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The acute effects of hip abductors fatigue on postural balance

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ABSTRACT

The aim of this study was to investigate the effects of unilateral hip abductor fatigue on body sway in ipsilateral and contralateral single legged stance. Acute effects repeated measurements design. Thirteen recreationally active middle aged subjects participated in the study. All subjects performed two 30s repetitions of unilateral stance on each leg. The first measurement was obtained at baseline, the second followed a control protocol of active hip abduction in supine position without additional resistance and the third measurement was conducted as aforementioned second protocol, only against elastic resistance. The center of pressure (CoP) movement characteristics during single-leg quiet stance (i.e. body sway) were analyzed by calculating the average velocity of the CoP movement and direction specific (medial-lateral and anterior-posterior) average velocity, amplitude and frequency of the CoP movement. The results of this study indicate that fatigue significantly affected body sway in both single leg stances ($p < 0.05$) and in both medial-lateral and anterior-posterior direction. However, medial-lateral body sway tended to be increased more than in anterior-posterior direction. A significant crossover effect of increased body sway on the opposing limb suggests that in addition to local muscle fatigue, changes in central nervous system might have taken place. The above findings are of greater importance as they allow a more thorough insight into the mechanisms responsible for controlling balance that could have an important implication on designing training programs.

Key words: *balance, body sway, fatigue, unilateral stance.*

Introduction

Maintenance of postural balance is an important requirement for the efficient performance in undertaking most sporting activities. Maintaining an upright stance is crucial throughout the performance especially in more challenging conditions that athletes face frequently. Athletes are therefore required to compensate for postural perturbations that challenge bilateral and unilateral stances. These stances are maintained and preserved by different balancing strategies known as ankle and hip strategy (Benvenuti, 2001) In the anterior-posterior (a-p) direction, balance is primarily controlled by ankle plantar/dorsal flexion and by hip flexion/extension while in the medial-lateral (m-l) direction; postural control mainly depends on ankle inversion/eversion and hip adduction/abduction (Benvenuti, 2001; Lee & Powers, 2014).

During tasks such as single legged landings and jumping as well as wider squatting in defense commonly observed in agility sports, maintaining posture and appropriate body alignment becomes more challenging. In order to ensure the desired state, the correct and synchronized muscle output is essential (Neumann, 2010; Ward, Winters, & Blemker, 2010). As these events last for a prolonged period of time, coupled with high intensity, expected neuromuscular fatigue develops especially towards the end of the game (Gehring, Melnyk, & Gollhofer, 2009).This causes deterioration of balance, especially in maintaining unilateral stance that reflects on poor landing technique and could possibly lead to lower limb injuries (Lee & Powers, 2014). Therefore understanding the effects of fatigue on unilateral stance is of great importance.

A number of studies have reported the diminished postural control in experimentally induced fatigue on distal parts of lower limbs (Bisson, Chopra, Azzi, Morgan, & Bilodeau, 2010; Boyas, Hajj, & Bilodeau, 2013; Boyas et al., 2011).

However, according to Allum, Bloem, Carpenter, Hulliger, and Hadders-Algra (1998) trunk and hip inputs may be more important in triggering human balance corrections, while proprioceptive input from the lower extremities mainly helps with the final shaping and intermuscular coordination of postural and gait movements. Therefore inability to produce and sustain force output of hip musculature is vital, especially in unilateral standing where hip strategy becomes more superior in maintaining balance (Winter, 1995). This was confirmed in the study by Reimer and Wikstrom (2010) where proximal muscle fatigue resulted in greater postural control deficits assessed in unilateral stance by fatiguing hip flexors and extensors.

According to Sarabon, Rosker, Loefler, and Kern (2013) standing on a single leg causes an increase of body sway parameters in m-l direction. The latter is suggested to be primarily controlled by hip adductors and abductors.Gribble and Hertel (2004)., as well as Salavati, Moghadam, Ebrahimi, and Arab (2007) have studied the effect of fatigue of hip adductors and abductors on unilateral standing task and found that fatigue alters balance control. However, the studies have focused only on the effects of fatigue on balance when fatiguing ipsilateral side. It is suggested that local muscle fatigue can also alter muscular

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performance of other non-fatigued muscles on the contralateral side (Halperin, Chapman, & Behm, 2015), it remains unknown how contralateral effect of fatigue influence balance control.

