Journal of Advanced Sport Technology 6(2):1-9

Received: May, 20, 2020 *Accepted: June, 19, 2020*

Original Research

Determination of Selected Lower Limb Muscles Electromyography Frequency Spectrum in Male Soccer Players with ACL Injury during Three Running Patterns

Ameneh Pourrahim Ghouroghchi[1*], AmirAli Jafarnezhadgero[2], Mohammad Abdollahpour Darvishani [3]

1. Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran. E-mail: amenehpoorrahim@yahoo.com, ORCID:0000-0003-3448-5950.
2. Department of Sport Management and Biomechanics, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili,, Ardabil, Iran. Email: amiralijafarnezhad@gmail.com, ORCID:0000-0002-2739-4340.
3. Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran. Email: nekamohamad2626@gmail.com, ORCID:0000-0002-0446-1037.

ABSTRACT

The aim of this study was to evaluate electromyography frequency spectrum of selected lower limb muscles in males with ACL injury during three different running patterns. Fourteen soccer players with ACL injury and 14 healthy soccer players were volunteered to participate in the study. A wireless electromyography system with 8 pairs of bipolar surface electrodes was used to record the electromyography frequency spectrum during three running patterns. The results showed that the median frequency of tibia anterior muscle in the ACL injury group during propulsion phase in the rear-foot strike running pattern was greater compared to the healthy group (p= 0.024)**.** The median frequency of semitendinosus muscle in the propulsion phase in mid-foot running patterns in the ACL group was higher compared to the healthy group (p=.0.044). Also, the median frequency of semitendinosus muscle in the loading response phase in forefoot running patterns in the ACL group was greater compared to the healthy group (p= 0.028). According to the research results, it can be stated increased agonist and antagonist muscle activity across different running patterns increase the risk of secondary injury in people with ACL injuries.

Keywords: Anterior cruciate ligament, Electromyography, Frequency spectrum, Running

Corresponding Author: Ameneh Pourrahim Ghouroghchi, Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran. E-mail:

INTRODUCTION

Anterior cruciate ligament injury is when the anterior cruciate ligament (ACL) is either stretched, partially torn, or completely torn. The most common injury is a complete tear. Symptoms include pain, a popping sound during injury, instability of the knee, and joint swelling. Swelling generally appears within a couple of hours. In approximately 50% of cases, other structures of the knee such as surrounding ligaments, cartilage, or meniscus are damaged. The underlying mechanism often involves a rapid change in direction, sudden stop, landing after a jump, or direct contact to the knee. It is more common in athletes, particularly those who participate in alpine skiing, football (soccer), American football, or basketball.

soccer is one of the most popular sports in the world, and high conflict and hard collisions are two inevitable factors in causing various injuries to players [1]. In soccer, static forces are exposed to large loads and cause ACL injury [2]. ACL injury in athletes can lead to irreparable costs [3]. People with ACL injury have a different mechanical pattern of running than normal people [4, 5]. Surface electromyography (EMG) represents the sum of the electrical activities of many active motor units in a muscle [6, 7].

A recent kinematic analysis of elite runners wearing shoes who participated in a half marathon indicated that 75% of the runners were heel strikers, 24% were midfoot strikers, and 1% were forefoot strikers [3]. When runners use a rear foot strike pattern, the knee is relatively extended and the ankle is in relative dorsi flexion upon initial contact. As the ankle moves into plantar flexion, the knee flexes and the knee extensors act eccentrically to dampen the ground reaction forces. Traditionally shod rear foot strikers often take long strides, characterized by a vertical displacement of the center of mass and an impact peak present at approximately 10% to 12% of the stance phase on the vertical ground reaction force curve [8]. For example, when using a rear foot strike, a runner will contact the ground with the lateral aspect of the heel eventually toeing off as in the other foot strikes [9]. Here, we use operational definitions for midfoot and forefoot striking [10, 11]. A midfoot strike is one in which the runner initially contacts the ground across the metatarsal heads with the heel subsequently contacting the running surface while the forefoot strike is also one in which the initial contact is also on the metatarsal heads but the heel never touches the ground [9]. Muscles have been reported to follow a different pattern of strength and force during movement when running the heel strikers, midfoot strikers and forefoot strikers [12]. Due to the differences in biomechanics, movements such as running in people with ACL injury, the pattern of activity of the muscles of the lower limbs while running with three different patterns show different performance [13].

