Research Paper

Effect of Double-density Insoles on Muscle Activity Frequency During Running and Side Cutting in Adolescent Volleyball Players

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ABSTRACT

Purpose: Volleyball is a complex sport with specific muscular demands and a variety of explosive physical characteristics. The present study aimed to examine the effect of double-density insoles on the frequency of muscle activity during running and side cutting in volleyball players.

Methods: This quasi-experimental study was conducted with 30 teenage boys and girls, divided into two groups of 15 participants. The electrical activity of seven lower limb muscles was recorded during six running attempts and lateral sliding attempts using a biometric 8-channel electromyography device with 2-pole surface electrodes, according to the SENIAM European protocol.

Results: The results revealed that double-density insoles significantly influenced the frequency of BF muscle activity during running (P=0.045, d=0.136). Group differences significantly affected the frequency of tibialis anterior (TA) muscle activity (P=0.027, d=0.163) and vastus medialis (VM) muscle activity (P=0.006, d=0.239) during lateral sliding. Additionally, the interaction between double-density insoles and group classification significantly influenced semitendinosus (ST) muscle activity during lateral sliding (P=0.037, d=0.146), with boys showing increased ST activity but not girls.

Conclusion: The use of double-density insoles at the frequency of the biceps femoris (BF) muscle can prevent anterior cruciate ligament (ACL) damage and acute muscle injuries during running. At the frequency of the ST muscle during sliding, it can be effective in preventing genu varum injury in volleyball players.

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Highlights

• Double-density insoles positively affect the performance of the BF muscle, reducing the load during running, preventing knee ligament injuries, and improving muscle function efficiency.

• The double-density insole increases the efficiency of the ST muscle in preventing genu varum injuries in teenage volleyball players.

• Double-density insoles strengthen the hamstring muscles during running and movement in young volleyball players, improving their skill performance.

• There are sex-specific effects on the TA and VM muscles in terms of muscle activity and mechanical knee stability in volleyball players.

Plain Language Summary

Muscles help distribute and absorb dynamic loads during running in the lower limbs. Volleyball's nature often causes muscle strength imbalances and reduced hip joint range of motion between limbs, leading to lower limb injuries. Orthotic aids, such as shoe insoles, are commonly used to prevent injuries and muscle dysfunction in athletes. Different muscle contraction patterns in running and lateral cutting movements can lead to soft tissue injuries. This study involved 30 male and female volleyball players from Ardabil city, Iran, aged 12–17, with 1–8 years of volleyball experience and no history of injuries. Electromyography (EMG) was used to record the activity of seven lower limb muscles: Tibialis anterior (TA), gastrocnemius medialis (Gas-M), vastus lateralis, vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), and semitendinosus (ST). Participants performed running and lateral cutting movements three times each, with and without double-density insoles, across an 18-meter track equipped with a force plate. Statistical analysis using a two-way analysis of variance with repeated measures showed significant effects of double-density insoles. These insoles significantly influenced BF activity during running (P=0.045, d=0.136) and ST activity during lateral cutting (P=0.037, d=0.146). Findings suggest that double-density insoles improve lower limb muscle activity and may help prevent knee ligament injuries, muscle inefficiency, and genu varum in teenage volleyball players.

