Research Paper: The Effects of Lower Extremity Muscle Fatigue on Dynamic Balance in Volleyball Players

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ABSTRACT

Objectives: Lower extremity muscles are critical for maintaining dynamic balance and athletic performance. Fatigue of these muscles may affect dynamic balance. It is unclear whether fatigue in a particular muscle group can affect dynamic balance more than that in other groups. This study was conducted to evaluate and compare the effects of fatigue in 5 muscle groups on dynamic balance in volleyball players.

Methods: Fifteen healthy male volleyball players separately performed the Star Excursion Balance Test before and immediately after the occurrence of fatigue of ankle Plantar Flexor (PF), knee extensor, knee flexor, hip abductor, and hip adductor muscles. Composite reach distance and distance in anterior, posteromedial, and posterolateral directions were recorded, accordingly.

Results: Repeated-measures Analysis of Variance (ANOVA) data indicated that fatigue of all muscle groups significantly decreased the mean score of composite ($P<0.001$). Anterior, posteromedial, and posterolateral distance scores decreased following muscle fatigue of knee extensors and ankle PFs ($P<0.05$).

Discussion: This study suggested that regarding composite reach score, fatigue of ankle, knee, and hip muscles similarly decreased dynamic balance. However, evaluating three main directions revealed that knee extensors and ankle PFs muscles fatigue presented more prominent effects on the explored volleyball players' balance, compared to the other muscles.

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Highlights

● Muscular fatigue of ankle plantar flexors, knee extensors, and flexors, as well as hip abductors and adductors, could decrease the balance in volleyball players.

● Comparing the dynamic balance of volleyball athletes after inducing muscular fatigue revealed that only knee extensors and ankle PFs could decrease anterior, posteromedial, and posterolateral reach distances.

Plain Language Summary

Nontraumatic injuries are common in volleyball players as a result of long durations of playing which induce fatigue. We examined the fatigue effects of 5 muscular groups on balance among volleyball players. Also, we compared the effects of fatigue between these muscle groups. The collected results revealed that fatigue of ankle, knee, and hip muscles decreased dynamic balance. However, fatigue in knee extensors and ankle PFs may result in more negative effects on volleyball players' balance than that in other muscle groups.

1. Introduction

Lower extremity injuries are common in sports [1]. Volleyball is a non-contact sport in which non-traumatic injuries prevalently occur due to long durations of playing which induce fatigue [2]. Fatigue of lower extremity muscles could happen following the changes in neuromuscular control; they may lead to imbalance [3] and predisposition to injuries.

In sports activities, like volleyball, dynamic balance is necessary to ensure instantaneous reaction to the changing environment [4-6]. Fatigue is a major factor that influences athletes' performance during the competition [7]. Exercise-induced reduction in voluntary muscle activation is described as fatigue [4]. Due to the accumulation of metabolites in muscles, the most common time for injuries to occur may be in the final sets of the matches on account of the onset of fatigue [8-11]. Numerous studies have reported the effects of muscular fatigue on static balance [12-14] and dynamic balance [13, 15] in different populations. However, fatigue is induced by various patterns, either locally or generally. There exist several jumping and landing movements in volleyball, especially during spike and block actions. Various muscular groups are activated during these actions, particularly hip extensors, knee extensors, and ankle Plantar Flexors (PFs). Thus, it is essential to assess the impact of these muscles' fatigue on dynamic balance in volleyball players.

The Star Excursion Balance Test (SEBT) is a feasible and reliable tool for assessing dynamic balance. The SEBT can be integrated into physical examinations to estimate the risk of injury in athletes [16]. Therefore, it has been preferred for assessing the effects of fatigue on dynamic balance [17]. To our knowledge, no study has compared the fatigue effects of different muscles on homogenous subjects. Thus, the present study aimed to assess the effects of fatigue in 5 muscle groups on the dynamic balance of healthy male volleyball players.

2. Methods

This prospective quasi-experimental study with a pretest-posttest design was conducted at a Sports Center affiliated with the university. All study protocols (balance assessment and fatigue induction) were approved by the Ethics Committee of the relevant university. A written informed consent form was received from all study participants.

Fifteen healthy professional male volleyball players (Mean±SD age: 22.0±3.4 years; height: 181.1±4.1 cm; weight: 74.4±5.2 kg) were selected by convenience nonprobability sampling method to participate in the present study. They practiced volleyball 3 times a week for a minimum of 2 years. They presented no history of lower extremity pathology or balance disorders in the previous year. All stages of the test were performed on all individuals at a specific time of the day (about 10:00 AM) to prevent daytime influences on balance and to control the variability of fatigue on the different days. Moreover, the research participants were requested to only perform their usual activities between the assessment days.

