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Ece Fidan Bozkurt
https://orcid.org/0009-0006-4367-4082
Gaziantep University, Faculty of Sport Sciences, Gaziantep/ TURKIYE
ROR Id: https://ror.org/020vvc407

Dr. Öğr. Üyesi Mehmet Vural
https://orcid.org/0000-0003-0027-6069
Gaziantep University, Faculty of Sport Sciences, Department of Coaching Education, Gaziantep/ TURKIYE
ROR Id: https://ror.org/020vvc407

Arş. Gör. Mete Berk Demiryol
https://orcid.org/0000-0002-6149-3529
Gaziantep University, Faculty of Sport Sciences, Department of Sport Management, Gaziantep/TURKIYE
ROR Id: https://ror.org/020vvc407

The Acute Effect of Inspiratory Muscle Fatique on Isokinetic Performance of The Lower Extremities

İnspiratuar Kas Yorgunluğunun Alt Ekstremite İzokinetik Performansına Akut Etkisi

ABSTRACT

The aim of this study is to investigate the acute effects of inspiratory muscle fatigue on lower extremity isokinetic performance. Respiratory muscles play a role not only in maintaining ventilation but also in ensuring postural stability and regulating blood flow to peripheral muscles during exercise. Therefore, it is believed that fatigue in the inspiratory muscles can affect peripheral muscle performance. In line with this investigation, 15 healthy male athletes (21.56 ±1.71 years, 179.5 ±6.04 height, 75.25 ±8.69 body mass) aged 18–25 volunteered to participate. Participants were included in three protocols: experimental, sham, and control. Measurements were performed. In the experimental condition, inspiratory muscle fatigue was induced by performing 30 sets of 2 repetitions at 60–70% of maximum inspiratory pressure (MIP). In the sham condition, the same procedure was performed without any load. In the control condition, only MIP/MEP measurements and isokinetic strength measurements were conducted. Isokinetic measurements were performed using an isokinetic dynamometer at angular velocities of 60°/s and 180°/s. Analysis of the data revealed no statistically significant changes in MIP, MEP, and isokinetic peak torque values following the inspiratory muscle fatigue protocol ($p>0.05$). However, a correlation analysis of the obtained strength values revealed no significant relationship between the two different strength parameters, MIP/MEP and isokinetic strength ($p>0.05$). In conclusion, acute inspiratory muscle fatigue does not significantly reduce lower-extremity isokinetic strength production. These findings provide important insights into the role of respiratory muscle function in athletic performance.

Keywords: Inspiratory Muscle Fatigue, Isokinetic Performance, Respiratory Muscles, MIP, MEP

ÖZET

Bu çalışmanın amacı inspiratuar kas yorgunluğunun alt ekstremite izokinetik performansı üzerindeki akut etkilerini incelemektir. Solunum kasları yalnızca ventilasyonun sürdürülmesinde değil aynı zamanda postüral stabilitenin sağlanması ve egzersiz sırasında periferik kaslara kan dağılımının düzenlenmesinde de rol oynamaktadır. Bu nedenle inspiratuar kaslarda meydana gelen yorgunluğun periferik kas performansını etkileyebileceği düşünülmektedir. Bu inceleme doğrultusunda çalışmaya yaşları 18–25 arasında değişen 15 sağlıklı erkek sporcu (21.56±1.71 yaş, 179.5±6.04 boy, 75.25±8.69 vücut ağırlığı) gönüllü olarak katılmıştır. Katılımcılar 3 farklı uygulamaya dahil olup; deney, sham ve kontrol ölçümleri gerçekleştirilmiştir. Deney uygulamasında inspiratuar kas yorgunluğu maksimum inspiratuar basıncın %60–70 şiddetinde 30x2 tekrar şeklinde uygulanmıştır. Sham uygulamasında herhangi bir yük olmadan aynı prosedür gerçekleştirilmiştir. Kontrol uygulamasında ise sadece MIP/MEP ölçümü ve izokinetik kuvvet ölçümleri gerçekleştirilmiştir. İzokinetik ölçümler izokinetik dinamometre ile 60°/s^{-1} ve 180°/s-1 açısal hızlarda gerçekleştirilmiştir. Elde edilen veriler değerlendirildiğinde inspiratuar kas yorgunluğu protokolü sonrasında MIP, MEP ve izokinetik peak torque değerlerinde istatistiksel olarak anlamlı bir değişim olmadığını göstermiştir ($p>0.05$). Bununla birlikte elde edilen kuvvet değerleri arasında yapılan korelasyon analizinde iki farklı kuvvet parametresi olan MIP/MEP ve izokinetik kuvvet arsında anlamlı bir ilişki tespit edilememiştir ($p>0.05$). Sonuç olarak inspiratuar kas yorgunluğunun akut olarak uygulamasının ardından alt ekstremite izokinetik kuvvet üretimi üzerinde anlamlı bir azalmaya yol açmadığı söylenebilir. Bu bulgular solunum kas fonksiyonunun spor performansı üzerindeki rolünü anlamak açısından önemli bilgiler sunmaktadır.