Introduction

Volleyball is a complex sport with specific muscular demands that have a variety of explosive physical characteristics and asymmetric movement skills [1]. Plyometric runs of volleyball players are used to shorten the stretching cycle and the capacity of nerve and muscle activity [2, 3]. Previous studies have reported the kinematics and activation of lower limb muscles in volleyball players. The knee may be the primary site of post-fatigue strength reduction, and biodynamic compensation occurs in the kinematics and muscle activation of the knee muscles, which exhibit lethal mechanical properties [4]. Recent studies on the adaptation of muscles and tendons in adolescent volleyball athletes have investigated electromyographic activity in the quadriceps muscles of adolescents, where knee extensor moments are significantly produced. Tendon stiffness is higher and tendon stress is higher during maximal contractions, which may result in tendon overuse injuries [5]. Ismailia mentioned that fatigue can cause changes in the muscle timing mechanism, which is the nervous system's effort to reduce the risk of injury to the body [6]. Lateral cutting includes different movements, such as multi-directional accelerations, quick changes, and diverse muscle movement patterns with varying frequencies in volleyball [7]. The ratio of activity of hamstring muscles to quadriceps in the stopping phase of the lateral cut maneuver is lower than in the lateral movement phase [8-12]. Mesa man pointed out that specific loading in volleyball can be a primary determinant of greater stiffness in tendons and an imbalance between muscle strength and the mechanical properties of tendons in lower limb muscles [5, 13]. Soleimani . point out that the nature of volleyball leads to an imbalance in muscle strength and range of motion of the hip joint between the two limbs, which can result in the lower limb injuries [14-16]. Some studies suggest that volleyball players, due to physical activity and muscle strengthening, exhibit good posture and a strong skeletal structure [5, 13]. However, in terms of motor skills, the nature of each discipline led to more effectiveness and better performance in certain parameters. Volleyball players also had more explosive power than basketball players; however, no significant difference was observed in strength and muscular endurance between the two groups due to the nature and characteristics of their respective sports fields. Variation in the types of insole construction can result in different effectiveness and changes, such that a change in the material of the insole is accompanied by changes in the amount of oxygen consumed, the level of muscle activity, and the frequency of muscle signals [17]. Changes in muscle activation from the sole conditions in the foot strike pattern may have a more dominant effect on muscle activation [18]. The double-density sole features an eight-degree slope from the inside to the outside, resulting in a different stiffness. Due to the unique nature of volleyball and its effects on muscle movement, it results in distinct patterns of muscle activity during competition and training. The different muscle contraction patterns involved in running and lateral cutting movements may lead to soft-tissue injuries in the lower limb muscles. To date, the use of insoles has not been investigated about the frequency of muscle activity during lateral cutting movements in volleyball players, and there are limited studies on running movements. This specialized research focuses on identifying changes in double-density soles to prevent muscle injuries and enhance training goals, ultimately increasing optimal muscle activity performance in volleyball players. The question has always been whether muscle activity changes during running and side-cutting movements in volleyball players when using insoles. Therefore, this study aimed to investigate the effect of double-density soles on the frequency of muscle activity during running and side-cutting movements in volleyball players.

Materials and and Methods

The clinical trial was conducted in 2024 in Ardabil City. This study was quasi-experimental and practical. The statistical population of the research included boys and girls with an average age of 14 years who had been involved in volleyball for a period of 1 to 8 years and participated in various levels of competitions throughout the city, province, and country. The statistical sample of the research consisted of 30 female and male volleyball players from Ardabil City volleyball centers, randomly divided into two groups of 15 each. The ball-kick test was used to determine the superior foot. The participants performed three runs and three sliding movements with double-density soles, and three runs and sliding movements without double-density soles, at an 18-meter distance located in the middle of the force plate, in accordance with the specified time. G*Power software, version 3.1.9.7 was used to determine the sample size [19]. The inclusion criteria included an age between 12 and 17 years, history of 1 to 8 years of volleyball activity, and participation in various levels of volleyball competitions at the city, province, and country, with no history of lower limb injuries. The exclusion criteria included players with neurological dysfunction, previous work-related surgical or structural problems, and lower limb injuries.

Instruments and examination

An electromyography (EMG) instrument was used to measure the frequency spectrum. One of the variables obtained from EMG data is the frequency spectrum. The frequency spectrum of the EMG signal indicates the firing rate at the neuromuscular junction, which is measured using the frequency spectrum index. Considering that the muscle frequency spectrum curve is skewed to the right, the best central index represents this variable [20]. The electrical activity of seven lower limb muscles was recorded using an eight-channel biometric electromyography device with two-pole surface electrode. Electrodes were placed on the tibialis anterior (TA), gastrocnemius medialis (Gas-M), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), and semitendinosus (ST), muscles by SENIAM European protocol [21]. The quadriceps muscles are the primary source of shock absorption, and the hamstring muscles, which are involved in hip extension and knee flexion, are associated with knee injuries. In runners, these injuries are often affected by the radius of the injury.

The distance from the center to the center of the electrode was equal to 2 cm. The sampling frequency was equal to 1000 HZ, low-pass and high-pass filters were equal to 500 and 20 HZ, respectively, and a notch filter equal to 50 HZ was used to smooth the raw EMG data (to target urban electricity noise), and the device's sampling rate was 1000 [22]. Maximum voluntary isometric contraction (MVIC) was assessed to normalize EMG during running relative to MVIC. EMG signals were recorded using a portable Wi-Fi transmitter with 1000 Hz analog-to-digital conversion, 16-bit resolution, and a 5-volt range. The signals were filtered using a band-pass filter with a frequency range of 10 to 500 Hz and an input impedance >10 Ω. Before starting the test, the location of each electrode on the body was determined, and after shaving, it was completely cleaned using alcohol disinfecting pads. To determine the different phases of movement during running and lateral sliding, a force plate device with a sampling frequency of 1000 Hz was used, along with a sync EMG device. Thus,