Based on the above discussion the first aim of this study was to investigate whether unilateral experimentally induce fatigue effects only ipsi- or also contra-lateral balance control (i.e. stance dominant (DO) and non-dominant (ND) leg). In addition, the second aim was to investigate whether isolated hip abductors fatigue alters balance in multiple planes.

Methods

Thirteen healthy and recreationally active subjects (8 women, 5 men; age, 33 ± 10,8 y, height 1.7± 0,1m, mass, 68,4 ± 19,8 kg) with no history of visual, vestibular, neurologic impairments or any injuries to the lower extremity participated in this study. All participants were required to read and sign an informed consent form. The study was approved by the Slovenian committee for Medical Ethics and was performed according to the Declaration of Helsinki.

Study protocol

Postural balance was tested with a single-leg quiet stance task. Subjects were required to stand barefoot on a force platform maintaining a unilateral stance while concentrating on the stationary target positioned at an eye level height at a 2m distance. Subjects were then instructed to remain as still as possible until told to relax. Four trials of 30 seconds (2 trials each leg) were performed at baseline (BSL), after control protocol (CO) and after at the end of fatiguing trials (FAT).

Following completion of the pre-fatigue balance task (BSL), each participant underwent a control protocol. This was set to rule out possible effects of alterations in proprioceptive feedback that could be a result of mono-articular hip movements. The control protocol was performed with subjects laid down on their back, abducting and adducting their DO with the range of motion of 0° to 45° of hip abduction. Participants were instructed to move the leg for three sets of 35 repetitions interspaced by 1-minute rest periods. Immediately after the control protocol and balance task that followed, subjects had a 5-minute rest period before starting the fatiguing protocol. Fatiguing protocol consisted of the same leg movement as in the aforementioned control protocol; however abduction was performed against an elastic resistance (concentric muscle activity in abduction and eccentric muscle activity in adduction) (Figure 1). The fatiguing protocol consisted of: 3 sets, load intensity of 25 to 45 repetition maximum and 1-minute breaks between sets.

Figure 1: Fatiguing task: 0° to 45° hip abduction (arrow) against resistance of the elastic tube attached to the leg (above the ankle of the stance dominant leg) using a cuff.

Measurement and equipment

The signals from the force plate (9260AA6, Kistler, Winterthur, Switzerland) were acquired with 1000 Hz sampling rate and filtered with 2nd order Butterworth, 0.1-20 Hz band-pass filter. The signals were analyzed using a specialized software (MARS, Kistler, Winterthur, Switzerland) calculating the following parameters: average CoP movement velocity (CoPV), average CoP movement velocity in a-p direction (CoPVa-p), average CoP movement velocity in m-l direction (CoPVm-l), average CoP amplitude in a-p direction (CoPAa-p), average CoP amplitude in m-l direction (CoPAm-l), average frequency of CoP movement direction changes in a-p direction (CoPFa-p) and average frequency of CoP movement direction changes in m-l direction (CoPFm-l). For each parameter an average of two trials were used for further statistical analysis.

Statistical analysis

Statistical analyses was performed using statistical software SPSS 18.0 software (SPSS Inc., Chicago, USA). Descriptive statistics were calculated for all parameters observed. Repeated measures analysis of variance (rANOVA) was used to analyze the differences in individual CoP movement parameters between BSL, CO and FAT. The two-way rANOVA (Leg (2) × Condition (3)). Pair-wise comparisons (2-tailed t-test with Bonferroni correction) were used for post hoc analysis. In all tests, statistical significance was set at $p < 0.05$. Additionally, effect sizes were calculated.

