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Original Research

Effect of Acute Functional Fatigue on Plantar Pressure Distribution and Foot Center of Pressure in Young Professional Volleyball Players

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ABSTRACT

This study aimed to investigate the effect of acute functional fatigue on plantar pressure distribution and center of pressure (CoP) in young professional male volleyball players. 38 young volleyball players voluntarily participated in this study and were randomly divided into two experimental and control groups. A plantar pressure scanner measured plantar pressure distribution and CoP during standing and walking. The dependent samples t-test was used to investigate inter-group differences, and the covariance test was used to compare between groups. The data were analyzed by SPSS software (version 21) at a significance level of $p \geq 0.05$. The results showed that fatigue had a significant effect on the percentage of plantar pressure distribution in the fore-foot of both feet and the left rear-foot in both control and training groups ($p<0.05$). Also, the CoP path length and the ellipse area of the CoP after fatigue showed a significant change in the experimental group ($p<0.05$). The results showed that fatigue increases the contact surface and impulse of the forefoot and the CoP movements. These factors can increase the probability of injury in participants.

Keywords: Acute functional fatigue, Plantar pressure distribution, Center of pressure, Volleyball

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INTRODUCTION

Balance and posture control is one of the most basic neuromuscular functions involved in simple and complex activities [1-4]. This ability in volleyball (like most sports) helps to control the body position during jumping and landing and can prevent injuries to a large extent [5]. On the other hand, fatigue is a common phenomenon in sports activities and also a common experience in daily activities [6, 7]. Fatigue can affect body stability by influencing the central and peripheral nervous system [8]. Impaired posture control due to fatigue may be a factor in skeletal-muscular injury and a decrease in the performance of athletes during training and competition [3, 9].

The study of fatigue and its effect on reducing balance, disrupting skill performance, and causing injury in athletes has been the focus of researchers. In this context, different fatigue protocols have been used, including isokinetic contractions [10], repetitive movements [11], isometric contractions [12], and functional activities [13, 14]. Most of the studies have used protocols unrelated to sports movements and competitions to investigate the effect of fatigue on the static and dynamic balance control system. In this study, specific volleyball exercises were used as a fatigue protocol.

Marco et al. (2007) used a treadmill to induce fatigue, which reduced balance [15]. In other studies, isometric and isotonic fatigue was applied to Plantarflexors [16, 17], Dorsiflexors [18], and a decrease in postural control was observed in healthy men and women. Gribble et al. (2004) reported a significant decrease in dynamic postural control in healthy cases after applying the seven-station functional fatigue protocol [19]. Zach (2012), after applying general and local fatigue to adult male handball players, concluded that fatigue will affect balance when it causes a reduction of the maximum contraction strength between 25% and 30% [20]. Pau and his team (2014) reported an increase in postural sway in all directions after fatigue caused by 6 repetitions of two shuttle speeds in 21 young male soccer players [21]. Considering the significant increase in sports abilities and performances in recent decades and also the attention that coaches and sports officials have to improving athletes' physical and physiological abilities, studying the factors involved in sports performances, such as fatigue and posture control. It can play a significant role in identifying these factors and preventing injuries and consequences related to fatigue [22].

The foot is the only anatomical structure of the body that is in contact with the ground and, as the last part of the movement chain of the lower limb, resists the applied forces. Improper distribution of forces causes unnatural movements and increased pressure, resulting in leg muscle damage [23, 24]. Volleyball players have fast movements, sudden changes of direction, and frequent jumps and landings, which increase the possibility of injury to the lower limbs, especially the ankles. The most common injury in volleyball players is an ankle injury during landing, with a prevalence of 63% [25, 26].

According to the background of the research, in a few kinds of research, the fatigue caused by the competition and specific exercises have been used on the performance and balance of the athletes. In most studies conducted on the effect of fatigue on the balance of athletes, non-functional protocols have been used. Also, the balance tests used in most of the research were not laboratory [19] or variables such as evaluation of fluctuations of the center of pressure (COP) [21]. Therefore, in this study, it was tried to use a fatigue protocol simulated by playing volleyball to create general fatigue in the muscles and to develop the ability to generalize it to the real conditions of the matches. This study aimed to investigate the effect of a bout of acute functional fatigue on the distribution of plantar pressure and the CoP displacement in elite young volleyball players.