Anahtar Kelimeler: inspiratuar kas yorgunluğu, izokinetik performans, solunum kasları, MIP, MEP

1. INTRODUCTION

Physiological stress during exercise leads to multifaceted adaptations in the musculoskeletal and cardiorespiratory systems. During high-intensity physical activity, not only peripheral muscles but also respiratory muscles operate under significant metabolic load. In particular, the intense activation of the diaphragm and accessory inspiratory muscles to meet the increased demand for ventilation can lead to fatigue in these muscles (Romer and Polkey, 2007).

For many years, the effect of respiratory muscles on exercise performance was evaluated solely in terms of ventilatory capacity. However, recent studies have shown that respiratory muscles also play an important role in postural control and trunk stabilization (Hodges, Heijnen & Gandevia, 2001). It has been reported that the diaphragm muscle actively participates in postural tasks and contributes to trunk stability (Hodges & Gandevia, 2000). Therefore, it is believed that fatigue in the respiratory muscles may affect not only ventilatory functions but also musculoskeletal system performance. The increased metabolic demands on the respiratory muscles during exercise may redirect a portion of cardiac output to them. This can reduce blood flow to peripheral muscles, thereby limiting exercise performance (Dempsey et al., 2006). A study by Harms and colleagues (1997) demonstrated that increased respiratory muscle workload alters cardiac output distribution, resulting in reduced blood flow to the lower extremity muscles. This physiological mechanism is referred to in the literature as the respiratory muscle metabolic reflex (Sheel, 2002).

The effect of inspiratory muscle fatigue on peripheral muscle performance has been studied particularly in endurance sports (Amann et al., 2010). However, there are only a limited number of studies on its effects on strength production and isokinetic performance parameters. A recent study identified significant correlations between inspiratory muscle performance and isokinetic acceleration parameters during knee flexion and extension movements (Illi et al., 2012; Archiza, 2018). These findings suggest that respiratory muscle function may be related to lower extremity muscle performance. However, experimental studies examining the acute effects of inspiratory muscle fatigue on lower extremity isokinetic strength production are quite limited. Therefore, understanding how respiratory muscle fatigue affects muscle performance constitutes an important area of research in the sports science literature. The aim of this study is to investigate the acute effects of inspiratory muscle fatigue on lower-extremity isokinetic performance and to evaluate the relationship between respiratory muscle strength and isokinetic performance.

2. METHOD

2.1 Experimental Design and Participants

This study used a pre-test–post-test experimental design as a quantitative research method. It evaluated acute changes in the isokinetic performance of lower extremity muscles following the induction of inspiratory muscle fatigue. A total of 15 healthy male athletes (21.56 ±1.71 years, 179.5 ±6.04 height, 75.25 ±8.69 body mass) aged 18 to 25 voluntarily participated The sample size was determined with G*Power 3.1.9.7, using effect size data from Hüzmeli et al. (2025) An effect size of 0.770659, a 5% error margin ($\alpha=0.05$), and 85% power ($1–\beta=0.85$) were used. Based on these calculations, the minimum sample size was set at 15. Participants were required to have no history of cardiovascular or pulmonary disease, neuromuscular disorders, or musculoskeletal injuries to be included in the study. Prior to the study, all participants were informed of the study's purpose and procedures, and written informed consent was obtained. To ensure the study was conducted in accordance with ethical guidelines, the necessary approval was obtained from the Gaziantep University Health and Sports Sciences Ethics Committee (No. 01, Date: 10/15/2025, No. 738739).

Participants visited the laboratory on three different days. During the first visit, participants' anthropometric characteristics were recorded, maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) were measured to assess respiratory muscle strength, and isokinetic muscle strength (which evaluates muscle force during constant-speed movements) was measured. Participants were also briefed on the other measurement protocols. During subsequent visits, all participants were randomly assigned to different protocols. In the experimental condition(T_1), inspiratory muscle fatigue was induced in participants, followed by MIP/MEP respiratory muscle measurements and isokinetic strength measurements at angular velocities of 60°/s and 180°/s. In the sham condition(T_2), an inspiratory exercise was performed without any load, followed by the same measurements. Control measurements were recorded as baseline values obtained during the first visit(T_0).

