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The Effect of Foot Deformities on the Electrical Activity of Selected Lower Limb Muscles During Jumping and Landing

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ABSTRACT

Introduction: Deformities of the foot are among the factors that affect the normal function of the foot in various movements and tasks. The purpose of this research was to determine the effect of foot deformities on the electrical activity of selected lower limb muscles during jumping and landing activities.

Methods: Forty-five participants were selected voluntarily. Based on the entry and exit criteria, the subjects were divided into groups of fifteen people, including normal feet, flat feet, and cave feet. The navicular drop index was used to divide the groups. The electrical activity of the muscles of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and biceps femoris (BF) was measured during jumping and landing. A 30 cm-high jumping platform was used to perform the double-leg jump landing task. A one-way analysis of variance test was used to compare the data. A significance level of 0.05 was also considered.

Results: The results showed significant feedforward activity of the vastus lateralis and rectus femoris muscles between normal, cave foot, and flat feet. Also, there was a significant difference between the feedback activity of the rectus femoris, semitendinosus, and biceps femoris muscles between the three groups of normal, cave, and flat feet.

Conclusion: According to the results, cave foot and flat foot may be associated with altered activation patterns of knee stabilizers and increase the risk of injuries in the knees during double-leg jumping and landing.

KEYWORDS
Electromyography, Foot deformity, Jumping

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Introduction

The foot is the main part of the interaction between the body and the ground because it is responsible for three main functions: absorbing impact forces, maintaining balance, and transferring propulsion forces (1). The foot shows more structural changes than other parts of the human body. One of the most important and variable structural features of the foot is the height of the internal longitudinal arch when bearing weight because the main function of the arch is to absorb the reaction forces of the ground when performing sports skills where the body's weight is on the foot (2). The abnormal position of the foot due to the decrease or increase in the height of the arch is a predisposing factor and causes the dysfunction of the foot in the lower limb (2). Therefore, examining the structure of the foot with the aim of its effective performance during sports activities is very important. Deformities of the foot are among the effective factors in the normal functioning of the foot in various movements and tasks (3). Meanwhile, flat and cave feet are two of the most common deformities of the lower limbs, which are usually associated with pain in the foot area and a decrease in the normal foot function, which can negatively affect people's athletic ability (4,5). A certain amount of pronation and supination of the subtalar joint is necessary for movement activities to provide direct and indirect shock absorption, improve the efficiency of muscle contraction, and help maintain balance and normal distribution of forces in the movement chain of the lower limb. Excessive or limited amounts of these movements can lead to the production of abnormal forces in the movement chain of the lower limbs, knee, pelvis, and lumbar spine. (6,7).

Excessive supination of the subtalar joint in people with cave feet can increase force absorption during landing, increase the activity of the dorsiflexor muscles, and decrease the activity of the peroneal muscles. Excessive pronation of the subtalar joint in people with flat feet reduces the activity of the dorsiflexor muscles and increases the activity of the peroneal muscles (8). Excessive supination and pronation cause internal and external rotation of the tibia, which in turn causes a change in the alignment of the knee in the frontal plane (9,10). Previous studies have shown that foot deformities can lead to impaired postural control, impaired pressure on the feet, soft tissue injuries to the lower limbs, and altered mobility of the ankles, which in turn can lead to changes in the activity pattern of the knee joint muscles (11,12). The knee joint is exposed to many injuries due to its position in the middle of the lower body and its role as a force transmitter from the pelvic girdle to the ground and vice versa from the foot and ankle to the pelvis (13). The muscles around this joint are largely responsible for the dynamic stability of the knee. Therefore, foot deformities can secondarily alter the function of the muscles around the knee, affecting the stability of the knee and making the joint susceptible to injury (14,15). The quadriceps, hamstrings, and gastrocnemius muscles are considered the most important stabilizers of knee dynamics. Any factor that disrupts the function of the neuromuscular system can expose the knee. As mentioned above, foot deformities can cause a change in the neuromuscular function of the muscles around the knee and expose this joint to damage (16,17).