Results

Descriptive statistics (mean and standard deviation), results of repeated measures ANOVA and results of paired T-test for each individual parameter of CoP movement are shown in Table 1 (for the ND leg) and Table 2 (for the DO leg). A general tendency of an improved balance was suggested following CO. Balance was decreased after FAT for both legs. All CoP parameters changed significantly between the BSL, CO and FAT for the DO leg (exceptions were CoPFa-p and CoPFm-l). On the contrary, balance didn't change between the conditions while standing on the ND leg (exception was the CoPFa-p). The improvement from BSL to CO was statistically significant only for DO leg (exceptions CoPFa-p and CoPFm-l). However, changes from CO to FAT were statistically significant for both legs. A more systematic and higher statistical significance were found in CoPVm-l and CoPAm-l as compared to CoPVa-p and CoPAa-p.

Table 1. Results of descriptive statistics, one-way rANOVA and post hoc t-tests for the stance dominant (i.e. exercised) leg; baseline (BSL), control (CO), and fatigued (FAT).

Parameter (unit)	**Descriptive (mean ± st. dev.)**			**rANOVA**	**t-test**		
	BSL	CO	FAT	BSL : CO : FAT	BSL : CO	FAT : CO	BSL : FAT
CoP$_{\text{V}}$ (mm/s)	33.1 ± 9.0	30.3 ± 8.0	35.0 ± 9.5	**F = 6.20; p = 0.01; ES = 0.34**	**t = 3.32; p = 0.01; ES = 0.69**	**t = 2.85; p = 0.01; ES = 0.64**	t = 1.35; p = 0.20; ES = 0.36
CoP$_{\text{Va-p}}$ (mm/s)	20.8 ± 5.8	19.0 ± 5.3	21.8 ± 6.1	**F = 5.43; p = 0.01; ES = 0.31**	**t = 3.24; p = 0.01; ES = 0.68**	**t = 2.67; p = 0.02; ES = 0.61**	t = 1.10; p = 0.29; ES = 0.30
CoP$_{\text{Vm-l}}$ (mm/s)	21.9 ± 6.2	20.0 ± 5.3	23.2 ± 6.6	**F = 5.24; p = 0.01; ES = 0.30**	**t = 2.83; p = 0.02; ES = 0.63**	**t = 2.70; p = 0.02; ES = 0.61**	t = 1.21; p = 0.25; ES = 0.33
CoP$_{\text{Aa-p}}$ (mm)	6.8 ± 2.0	6.0 ± 1.9	6.9 ± 2.1	**F = 5.74; p = 0.01; ES = 0.32**	**t = 2.83; p = 0.02; ES = 0.63**	**t = 2.54; p = 0.03; ES = 0.59**	t = 0.15; p = 0.88; ES = 0.04
CoP$_{\text{Am-l}}$ (mm)	7.7 ± 2.1	6.7 ± 1.9	8.2 ± 1.9	**F = 7.81; p = 0.00; ES = 0.39**	**t = 2.46; p = 0.03; ES = 0.58**	**t = 3.45; p = 0.00; ES = 0.71**	t = 1.63; p = 0.13; ES = 0.43
CoP$_{\text{Fa-p}}$ (Hz)	3.1 ± 0.4	3.3 ± 0.5	3.2 ± 0.6	F = 1.05; p = 0.36; ES = 0.08	t = -1.47; p = 0.17; ES = 0.39	t = -0.16; p = 0.88; ES = 0.05	t = 1.43; p = 0.18; ES = 0.38
CoP$_{\text{Fm-l}}$ (Hz)	2.9 ± 0.6	3.0 ± 0.5	2.9 ± 0.7	F = 2.37; p = 0.12; ES = 0.16	t = -1.73; p = 0.11; ES = 0.45	t = -1.72; p = 0.11; ES = 0.44	t = -0.22; p = 0.83; ES = 0.06

Table 2. Results of descriptive statistics, one-way rANOVA and post hoc t-tests for the stance non-dominant (i.e. non-exercised) leg; baseline (BSL), control (CO), and fatigued (FAT).