However, to the authors' knowledge, no study has examined the selected lower limb electromyography frequency spectrum during running in male soccer players with ACL injury during three running patterns. Therefore, the aim of this study was to evaluate selected lower limb electromyography frequency spectrum in male soccer players with ACL injury during three running patterns. In a way, the present study seeks to answer the question of whether the frequency spectrum differs in people with ACL injury when using different running patterns?

MATERIAL AND METHODS

Participants

The present study was an interventional study conducted in the Mohaghegh Ardabili University Health Center. The statistical population of the study was all healthy people (age range 19-24) and male soccer players with ACL injury (age range 21-25) in Ardabil city. A priori power analysis software (G*3 Power) revealed that for a statistical power of 0.80 at an effect size of 0.80 and with an alpha level of 0.05 a sample size of at least 24 participants were required [11, 14]. Fourteen soccer players with ACL injury and 14 healthy soccer players were volunteered to participate in the study. The experimental group has never performed knee surgery. A questionnaire was developed to record the following characteristics: date of birth, medical condition, date of ACL injury. The following inclusion criteria were adopted: a sporting career of at least 5 years; no previous, current or ongoing neuromuscular diseases or musculo-skeletal injuries affecting the knee-joint; current participation in competitive soccer championship. The dominant limb was chosen for this test by asking participants which was their preferred kicking leg [15]. Participants were instructed to refrain from any kind of physical training in the 24 h prior to the data collection, to ensure their ability to perform the trial in their best possible physical conditions. Ethics approval was obtained from the ethical committee of the Ardebil University of Medical Sciences.

EMG recordings

Medical adhesive tape was used to fix electrodes and probes on the skin to minimize any motion artifact. A switch was fixed upon the participant legs to trigger the onset of muscle contraction, to ensure synchronization between EMG and dynamometers signals. EMG and switch signals were sampled at 1 kHz analog-to-digital conversion rate at 16-bit resolution (band pass filtered 10-500 Hz; input impedance > 10 GOhm; common mode-rejection ratio >110 dB) by a portable Wi-Fi transmission device.
An electromyography system (DataLITE EMG, Biometrics Ltd, Bandwidth: 10-490HZ) Made in England was used to record muscle activity. Gastrocnemius medialis (GM), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), gluteal medius (Glut-M) and tibialis anterior (TA) muscle activities were recorded by Bio systems during three running patterns. The electrodes were positioned on each muscle in the direction of the muscle fibers. Electrode position was determined for TA, Gas-M, BF, VM, VL and Glut-M muscles according to SENIAM recommendation [13, 16]. Three different running patterns included were heel strike, midfoot strike and forefoot strike.

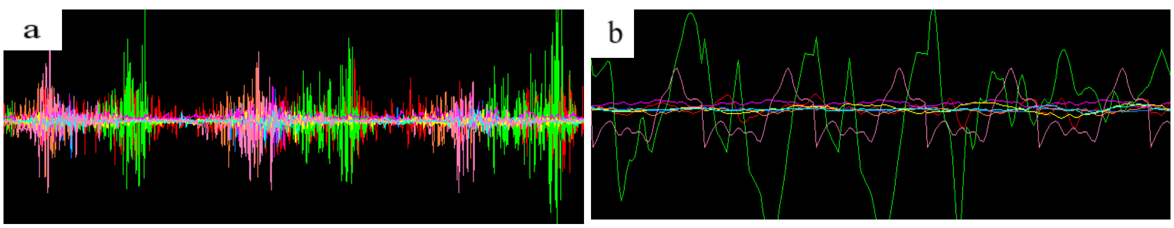

Figure 1. a) Raw signal, b) Signal cut during the running stance phase

Data analysis

The normality of the data distribution was confirmed by Shapiro-Wilk test. ANOVA with repeated measure test was used for statistical analysis. All analyzes were performed at the significant level of 0.05 using SPSS 24 software.