The SEBT was used as a dynamic balance test with high reliability and feasibility [16, 18]. The SEBT was performed before and immediately after inducing fatigue

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in 5 lower extremity muscles; knee extensors and flexors, hip abductors and adductors, and ankle PFs.

The dominant leg was considered as the support leg on the center of the star. It was determined as the leg by which the study participant preferred to kick a ball. Each study participant performed the test 3 times for familiarization. Those with dominant right limb and left limb accomplished the test counterclockwise and clockwise, respectively.

Each study participant stood on his dominant leg at the center of the star and performed the reach action using the other leg without error in each vector of the star. Reach distance was recorded by measuring the distance between the contact point of the free leg and the center of the star. The research participant performed the test 3 times per direction. The average value of these repetitions was calculated and divided by the limb length. Then, the value was multiplied by 100 to obtain the distance as a percentage of limb length per direction [19]. For measuring the composite reach distance score, the average value of the reach distance in 8 directions was calculated [20]. In total, 6 evaluation sessions were conducted for each study participant. In the first session, the only familiarity with the test was performed.

An ankle PF machine, a knee extensor, and a flexor machine, as well as a hip abductor and adductor machine, were applied to induce muscular fatigue. Initially, the research participant was requested to complete a 5-minute warm-up. Then, the Maximum Voluntary Contraction (MVC) of the knee extensor muscles was measured by a dynamometer (Lafayette, USA.116). Accordingly, the study participant was requested to extend his knee as strongly as possible for 5 seconds. This action was repeated two times more; subsequently, the maximum value was considered as the MVC for the knee extensors. The MVC for the knee flexors, ankle PFs, hip abductors, and adductors were measured, similarly.

Next, the explored athlete was requested to perform one set, including 50 repetitions of knee extension using 50% of 1 Repetition Maximum (RM) by the knee extension machine (Figure 1). If the study subject was unable to complete 50 knee extension movements, the MVC was re-measured by the dynamometer. If the MVC was reduced to 50%, fatigue was confirmed. However, if after 50 extension movements the study participant could continue the movements, a 4-minute break was given to him. Then, he was requested to repeat the knee extension movements like the first stage and the dynamometer was used for measuring the MVC [21].

Fatigue in other muscles was induced similarly with a 72-hour interval between each muscle group test [22].

Statistical analyses were performed using SPSS v 22. Kolmogorov-Smirnov test was applied to determine the normality of the collected data. The mean composite reaching scores of the SEBT as well as mean reaching scores per common direction (anterior, posteromedial, posterolateral) were compared before and after fatigue induction in the 5 muscle groups (ankle PF, knee extensor, knee flexor, hip abductor, & hip adductor muscles) by a one-way repeated-measures Analysis of Variance (ANOVA). Mauchly's Test of Sphericity data indicated that the assumption of sphericity had been violated P<0.05; therefore, a Greenhouse-Geisser correction was performed. Bonferroni test was also used as a post-hoc examination. Effect sizes and Partial Eta-squared are reported by . The significance level was set at 0.05.

3. Results

Fifteen healthy professional male volleyball athletes with the Mean±SD age of 22±3.4 years were tested before and after fatigue induced in the 5 muscle groups by the SEBT. Before fatigue induction, the minimum and maximum of the reach distance, for the average of 8 directions were measured as 84cm and 95.1cm, respectively (Table1).

For composite reach scores, we achieved a result of $F_{2.8, 39.18}=23.23$, P=0.0001, $\eta^2=0.62$) Repeated-measures ANOVA results indicated the significant effects of fatigue on the composite reach score of the SEBT (Graph 1). Bonferroni post-hoc test data revealed that the fatigue of all muscle groups significantly decreased the mean

Figure 1. Knee extension machine **Iranian Rehabilitation Journal**

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Table 1. The Star Excursion Balance Test scores before and after fatigue induction in the 5 muscle groups for the average of 8 directions and 3 directions separately (n=15)

