.9)	46.1 (15.0)
professional male fencers before the training season (n=11)	565.6 (27.5)	560.0 (28.9)	35.65 (10.8)	38.9 (13.4)
professional female fencers before the training season (n=16)	483.2 (24.8)	478.6 (26.1)	30.4 (8.3)	30.8 (7.8)
professional male fencers during the training season (n=4)	587.6 (20.2)	561.2 (25.7)	32.1 (9.7)	39.7 (7.5)
professional female fencers during the training season (n=6)	514.2 (12.9)	463.2 (16.4)	25.7 (8.0)	30.7 (6.7)

Table 3. Mean (SD) peak values of knee angle for non-professional athletes and for professional fencers before and during the training season

	Peak value of extension [degree]		Peak value of flexion [degree]	
	dominant	non-dominant	dominant	non-dominant
non-professional male athletes (n=45)	5.5 (0.98)	5.4 (1.05)	52.3 (1.32)	51.2 (1.74)
non-professional female athletes (n=23)	7.3 (1.29)	7.7 (1.88)	57.3 (1.96)	57.6 (1.85)
professional male fencers before the training season (n=11)	4.3 (0.31)	4.8 (0.61)	45.4 (1.64)	46.1 (1.74)
professional female fencers before the training season (n=16)	4.1 (1.11)	4.2 (1.29)	45.4 (1.33)	51.4 (1.54)
professional male fencers during the training season (n=4)	3.9 (0.29)	4.7 (0.60)	40.5 (1.60)	45.1 (1.77)
professional female fencers during the training season (n=6)	3.7 (0.27)	4.5 (1.14)	43.2 (1.28)	52.4 (1.40)

Table 4. Mean (SD) relative ligament-movement parameters for non-professional athletes and for professional fencers before and during the training season

	Relative ACL - movement		Relative PCL - movement		Relative MCL - movement		Relative LCL - movement	
	dominant	non-dominant	dominant	non-dominant	dominant	non-dominant	dominant	non-dominant
non-professional male athletes (n=45)	0.25 (0.020)	0.26 (0.018)	0.34 (0.017)	0.34 (0.016)	0.32 (0.032)	0.32 (0.032)	0.062 (0.0050)	0.062 (0.0044)
non-professional female athletes (n=23)	0.25 (0.016)	0.26 (0.017)	0.33 (0.014)	0.33 (0.017)	0.35 (0.030)	0.36 (0.035)	0.067 (0.0046)	0.066 (0.0042)
professional male fencers before the training season (n=11)	0.15 (0.015)	0.14 (0.012)	0.24 (0.018)	0.23 (0.015)	0.25 (0.032)	0.25 (0.035)	0.053 (0.0038)	0.056 (0.0036)
professional female fencers before the training season (n=16)	0.16 (0.016)	0.16 (0.017)	0.26 (0.016)	0.27 (0.015)	0.26 (0.25)	0.26 (0.026)	0.053 (0.0034)	0.053 (0.0030)
professional male fencers during the training season (n=4)	0.10 (0.010)	0.15 (0.012)	0.19 (0.017)	0.23 (0.015)	0.21 (0.028)	0.25 (0.026)	0.047 (0.0031)	0.056 (0.0034)
professional female fencers during the training season (n=6)	0.11 (0.012)	0.15 (0.015)	0.19 (0.015)	0.23 (0.014)	0.22 (0.026)	0.25 (0.026)	0.045 (0.0039)	0.056 (0.0030)

No significant statistical differences were observed between the dominant and non-dominant limbs for the control group and professional athletes before the training season (p>0.39). Significant statistical differences were observed between the dominant and non-dominant limbs for professional athletes during the training season (p<0.001). Significant differences were observed between the professional and non-professional group (p<0.0031).

3.3. Muscle EMG

Fig. 2 shows a graphical representation and comparisons for professional athletes before and during training season and for the control group. No significant differences were observed between the three groups' vastus medialis, lateralis and biceps femoris EMG activity throughout gait.

