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Effect of quadriceps and calf muscles fatigue on standing balance in healthy young adult males

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Abstract

Objective: The present study aimed to compare the effects of quadriceps or calf muscles fatigue on static and dynamic standing balance in young healthy adult males. **Methods:** Forty-five healthy, physically active male adults aged 18-30 years were randomly divided into three groups; Quadriceps muscle fatigue group (n=15), Calf muscles fatigue group (n=15), and a control group (n=15). The Modified Clinical Test of Sensory Interaction on Balance, Unilateral Stance, and Limits of Stability (reaction time and movement velocity) were selected as outcome measures for this study. **Results:** The results showed a non-significant difference between pretest and posttest balance scores (p>0.05) for quadriceps and calf muscles fatigue on balance. Similarly, there were non-significant differences in posttest balance scores when comparing fatigue effects between the groups (p>0.05). **Conclusions:** These results suggested that the fatigue of the quadriceps or calf muscles did not influence standing balance in healthy young adult males. Future longitudinal studies are recommended to further understanding the mechanisms behind localized muscle fatigue effects on standing balance in subjects of different age groups of both genders.

Keywords: Fatigue, Balance, Limit of Stability, Male

Introduction

Decreased balance is common among the elderly people whose postural control system exhibits reduced sensitivity due to deficits in their sensory systems[1,2]. There are various factors that affect balance such as proprioceptive deficits and muscle weakness[3]. When considering the relationship between muscle weakness and balance, the weakness of the hamstring, calf, and quadriceps muscles are important[4]. This can have an adverse effect, as maximal muscle strength of the lower limbs is necessary for maintaining optimal postural control, and poor strength levels have been commonly accepted as risk factors which can contribute to falls in the elderly[5].

Muscle fatigue is another factor that may affect postural control in healthy young and elderly population resulting increased risk of fall[6-8]. In addition, muscle fatigue can further increase the risk of injury[9]. Muscle fatigue is characterized as diminished ability of the muscle to contract and apply a force that develops immediately after the onset of the sustained physical activity[10,11]. One of the outcomes of fatigue is that it minimizes the skill-related physical fitness performance, for example, balance[12], strength[9,12], and agility[13] which thusly affect sports performance. A study showed that the lower-limb muscular fatigue caused increased postural sway in

Abbreviations
BMI = body mass index
mCTIB = Modified Clinical Test of Sensory Interaction on Balance
US = Unilateral Stance
EO = Eyes open
EC = Eyes closed
LOS = Limits of Stability
RT = Reaction time
MVL = Movement velocity

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young people[14]. Moreover, fatigue of postural back muscles caused decreased head and trunk balance control and the quadriceps muscular fatigue affects the gait parameters related to slip propensity[15]. However, in both young and older people, the effects of fatigue of specific muscle groups on muscular strength have been widely investigated[16]. In this respect, despite age-related loss or reduction in muscle strength, previous studies have demonstrated that elderly people show better muscle fatigue resistance than young people following dynamic and isometric lower extremity muscle tests[17-19].

It is not clear how localized muscle fatigue may affect the balance. Moreover, due to muscular fatigue, increased joint laxity indirectly leads to alterations in joint kinesthesia and position sense[20]. It is suggested that muscle fatigue may decreased muscle response to neural excitation[21] and decreased contraction activities of the muscles[22]. In this respect, it can disrupt afferent feedback and alters joint awareness. However, fatigue may occur as a result of an interruption to the chain of events from the central nervous system to the muscle fiber. Previous studies have reported that muscle fatigue negatively affects the balance and control of body position[17,20]. Researchers have investigated ways in which fatigue affects balance by applying strenuous aerobic exercise or selective muscle-fatiguing protocols to induce generalized muscle fatigue[9,11].

