

The effect of hip abductor fatigue on static balance and gait parameters

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Objective: Hip abductors play a role in providing stability and movement to the lower limbs. The purpose of this study was to examine the effects of hip abductor fatigue on static balance and gait in the general population.

Design: One group pre-test post-test design.

Methods: Thirteen university students in their twenties volunteered for the study and had undergone a functional assessment. To induce fatigue, the subjects were instructed to raise their dominant lower extremity up against a load of 50% of 1 repetition maximum while producing hip abduction in a side-lying position. Subjects were instructed to maintain an abduction speed of 30 repetitions per minute to induce fatigue. Muscle fatigue was considered to be established when subjects were unable to perform hip abduction three consecutive times along with the metronome. A post-test of balance and gait was performed immediately in order to prevent fatigue recovery. The center of pressure (COP) distance area was measured using the Zebris FDM-S Multifunction Force measuring plate. Gait performance was analyzed using the GAITRite.

Results: The COP distance was increased after fatigue was induced. There was a significant increase in the standard deviation of the medio-lateral and antero-posterior distance ($p < 0.05$). Although there was no significant difference in gait parameters, there was a significant decrease in single support time after fatigue was induced ($p < 0.05$).

Conclusions: There was an increase in static balance instability and a significant decrease in single support time during gait due to hip abductor muscle fatigue.

Key Words: Fatigue, Gait, Postural balance

Introduction

Hip abductor muscles play a role in providing a connection between the pelvis and the lower limbs and producing stability and lower limb control. Not only is there a relationship between hip abductor weakness and dysfunction, but also femoroacetabular impingement [1], patellofemoral pain [2], and low back pain [3]. One study reported that persons with hip abductor weakness also experienced ankle sprains [4].

Hip abductor muscles have an important function in preventing of a pelvic drop of the opposite side during a one-legged stance. Hip abductor muscle weakness produces

a drop or oblique appearance of the pelvis, and in order to maintain stability, leaning of the ipsilateral trunk can be seen for compensation [5]. The gluteus medius muscle on the lateral side provides lateral stability but also has an important function in maintaining the center of mass (COM) during the single limb support phase of the gait cycle [6]. During the performance of a closed kinetic chain exercise, the femur controls for internal rotation, and plays an important role in producing stabilization of the hip [7]. If the function of the gluteus medius is not appropriate, a complete hip abduction movement cannot occur, and consequently leads to poor postural control and hip external rotation [8]. The gluteus medius muscle plays a role in producing pelvic stability and

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femoral motion control [9].

Muscle fatigue reduces the ability to produce force within the neuromuscular system [10], and is defined as a disability in the production of maximum force [11]. Muscle fatigue corrupts the muscle spindles [12], joint position sense [13], and similar structures. Muscle fatigue produces changes in somatosensory input and results in defective postural control [14].

As already known, damage caused by muscle fatigue includes instability and injury during exercise performance [15]. In addition, one can experience these injuries during daily life activities. Hip abductor muscle fatigue has an effect on hip joint position sense and gait control within healthy elderly people [16]. Local muscle fatigue leads to poor postural control, and furthermore, fatigue of the proximal muscles produce an even greater negative impact on balance ability compared to fatigue of the distal muscles [17].

Fatigue is defined as decreased muscle strength after repeated muscle contractions [18-20]. Fatigue is also considered one of the factors for balance injury [19,20]. The gluteus medius muscle plays a large role with balance during one-legged standing. Although studies on fatigue have been performed in the athletic population, studies that have been conducted in the non-athletic population are lacking.

This study was conducted to examine the effects of hip abductor fatigue on static balance and gait parameters in the non-athletic population for postural control as well as the significance of the role of proximal lower extremity muscles on gait.

Methods

Subjects

Thirteen healthy university students in their twenties have agreed to volunteer after being informed of the purpose of

the study and signing an informed consent (Table 1). All subjects were instructed to avoid being involved in extreme sport activities one week prior to the study. The inclusion criteria were as follows: between the ages of 20-29 years, ability to perform a one-legged standing position, and an mini-mental state examination Korean version score of >24. The exclusion criteria were as follows: presence of low back pain or neuromuscular injury, disease of the cardiorespiratory system, presence of pain that would make it difficult to participate in the study, consumption of alcohol prior to the study, and inability to appropriately recover from muscle fatigue. Aside from the examiner, an assistant was on stand-by next to the subject at all times for safety and fall prevention purposes.

Intervention

In order to induce fatigue onto the gluteus medius muscle of the dominant side, subjects were instructed to lift their dominant lower extremity upwards while the non-dominant lower extremity was placed in 20 degrees of hip and knee flexion on the bottom. A plastic bar was placed as a procedure to promote 30 degrees of hip abduction of the dominant lower extremity (Figure 1) [21]. Subjects were to perform hip abduction without any hip internal or external rotation. A metronome was used to cue subjects to perform hip abduction 30 times per minute.