Parameter (unit)	**Descriptive (mean ± st. dev.)**			**rANOVA**	**t-test**		
	BSL	CO	FAT	BSL : CO : FAT	BSL : CO	FAT : CO	BSL : FAT
CoP$_{\text{V}}$ (mm/s)	32.6 ± 8.9	30.9 ± 7.8	34.5 ± 10.9	F = 2.65; p= 0.09	t = 1.06; p= 0.31; ES= 0.29	**t = 3.37; p= 0.01; ES= 0.70**	t = 1.00; p= 0.34; ES= 0.28
CoP$_{\text{Va-p}}$ (mm/s)	21.3 ± 6.1	19.7 ± 5.1	21.6 ± 7.0	F = 2.05; p= 0.17; ES= 0.15	t = 1.50; p= 0.16; ES= 0.40	**t = 3.11; p= 0.01; ES= 0.67**	t = 0.26; p= 0.80; ES= 0.07
CoP$_{\text{Vm-l}}$ (mm/s)	20.8 ± 5.6	20.1 ± 5.4	22.9 ± 7.6	F = 2.95; p= 0.07; ES= 0.20	t = 0.57; p= 0.58; ES= 0.16	**t = 3.23; p= 0.01; ES= 0.68**	t = 1.46; p= 0.17; ES= 0.39
CoP$_{\text{Aa-p}}$ (mm)	6.6 ± 1.9	6.5 ± 1.7	6.8 ± 2.8	F = 0.01; p= 0.99; ES= 0.00	t = 0.09; p= 0.93; ES= 0.03	t = 0.10; p= 0.92; ES= 0.03	t = -0.01; p= 0.99; ES= 0.00
CoP$_{\text{Am-l}}$ (mm)	7.3 ± 1.7	7.1 ± 2.1	7.8 ± 2.6	F = 1.61; p= 0.22; ES= 0.12	t = 0.86; p= 0.41; ES= 0.24	**t = 2.73; p= 0.02; ES= 0.62**	t = 0.73; p= 0.48; ES= 0.21
CoP$_{\text{Fa-p}}$ (Hz)	3.3 ± 0.4	3.1 ± 0.5	3.3 ± 0.5	**F = 3.46; p= 0.05; ES= 0.22**	t = 1.91; p= 0.08; ES= 0.48	**t = 2.40; p= 0.03; ES= 0.57**	t = 0.26; p= 0.80; ES= 0.08
CoP$_{\text{Fm-l}}$ (Hz)	2.9 ± 0.6	2.9 ± 0.5	2.9 ± 0.6	F = 0.59; p= 0.56; ES= 0.05	t = -0.44; p= 0.67; ES= 0.13	t = 0.77; p= 0.45; ES= 0.22	t = 0.99; p= 0.34; ES= 0.27

The results of two-way rANOVA are presented in Table 3. Statistical significance was observed between the conditions (exceptions were CoPAa-p, CoPFa-p and CoPFm-l) but not between the legs. The interaction effects were observed only for CoPAa-p and CoPFa-p but did not show any distinctive tendencies.

Table 3. Results of two-way rANOVA with intra-subject factors Leg (dominant (DO) and non-dominant (ND)) and Condition (baseline (BSL), control (CO), and fatigued (FAT)) and their interaction. Statistically significant outcomes are marked bold