The study of the effect of foot deformities on lower limb muscle activity is important because it can further explain the neuromuscular and biomechanical function of the lower limb during double-leg jump landing, and the existence of this information, considering the relatively high prevalence of lower limb injuries in sports involving landing and the severity of these injuries, shows the necessity of creating a preventive training program even more. According to the explanations given, if the deformities of the feet cause changes in the electrical activity of the muscles, the possibility of injury in people increases, and to prevent the occurrence of injury, it is necessary to carefully and comprehensively examine the abnormal condition of the foot on the function of the lower limbs to design a program. Appropriate treatment and rehabilitation are emphasized. Therefore, the purpose of this study was to investigate the effect of foot deformities on the electrical activity of selected lower limb muscles during jumping and landing activities.

Material and Methods

Participants

The statistical sample of the current study comprised active female university students aged 20–25 years who were selected from the statistical population based on the inclusion and exclusion criteria. Forty-five qualified subjects were considered as subjects in three groups of fifteen subjects with normal feet, flat feet, and cave feet. The sample size was determined using the G-Power program (version 3.1.3). The sample size was achieved with a significance level of 0.05, an effect size of 0.8, and a power of 0.95. Inclusion criteria for the study included abnormal body mass index (outside the range of 25 and below 18), no history of ankle sprain in the past year, no history of functional instability of the ankle, no history of fracture or surgery on lower limb joints, no history of ligament or meniscus damage in the knee, and no history of the lower limb rehabilitation program in the past six months (18). Exclusion criteria included lack of subject satisfaction, unwillingness to continue with the research process, and injury and pain during the research process.

Measuring navicular drop

The specific criteria for entering the research for the flat foot group was a navicular drop of 10 mm or more, and for the cave foot group, a navicular drop of 4 mm or less in navicular drop test (19,20). The range between 5 and 9 mm was considered normal for a foot (21,22). This test has internal and external reproducibility (0.73-0.83) and validity (0.61-0.89) compared to radiographs (23,24). To perform this test, the subject is asked to sit on a chair with bare feet and place his foot on the box. The seat height was adjusted so that the angles of the thigh and knee were 90 degrees. In this state, the hip joint should not have any abduction or adduction and should be in a normal position. The examiner places his thumb and index finger on the front edge of the fibula and the front and lower parts of the inner ankle and touches the inner and outer edges of the talus. In the neutral position of the foot, the subject identifies and marks the location of the navicular tuberosity. Then, using a ruler, the distance from the navicular tuberosity to the surface of the box was measured in millimeters. The subject was asked to stand in such a way that the weight was distributed on both legs. In this case, the distance of the navicular tuberosity to the ground was measured and recorded (20).

Measurement of EMG

An 8-channel neuro-style device with sampling frequency of 2000 Hz, band width of 10–500 Hz/3dB and common mode rejection ratio of 110 dB in differential amplifier was used. In order to record the selected muscles of the knee joint, disposable electrodes were used, the diameter of the central part of which was one centimeter. To determine the exact location of the connection of the electrodes, touching the bone landmarks and the maximal isometric contraction of the muscles were used, and then the electrodes were glued to the skin and in line with the muscle fibers. To collect the electrical activity of the muscles, surface electrodes after skin preparation (cleaning the skin with cotton soaked in medical alcohol), to reduce the skin resistance, on the rectus femoris muscles (50% of the distance between the superior cruciate ligament and the patella), vastus lateralis (50% of the distance between the greater trochanter of the femur and the external epicondyle of the femur), vastus medialis (lower 20% of the distance between the anterior superior iliac spine and the inner space of the knee joint), biceps femoris (between the line that connects the middle of the gluteal fold to the knee), semitendinosus (at the 50% point of the line between the ischium and the inner part of the tibial epicondyle), based on previous studies, was installed according to the European SENIAM protocol (25,26). The center-to-center distance of the electrodes was 2 cm, and the ground electrode was installed on the tibia. First, a 10-500 Hz bandpass Butterworth filter was used to filter the data. To distinguish between the feedforward and feedback phases, a time window length of 100 milliseconds was considered (27). The feedforward phase was considered in a time range of 200 ms (from 160 ms before first foot contact with the ground to 40 ms after contact). The feedback phase was considered in a time range of 100 ms (from 40 to 140 ms after contact) (28). Then the RMS of the electromyography signal was taken. The average electromyographic signal was calculated during the feedforward and feedback phases. By dividing muscle activity by MVIC and multiplying by 100, the percentage of muscle activity was calculated. All electromyography data were analyzed using the MATLAB 2014 software (29).