MATERIAL AND METHODS

Participants

This is a semi-experimental study with a pre-test and post-test method conducted in a sports biomechanics laboratory. To determine the number of research samples with G*Power software, with $\alpha = 0.05$ and a statistical power of 80% [27], at least 16 people were considered for each group. In this research, the statistical population was young male volleyball players, 38 selected by available sampling method, divided into two groups, 18 individuals as a control group (not participating in the functional fatigue protocol) and 20 individuals as an experimental group (participation in Functional Fatigue Protocol). Before and after the fatigue protocol, the participants of both groups were tested for static balance and walking. The criteria for entering the research included participants in the age range of 16 to 20 years, with experience of participation in provincial volleyball competitions and continuous and regular attendance at training during the past two years. Also, the exclusion criteria included the presence of injury before and during the study period or any physical abnormality that affected the results. Players completed the consent form to participate in the test, and then the test procedures, how to measure the variables, and the working method were fully explained to the subjects. The current research protocol was approved by the ethics committee of the Research Institute of Physical Education and Sports Sciences with the number IR.SSRI.REC.1400.1110.

Instruments and Examinations

In this research, the foot scanner (Footscan (RsScan International, Belgium, 578 mm *418 m* 12 mm, 4096 sensors)) with a frequency of 253 Hz was used to measure the variables of plantar pressure distribution and CoP displacement while performing exercises.

At first, how to perform the test in a static position was explained to the participants. Each person should stand on the footscan for 10 seconds with their eyes open [28]. The average of three repetitions in this condition was considered as the pre-test. Also, after the implementation of the post-test fatigue protocol, it was taken from the subjects of both groups. In the control group, where the fatigue protocol was not implemented, the interval between the pre-test and post-test was 120 minutes [28]. Selected biomechanical variables investigated in this research included pressure distribution in each leg, pressure distribution in the rear and fore-foot of each foot, the area of COP changes, and the COP movement path length.

To evaluate variables in gait, the subjects were asked to walk at their normal speed on a 12-meter walking path where the foot scanner was located in the center of this path. The distance from the starting point of walking to the device was such that the subject had to take at least 7 steps before reaching the device [29] and the path length was 12 meters, making it possible to take at least 7 steps after the device. With these conditions, the effect related to the start and stopping in gait was removed.

To investigate the effect of the fatigue protocol on the subjects, the maximum vertical jump height was recorded for each participant using Sargent's test [30]. For this purpose, after each cycle of the fatigue protocol, the maximum vertical jump height is immediately evaluated until the jump height of each person is reduced to 30% of the initial maximum jump height, which was considered to determine the point of fatigue [30]. The fatigue protocol in this study included functional volleyball movements, which included several repeated cycles until the desired fatigue level was reached. Each cycle includes: 1) ten repetitions of the claw skill along with going back and forth at a distance of 3 meters, 2) ten repetitions of the forearm skill with the lower guard along with going back and forth with the side leg at a distance of 3 meters, 3) 10 consecutive ankle jumps on the ladder, 4) 10 times performing the defense movement on the net with the maximum possible jump on the net, 5) 10 times performing the three-step spike 6) 10 times performing the follow-up movement (i.e., short jump and chest press) was consecutive (Fig.1).

Statistical Analysis

In this research, the Shapiro-Wilk test was used to measure the normality of the data. To investigate the inter-group difference, the dependent samples T-test was used, and the covariance test was used to compare between groups. The data were analyzed by SPSS software (version 21) at a significance level of $p<0.05$..

RESULTS

The average and standard deviation of the participants' characteristics are given in Table 1. As can be seen, players of the control group did not differ significantly from the people in the experimental group in terms of demographic characteristics.