Centil et al.[17] investigated the fatigue effect of lower-extremity and trunk muscles on the balance in healthy adults. They reported an impaired balance following a generalized fatigue protocol of the lower-extremity and trunk muscles. Another study additionally proposed that muscle fatigue appears to affect active joint reposition sense[23]. Accordingly, muscle fatigue causes muscle spindle information less effective. More recently, Nam et al.[7] investigated the fatigue effect of gastrocnemius muscle on postural control. They reported impaired medio-lateral stability following gastrocnemius muscle fatigue in the elderly. The detrimental effects of localized muscle fatigue on static balance have been investigated[4,24], but its effects on measures of dynamic balance are unknown. This study aims to compare the effects of quadriceps or calf muscles fatigue on static and dynamic standing balance in healthy young adult males.

Materials and methods

Study design

This was a randomized controlled study. The independent variables were (a) fatigue, which included the quadriceps muscle fatigue and calf muscles fatigue and, (b) non-fatigue. Balance indices (Modified Clinical Test of Sensory Interaction on Balance, Unilateral Stance, and Limits of Stability) measured using the Balance Master were the dependent variables.

Participants

Healthy male adults aged 20-30 years from the 'College of Applied Medical Sciences' at 'King Saud University', Riyadh, participated in this study. Subjects were excluded if they had any history of musculoskeletal, neurological, auditory and visual, cardiovascular, respiratory disorders, and were current smokers, or obese individuals [body mass index (BMI)>35 kg/m^2].

Sample size calculation

Based on the results of power analysis, a total sample of forty-five subjects was required to achieve 80% power at a p value of less than 0.05. The sample size was calculated using GraphPad StatMate version 2.00 for Windows (GraphPad Software, San Diego California USA).

Procedure

After a brief description of the study, subjects who fulfilled the inclusion criteria were asked to provide written informed consent. Subjects had the ability to withdraw from the study at any time. The study was approved by the ethics committee of the College of Applied Medical Sciences, King Saud University. After initial evaluation and pretest, participants were allocated randomly to group A (quadriceps muscle fatigue), group B (calf muscles fatigue) or group C (non-fatigue) by choosing an opaque envelope, which contained the names of one of the three groups.

The participants in the fatigue groups performed 5 minutes of warming up on a stationary bicycle at a self-selected speed. One maximal repetition for quadriceps muscle was measured on quadriceps exercise bench[25]. The fatiguing exercises took place beside the Balance Master in order to obtain a very short lag time between the exercise induced fatiguing activity and the Balance Master assessment[26]. The average approximate time between the fatiguing process and measurement was 20 seconds. The rating of perceived exertion from the participants was assessed prior to the fatigue intervention to indicate the level of fatigue[27]. A second rating of perceived exertion was recorded as soon as the participants completed the fatigue protocol. Adequate fatigue was deemed to be a rating of perceived exertion of 14 to 17, which represents 75% to 90% maximum oxygen consumption posttest[27,28].

In order to induce fatigue in the quadriceps muscles, the participants were asked to perform knee extensions on the quadriceps exercise bench. They performed two sets of 50 repetitions each with 50% of one maximal repetition and a 4 minute rest interval between the sets[25]. When the participants could not continue the 50 repetitions in the first set, the fatigue protocol was stopped and the balance test administered. However, if they could complete the first set of 50 repetitions, they continued the protocol after a 4-minute rest[25].

Calf muscle fatigue was achieved by asking the subject to perform toe lifts carrying sand weights (10% of body weight) on his shoulders. The fatigue level was reached when subjects were no longer able to perform or finish two sets of 50 repetitions with 4-minute rest between sets[29,30]. This protocol was chosen based on previous studies with

Table 1. Effect of quadriceps muscle fatigue on balance scores.