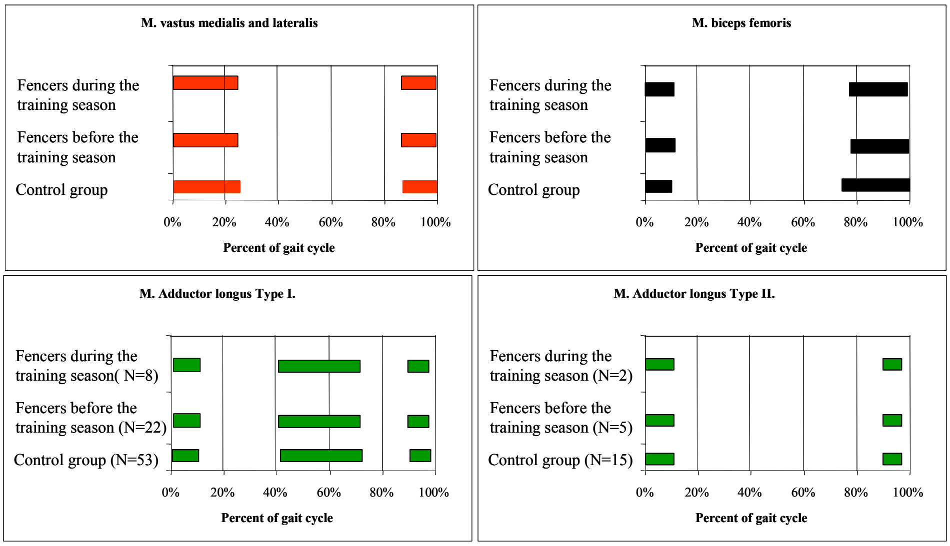

Fig. 2. EMG pattern of muscles vastus medialis, lateralis, biceps femoris, and adductor longus for control subjects and for professional fencers before and during the training season

53 non-professional athletes and 22 professional fencers did not exhibit an adductor longus avoidance gait. This means that adductor longus produced EMG activity during the early stance, preswing, and late swing phases. 14 non-professional athletes and five professional fencers exhibited an adductor longus avoidance gait pattern, m. adductor longus did not produce any activity during the pre-swing phase (Fig.2). The differences do not depend on gender, sport activity level, and age.

3.4. Thigh kinematics

Table 5 presents a summary of comparisons for professional and non professional athletes without adductor longus avoidance and with adductor longus avoidance gait. Significant statistical differences in thigh rotation during preswing were observed between the group with and without adductor longus avoidance gait (p<0.0024).

Table 5. Mean (SD) thigh rotation during the preswing phase for subjects with and without a adductor longus avoidance pattern, respectively

	Thigh's rotation		Pelvic's rotation		Pelvic's obligation		Pelvic's flexion-extension	
	dominant	non-dominant	dominant	non-dominant	dominant	non-dominant	dominant	non-dominant
Non-professional subjects with normal gait pattern (n=15)	4.08 (0.17)	3.89 (0.19)	3.96 (0.17)	3.87 (0.14)	5.04 (0.15)	4.91 (0.15)	11.05 (0.18)	10.91 (0.19)
Non professional subjects with adductor longus avoidance gait (n=53)	0.90 (0.21)	0.62 (0.25)	1.39 (0.21)	1.40 (0.23)	7.89 (0.38)	7.65 (0.37)	10.36 (0.17)	10.81 (0.18)
Professional subjects with normal gait pattern (n=22)	3.99 (0.12)	3.55 (0.11)	3.77 (0.15	3.67 (0.12)	4.67 (0.17)	4.67 (0.16)	10.97 (0.11	10.86 (0.22)
Professional subjects with adductor longus avoidance gait (n=5)	1.2 (0.16	0.97 (0.15)	2.39 (0.17)	1.80 (0.16)	8.76 (0.21)	8.65 (0.27)	9.99 (0.18)	10.66 (0.21)

5. DISCUSSION

Several gait characteristics of professional athletes observed in the present study were significantly different from the control group's values. The step length of professional athletes is 5-8 cm longer compared to non-professional's values (Table 2). Professional athletes were approximately five degrees less flexed at the knee compared to non-professional athletes' values (Table 3). Muscle activation is similar to non-professional athletes (Fig. 2), but a significantly increased effectiveness could be observed. The differences are more impulsive during the training season and could be determined between the dominant and non-dominant limbs. The results indicated that professional athletes demonstrated a more effective gait pattern compared to non-professional athletes.