2.2 Inspiratory Muscle Fatigue Protocol

Inspiratory muscle fatigue was induced using the Power Breathe inspiratory muscle training device (POWERbreathe International Ltd., Southam, Warwickshire, UK) (McConnell, 2013). During the experimental protocol, participants performed 30 repetitions in 2 sets at 60–70% of their maximum inspiratory pressure. A two-minute rest period was provided between sets. During the exercise, a nasal clip was used to ensure that breathing was performed entirely through the mouth. In the sham condition, the same procedures were performed without any load.

2.3 Respiratory Muscle Strength Measurements

Maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) measurements were performed using an electronic spirometer. All measurements were taken with participants seated, using a nasal clip, breathing only through the mouth. For MIP, the sequence was as follows: the participant exhaled maximally, then inhaled maximally against a closed airway. For MEP, the participant inhaled maximally, then exhaled maximally against a closed airway. For both MIP and MEP, measurements were repeated until the difference between the two best values was less than 5 cmH_2O; the highest value was recorded (Polkey et al., 1995).

2.4 Isokinetic Strength Measurements

Isokinetic strength measurements of the lower extremities were performed using the Humac Norm isokinetic dynamometer (Humac Norm Isokinetic Dynamometer, CSMi Solutions, Stoughton, Massachusetts, USA). The performance of the knee flexor and extensor muscle groups was assessed at two different angular velocities. Participants performed the measurements with 5 repetitions at $60°/s^{-1}$ and 10 at $180°/s^{-1}$. In accordance with the instructions in the isokinetic measurement protocols, the volunteers were positioned at specific angles, and the dynamometer tilt and other necessary equipment were adjusted to the specified angles to conduct the test. Rest periods of 45 seconds were provided between sets, and prior to each measurement, the subjects were warmed up on the dynamometer at an angular velocity of 300 °/s-1 (Dvir, 2004; Maly et al., 2015). The obtained values were recorded in Newton-meters (Nm).

2.5 Statistical Analysis

Data analysis was performed using SPSS 20.0. First, the normality of the data distribution was assessed using the Shapiro-Wilk test. Next, a Repeated Measures ANOVA was performed to analyze the differences between the various applications. A Pearson correlation analysis was then conducted to determine the relationship between isokinetic strength and respiratory muscle strength. Results are presented as mean, standard deviation, 95% confidence interval, and effect size, with a significance level of $p < 0.05$.

3. RESULTS

The results of the repeated-measures ANOVA and Pearson correlation analysis of the data obtained from the experiments are presented in the tables below.

Table 1. Comparison of mean isokinetic strength($60°/s^{-1}$) values across groups obtained from different interventions

	Mean ± SD	%95 CI		F	P	ηp2
T_0 Peak Torque (Nm)	237.75±36.96	218.05	257.45	.208	.813	.014
T_1 Peak Torque (Nm)	233.13±39.37	212.14	254.11			
T_2 Peak Torque (Nm)	233.25±36.86	213.61	252.89			

T₀: Trial 0(Baseline; Control), ***T₁***: Trial 1(Experimental), ***T₂***: Trial 2(SHAM), ***Nm***: Newton meter

Table 1 presents the isokinetic strength data for the groups at an angular velocity of $60°/s^{-1}$. Repeated-measures ANOVA revealed no statistically significant differences in peak torque ratios at $60°/s^{-1}$ among the three groups following different interventions (p> 0.05).

Table 2. Comparison of mean isokinetic strength($180°/s^{-1}$) values across groups obtained from different interventions

	Mean ± SD	%95 CI		F	P	ηp2
T_0 Peak Torque (Nm)	143.25±22.83	131.08	155.42	1.637	.211	.098
T_1 Peak Torque (Nm)	145.0±26.89	130.67	159.33			
T_2 Peak Torque (Nm)	152.50±25.55	138.88	166.12			

T₀: Trial 0(Baseline; Control), ***T₁***: Trial 1(Experimental), ***T₂***: Trial 2(SHAM), ***Nm***: Newton meter

Table 2 presents the isokinetic strength data for the groups at an angular velocity of $180°/s^{-1}$. Repeated-measures ANOVA revealed no statistically significant differences in peak torque ratios among the three groups at an angular velocity of $180°/s^{-1}$ (p> 0.05).