Muscle Group	Composite Reach Score		Direction A		Direction PM		Direction PL	
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)
Base	86.80±3.67	85.02 (84.00-95.10)	98.48±3.91	97.95 (91.82-106.52)	99.68±6.52	98.91 (91.83-111.11)	95.56±6.18	93.87 (88.23-108.88)
Ext.	77.00±5.20	76.96 (69.77-87.72)	83.19±3.95	82.97 (77.77-90.58)	92.16±7.43	91.48 (80.613-225.88)	86.08±9.88	86.95 (71.42-102.35)
Flex.	79.05±4.43	78.48 (71.41-86.34)	83.18±3.74	82.22 (77.55-89.36)	95.63±8.40	96.80 (80.613-224.70)	89.99±9.14	89.79 (75.513-225.88)
Add.	78.60±5.20	78.35 (72.13-89.32)	84.53±3.76	83.69 (80.00-93.68)	94.55±8.83	91.11 (82.65-113.68)	88.52±9.02	90.42 (71.42-102.10)
Abd.	80.20±4.7	79.62 (72.65-87.04)	89.24±5.91	88.29 (82.65-97.64)	94.70±6.72	94.68 (86.73-105.88)	86.77±10.67	90.21 (73.46-100.00)
PF.	77.20±3.28	75.15 (73.12-81.89)	81.47±3.62	81.91 (76.08-87.36)	93.21±7.86	91.4800 (84.69-106.31)	86.73±9.82	82.65 (75.53-102.35)

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Base: Before inducing fatigue; Ext: Knee extensor; Flex: Knee flexor; Add: Hip adductor; Abd: Hip abductor; PF: Ankle plantar flexor; A: Anterior direction; PM: Posteromedial direction; PL: Posterolateral direction.

Table 2. Confidence interval 95% of the differences of before and after the induction of fatigue in different directions

Direction	Pre-fatigue Score	Muscle Group	P	Lower Bound (cm)	Upper Bound (cm)
A	Base	Ext.	0.0001	10.47	20.12
		Flex.	0.0001	9.60	21.02
		Add.	0.0001	7.90	20.01
		Abd.	0.0001	4.50	13.99
		PF.	0.0001	11.11	22.92
PM	Base	Ext.	0.021	.84	14.20
		PF.	0.001	2.38	10.55
PL	Base	Ext.	0.006	3.27	15.68
		Add.	0.011	1.86	12.22
		Abd.	0.006	2.95	14.62
		PF.	0.005	3.09	14.58
Composite reach score	Base	Ext.	0.0001	4.56	15.05
		Flex.	0.0001	3.37	12.13
		Add.	0.001	2.83	13.57
		Abd.	0.001	2.61	10.58
		PF.	0.0001	6.21	12.99

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Base: Before inducing fatigue; Ext: Knee extensor; Flex: Knee flexor; Add: Hip adductor; Abd: Hip abductor; PF: Ankle plantar flexor; A: Anterior direction; PM: Posteromedial direction; PL: Posterolateral direction.
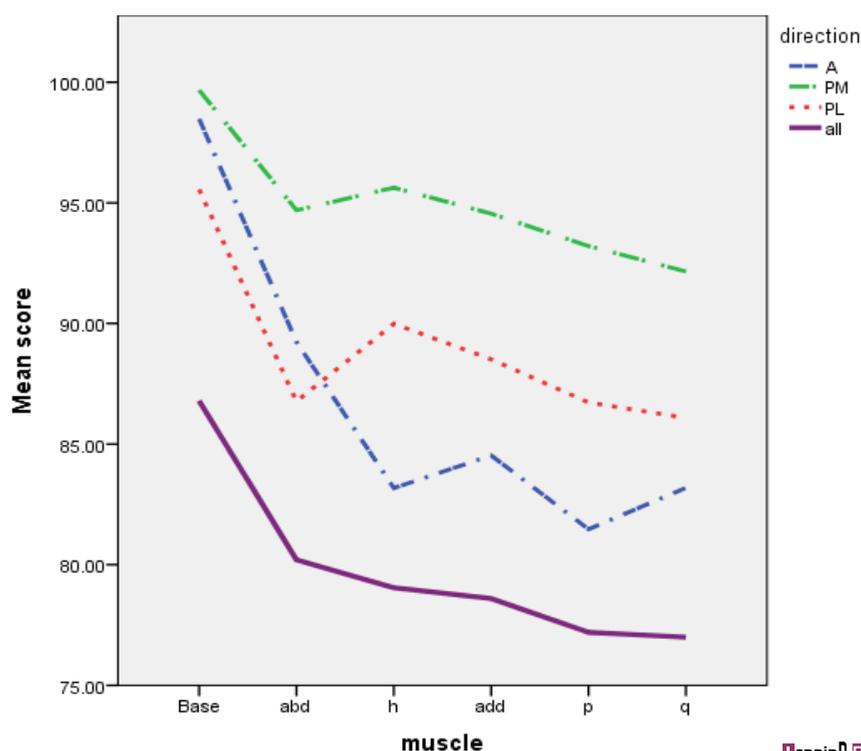
Figure 2. Mean trend of the SEBT scores in different directions

Base: Before inducing fatigue; abd: Abductors; h: Hamstrings; add:Adductors; p:Plantar flexors; q: Quadriceps; A: Anterior; PM: Posteromedial; PL: Posterolateral.

value of composite reach, compared to the pre-fatigue conditions (Table 2).