Variables	Pretest Mean ± SD	Posttest Mean ± SD	T test P
mCTIB Firm - EO (deg/sec)	0.42 ± 0.50	0.45 ± 0.15	0.788
mCTIB Firm - EC (deg/sec)	0.31 ± 0.08	0.35 ± 0.09	0.164
mCTIB Foam - EO (deg/sec)	0.77 ± 0.22	0.77 ± 0.20	1
mCTIB Foam - EC (deg/sec)	1.43 ± 0.43	1.33 ± 0.39	0.29
US - EO Left (deg/sec)	0.96 ± 0.22	1.16 ± 0.58	0.154
US - EC Left (deg/sec)	2.87 ± 0.89	2.80 ± 0.82	0.63
US - EO Right (deg/sec)	0.97 ± 0.28	1.17 ± 0.39	0.101
US - EC Right (deg/sec)	2.76 ± 1.13	3.06 ± 0.93	0.285
LOS - RT Forward (sec)	1.12 ± 0.34	0.88 ± 0.34	0.223
LOS - RT Right (sec)	0.90 ± 0.28	0.85 ± 0.31	0.453
LOS - RT Back (sec)	0.79 ± 0.27	0.78 ± 0.32	0.859
LOS - RT Left (sec)	0.94 ± 0.30	0.92 ± 0.23	0.833
LOS - MVL Forward (deg/sec)	3.3 ± 0.91	3.44 ± 1.61	0.69
LOS - MVL Right (deg/sec)	4.11 ± 1.28	4.60 ± 1.48	0.139
LOS - MVL Back (deg/sec)	3.02 ± 1.08	2.89 ± 0.83	0.641
LOS - MVL Left (deg/sec)	4.8 ± 1.58	5.06 ± 1.72	0.305

mCTIB, Modified Clinical Test of Sensory Interaction on Balance; US, Unilateral Stance; EO, Eyes open; EC, Eyes closed; LOS, Limits of Stability; RT, Reaction time; MVL, Movement velocity.

few modifications to induce similar types of fatigue in both muscle groups.

For the non-fatigue group, the participants sat on a chair for 15 minutes between the pretest and posttest balance assessments.

Outcome assessment

The 'Modified Clinical Test of Sensory Interaction on Balance' (mCTSIB) is a modified version of the original Clinical Test of Sensory Interaction on Balance[31]. It was designed to provide information about a patient's functional balance control and to assess postural stability during four sensory conditions including: (1) eyes open on a firm surface, (2) eyes closed on a firm surface, (3) eyes open on foam, and (4) eyes closed on the foam. The mCTSIB test provides an objective measure of patient sway velocity (degrees per second) for each of the aforementioned four task conditions[31]. The Unilateral Stance (US) is a test to investigate the postural stability during one leg stance with the eyes open and closed (ICC=0.79 to 0.95)[32]. The US improves on the observational testing of unilateral standing performance by providing an objective measure of sway velocity (in degrees per second). Subjects performed three trials for each of the task conditions[33]. The Limits of Stability (LOS) is a performance assessment based on a set of motor tasks that identify the total distance the patient can purposely displace his center of gravity without losing balance (ICC=0.82-0.48)[14]. It has the capacity to assess the patient's ability to perform specific dynamic balance tasks while monitoring a real-time display of the body's center of gravity position with regards to targets centered over a given base of support and at the stability limits. The test objectively measures movement reaction time (sec) and movement velocity (degrees per second) for each direction[34]. All the tests were measured at baseline and posttest after the fatigue protocol.

Statistical analysis

All the data were analyzed using SPSS software version 19 (SPSS, Chicago, Illinois). Results were reported as mean ± standard deviation. Data were tested using the paired t-tests to compare between and within group differences for balance indices ('modified clinical test of sensory interaction on balance', 'unilateral stance', and 'limits of stability'), respectively. The probability level for all the tests was set at 0.05 to indicate significance.

Results

The demographic parameters of the participants between the Quadriceps Fatigue (age, 21.4±2.2 years; height, 1.71±.06 m; weight, 72.4±13.1 kg; BMI, 25.2±4.6 kg/m^2), Calf Fatigue (age, 21.6±2.1 years; height, 1.70±.04 m; weight, 69.7±14.8 kg; BMI, 24.2±4.7 kg/m^2), and Non-Fatigue groups (age, 21.2±0.8; height, 1.71±.01; weight, 75.3±19.6; BMI, 25.5±6.2) showed no significant difference between the groups.

For the Quadriceps Fatigue Group, the effect of fatigue on balance scores (mCTSIB, US, and LOS) showed no significant difference in all tested positions ($p>0.05$) (Table 1). Similarly, in the Calf Fatigue Group, the effect of

Table 2. Effect of calf muscle fatigue on balance scores.