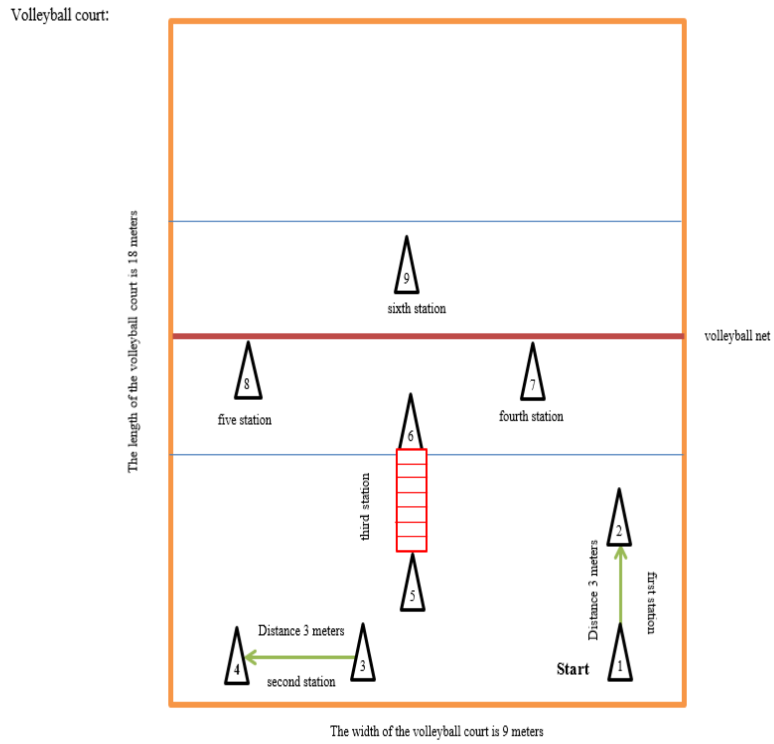

Fig. 1. The fatigue protocol in this study included functional volleyball movements

Table 1. Demographic characteristics of the research participants

	Groups		
	Control	**Experimental**	**Sig.(t)**
Number	18	20	-
Age (year)	17.05 ± 0.63	17.55 ± 0.99	0.08 (-1.79)
Height (M)	1.84 ± 0.06	1.85 ± 0.06	0.60 (-0.52)
Weight (kg)	71.72 ± 5.07	70.15 ± 6.72	0.42 (0.80)
BMI	21.27 ± 2.46	20.52 ± 2.35	0.34 (0.95)

BMI: Body mass index (weight/height squared)

Static balance

The results of the inter-group comparison are given in Table 2. As can be seen, the comparison of pre-test and post-test averages in the experimental group showed the effect of fatigue on the reduction of pressure distribution percentage in the fore-foot of both feet and an increase in the left rear-foot. Also, after fatigue, the CoP path decreased, and the CoP ellipse increased. However, the difference between the pre-test and post-test in the control group was only significant in one variable, which can be seen in Table 2, and there was no significant change in the rest of the cases. The results of covariance analysis in static balance variables showed that, after fatigue, the pressure distribution in the right fore-foot in the control group was significantly higher than in the experimental group ($p=0.036$, $F=4.75$). Also, in the post-test, the CoP ellipse in the experimental group was significantly higher than the control group ($p=0.028$, $F=5.23$) and the difference between the groups was not significant in the other variables.

Table 2. The results of inter-groups comparison of static balance variables in control and experimental groups before and after fatigue

	groups	pretest	Postest	t	Sig.
Left foot pressure (%)	Control	57.24 (5.69)	52.47 (7.77)	-1.415	0.173
	Experimental	35.03 (7.82)	55.66 (5.44)	1.938	0.069
Left fore-foot pressure (%)	Control	42.76 (5.69)	26.32 (5.59)	0.242	0.811
	Experimental	42.72 (3.92)	24.39 (4.36)	8.616	**0.000**
Left rear-foot pressure (%)	Control	31.08 (5.30)	26.37 (6.59)	2.377	**0.029**
	Experimental	28.21 (6.37)	31.15 (4.89)	-2.956	**0.008**
Right foot pressure (%)	Control	42.76 (5.69)	47.53 (7.77)	-1.938	0.069
	Experimental	47.12 (7.71)	44.34 (5.44)	1.515	0.146
Right fore-foot pressure (%)	Control	42.76 (5.69)	22.96 (5.87)	1.123	0.276
	Experimental	24.49 (6.09)	23.19 (5.53)	11.080	**0.000**
Right rear-foot pressure (%)	Control	19.35 (5.58)	24.34 (7.71)	1.070	0.298
	Experimental	22.59 (6.37)	21.26 (4.27)	-1.899	0.075
CoP ellipse	Control	216.30 (240.00)	150.19 (110.70)	-0.806	0.420
	Experimental	84.35 (62.48)	269.15 (223.83)	-3.771	**0.000**
CoP path	Control	122.85 (56.47)	139.71 (29.32)	-1.115	0.280
	Experimental	154.71 (211.68)	144.79 (47.21)	-2.072	**0.038**

Note: Bolded p-values indicate significance ($p < 0.05$).