Parameter (Unit)	Leg	Condition	Leg × Condition
CoP$_{V}$ (mm/s)	F = 0.04; p = 0.85; ES= 0.00	**F = 7.30; p = 0.00; ES= 0.38**	F = 0.23; p = 0.80; ES= 0.02
CoP$_{Va\text{-}p}$ (mm/s)	F = 0.32; p = 0.58; ES= 0.03	**F = 5.55; p = 0.01; ES= 0.32**	F = 0.33; p = 0.72; ES= 0.03
CoP$_{Vm\text{-}l}$ (mm/s)	F = 0.60; p = 0.45; ES= 0.05	**F = 7.01; p = 0.00; ES= 0.37**	F = 0.37; p = 0.62; ES= 0.03
CoP$_{Aa\text{-}p}$ (mm)	F = 0.08; p = 0.79; ES= 0.01	F = 1.78; p = 0.19; ES= 0.13	**F = 4.15; p = 0.03; ES= 0.26**
CoP$_{Am\text{-}l}$ (mm)	F = 0.63; p = 0.44; ES= 0.05	**F = 9.62; p = 0.00; ES= 0.44**	F = 1.21; p = 0.31; ES= 0.09
CoP$_{Fa\text{-}p}$ (Hz)	F = 0.04; p = 0.84; ES= 0.00	F = 0.69; p = 0.51; ES= 0.05	**F = 5.44; p = 0.01; ES= 0.31**
CoP$_{Fm\text{-}l}$ (Hz)	F = 0.15; p = 0.70; ES= 0.01	F = 1.06; p = 0.36; ES= 0.08	F = 1.65; p = 0.21; ES= 0.12

Discussion

The main finding of this study was that unilateral stance postural balance was affected bilaterally (dominant and non-dominant side) by fatigue induced on the stance dominant side. Body sway in both single leg stances was increased in a-p and m-l direction; however the increase was more apparent in m-l direction. These findings suggest that central mechanisms might have been involved in alterations of balance control. In addition, mono-articular non-fatiguing movement of the hip (i.e. CON) improved balance, signifying the importance of hip proprioceptors in relation to body sway control.

Central mechanisms of cross-education have been well studied in relation to strength and power, but not in relation to postural balance control. Unilateral strength training could affect supraspinal centers that control the opposing limb and cause short lasting neuro-mudulations. These changes can last longer following continuous training. Unilateral adaptations in balance have been suggested in different pathologies (Hung, 2015), with the opposing limb also suffering from neuro-muscular adaptations that are not identical to the injured limb.

Contralateral changes in balance could have been caused by the phenomenon known as non-local muscle fatigue (Halperin et al., 2015). It has been demonstrated that the decreased local muscle performance could lead to changes in function of the contralateral or other remote non-fatigued muscles. Halperin et al. (2015) suggest that fatigue could have a negative effect on other muscles via neurological pathways, biochemical mediators, biomechanical alterations and finally by psychological effects. On the other hand, decreased pH accompanying local fatigue can decrease muscle spindle firing rate (Fischer & Schafer, 2005), leading to impaired proprioceptive input especially regarding position and movement sense (Proske & Gandevia, 2012). This was not in accordance with the present study, as no differences were observed between the limbs. It could be hypothesized that negative effects of fatigue on muscle spindle function was compensated by sensory input from other muscle or joint proprioceptors.

The contralateral effect of fatigue could also be a result of decreased muscle functioning of important pelvis and trunk stabilizers that have been active during the fatiguing task. Possible conditioning of these muscles would affect body sway control in contralateral stance as they control the pelvic tilt and trunk alignment. An interesting finding of this study was the positive effect of uni-articular hip movement on balance. It could be suggested that by moving the leg through abduction and adduction would cause activation of slow adapting hip proprioceptors, proposing increased and continuous sensory drive to the central nervous system. As described in the introduction, the hip is important for initiating corrective reactions in balance that could benefit from more abundant proprioceptive feedback.

The third finding indicated an increase in body sway, both in m-l and in a-p direction. This is in line with the study conducted by Bisson, McEwen, Lajoie, and Bilodeau (2011), in which they observed bi-planar increase of body sway as a consequence of experimentally induced fatigue to hip flexors and extensors. The above results were expected due multiple functions of the fatigued hip abductors (i.e. gluteus medius) that are also synergists of hip extension and rotation. As a result, altered body sway control is decreased in all directions; yet, m-l CoP movement was more affected than in the a-p direction. Future research should consider looking at the effects of plyometric and more demanding eccentric fatiguing protocols, as these are more common in sports and have been shown to affect proprioception differently than concentric contractions (Fortier, Basset, Billaut, Behm, & Teasdale, 2010), possibly causing different changes in body sway control.

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