Procedure

In the present research, a 30 cm-high jumping platform was used to perform the double-leg jump landing task. Since neuromuscular control defects are identified when landing from a height of 30 cm or more, a box with this height was also used in this research (30). It should be noted that the jump box was built with a height of 30 cm and a length and width of 80 x 40 cm. The double-leg jump landing task was used in this research because it is a reliable method to analyze the factors that influence lower limb injuries (30). The test was that, after standing on a 30-cm box and placing his hands on the top of his iliac, the person was asked to bend his legs from the knees and slowly jump up 5 cm, then land with both feet and bent knees on the ground. Hold this position for 3 seconds to return to the standing position. The average of three correct repetitions was used to calculate the muscle electromyography indices. To detect the moment of separation of the feet from the box and the moment of contact between the heel and the toe, two-foot switches placed under the heel and the lower surface of the thumb were used (31).

Statistical Analysis

In this study, the Shapiro-Wilk test was used to check the normal distribution of the data. A one-way analysis of variance was used to compare the results obtained in three groups, and Tukey's post hoc test was used to calculate the differences between groups with a significance level of 0.05. All data were analyzed using SPSS version 24 software.

Results

The demographic characteristics of the subjects are shown in Table 1. The statistical analysis indicated no significant differences in age, height, weight, and BMI between the subjects. The results of muscle activity in the feed-forward phase during the double-leg jump-landing are shown in Table 2. The results showed that there was a significant difference in the amount of feedforward activity of the vastus lateralis and rectus femoris between the three groups of normal, cave, and flat feet during the double-leg jump landing ($p \leq 0.05$). There was no significant difference between the feedforward activity of the vastus medialis, semitendinosus, and biceps femoris between the three groups ($p \leq 0.05$).

Table 1. Demographic characteristics of the subjects

Group	Age (years)	Hight (cm)	Mass (kg)	BMI (kg/m^2)	Navicular drop (mm)
Normal	23.2±2.6	165.5±2.2	60.7±2.6	22.1±2.2	6.3±1.6
Flat	22.2±2.7	167.6±3.3	59.8±2.2	22.1±2.4	10.4±0.8
Cave	23.3±1.1	169.7±2.1	61.7±4.2	22.2±2.3	2.7±1.5

Note. BMI: body mass index

Table 2. The result of the one-way analysis of variance (ANOVA) test in examining the feedforward activity of the muscles during the double-leg jump-landing. (*=$p \leq 0.05$)

Muscles %mvic	Normal	Flat	Cave	F	Sig
L	45.1±12.3	62.1±3.6	58.1±15.5	9.05	0.001*
VM	61.1±13.7	63.1±14.6	59.3±17.2	1.02	0.411
RF	28.5±6.4	27.6±15.1	21.5±8.2	3.17	0.014*
ST	19.5±14.2	17.4±6.7	22.7±9.1	0.69	0.514
BF	18.5±13.3	21.1±8.4	19.3±8.5	0.64	0.756

Note. VL=vastus lateralis, VM=vastus medialis, RF=rectus femoris,

ST=semitendinosus, Bf=biceps femoris, maximum voluntary isometric contraction

The results of Tukey's post hoc test for the feedforward activity of the vastus lateralis and rectus femoris are shown in Table 3. As seen, the feedforward activity of the vastus lateralis muscle in the flat foot group was significantly higher than the cave foot group ($p=0.03$), and the amount of feedforward activity of the vastus lateralis muscle in the normal foot group was significantly higher than the cave foot group ($p=0.015$). However, no significant difference was observed between the activity level of this muscle in the two normal and flat foot groups ($p=0.49$). There was no significant difference in the feedforward activity of the rectus femoris between the two groups of flat and cave foot ($P=0.59$), but the feedforward activity of the rectus femoris muscle in the normal foot group was significantly higher than that of the cave foot ($p=0.036$), but no significant difference was observed between the activity level of this muscle in the two normal and flat groups ($P=0.066$).