RESULTS

The anthropometric parameters of individuals are given in Table 1. There was no significant difference in the anthropometric parameters between groups.

Table 1. Demographic characteristics of height, weight, age and body mass index in two group of ACL injury and healthy (mean and standard deviation)

Variable	ACL group	Healthy group	Sig.
Age (year)	22.8±1.4	23.4±1.1	0.235
Height (cm)	175.1±3.4	177.4±5.9	0.521
Weight(kg)	71.3±7.8	75.1±8.7	0.085
BMI(kg/m^2)	23.2±2.3	23.8±1.9	0.759

The results showed that the main effect of strike pattern in the loading phase for tibia anterior muscle was significant (p=0.032) (Table 2). The main effect of strike pattern in the propulsion phase for vastus lateralis (p=0.034) and semitendinosus (p=0.036) muscle was significant (Table 2). The interaction effect of strike pattern *group in the propulsion phase for rectus femoris muscle was significant (p=0.012) (Table 2).

Table 2. Main effect of strike pattern, group and their interaction for frequency spectrum of selected muscles of lower limbs during loading and push off phases

Muscle	loading response			propulsion phase		
	Main effect: strike pattern	Main effect: group	Interaction: strike pattern *group	Main effect: strike pattern	Main effect: group	Interaction: strike pattern *group
TA	*0.032(0.437)	0.540(0.030)	0.684(0.061)	0.161(0.262)	0.069(0.232)	0.349(0.161)
GC	0.848(0.003)	0.305(0.075)	0.937(0.011)	0.929(0.012)	0.736(0.009)	0.593(0.083)
VL	0.552(0.094)	0.133(0.165)	0.214(0.227)	0.998(0.000)	*0.034(00.302)	0.685(0.061)
VM	0.469(0.118)	0.828(0.004)	0.392(0.145)	0.440(0.128)	0.688(0.013)	0.069(0.359)
RF	0.674(0.064)	0.346()0.068	0.374(0.151)	0.074(0.352)	0.414(0.052)	*0.012(0.523)
BF	0.493(0.111)	0.201(0.123)	0.569(0.090)	0.325(0.171)	0.148(0.154)	0.493(0.111)
ST	0.350(0.161)	0.295(0.084)	0.285(0.189)	0.892(0.019)	*0.036(0.295)	0.127(0.291)
GM	0.494(0.111)	0.346(0.068)	0.926(0.013)	0.827(0.031)	0.426(0.049)	0.416(0.136)

Notes: Gastrocnemius medialis(GM), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), gluteal medius (Glut-M) and tibialis anterior (TA).

The results showed that the median frequency of tibia anterior muscle in the ACL group during propulsion phase in the rear-foot strike running pattern was increased compared to the healthy group (p= 0.024) (Table 3**).**

Table 3. Comparison of muscle activities during rear-foot strike running pattern in two healthy and ACL groups

Muscle	loading response			propulsion phase		
	ACL	Healthy	Sig.	ACL	Healthy	Sig.
TA	112.22±15.52	110.23±32.31	0.868	117.31±67.57	92.26±12.01	0.024*
GC	91.45±10.57	94.40±19.12	0.614	91.87±19.34	88.45±22.72	0.623
VL	70.41±11.66	70.81±15.91	0.931	75.22±14.73	62.87±16.11	0.068
VM	55.76±6.41	60.21±12.12	0.324	70.70±15.98	68.37±19.82	0.741
RF	63.27±11.76	63.38±14.34	0.981	69.15±9.02	67.67±15.27	0.751
BF	81.09±23.72	82.01±22.13	0.909	88.07±17.82	81.88±19.43	0.404
ST	79.83±16.94	75.80±17.67	0.614	76.22±21.76	73.29±12.76	0.621
GM	59.35±16.74	59.94±14.45	0.705	64.64±13.96	63.94±22.34	0.621

Gastrocnemius medialis muscle Activity (GM), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), gluteal medius (Glut-M) and tibialis anterior (TA).

The results showed that the median frequency of semitendinosus muscle in the propulsion phase in mid-foot running patterns in the ACL group was greater compared to the healthy group (p= 0.044) (Table 4).