Variables	Pretest Mean ± SD	Posttest Mean ± SD	T test P
mCTIB Firm - EO (deg/sec)	0.39 ± 0.20	0.44 ± 0.12	0.396
mCTIB Firm - EC (deg/sec)	0.31 ± 0.05	0.5 ± 0.50	0.162
mCTIB Foam - EO (deg/sec)	0.68 ± 0.12	0.68 ± 0.10	1
mCTIB Foam - EC (deg/sec)	1.41 ± 0.27	1.25 ± 0.36	0.112
US - EO Left (deg/sec)	0.84 ± 0.17	0.81 ± 0.08	0.43
US - EC Left (deg/sec)	2.37 ± 0.62	2.13 ± 0.90	0.395
US - EO Right (deg/sec)	0.82 ± 0.19	0.99 ± 0.52	0.255
US - EC Right (deg/sec)	2.31 ± 0.59	2.23 ± 0.77	0.715
LOS - RT Forward (sec)	0.89 ± 0.34	0.92 ± 0.22	0.763
LOS - RT Right (sec)	0.83 ± 0.32	0.90 ± 0.24	0.422
LOS - RT Back (sec)	0.81 ± 0.25	0.78 ± 0.32	0.794
LOS - RT Left (sec)	0.86 ± 0.25	0.84 ± 0.28	0.83
LOS - MVL Forward (deg/sec)	3.64 ± 1.48	3.76 ± 1.54	0.738
LOS - MVL Right (deg/sec)	5.29 ± 2.88	4.56 ± 2.33	0.222
LOS - MVL Back (deg/sec)	3.01 ± 1.14	3.06 ± 1.09	0.825
LOS - MVL Left (deg/sec)	4.92 ± 2.29	5 ± 1.79	0.867

mCTIB, Modified Clinical Test of Sensory Interaction on Balance; US, Unilateral Stance; EO, Eyes open; EC, Eyes closed; LOS, Limits of Stability; RT, Reaction time; MVL, Movement velocity.

Table 3. Comparison of balance scores in non-fatigue group.

Variables	Pretest Mean ± SD	Posttest Mean ± SD	T test P
mCTIB Firm - EO (deg/sec)	0.37 ± 0.13	0.38 ± 0.23	0.885
mCTIB Firm - EC (deg/sec)	0.35 ± 0.14	0.35 ± 0.21	1
mCTIB Foam - EO (deg/sec)	0.66 ± 0.11	0.67 ± 0.16	1
mCTIB Foam - EC (deg/sec)	1.40 ± 0.48	1.31 ± 0.31	0.329
US - EO Left (deg/sec)	1.24 ± 0.76	1.01 ± 0.50	0.093
US - EC Left (deg/sec)	2.87 ± 1.03	2.79 ± 1.12	0.761
US - EO Right (deg/sec)	1.13 ± 0.70	1.36 ± 1.04	0.222
US - EC Right (deg/sec)	2.81 ± 1.13	2.72 ± 1.33	0.647
LOS - RT Forward (sec)	0.91 ± 0.38	0.88 ± 0.20	0.742
LOS - RT Right (sec)	0.80 ± 0.29	0.86 ± 0.30	0.343
LOS - RT Back (sec)	0.82 ± 0.29	0.72 ± 0.26	0.139
LOS - RT Left (sec)	0.86 ± 0.23	0.71 ± 0.29	0.068
LOS - MVL Forward (deg/sec)	3.29 ± 1.23	3.83 ± 1.36	0.14
LOS - MVL Right (deg/sec)	4.16 ± 1.55	5.02 ± 2.38	0.061
LOS - MVL Back (deg/sec)	3 ± 0.97	3.31 ± 0.97	0.182
LOS - MVL Left (deg/sec)	5.03 ± 1.84	5.99 ± 2.49	0.118

mCTIB, Modified Clinical Test of Sensory Interaction on Balance; US, Unilateral Stance; EO, Eyes open; EC, Eyes closed; LOS, Limits of Stability; RT, Reaction time; MVL, Movement velocity.

fatigue on balance scores (mCTSIB, US, and LOS) showed no significant difference in all tested positions ($p>0.05$) (Table 2). The comparison of balance scores (mCTSIB, US, and LOS) from pretest to posttest in the Non-Fatigue Group showed no significant difference in all the tested positions (Table 3). The posttest values were used to compare the differences of balance scores between the three groups. The comparison of balance scores (mCTSIB, US, and LOS) between Quadriceps, Calf and Non-Fatigue groups showed no significant difference (Table 4).