Table 3. The result of Tukey's test in examining the amount of feedback activity of VL and RF muscles during the double-leg jump-landing (Variables that are significantly different from each other are marked with)

Muscles	Group(i)	Group(j)	Mean (i-j)	SD	Sig
VL	Normal	Flat	-6.7	4.7	0.494
	Normal	Cave	15.2	4.6	0.015*
	Flat	Cave	18.7	4.9	0.003*
RF	Normal	Flat	1.2	1.6	0.664
	Normal	Cave	6.2	2.4	0.036*
	Flat	Cave	5.3	2.8	0.059

Note. VL=vastus lateralis, RF=rectus femoris,

The results of muscle activity in the feedback phase during the double-leg jump landing are shown in Table 4. The results showed that there was no significant difference in the amount of vastus medialis and vastus lateralis muscle feedback activity among the three groups during the double-leg jump landing ($p \leq 0.05$). However, there was a significant difference between the feedback activity of the rectus femoris, semitendinosus, and biceps femoris muscles between the three groups of normal, cave, and flat feet during the double-leg jump landing ($p \geq 0.05$)

Table 4. The result of the one-way analysis of variance (ANOVA) test in examining the feedback activity of the muscles during the double-leg jump-landing (*=$p \leq 0.05$)

Muscles %mvic	Normal	Flat	Cave	F	Sig
VL	66.1±14.2	62.2±12.3	61.2±11.7	1.03	0.598
VM	66.2±12.3	61.2±17.4	62.3±18.2	0.42	0.842
RF	50.2±16.7	38.2±11.8	56.2±17.5	0.56	0.011*
ST	34.5±5.2	29.8±7.1	38.6±6.9	5.9	0.025*
BF	24.8±2.5	29.1±2.3	37.1±3.4	5.13	0.022*

Note. VL=vastus lateralis, VM=vastus medialis, RF=rectus femoris,

ST=semitendinosus, Bf=biceps femoris, mvic= maximum voluntary isometric contraction

The results of Tukey's follow-up test of the feedback activity of the rectus femoris muscle, semitendinosus, and biceps femoris are shown in Table 5. There was no significant difference in the level of feedback activity of the rectus femoris in the flat and cave foot (p=0.54), but the level of feedback activity of the rectus femoris muscle in the cave foot group was significantly higher than in the normal foot (p=0.038). No significant differences were observed between the activity levels of this muscle in the two groups of normal and flat foot groups (p=0.146). The amount of feedback activity of the semitendinosus muscle in the cave foot group was significantly higher than the normal foot group (p=0.028), and the feedback activity of this muscle in the cave foot group was significantly higher than the flat foot group (p=0.03). There was no significant difference between the activity level of the semitendinosus muscle in the two normal and flat feet (p=0.62). The amount of feedback activity of the biceps femoris muscle in the cave foot was significantly higher than the normal foot group (p=0.23). The feedback activity of the biceps femoris muscle in the cave foot group was significantly higher than the flat foot group (p=0.041), but no significant difference was observed between the activity of this muscle in the normal and flat foot groups (p=0.69).

Table 5. The result of Tukey's test in examining the amount of feedback activity of RF, SM and BF muscles during the double-leg jump-landing (Variables that are significantly different from each other are marked with*)

Muscles	Group(i)	Group(j)	Mean (i-j)	SD	Sig
RF	Normal	Flat	-15.1	2.2	0.146
	Normal	Cave	-16.5	3.3	0.038*
	Flat	Cave	-8.1	4.7	0.54
ST	Normal	Flat	2.6	4.1	0.62
	Normal	Cave	-12.5	5.7	0.028*
	Flat	Cave	-10.6	4.9	0.03*
BF	Normal	Flat	-0.28	5.3	0.69
	Normal	Cave	17.1	2.2	0.023*
	Flat	Cave	-15.3	3.8	0.041*