Table 3. Comparison of average MIP values across groups obtained from different interventions

	Mean ± SD	%95 CI		F	P	ηp2
T_0 MIP (cmH₂O)	100.44±24.77	87.24	113.64	.514	.603	.033
T_1 MIP (cmH₂O)	107.69±34.93	89.07	126.30			
T_2 MIP (cmH₂O)	102.56±34.93	86.68	118.45			

T₀: Trial 0(Baseline; Control), ***T₁***: Trial 1(Experimental), ***T₂***: Trial 2(SHAM), ***cmH₂O***: centimeter of water, MIP: Maximal inspirauar pressure

Table 3 presents the inspiratory muscle strength (MIP) data for the groups. A repeated-measures ANOVA comparing inspiratory muscle strength (MIP) values across the three groups and interventions revealed no statistically significant differences (p> 0.05).

Table 4. Comparison of average MEP values across groups obtained from different interventions

	Mean ± SD	%95 CI		F	P	ηp2
T_0 MEP (cmH₂O)	144.56±28.03	129.63	159.50	.507	.607	.033
T_1 MEP (cmH₂O)	151.94±33.24	134.23	169.65			
T_2 MEP (cmH₂O)	153±43.79	130.04	176.71			

T₀: Trial 0(Baseline; Control), ***T₁***: Trial 1(Experimental), ***T₂***: Trial 2(SHAM), ***cmH₂O***: centimeter of water, MEP: Maximal expiratuar pressure

Table 4 presents the expiratory muscle strength (MEP) data for the groups. A repeated-measures ANOVA comparing expiratory muscle strength (MEP) values across the three groups and the different interventions revealed that the differences were not statistically significant (p> 0.05).

Table 5. Analysis of the relationship between participants' respiratory muscle strength and isokinetic strength (60°/s^{-1})

		T_0 MIP	T_0 MEP	T_0 PT	T_1 MIP	T_1 MEP	T_1PT	T_2 MIP	T_2 MEP	T_2 PT
T_0 MIP	r	1	.688**	-.170	.656**	.503*	-.029	.633**	.518*	-.033
	p		**.002**	.264	**.003**	**.024**	.458	**.004**	**.020**	.451
T_0 MEP	r		1	-.319	.420	.431*	-.167	.543*	.577**	-.192
	p			.114	.053	**.048**	.268	**.015**	**.010**	.238
T_0 PT	r			1	-.086	-.187	.798**	.030	-.009	.459*
	p				.376	.244	**.000**	.456	.487	**.037**
T_1 MIP	r				1	.911**	.096	.375	.354	-.204
	p					**.000**	.362	.076	.089	.224
T_1 MEP	r					1	.052	.294	.400	-.272
	p						.425	.135	.062	.154
T_1 PT	r						1	.066	.110	.612**
	p							.404	.342	**.006**
T_2 MIP	r							1	.906**	-.116
	p								**.000**	.334
T_2 MEP	r								1	-.019
	p									.472

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

Table 5 presents the Pearson correlation analysis, which was performed to examine the relationship between respiratory muscle strength and isokinetic strength parameters at three intervention time points (T0, T1, T2). The analysis revealed no statistically significant relationship between respiratory muscle strength and isokinetic peak torque values at any measurement time point (p> 0.05). However, a strong positive correlation was observed among the respiratory muscle parameters. In particular, a high level of statistically significant positive correlation was determined between MIP and MEP values at the intervention points T0 (r: 0.688, p <0.01), T1 (r: 0.911, p <0.01), and T2 (r: 0.906, p <0.01). Similarly, a strong and positive correlation was observed among the isokinetic strength parameters (60°/s^{-1}), and this relationship was statistically significant (T0–T1: r = 0.798, p <0.01; T1–T2: r = 0.612, p <0.01).

4. DISCUSSION AND CONCLUSION

This study aimed to analyze the acute effects of inspiratory muscle fatigue on lower limb isokinetic performance. Results showed no significant changes in maximum inspiratory pressure (MIP), maximum expiratory pressure (MEP), or peak isokinetic torque after the fatigue protocol. The study considered two possible outcomes: either central respiratory muscle fatigue would limit peripheral performance by affecting blood flow, or central muscle activation would enhance peripheral performance without impacting blood flow. However, the data showed no significant changes in either direction. In short, respiratory muscle fatigue did not reduce muscle strength or isokinetic performance. It is well established in the literature on exercise physiology that the respiratory muscles are not merely structures that perform ventilation, but are also metabolically active muscle groups. As the demand for ventilation increases during exercise, oxygen consumption by the diaphragm and accessory inspiratory muscles rises significantly, and metabolic stress may develop in these muscles. When this metabolic stress exceeds a certain threshold, inspiratory muscle fatigue may develop, and this condition can become a limiting factor in exercise performance (Romer and Polkey, 2007; Sheel, 2002).