Table 4. Comparison of balance scores among quadriceps, calf and non-fatigue groups.

Variable	Quadriceps Group Mean ± SD	Calf Group Mean ± SD	Non Fatigue Group Mean ± SD	ANOVA P
mCTIB Firm - EO (deg/sec)	0.45 ± 0.15	0.44 ± 0.13	0.380 ± 0.24	0.493
mCTIB Firm - EC (deg/sec)	0.35 ± 0.09	0.50 ± 0.50	0.353 ± 0.22	0.345
mCTIB Foam - EO (deg/sec)	0.77 ± 0.21	0.68 ± 0.11	0.67 ± 0.16	0.164
mCTIB Foam - EC (deg/sec)	1.33 ± 0.39	1.25 ± 0.36	1.31 ± 0.31	0.846
US - EO Left (deg/sec)	1.16 ± 0.58	0.81 ± 0.09	1.01 ± 0.50	0.107
US - EC Left (deg/sec)	2.80 ± 0.83	2.13 ± 0.91	2.79 ± 1.12	0.100
US - EO Right (deg/sec)	1.17 ± 0.39	0.99 ± 0.53	1.36 ± 1.04	0.378
US - EC Right (deg/sec)	3.06 ± 0.93	2.23 ± 0.77	2.72 ± 1.33	0.103
LOS - RT Forward (sec)	0.88 ± 0.34	0.92 ± 0.22	0.88 ± 0.20	0.900
LOS - RT Right (sec)	0.85 ± 0.32	0.90 ± 0.25	0.85 ± 0.30	0.853
LOS - RT Back (sec)	0.78 ± 0.33	0.78 ± 0.32	0.71 ± 0.26	0.827
LOS - RT Left (sec)	0.92 ± 0.24	0.84 ± 0.28	0.71 ± 0.29	0.113
LOS - MVL Forward (deg/sec)	3.44 ± 1.62	3.76 ± 1.55	3.83 ± 1.37	0.758
LOS - MVL Right (deg/sec)	4.60 ± 1.48	4.57 ± 2.33	5.02 ± 2.38	0.807
LOS - MVL Back (deg/sec)	2.89 ± 0.84	3.06 ± 1.10	3.31 ± 0.98	0.500
LOS - MVL Left (deg/sec)	5.06 ± 1.73	5.00 ± 1.80	5.99 ± 2.5	0.335

mCTIB, Modified Clinical Test of Sensory Interaction on Balance; US, Unilateral Stance; EO, Eyes open; EC, Eyes closed; LOS, Limits of Stability; RT, Reaction time; MVL, Movement velocity.

Discussion

The aims of this study were to investigate and compare the effects of quadriceps and calf muscles fatigue on quiet standing balance in young healthy adult males. In the current study, participants were tested for sway velocity (degrees per second) for mCTSIB and US under four conditions. In addition, limits of stability in eight directions were measured for the movement velocity (degrees per second) and reaction time (sec). The results showed no significant difference between pretest and posttest scores for all the variables. Our findings are not in agreement with the previous studies, which reported significant effects of quadriceps and calf muscles fatigue on quiet standing balance[25,35]. Another study reported reduced dynamic balance following muscle fatigue in adult male[36]. Similarly, other studies reported reduced dynamic balance following muscle fatigue[37,38]. This difference in the results might be due to various methodological differences between the present and previous studies. The previous studies have investigated older participants whereas in our study, we used young participants[25,35]. Many studies have investigated the effects of aging on balance. Zettel et al.[39] concluded that the attentional demand related with balance recovery was impaired in older adults. Abdulvahabi et al.[35] and Islami et al.[25] reported that there was a meaningful decrease in balance score posttest (after fatigue) as compared with pretest (baseline) conditions in elderly subjects, which indicated that aging had a negative effect on dynamic standing balance. In contrast, our participants were comprised of young adults and we found that fatigue did not have a significant effect on standing balance. In addition, the gender of participants in this study was males while previous studies that reported a significant difference in the effect of fatigue on balance studied female participants[25,35]. This might be due to differences in body muscle mass between genders. Studies have shown that males have greater skeletal muscle mass than females. In one study that examined 468 males and females, they determined that males had an average of 33 kilograms of muscle compared to the 21 kilograms found in females. The males had 40 percent more muscle mass in the upper body and 33 percent more in the lower body[40]. Higher muscle mass might contribute to better standing balance for males compared to females.