Relative ligament movement parameters are significantly smaller than the values of non-professionals (Table 4). It is possible that well-proportioned muscles allow smaller tibial translation during the gait.

In our study, the synchronized analysis of kinematic and EMG variables verified that the activity level of sport influences the gait pattern. Analyzing these data, we see that the influence of well-proportioned muscles is not due to a reduction of muscle activity during all-day motion, but rather a more complex neuromuscular mechanism, which brings about effectiveness in gait and joint stability.

The adductor longus avoidance pattern is defined as a patient tendency to reduce thigh rotation during the preswing phase of gait (during late stance). As such, significant alteration in gait mechanics may occur (Kiss and Knoll, 2002).

In the present investigation, evidence of an adductor longus avoidance pattern was observed in 18% of professional fencer subjects (Fig. 2) and 21% of non-professional athletes (Kiss and Knoll, 2002). This finding is in contrast to Bechtol (1975), who has not reported any adductor longus avoidance pattern. However, the results of the present investigation are consistent with the investigation of Ciccotti et al. (1994), who have reported that an adductor longus avoidance phenomenus could be developed in a low percent of healthy subjects. Our research shows that the adductor longus avoidance gait does not depend on sport activity because the incidence rate of adductor longus avoidance gait is similar in both groups. The results strengthen that the development of adductor longus avoidance gait does not depend on gender and age. On the basis of the comparison of thigh and pelvic motion we can confirm our earlier assumption (Kiss and Knoll, 2002) that the reduced rotation of the thigh measured during preswing (Table 5) could be interpreted as the cause of adductor longus avoidance gait. The reduced rotation of the thigh could result in a reduced rise in adductor longus EMG activity during preswing and the behaviour was compensated by an increase in pelvic obligation. However, no differences could be found in other kinematic gait characteristics.

The development of adductor longus avoidance gait pattern does not depend on gender, age and sport activity level. Future studies investigating EMG patterns in adductor magnus in professional and non-professional athletes may shed more light on this topic.

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MODEL HODA KOD PROFESIONALNIH MAČEVALACA

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U studiji je korišćen razumni pristup uključujući kinematičke i EMG podatke analize da se utvrdi kako normalan obrazac (model) hoda može promeniti rezultat profesionalnih necikličnih sportskih aktivnosti i da se utvrde elektromiografski obrasci m.adductor longus-a. Ova studija je izvedena na 37 profesionalnih mačevalaca i 68 zdravih nesportista, kao kontrolna grupa. Analiza hoda izvedena je korišćenjem "zabris" trodimenzionalnim sistemom baziranim na ultrazvuku sa površinom elektromiograma ("zebris). Kinematički podaci (prostorno-vremenski parametri, kinematika zgloba kolena i relativan parametar pokreta (ligamenta) bili su beležene za donji *ekstremitet. Pregledani su mišići: vastus lateralis i medialis, biceps femoris i adductor longus. Analiza vrednosti profesionalnih i neprofesionalnih subjekata pokazuje da dobro proporcionalni mišići ne utiču na redukciju mišićne aktivnosti tokom celo-dnevnog kretanja, već više kompleksan neuro-mišićni mehanizam koji dovodi do veće efektivnosti u hodu i stabilnosti zgloba. EMG skica m adductor longusa pokazuje izbegavanje adductor longusa kod hoda malog broja subjekata, što ne zavisi od pola, godišta i nivoa sportske aktivnosti. Rezultat sugeriše da smanjena rotacija bedra može rezultirati smanjenim podizanjem EMG aktivnosti kod adductor longusa pre zamaha.*

Ključne reči: *analiza hoda, 3D kinematika, elektromiografija*