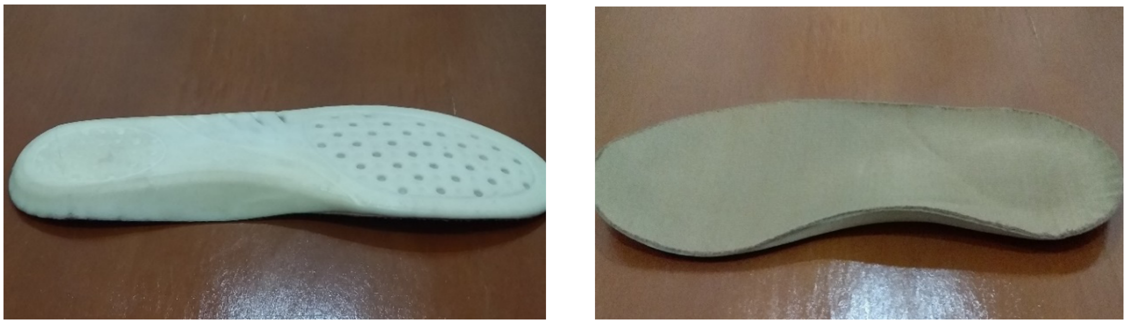

Figure 1. Double density insole

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the contact moment of the heel was determined by identifying the first data point of the vertical ground reaction force that exceeded 20 N and the moment of lifting the toe from the last data point of the vertical ground reaction force that was <20 N. The force plate was located in the middle of an 18 m-long track. Before the test, the participants warmed up their lower limbs for five minutes. Before the test, the participants were asked to walk the test route once with running and lateral sliding. Therefore, the heel of the dominant foot was placed on the force plate when performing the movements. During the test, each participant ran six times along the mentioned path at a speed of 3.3 m/s and performed six lateral sliding movements. The mean frequency values of the signals' stance phase in running and lateral sliding were calculated. The mean values of the muscle activity frequency were determined using Data Lite software, version 2.0. The reason for choosing the median frequency values was that the frequency spectrum distribution of muscle activity was skewed to the right. None of the participants had a history of using double-density insoles. Running speed of 3.3 m/s was measured using a stopwatch under conditions of running and lateral sliding with and without double-density insoles. Each participant performed running and lateral sliding with their sports shoes, both with and without insoles. The participants ran three times with double-density soles and three times without double-density soles at a distance of 18 m, measured from the center of the force plate, according to the specified time and at their chosen speed. Subsequently, lateral sliding was performed under the same running conditions. Double-density shoe soles were used by the participants during movement, including running and lateral sliding. The double-density sole features an eight-degree slope from the inside to the outside, resulting in a different stiffness (Figure 1). A survey was conducted on volleyball players. After running in two ways, with and without soles, the players were asked to express a score from 20 to 100 based on the quality of their run. The same quality survey was performed for the lateral sliding motion.

Statistical analysis

The statistical method used in this study was a two-way variance test with repeated measures to analyze the frequency variables of muscle activity. The normalization test was performed using the body weight of the participants in the force values [23]. Using the correlated t-test to achieve a statistical power of 0.8 with an effect size of 0.8 and a significance level of 0.05, at least 30 subjects were required. The lone test for homogeneity and significance ($P \leq 0.05$) was equal. All statistical analyses were performed using Excel software, version 2016 and SPSS software, version 23.

Results

Table 1 presents demographic and anthropometric characteristics of the participants.

The findings revealed that the double-density insole significantly impacts the frequency of BF muscle activity during running (P=0.045, d=0.136). The results did not demonstrate a significant main effect of group and group-by-FO interactions on muscle activities during all phases (P>0.05, Table 2).

The effect of group on the frequency of TA (P=0.027, d=0.163), muscle activity, and VM (P=0.006, d=0.239) was statistically significant. The results revealed a significant increase in the mean frequency of TA muscle activity in boys compared to girls. In contrast, the mean frequency of VM muscle activity was significantly higher in girls than boys. The interaction between double-density insoles and group classification significantly affected the frequency of ST muscle activity during lateral sliding movements (P=0.037, d=0.146). Follow-up tests indicated that the frequency of ST muscle activity increased during lateral sliding movements in boys but not in girls (Table 3, Figure 2).