Another factor can be related to the compensatory mechanisms thought to come into play after implementation of a fatigue protocol for maintaining standing balance. The fatigue of localized muscle does not affect standing balance because of compensatory mechanisms. Other muscle groups might work together in order to compensate for the fatigued muscle group. Therefore, no effect of fatigue would appear on general standing balance[25,35]. There were methodological differences used in detecting standing balance changes amongst the various studies[25,35]. In the present study, we used the Balance Master, because of its ability to detect minimal changes during static and dynamic standing balance[25,35]. Previous reports used functional balance measures such as the Berg Balance Scale, which combines static and dynamic measures into one composite score and might not necessarily reflect the individual static and dynamic standing performances[25]. Another study used the Star Excursion test, which focuses on dynamic balance only, measured manually in centimeters, and is not as accurate as the computerized measures from the Balance Master[35].

In the present study, we reported no significant difference in posttests balance scores for all the groups. In contrast, previous studies reported significant differences between quadriceps and calf muscle fatigue on balance[25,35]. In addition, both quadriceps and calf muscles contain two types of muscle fibers: slow twitch (type I) and fast twitch (type II). A previous study reported that the soleus, gastrocnemius, and vastus lateralis muscles had a high proportion of slow twitch fibers (Type I)[41]. In addition, the glycolytic activity was lower in the slow twitch fibers (Type I) compared to those with a high proportion of high twitch fibers (Type II)[41]. Since, the antigravity muscles in the lower limb such as quadriceps and calf muscles have more type I fibers; therefore, these muscles may have a higher resistance to fatigue than other muscles. Since both the muscles are similar in morphological structure, it is assumed that the fatigue of both muscles (quadriceps and calf muscles) have similar effects on balance[41,42].

This study is limited to healthy young adult subjects with no history of falls or balance impairments. To what degree acute fatigue would affect balance in young subjects with a history of falling is unknown and worthy of study. In addition, the present study assessed the participant's perceived level of fatigue but the lasting effects of fatigue were not tested. These could also affect the present results.

Future studies should incorporate EMG data of lower limb musculature in order to a better understanding the possible compensatory measures exhibited by our subjects under fatigued conditions. In addition, using surface EMG is highly recommended to ensure that the participants reached a fatigued state following the fatiguing protocol, and a threshold for decreased in muscular strength could be established. In addition, the effects of physiological parameters of fatigued muscles such as oxidative free radicals, lactate dehydrogenase, and creatine kinase on balance performance could be studied.

In conclusion, the fatigue of the quadriceps or calf muscles did not influence standing balance in healthy young adult males. Future longitudinal studies are warranted to further understanding the mechanisms behind localized muscle fatigue effects on standing balance in subjects of different age groups of both genders.

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Ethics approval and consent to participate

The study was approved by the ethics committee of the College of Applied Medical Sciences, King Saud University. The participants were asked to sign a written informed consent form approved by the institution ethics committee of King Saud University.

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Authors' contributions

AAJ: participated in the study design, participated in the data collection, and drafted the manuscript. SA: corresponding author, participated in the study design, participated in the data collection, revised the manuscript critically, and finalized the manuscript. AA: participated in the study design, helped with the ethics application and revised the manuscript critically. HZ: participated in the study design, developed the protocol, and revised the manuscript critically. EA: participated in the study design and revised the manuscript critically. SME: participated in the study design and revised the manuscript critically. CT: participated in the study design and revised the manuscript critically. All authors read and approved the final manuscript.

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