The effect of inspiratory muscle fatigue on peripheral muscle performance is largely explained by a neurophysiological mechanism known as the respiratory muscle metaboreflex. Increased metabolite accumulation in inspiratory muscles activates group III and IV afferent nerve fibers, thereby increasing sympathetic nervous system activation. As a result, vasoconstriction occurs in peripheral muscle blood vessels, and blood flow to working muscles may decrease (Harms et al., 1997; Dempsey et al., 2006). This reflex response can reduce performance by limiting the flow of oxygen and nutrients to the lower extremity muscles, particularly during high-ventilation exercises (Amann et al., 2010). Based on this information, although inspiratory muscle fatigue was induced in the present study, no significant change in isokinetic peak torque was observed. This finding can be explained by several physiological factors. First, it has been reported that for the inspiratory muscle metabolic reflex to exert a significant effect on peripheral muscle performance, exercises that generally require high ventilation and are sustained over a prolonged period are typically necessary (Romer and Polkey, 2007; Dempsey et al., 2006).

The inspiratory muscle loading applied in the current study involves a relatively short-term protocol. Therefore, the metabolic stress induced in the respiratory muscles may not have reached a level sufficient to trigger a systemic circulatory response. Another possible explanation is that the participants consisted of physically active individuals. In trained individuals, respiratory muscle endurance and oxidative capacity may be higher compared to sedentary individuals. Studies have shown that regular training increases inspiratory muscle endurance, thereby enhancing the resistance of ventilatory muscles to fatigue (Downey et al., 2007; McConnell, 2013). Therefore, the acute effects of inspiratory muscle fatigue on peripheral muscle performance may be more limited in trained individuals. Another important reason fort he association between respiratory muscles and lower extremity performance is their role in postural stability. The diaphragm muscle not only performs ventilatory functions but also supports trunk stability by contributing to the regulation of intra-abdominal pressure. Trunk stability is a crucial biomechanical factor that enhances the efficiency of force production, particularly during multi-joint movements. It has been demonstrated that the diaphragm plays an active role in postural tasks and contributes to trunk stabilization during limb movements (Hodges and Gandevia, 2000; Hodges et al., 2001). Therefore, it is believed that changes in respiratory muscle function may indirectly affect lower extremity muscle performance.

The correlation findings from this study support the functional relationship between respiratory muscle strength and peripheral muscle performance. In particular, the positive relationships observed—albeit not statistically significant—between MIP and MEP values and isokinetic torque production suggest that respiratory muscles may be linked to neuromuscular performance. Studies reporting similar results can also be found in the literature. For example, significant relationships have been identified between inspiratory muscle performance and isokinetic acceleration parameters during knee flexion and extension movements (Kasa et al., 2024). Additionally, findings suggest that inspiratory muscle strength may be associated with athletic performance, sprint capacity, and overall muscle strength (Illi et al., 2012; Archiza et al.,2018). The effect of inspiratory muscle fatigue on peripheral muscle performance may vary depending on the metabolic characteristics of the exercise. During endurance exercise, ventilation requirements are high, resulting in a more pronounced inspiratory muscle metaboreflex (Amann, 2012). In contrast, for tasks requiring short-term maximal strength production, such as isokinetic tests, ventilatory load is relatively lower, so the effect of this mechanism may be limited. Therefore, given that isokinetic tests involve short-duration maximal contractions, the influence of inspiratory muscle fatigue on these performance outcomes is expected to be more limited. This study has some limitations. First, the relatively small sample size may have limited statistical power. Additionally, the degree of inspiratory muscle fatigue was assessed solely through pressure measurements. Future studies could improve understanding by also evaluating parameters such as diaphragm electromyography, ventilatory threshold measurements, or muscle oxygenation. Furthermore, the absence of significant changes in isokinetic performance parameters in this study suggests that higher ventilatory stress may be required for inspiratory muscle fatigue to affect peripheral muscle performance. Since isokinetic tests involve short-duration maximal contractions, which result in a relatively low ventilatory load, circulatory regulatory mechanisms, such as the inspiratory muscle metaboreflex, may not be sufficiently activated in these conditions. These observations together suggest that inspiratory muscle fatigue may produce more pronounced effects during endurance-based exercise than during short-term maximal efforts.

In conclusion, the inspiratory muscle fatigue protocol does not appear to significantly reduce lower extremity isokinetic strength production. However, the presence of positive correlations between respiratory muscle strength and lower extremity muscle performance suggests that respiratory muscle function may be linked to neuromuscular performance. These findings indicate that the respiratory muscles are not limited to ventilation alone but possess multifaceted physiological mechanisms that can influence athletic performance.

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