Dynamic balance

The results of the group comparison in the walking variables are shown in Table 3. As can be seen, fatigue has caused a significant decrease in the contact surface of the left rear-foot, the impulse of the right rear-foot, and an increase in the percentage of contact between both feet in the right foot was observed. The difference between groups using the covariance test showed a significant increase in the impulse of the right fore-foot (p=0.013, F=6.79) and left (p=0.027, F = 5.32) after applying fatigue in the experimental group compared to the control group, and no significant difference was observed in the rest of the cases.

DISCUSSION

The main purpose of this research was to investigate the effect of functional fatigue on the distribution of foot pressure during walking and static balance in young professional volleyball players. The inter-group results regarding the pressure distribution during standing showed that after fatigue, the percentage of pressure distribution in the left and right fore-foot decreased. Still, fatigue increased the CoP ellipse in the experimental group. Moreover, the comparison between the two groups showed that after the application of fatigue, the fore-foot pressure distribution in the experimental group was reduced compared to the control group. Still, the movement area of the CoP was increased, which was in line with the results within the group. In general, the results showed an increase in the range of CoP movements after fatigue, while before fatigue, the pressure distribution was more concentrated. According to the findings of this research, after fatigue, the CoP movements increased by about 200%. Previous studies in line with these results show that muscle fatigue has caused an increase in the range of postural sway, which indicates a decrease in the ability to maintain balance [9, 10, 31]. Reports have indicated that fatigue can cause disturbances in proprioceptive system, which may send less information to the central nervous system.about the distribution of pressure on different parts of the foot. As a result, the CoP movements occur in the greater range in foot [32]. In line with these findings, Naderi et al. (2019) showed that following functional and non-functional fatigue, CoP movements increase in the anterior-posterior direction compared to the medial-lateral direction [33]. Nagel et al. (2008) also found that after fatigue, CoP movements were changes in the anterior-posterior direction [34]. The results of the present study also showed that the CoP movements in the fore-foot increased after fatigue. Therefore, it may be concluded that the CoP tend to forward after fatigue.

Table 3. Results of inter-groups comparison of dynamic balance variables in control and experimental groups before and after fatigue

	groups	pre test	pos test	t	Sig.
Left rear-foot surface	Control	28.64 (2.53)	28.52 (3.17)	0.224	0.825
	Experimental	29.33 (2.44)	28.06 (2.29)	2.373	**0.028**
Left mid-foot surface	Control	18.57 (3.94)	19.19 (5.30)	-0.634	0.534
	Experimental	17.68 (2.44)	18.24 (4.88)	-6.804	**0.000**
Left fore-foot surface	Control	53.47 (3.32)	52.30 (3.53)	1.119	0.279
	Experimental	52.98 (3.81)	53.71 (3.56)	-1.213	0.240
Left rear-foot impulse	Control	35.15 (7.33)	35.73 (4.75)	-0325	0.749
	Experimental	36.13 (6.63)	32.83 (9.83)	1.282	0.215
Left mid-foot impulse	Control	10.22 (5.24)	10.41 (4.75)	-0.165	0.871
	Experimental	8.67 (5.02)	8.60 (4.51)	0.093	0.927
Left fore-foot impulse	Control	53.35 (4.99)	53.85 (4.45)	-0.320	0.753
	Experimental	50.23 (6.69)	58.56 (7.54)	-1.421	0.172
Right rear-foot surface	Control	27.96 (5.00)	27.66 (3.81)	-1.242	0.214
	Experimental	29.03 (2.53)	19.55 (5.42)	-1.731	0.083
Right mid-foot surface	Control	20.32 (6.25)	19.55 (3.78)	0.613	0.548
	Experimental	17.13 (5.43)	19.56 (5.42)	-1.997	**0.046**
Right fore-foot surface	Control	51.77 (2.16)	52.27 (2.83)	-0.765	0.455
	Experimental	53.83 (3.91)	52.42 (3.32)	2.046	0.055
Right rear-foot impulse	Control	36.22 (8.99)	34.26 (4.51)	-2.222	**0.026**
	Experimental	34.73 (5.92)	31.80 (6.31)	-1.531	0.126
Right mid-foot impulse	Control	10.03 (9.74)	9.82 (4.69)	-1.633	0.102
	Experimental	8.65 (5.03)	11.76 (9.79)	-1.867	0.062
Right fore-foot impulse	Control	53.16 (3.49)	55.92 (3.93)	-2.270	0.137
	Experimental	56.63 (5.18)	56.44 (5.66)	-0.075	0.940

Note: Bolded p-values indicate significance ($p < 0.05$).