Note. RF=rectus femoris, ST=semitendinosus, Bf=biceps femoris

Discussion

The present study investigated the effect of foot deformities on the electrical activity of selected lower limb muscles during jumping and landing. In this study, the results showed that during the feedforward phase, the activity of the vastus lateralis muscle in the flat foot group was significantly higher than in the cavus foot group. Additionally, the activity of the vastus lateralis and rectus femoris muscles in the normal foot group was significantly higher than in the cavus foot group. During the feedback phase, the activity of the rectus femoris, semitendinosus, and biceps femoris muscles in the cavus foot group was significantly higher than in the normal foot group. Moreover, the activity of the semitendinosus and biceps femoris muscles during the feedback phase in the cavus foot group was significantly higher than in the flat foot group. The present study is the first study on the effect of foot deformities on knee muscle activity during the double-leg jump landing, and no similar study was found to compare the results. The double-leg jump landing is one of the most common sports movements that can generate an impact force of 2 to 12 times body weight. The increase in impact forces during landing and the repetition of these forces provide the basis for the structural damage to the soft tissue around the lower limb joints (32). During weight-bearing activities (such as landing), the lower limbs are largely responsible for the body's ability to absorb force when the foot contacts the ground. Before contact with the ground, the muscles of the lower limbs are activated feedforward to absorb the contact forces after landing. After contact with the ground, the muscles try to absorb the forces on the body with their outward contraction (31). The inability of the body to produce eccentric contractions by the muscles of the lower limbs significantly increases the ground reaction forces and the time to reach stability (30).

In this study, there was a significant decrease in the activity of the vastus lateralis muscle in the feedforward phase of subjects with cave foot deformities compared to subjects with normal feet. Subjects with cave foot generally experience secondary effects such as outward rotation of the tibia and varus of the knee, as a result of which the line of force changes from the center of the knee to the inner part, and the load on the internal compartment increases and causes the line of gravity to move inward (33). With the decrease in the activity of the vastus lateralis muscle in subjects with cave foot, probably due to the change in the length-tension relationship of these muscles, a lower amount of anterior shear force is applied to the tibia during landing, and as a result, the anterior shear force is reduced (34). In this research, the vastus lateralis muscle activity level in subjects with cave foot deformity in the feedforward phase was lower than in subjects with flat feet. Probably due to the change in valgus shape in the knee joint of subjects with flat feet, more activity of the vastus lateralis muscle is needed to support the inner surface and the internal ligamentous structure of the knee during landing (35). Because increasing the activity of this muscle causes abduction torque in the knee joint and prevents the increase of valgus and injury with a protective mechanism, this increase in muscle activity in the flat foot group increases the shear force and anterior knee movement and increases the risk of the knee injury (36).

The semitendinosus and biceps femoris muscles in the feedforward phase did not show significant differences between the three groups. This issue can be due to the absorption of force using the quadriceps muscles at this stage of landing, which did not affect the hamstring muscles. As a result, the absorption of force by these muscles did not happen. There was no significant difference between any of the studied groups in the feedback phase of the vastus lateralis and vastus medialis muscles. Due to the lack of a similar study in this field, it was not possible to compare the current results and understand the cause-and-effect relationships.

The activity of the rectus femoris muscle of subjects with cave foot deformities compared to subjects with normal and flat feet decreased significantly in the feedforward phase, and in the feedback phase, the activity of this muscle in subjects with cave foot deformities was significantly higher than that of subjects with normal feet (37). Subjects with cave feet generally experience secondary effects such as outward rotation of the tibia and knee varus (38). A change in the direction of the lower limb in subjects who have any kind of abnormality in their body causes the biomechanical relations of the muscle to change, such as its length-tension and force-speed relations, and it will affect the way it works, and as a result, the forces. It will have a direct effect on the knee ligaments. This muscle, like other quadriceps muscles, exerts a shearing force on the tibia, and if its activity decreases, this force will decrease and less stress will be applied to the knee joint (39).