In the anterior direction, repeated-measures ANOVA findings demonstrated that fatigue in 5 muscle groups significantly impacted the SEBT score ($F_{2.53, 35.4}$=38.55, P=0.0001, η^2=0.73) (Figure 2). Post-test results signified that the fatigue of all muscle groups significantly decreased the mean distances in the anterior direction, compared to the pre-fatigue conditions (Table 2).

In the posteromedial direction; fatigue in 5 muscle groups significantly affected the SEBT score ($F_{2.43, 34.1}$=3.11, P=0.048, η^2=0.18) (Figure 2). Bonferroni post-hoc test data demonstrated that only the fatigue of knee extensor and ankle PF muscle groups significantly decreased the mean distances in posteromedial direction, compared to the pre-fatigue conditions (Table 2).

In posterolateral direction, fatigue in 5 muscle groups significantly influenced the SEBT score ($F_{2.79, 38.99}$=5.52, P=0.004, η^2=0.28) (Figure 2). Bonferroni post-hoc test results indicated that only the fatigue of knee extensor (P=0.006), hip abductor (P=0.011), hip adductor (P=0.006), and ankle PF (P=0.005) muscle groups significantly decreased the mean distances, compared to the pre-fatigue conditions (Table 2).

4. Discussion

The present study assessed the effects of lower extremity muscle fatigue on dynamic balance in healthy male volleyball players. We also examined the potential differences between these effects. The relevant results indicated that fatigue in the ankle PFs, knee extensors, and flexors, hip abductors and adductors, decreased the composite reach score of the SEBT. Additionally, we found no difference between the effects of fatigue in various muscle groups on the SEBT. Furthermore, all muscles presented similar negative effects on reaching distance in the anterior direction. In the posteromedial direction, only knee extensors and ankle PFs decreased the reach. In posterolateral direction, the fatigue of all muscles decreased the reaching distance, except for the knee flexors.

Literature about the effects of lower extremity muscle fatigue on dynamic balance is sporadic; thus, it is impossible to make a proper judgment to compare the effects of major muscle groups on volleyball players' balance. This is especially true when these are evaluated by the SEBT as a sports-specific inventory.

In agreement with our results, Abdolvahabi et al. [21] found a significant decrease in all 8 directions following the fatigue of ankle PFs and knee extensors in the el-

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derly. Vuillerme et al. [7] also found balance disturbance following the fatigue of calf muscles in healthy students.

In contrast to our findings, Joudeh et al. [23] reported that fatigue of PFs and knee extensors reflected no influence on the balance of the healthy male population. However, the fatigue-inducing protocol and the outcome measure of our study were different from that study. We used the SEBT which evaluates dynamic balance and can predict lower extremity injury.

Regarding the fatigue effect on reaching scores in anterior and posterior directions, Abdolvahabi et al. suggested a further decrease for knee extensors, compared to ankle PFs [21]. This is inconsistent with our findings, where knee extensors and PFs presented similar effects in all directions. This may be due to the different populations and genders used in these investigations. Knee extensors and ankle PFs are more active than other muscles, especially during jumping and landing in volleyball [24]. Evaluating the composite and 3 main directions scores highlights that knee extensors and ankle PFs' fatigue provide more prominent effects on balance than the other muscles.

These findings suggest that the effects of muscular fatigue on the dynamic balance may be different according to the direction, i.e., tested or the fatigued muscle group. Thus, it may be better to increase the knee extensors' and ankle PFs' strength in the volleyball players. This is especially true when the goal is preventing fatigue and improving functional performance in the late stages of rehabilitation.

5. Conclusion

According to our results, regarding composite reach distance, the fatigue of ankle, knee, and hip muscles similarly decreased dynamic balance. However, evaluating 3 main directions revealed that knee extensors and ankle PFs fatigue present more prominent effects on volleyball players' balance than the other muscles.

Ethical Considerations

Compliance with ethical guidelines

The current study was approved by the Ethics Committee of the Tehran University of Medical Sciences. All study participants signed a written informed consent form.

Conflict of interest

The authors declared no conflicts of interest.

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