The results within the group regarding the pressure distribution of the feet during walking showed that the impulse and pressure distribution in the rear-foot decreased. Still, the contact surface of the middle foot increased. Besides, the comparison between groups stated that the experimental group showed a significant increase in the impulse of the fore-foot after fatigue. This means that after fatigue, the amount of force applied to the rear-foot surface has decreased, but this force has significantly increased in the fore-foot. The results of this research were in the same direction in static and dynamic balance. In both cases, the force and pressure exerted on the fore-foot increased after fatigue. In addition, the CoP movements occurred on a wider level. According to these findings, it can be concluded that after functionally causing fatigue, the probability of losing balance in the anterior direction will be higher.

In the study of Hamzavi and Esmaili (2021), it has been shown that the smallest changes in the CoP path during movement can change the ratio of torques on the joints and affect the balance function, ultimately causing the development of biomechanical injuries [35]. According to similar studies, fatigue causes a decrease in the function of the lower limbs and a decrease in the dynamic balance due to the disruption of proprioceptive receptors in the joints, all of which play an effective role in predicting the occurrence of lower limb injuries [36]. Fatigue may inhibit this system by affecting neuromuscular afferents in the feedback loop, thus having a negative effect on neuromuscular function. This effect is probably due to reduced activation of gamma motor neurons and decreased discharge of alpha motor neurons due to fatigue. As a result, there is a disturbance in sending appropriate corrective commands to the muscles controlling the posture [33, 37]. Another important factor in reducing balance after fatigue is the reduction and depletion of glycogen in some muscle fibers, thereby reducing the number of fibers that can be used to compensate for the lack of muscle power. Therefore, the muscle cannot produce enough force during intense training. In other words, it can be said that the decrease in the balance due to fatigue is probably due to the decrease in the number of fibers that can be used to produce force to maintain posture [13, 38].

CONCLUSION

The results of this study showed that fatigue increases the contact surface and impulse of the fore-foot, as well as increases the CoP movements. These factors may increase the probability of injury in players. Considering that the most common time for sports injuries is at the end of the competition, fatigue, increased activity intensity, or sudden force may cause injury. Therefore, delaying fatigue or controlling it during competitions is important for properly executing the technique and obtaining the game's result.

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

Data Availability Statement: Data will be available at request.

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چکیده:
هدف از انجام این پژوهش بررسی تاثیر یک وهله خستگی حاد عملکردی بر توزیع فشار کف‌پایی و مرکز فشار در والیبالیست‌های جوان حرفه‌ای پسر بود. تعداد ۳۸ والیبالست جوان داوطلبانه در این تحقیق شرکت کردند و به صورت تصادفی به دو گروه تجربی و کنترل تقسیم شدند. با استفاده از دستگاه اسکنر فشار کف‌پا، توزیع فشار کف پایی و مرکز فشار (CoP) در حین ایستادن جفت پا و راه رفتن اندازه‌گیری گردید. به منظور بررسی اختلاف درون‌گروهی از آزمون تی همبسته و برای مقایسه بین گروهی از آزمون کوواریانس استفاده گردید. داده‌ها توسط نرم‌افزار SPSS (نسخه ۲۱) در سطح معنی‌داری $p \leq ۰/۰۵$ مورد تحلیل قرار گرفتند. نتایج نشان داد خستگی بر درصد توزیع فشار کف پا در بخش جلوی هر دو پا و بخش عقبی پای چپ در هر دو گروه کنترل و تمرین تاثیر معنی‌دار داشته است ($p < ۰/۰۵$). همچنین طول مسیر جابجایی و مساحت بیضی CoP پس از اعمال خستگی تغییر معنی‌داری را در گروه تجربی نشان داد ($p < ۰/۰۵$). نتایج نشان داد خستگی موجب افزایش سطح تماس و ایمپالس قسمت جلویی کف پا و همچنین افزایش حرکات مرکز فشار می‌گردد. این عوامل می‌تواند موجب افزایش احتمال آسیب‌دیدگی در افراد گردد.
واژه های کلیدی: خستگی حاد عملکردی، توزیع فشار کف پایی، مرکز فشار، والیبال