Table 1. Demographic characteristics of the participants

Characteristics	Mean±SD	
	Boys Group	Girls Group
Age (y)	14.42±1.82	14.62±1.92
Height (cm)	1.76±0.08	1.66±0.10
Weight (kg)	63.70±10.24	55.79±10.99
Body mass (kg)	20.49±2.20	19.94±2.53

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Discussion

This study investigated the effect of double-density insoles on the activity frequency of selected lower limb muscles during running and lateral sliding in volleyball players. The pattern of muscle activity can be assessed by the intensity of contraction, maximum contraction, and time taken to reach maximum contraction [24]. The results of the present study showed that the use of double-density insoles causes a significant difference in the frequency of certain muscle activities during running and lateral cutting. The results showed that the use of double-density insoles in sliding movements caused a decrease in the frequency of the ST muscle in volleyball players. In volleyball, the repetitive actions of hitting, running, jumping, and landing place significant stress on the knees, leading to the weakening of the internal hamstring muscles (ST and semimembranosus). Over time, this can result in the development of crossed knee abnormalities, which can be corrected through appropriate exercise [25, 26]. Double-density insoles can be useful in reducing the stress on the ST muscle during lateral cutting movements, thereby preventing knock-knee syndrome in volleyball players. An increase in the activity ratio of the internal and external parts of the quadriceps and hamstring muscles, as well as an increase in the activity ratio of the internal compartment to the external compartment of the knee, indicates an increase in the activity of the muscles in the internal compartment of the knee which is considered a positive factor in stabilizing the knee and preventing anterior cruciate ligament (ACL) damage during cutting maneuvers in sports [27]. Creating knee valgus during knee flexion is inevitable; therefore, proper contraction in the internal compartment (semi tendon and VM) is considered a basic requirement to prevent dangerous movement [28]. The findings

Table 2. The means of muscle activity during the stance phase when running in the group with insole compared to the group without insole

Variables	Mean±SD				Main Effect (Eta Squared)		
	Boys Group		Girls Group				
	Without Insole	With Insole	Without Insole	With Insole	Groups	Orthotics	Interaction of Orthotics and Group
TA	104.32±19.54	106.43±13.70	98.55±6.76	95.44±13.37	0.086(0.102)	0.813(0.002)	0.220(0.053)
Gas-M	108.35±30.71	111.98±15.69	117.03±16.11	119.63±18.53	0.222(0.053)	0.455(0.020)	0.900(0.001)
VL	88.55±11.94	93.89±16.48	89.47±17.54	89.04±15.48	0.696(0.006)	0.372(0.029)	0.295(0.039)
VM	85.55±11.43	88.13±10.84	85.77±8.62	85.41±10.81	0.690(0.006)	0.628(0.008)	0.523(0.015)
RF	94.03±14.23	91.32±14.48	88.45±11.42	85.84±13.20	0.222(0.053)	0.211(0.550)	0.980(0.000)
BF	99.69±16.20	105.19±20.17	89.54±16.29	96.19±12.37	0.081(0.105)	0.045(0.136)	0.842(0.001)
ST	99.22±15.77	98.67±20.28	95.80±12.88	98.15±13.63	0.692(0.006)	0.772(0.003)	0.641(0.008)

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Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; BF: Biceps femoris; ST: Semitendinosus; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris.

Table 3. Means of muscle activity during the stance phases when lateral cutting in with and without insole group

Variables	Mean±SD				Main Effect (Eta Squared)		
	Boys Group		Girls Group				
	Without Insole	With Insole	Without Insole	With Insole	Group	Orthotics	Interaction of Orthotics and Group
TA	94.16±19.09	95.11±15.72	82.74±12.15	83.06±9.50	0.027(0.163)	0.073(0.005)	0.858(0.001)
Gas-M	117.90±15.15	113.95±14.20	120.34±28.13	120.54±21.78	0.541(0.013)	0.314(0.036)	0.264(0.044)
VL	78.80±12.29	74.77±9.49	76.15±12.16	74.19±11.93	0.673(0.006)	0.117(0.085)	0.582(0.011)
VM	86.68±16.36	84.39±11.40	71.04±9.45	74.71±11.49	0.006(0.239)	0.661(0.007)	0.116(0.116)
RF	83.91±13.92	83.22±12.28	80.04±10.94	79.92±11.64	0.416(0.024)	0.709(0.005)	0.788(0.003)
BF	22.20±81.56	77.91±20.45	72.63±17.94	72.73±18.04	0.325(0.035)	0.248(0.047)	0.224(0.052)
ST	74.42±17.77	78.60±12.54	86.99±14.27	84.44±15.67	0.095(0.096)	0.599(0.010)	0.037(0.146)

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Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; BF: Biceps femoris; ST: Semitendinosus; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris.

of this study align with those reported by Sedighi and Anbarian, which indicate that the semi-hard sole significantly reduces the activity of the ST muscle in running [29]. Athletic trainers are advised to use double-density insoles (with enhanced internal stiffness) to improve the running mechanics of their athletes, as these insoles can help reduce injury rates [30]. According to the contractions that occur in the lateral cutting maneuver stage in volleyball players. These contractions involve the ST muscle. The double-density insole has been able to reduce the forces and tension in this muscle by affecting the frequency values of the ST muscle.