An external load of 50% of 1 repetition maximum (RM) was placed. The reliability level of one RM is considered to be high (intraclass correlation coefficient >0.91) [22]. Fatigue was defined by the subjects' inability to perform 3 consecutive hip abduction movement along with the metronome. The subjects were instructed to perform the post-test requirement within 10 seconds of hip abductor fatigue induction in order to prevent fatigue recovery [23]. The

Table 1. Characteristics of participants (N=13)

Variable	Value
Sex (male/female)	6/7
Age (y)	23.5 (1.94)
Height (cm)	169.6 (8.61)
Weight (kg)	62.4 (9.21)
Leg length (cm)	83.5 (6.3)
RM (kg)	17.1 (9.57)
BMI (Kg/cm ²)	21.66 (1.61)

Values are presented as number only or mean (SD). RM: repetition maximum, BMI: body mass index.



Figure 1. Position inducing fatigue on the gluteus medius.

post-test examination was performed within a total of 6 minutes.

Outcome measures

Static balance was considered as the ability to stand bare-footed on the dominant lower extremity with the non-dominant lower extremity in 30 degrees of hip flexion and 45 degrees knee flexion, and gazing in front with bilateral eyes open (Figure 2) [24]. The center of pressure (COP) was measured for 30 seconds using the Zebris FDM-S Multifunction Force measuring plate (Zebris Medical GmbH, Isny im Allgäu, Germany). The system includes a pressure that consists of 2,560 embedded sensors, and the pressure is recorded by each sensor. If the subject's heel of the dominant lower extremity began to descend or if the opposite lower extremity touched the ground, the COP was re-measured. The GAITRite (CIR Systems Inc., Lafayette, NJ, USA) is reported to have a very high reliability was used to assess for the subjects' spatial and temporal parameters while walking [25,26]. The GAITRite is a gait analysis system and an electronic gait-analyzing board consisting of a 192 inches (488 cm) electrical walkway that contains six sensor pads encapsulated in a roll-up carpet to produce an active area that is 24 inches (61 cm) wide and 0.6 cm high. The active area is a grid with 48 sensors by 384 sensors, with a distance of 0.5 inch (1.27 cm) between each sensor, totaling up to 16,128 sensors. A sampling rate of 80 Hz was used to measure the loading of the subject's feet when the subjects walk on it. A serial interface cable was used to transmit data. Spatiotemporal data collected was processed using the GAITRite GOLD, Version 3.2b software. Subjects were instructed to stand in front of the gait board, and then walk at



Figure 2. Measurement of static balance.

a self-selected comfortable speed until the end of the board. Subjects were asked to begin walking 1 meter before the GAITRite walkway and up until 1 meter after the walkway at a comfortable speed while the spatial and temporal data were obtained during the middle 5 m (Figure 3).

Subjects were measured for static balance and gait parameters prior to and after fatigue induction. The static balance parameters assessed were the distance of COP, including medio-lateral, anterior-posterior, the total distance of the COP, as well as the sway variability of the COP, indicating the standard deviation of the medio-lateral and antero-posterior distance [27]. The gait parameters assessed were velocity, cadence, step length, stride length, single support time and double support time. A total of three measurements were taken and the mean value was obtained.

Due to a small sample size, the Kolmogorov-Smirnov test was used and has shown that there was a significant increase in the SD of the medio-lateral and antero-posterior distance ($p < 0.05$).

Data analysis

Data was analyzed using the PASW Statistics ver. 18.0 (IBM Co., Armonk, NY, USA). The general characteristics of the subjects are described as the mean and standard deviation (SD) values, and the physical function of the subjects before and after intervention were analyzed using the paired t-test. Data was analyzed with a significance level of $p < 0.05$.

Results

Although the COP distance was greater after fatigue was induced, there was no significant increase. Although there

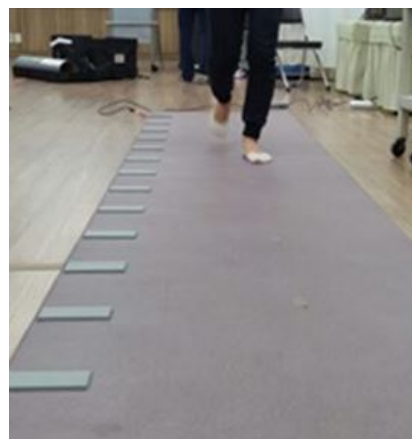


Figure 3. Measurement of gait.

was no significant improvement in the COP medio-lateral and anterior-posterior distance, there was a significant improvement in the SD values of the COP medio-lateral and antero-posterior distance ($p < 0.05$) (Table 2).