Table 4. Comparison muscle activities during mid-foot strike running pattern in two healthy and ACL groups

Muscle	Loading phase			propulsion phase		
	ACL	Healthy	Sig.	ACL	Healthy	Sig.
TA	103.77±23.75	99.21±20.43	0.623	106.28±21.79	94.56±21.07	0.223
GC	96.69±20.11	96.37±20.51	0.966	88.10±25.22	90.67±23.82	0.773
VL	69.88±10.48	63.60±11.14	0.092	74.66±20.40	63.62±13.72	0.084
VM	61.43±14.45	59.12±12.85	0.646	67.81±15.00	66.89±19.36	0.882
RF	70.26±12.26	61.73±10.76	0.132	67.54±10.66	70.33±12.89	0.432
BF	85.38±17.92	75.05±18.46	0.165	92.35±25.30	78.05±15.11	0.099
ST	76.83±16.83	77.78±24.49	0.920	83.73±23.70	66.94±16.26	0.044
GM	63.22±13.15	59.94±15.56	0.582	67.55±14.77	58.80±11.29	0.621

The results showed that the median frequency of semitendinosus muscle in the loading response phase in forefoot running patterns in the ACL group was greater compared to the healthy group (p= 0.028) (Table 5).

Table 5. Comparison muscle activities during forefoot running pattern in two healthy and ACL groups

Muscle	Loading phase			propulsion phase		
	ACL	Healthy	Sig.	ACL	Healthy	Sig.
TA	101.05±23.78	92.41±15.12	0.254	100.93±26.86	90.72±23.68	0.332
GC	91.20±11.30	91.50±32.02	0.974	91.10±22.23	85.61±27.14	0.436
VL	75.47±23.79	61.89±18.48	0.121	71.31±21.94	66.48±9.79	0.459
VM	58.39±12.36	53.77±12.54	0.401	60.36±13.58	70.53±18.54	0.094
RF	66.48±14.21	63.80±8.39	0.593	69.42±9.88	58.87±14.80	0.0.57
BF	81.39±23.30	71.37±18.40	0.231	80.45±22.22	77.68±18.61	0.695
ST	92.41±15.22	76.56±22.31	0.028*	81.17±14.80	74.35±15.59	0.166
GM	62.60±15.92	56.95±16.73	0.346	64.03±12.07	60.49±16.58	0.621

DISCUSSION

The results showed that the median frequency of tibia anterior muscle in the ACL group during propulsion phase in the rear-foot strike-running pattern was greater compared to the healthy group**.** People who experience an ACL injury are at higher risk of developing osteoarthritis in the knee. Arthritis may occur even if you have surgery to reconstruct the ligament. The prognosis of ACL injury is generally good, with many people regaining function of the injured leg within months. ACL injury used to be a career-ending injury for competitive athletes; however, in recent years ACL reconstruction surgery followed by physical therapy has allowed many athletes to return to their pre-injury level of performance. Long-term complications of ACL injury include early onset arthritis of the knee and or re-tearing the ligament. Factors that increase risk of arthritis include severity of the initial injury, injury to other structures in the knee, and level of activity following treatment. Not repairing tears to the ACL can sometimes cause damage to the cartilage inside the knee because with the torn ACL, the tibia and femur bone are more likely to rub against each other. Multiple factors likely influence the risk of arthritis, such as the severity of the original injury, the presence of related injuries in the knee joint or the level of activity after treatment. The median frequency of semitendinosus muscle in the propulsion phase in mid-foot running patterns in the ACL group was greater compared to the healthy group. Also, the median frequency of semitendinosus muscle in the loading response phase in forefoot running pattern in the ACL group was higher compared to the healthy group. Lower frequency spectrum in during a continuous contraction indicates muscle local fatigue [17]. Reisberg et al. [18] showed that in people with ACL injury, there is a functional violation in the knee of these people, which is compensated by an increase in the movement of the ankle and hip joints [19]. Ristanis et al. [20] showed that people with ACL injury have greater rotational mobility in tibia anterior muscle when running than healthy people. The tibia anterior muscle is one of the most important muscles during the propulsion phase of running [21, 22]. The semitendinosus muscle is also one of the muscles that plays an important role in bending and rotating the knee joint [23]. People with ACL injury appear to have caused changes in the median frequency of the semitendinosus and tibia anterior muscles due to reduced knee rotation restriction and increased knee strength in the propulsion phase [24]. The biomechanical changes caused by ACL injury affect the joint hip, the mechanical efficiency of the muscles, and the neuromuscular control of the lower limbs during running. It can be said that one of the reasons for the increase in semitendinosus and tibia anterior muscles activity during the loading response phase during the rear-foot and forefoot strike running pattern in the ACL group could be changes in muscle mechanical efficiency, excessive rotation and flexion of the knee joint. The present study has some limitations such as lack of female gender in the statistical sample and self-selection speed while running. On the other hand, lack recording of kinematics and kinetics were another limitations of this study.