The results of the present study showed that using double-density insoles caused a decrease in the frequency of BF muscle activity during the stance phase in volleyball players. In a study on the nervous system, Ismailia found that maintaining the timing of joint movements involves adjusting the timing of muscle activity. Specifically, showed that in the absorption phase of running, following fatigue, the activity of the BF muscle decreases [6], which is consistent with the results of the present study. Regarding ACL rupture, excessive mechanical loading of the knee, combined with a rapid decrease in acceleration and a sudden change in direction while running,

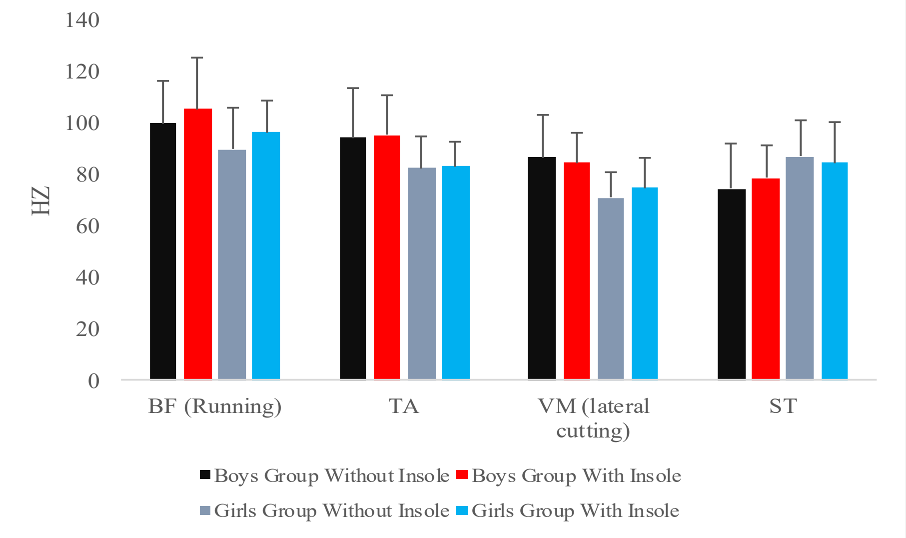

Figure 2. Diagram of significant muscles during running and lateral cutting

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are risk factors [31]. One way to reduce the risk of ACL injury in high-risk cutting and running movements is to strengthen the muscles surrounding the knee, especially the hamstrings [32]. Double-density insoles can prevent ACL rupture by changing the frequency of the hamstring muscles in both femoral heads and the hamstring. Two-density insoles can also help prevent ACL injuries through pressure distribution mechanisms, arch support, impact absorption, and by improving stability and adjusting foot position. Andres . noted that running is associated with individual patterns that create a high activity pattern in the hamstring muscle, similar to speed, in their study on the activity of a specific muscle area at different speeds during running [33]. By reducing the frequency values of the BF during running, double-density insoles can help prevent acute running injuries in the BF [17]. The movements of running and lateral sliding in volleyball, which occur together with sitting and squatting movements during the performance of skills, can cause an imbalance of forces in both static and dynamic movements at the knee joint.

Conclusion

The use of double-density insoles can help reduce EMG activity in selected lower limb muscles during running and lateral cutting movements, potentially preventing injuries, such as knock knees and cruciate ligament tears in the knee joint in volleyball players. Given the unique demands volleyball places on the lower body and the resulting variations in muscle activation patterns, double-density insoles may serve as a valuable tool for both clinical applications and enhancing the athletic performance of young players. This study, like other studies, had limitations, including the small statistical sample size, which makes it difficult to generalize, and the type of shoes was not determined.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of University of Mohaghegh Ardabili (Code: IR.SSRC.REC.1401.140). Participants entered the study after completing a written informed consent form and had the option to withdraw from the research at any time.

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Authors' contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interception of the results, and manuscript drafting. Each author approved the submission of the final version of the manuscript.

Conflict of interest

The authors declared no conflict of interests.

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