There was no significant difference in gait velocity, cadence, step length, and stride length due to hip abductor fatigue post intervention, however, there was a significant decrease in single support time after intervention ($p < 0.05$) (Table 3).

Discussion

With hip abductor muscle fatigue, there is a decrease in postural control ability and therefore compensation occurs for neuromuscular adaptation [23]. Fatigue induces changes in the proprioceptive and kinesthetic properties of joints [28,29]. Local fatigue within the hip joint brings about postural instability during a single leg task [30]. During the late stance phase, the gluteus medius adjusts for balance by moving the COM towards the medial side [31].

The results of this study show that there was a significant difference in the SD values of the anterior-posterior and medial-lateral excursion of the COP ($p < 0.05$). Bisson *et al.* [27] reported a significant improvement in the SD of the anterior-posterior COP excursion only when the hip flexors and extensor muscles were fatigued ($p < 0.05$). Since the hip abductor muscles have an affect on postural control in the coronal plane, it would cause variability in the medio-lateral distance. In general, the hip, knee, or ankle strategy is used to compensate for postural instability. Weak hip abductor muscles increase knee abduction [32,33]. It is possible to discover weak hip abductor muscles in patients with knee osteoarthritis [34]. In addition, weak hip abduction motion was observed in subjects with chronic unilateral ankle sprain [4]. One study by Kurz *et al.* [35] mentions that medio-lateral

fluctuation variable is the coefficient of variation (CV) of the medio-lateral COP range. The CV of the medio-lateral COP was calculated as the $SD/mean \times 100$. Therefore, the SD of the medial-lateral and anterior-posterior COP infer fluctuation of the COP.

It is important to have a high COM and a small base of support (BOS) when walking forward and perpetually maintaining posture. In particular, it is especially important to maintain postural stability during the mid-stance phase of a single leg stance due to a small BOS. During the stance phase, the COM tries to move outwards due to gravity, however, the gluteus medius, which is a hip abductor, quickly pulls the COM back inwards and thus, providing postural control [31]. This study showed that the single support time was reduced after inducing fatigue onto the gluteus medius muscle, which prevented the muscle from performing its action in completion, and although it was not significant, an increase in cadence was observed. Among the healthy elderly population, when the hip abductor muscle was fatigued, there was no significant improvement in stride time. However, there was a significant increase in stride time SD, and the harmonic ratio was reduced in the medio-lateral direction [16]. When comparing patients during the early stage of total hip arthroplasty with age-matched control subjects, they displayed a slower gait speed, shortened stride length, decreased cadence, and increase trunk lateral displacement. Therefore, total hip arthroplasty patients with weak hip abductor muscles and with limited motion walk using compensation [36]. People who are at risk of falling exhibit a short single support time when walking [37]. Therefore, single support time implies the overall stability [38].

Presence of hip abductor fatigue has shown to cause variation of the COP and affect single support time. It is important to note that hip abductor fatigue is related to the quality of balance and gait patterns and that it should be consid-

Table 2. Static balance parameters of participants (N=13)

Variable	Pre-test	Post-test	<i>p</i>
COP ML (cm)	15.4 (1.34)	14.9 (1.34)	0.128
COP AP (cm)	31.3 (6.47)	31.7 (6.5)	0.227
COP distance (cm)	85.7 (17.7)	102.3 (30.8)	0.067
Standard deviation ML (cm)	0.7 (0.15)	0.8 (0.26)	0.048
Standard deviation AP (cm)	0.4 (0.85)	0.5 (0.86)	0.024

Values are presented as mean (SD).

COP: center of pressure, ML: medio-lateral, AP: antero-posterior.

Table 3. Gait parameters of participants (N=13)

Variable	Pre-test	Post-test	<i>p</i>
Velocity (cm/s)	136.84 (17.98)	139.88 (16.70)	0.249
Cadence (steps/min)	119.11 (7.80)	121.13 (8.96)	0.133
Step length (cm)	68.45 (6.27)	69.11 (5.59)	0.504
Stride length (cm)	138.04 (12.38)	138.58 (11.54)	0.707
Single support time (s)	0.22 (0.02)	0.21 (0.02)	0.019
Double support time (s)	0.16 (0.04)	0.16 (0.03)	0.523

Values are presented as mean (SD).

ered and taken into account during balance and gait training.

Study limitations included a few number of subjects, and, since the subjects were of young age, there was a possibility for a natural quick recovery of the fatigue. Further studies should include a larger sample size and identify the relationship between fatigue and function according to age group and disease in order to develop a rehabilitation program where fatigue will not interfere with the training process.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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