CONCLUSION

According to the research results, it can be stated increased agonist and antagonist muscle activity across different running patterns increase the risk of secondary injury in people with ACL injury. Therefore, it is recommended to try to minimize this injury by using the best running pattern and providing appropriate exercises.

Author Contributions: Conceptualization, methodology, APG; formal analysis, AAJ, MAD; investigation, MAD; resources, AMG; data curation, AAJ, MAD; writing—original draft preparation, AAJ, MAD; writing—review and editing, APG, AAJ, MAD; supervision, APG; project administration, AAJ. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The protocol of this study was approved by Research Ethics Committees of Ardabil University of Medical Sciences.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available at request.

Acknowledgments

The authors are thankful to all the participants and their coaches for their participation in this study.

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تعیین طیف فرکانس الکترومایوگرافی منتخبی از عضلات اندام تحتانی در مردان فوتبالیست دارای آسیب ACL طی سه الگوی دویدن

آمنه پوررحیم قورقچی*[1]، امیرعلی جعفرنژادگرو[2]، محمد عبدالله پور درویشانی[3]

۱.گروه فیزیولوژی ورزشی، دانشکده علوم تربیتی و روانشناسی، دانشگاه محقق اردبیلی، اردبیل، ایران.

۲.گروه مدیریت و بیومکانیک ورزشی، دانشکده علوم تربیتی و روانشناسی، دانشگاه محقق اردبیلی، اردبیل، ایران.

۳. گروه مدیریت و بیومکانیک ورزشی، دانشکده علوم تربیتی و روانشناسی، دانشگاه محقق اردبیلی، اردبیل، ایران.

چکیده:

هدف از پژوهش حاضر بررسی طیف فرکانس الکترومایوگرافی منتخبی از عضلات اندام تحتانی در افراد دارای آسیب ACL طی سه الگوی مختلف دویدن بود. ۱۴ نفر فوتبالیست دارای آسیب ACL و ۱۴ نفر فوتبالیست سالم داوطلب شرکت در پژوهش شدند. با استفاده از یک سیستم الکترومایوگرافی بدون سیم با ۸ جفت الکترود سطحی دو قطبی برای ثبت طیف فرکانس الکترومایوگرافی طی سه الگوی دویدن استفاده شد. نتایج نشان داد فرکانس میانه عضله درشت نئی قدامی در مرحله پیش‌روی در الگوی دویدن پاشنه-پنجه در گروه آسیب در مقایسه با گروه سالم بیشتر بوده است (p= ۰/۰۲۴). فرکانس میانه عضله نیمه‌وتری در مرحله پیش‌روی در الگوی دویدن میانه‌ی اتکا در گروه آسیب در مقایسه با گروه سالم بیشتر بوده است (p= ۰/۰۴۴). همچنین فرکانس میانه عضله نیمه‌وتری در مرحله بارگذاری در الگوی دویدن پنجه-پاشنه در گروه آسیب در مقایسه با گروه سالم بیشتر بوده است (p= ۰/۰۲۸). با توجه به نتایج تحقیق، می‌توان گفت احتمالا افزایش فعالیت عضلات موافق و مخالف طی الگوی‌های مختلف دویدن احتمال آسیب‌ای ثانویه در افراد دارای سیب ACL را افزایش دهد.

واژه های کلیدی: الکترومایوگرافی، دویدن، رباط صلیبی قدامی، طیف فرکانس