In the feedback phase, the activity of the semitendinosus and biceps femoris muscles was significantly higher in subjects with cave foot deformities than in subjects with normal and flat feet. Lee et al. (1999) and Williams et al.(1999) concluded that there is a relationship between hamstring muscle and anterior shear force (5,40). That is, with the increase in the activity of the hamstring muscle, the anterior shear force decreases. In the current study, all three groups had increased activity in the semitendinosus muscle in the feedback phase, with the difference that the cave foot group showed a greater increase compared to the other two groups, which could be due to the change in the biomechanical structure of the lower limb muscles, and this increase caused a reduction in the shear force on the tibia and a reduction in the risk of the knee joint injury (41). The results of Withrow et al. (2008) showed that increasing the hamstring muscle force during knee flexion in the jump-landing movement significantly reduces the maximum strain on the knee joint ligaments (42). These researchers stated that when a jump landing occurs, a large anterior shear force by the quadriceps muscle moves the tibia forward. The reduction of this force is explained by the increased tension of the hamstring, which itself helps to limit the strain on the knee joint when the load (42). Although knee alignment was not measured in the current study, it is expected that biomechanical events during the landing sequence may have influenced muscle function. In the present study, there were limitations such as the lack of kinematic and kinetic information for accurately interpreting the results and assessing the effect of foot deformities on joint kinematics and kinetic in the lower limbs. Another limitation of the present research is the nature of the research method. Because this research was a cross-sectional study, it is necessary to conduct longitudinal and prospective studies to clarify the effect of observed changes on athletes' performance and injuries. Additionally, this study utilized a surface electromyography device. The results of this type of measurement of muscle activity may be influenced by the activity of other muscles or environmental noise.

Conclusion

The electrical activity of the muscles of people with cave feet during the feedforward and the feedback phase was higher than that of other groups. According to the results of this study, it can be stated that during activities such as jumping and landing, people with cave feet are more at risk of ligament and joint injuries than those with flat feet. The foot deformity leads to altered muscle activity during the feedforward and feedback phases of jumping and landing tasks. These changes can affect knee alignment and increase the risk of knee joint injuries. Therefore, it is recommended that individuals with these issues engage in corrective exercises and use orthotics to improve knee mechanics and prevent changes in muscle activity during activities such as jumping and landing.

Ethical Considerations:

Compliance with ethical guidelines

The Research Ethics Committee of Hamedan University of Medical Sciences approved the study (IR.BASU.REC.1403.014), and all participants provided informed consent. The research was conducted in accordance with the Declaration of Helsinki and adhered to all relevant guidelines and regulations.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

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«مقاله پژوهشی»

تاثیر پاسچر پا بر فعالیت الکتریکی عضلات منتخب اندام تحتانی حین فعالیت پرش و فرود دختران جوان

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چکیده

هدف: ناهنجاری‌های پا از جمله عواملی هستند که بر عملکرد طبیعی پا در حرکات و فعالیت‌های مختلف تاثیر می‌گذارد. هدف از این تحقیق بررسی ناهنجاری پا بر فعالیت الکتریکی عضلات منتخب اندام تحتانی حین فعالیت پرش و فرود بود.

روش شناسی: چهل و پنج شرکت کننده به صورت داوطلبانه انتخاب شدند. بر اساس معیارهای ورود و خروج، آزمودنی ها به گروه های ۱۵ نفری شامل کف پای نرمال، صافی کف پا و کف پای غاری تقسیم شدند. برای تقسیم گروه ها از شاخص افت ناوبری استفاده شد. فعالیت الکتریکی عضلات راست رانی، پهن خارجی، پهن داخلی، نیمه تری و دوسر ران طی پرش و فرود اندازه‌گیری شد. برای انجام وظیفه فرود پرش دو پا از سکوی پرش به ارتفاع ۳۰ سانتی متر استفاده شد برای مقایسه داده ها از آزمون تحلیل واریانس یک طرفه استفاده شد. سطح معنی داری ۰/۰۵ نیز در نظر گرفته شد.

نتایج: نتایج نشان داد تفاوت معنی داری در فعالیت فید فورواردی عضلات راست رانی و پهن خارجی بین گروه کف پای نرمال، گود و صاف وجود دارد. همچنین بین فعالیت فیدبکی عضلات راست رانی، نیمه وتری و عضله دو سر رانی بین سه گروه کف پای نرمال، گود و صاف تفاوت معناداری وجود داشت.

نتیجه گیری: با توجه به نتایج، ناهنجاری کف پای گود و کف پای صاف ممکن است با تغییر الگوهای فعال سازی عضلات تثبیت کننده زانو مرتبط باشد و خطر آسیب دیدگی در زانوها را در هنگام پرش و فرود با دو پا افزایش دهد.

واژه‌های کلیدی

پاسچر پا، پرش–فرود، فعالیت الکتریکی

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