POSTURAL STABILITY AND ANTICIPATORY POSTURAL ADJUSTMENTS PERFORMANCES AFTER GENERAL MUSCLE FATIGUE IN TRAINED AND UNTRAINED ADULTS

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The objective of this study was to explore the differences of postural stability and Anticipatory Postural Adjustments (APAs) performances after general muscle fatigue between trained and untrained adults. The displacements of Center of Pressure (COP) during static bipedal standing, the APAs of deep trunk muscles induced by voluntary movements, the Heart Rate (HR) and the Borg Rating of Perceived Exertion Scale (RPE) were recorded before and after a 20-minute general muscle fatigue on a rowing ergometer for eighteen trained and eighteen untrained subjects. After fatigue, the trained group exhibited less disturbed postural stability performances. Meanwhile, earlier and larger APAs activations of lumbar multifidus (LMF) were found in trained group regardless of fatigue conditions. These results suggest a beneficial effect of long-term training experience on counter-perturbation feedforward control and highlight the distinguishing role of LMF in evaluation and rehabilitation of motor dysfunction.

KEYWORDS: postural stability, anticipatory postural adjustments, general muscle fatigue, long-term training experience

INTRODUCTION: Low back pain (LBP) was reported as one of the common health problems around the world that 50-80% of adults experienced it at some point in their life (Fatoye, Gebrye, & Odeyemi, 2019). Most of the patients with LBP were accompanied with altered posture performances such as deteriorated postural stability and delayed activations of the postural muscles (Hodges & Richardson, 1996; Ruhe, Fejer, & Walker, 2010), which was considered to be correlated with the inefficiency of the controller, central nervous system (CNS), under the condition of deficits in muscle fatigue-resistance (Brooks, Kennedy, & Marshall, 2012; Seyed Hoseinpoor, Kahrizi, Mobini, & Naji, 2015). Thus, following muscle fatigue, the adaptive changes of anticipatory postural adjustments (APAs), a centrally feedforward postural control mechanism which generated unconscious muscle activations that occurred prior to a predictable perturbation (Latash, 2012; Strang, Berg, & Hieronymus, 2009), could be regarded as an indicator in evaluating the output of functional rehabilitation in LBP patients. Recently, APAs has been proposed to be plastic (Tsao & Hodges, 2007) and trainable. But the results concerned the effect of long-term training experience on APAs reached a contradiction (Brooks et al., 2012; Ganesan, Acharya, Chauhan, & Acharya, 2017; Tsao & Hodges, 2007). Therefore, the objective of this study was to compare the effect of general muscle fatigue on feedforward postural control mechanism and postural stability performances between groups with and without long-term athletic training experience.

METHODS:

Subjects: Eighteen untrained (age 22.6±1.2yrs, weight 67.3±8.1kg, height 1.76±0.04m) and eighteen trained adults (age 22.2±0.7yrs, weight 69.2±7.4kg, height 1.78±0.06m, national second-level athletes) were recruited and given identical information regarding the purpose of this study. Subjects gave their written informed consent approved by Ethics Review Board of Zhejiang University.

Procedures: Subjects in both groups completed the same single experimental session. After protocol familiarization and equipment outfitting, a postural stability test, three trials of Bilateral Fast Arm Raising (BFR) tests, Borg Rating of Perceived Exertion Scale (RPE) and Heart Rate (HR) were recorded before and after fatigue protocol.

For postural stability test, subjects stood still and quietly in a force platform for 30 seconds, barefooted with their feet together, eyes open while concentrating on a black cross marked on the wall at eye level 1.5 meters in front of them (Gribble & Hertel, 2004). For BFR test, subjects grasped a bar (2 kg, 43 cm long) with both hands and were instructed to “raise both their arms as fast as possible” at the onset of the light in their central visual field (Allison & Henry, 2002), stopped at the shoulder level for 2-3 seconds, and then slowly returned to the starting position (Kanekar, Santos, & Aruin, 2008). Before fatigue protocol, subjects were asked to perform a self-paced 1000-meter rowing warm-up. After a 3-minute break, subjects were requested to row at a speed of 200-meter per minute for 20 minutes, 4000 meters in total.

Instruments and data processing: A force platform (OR-6, AMTI, USA) was used to record the mediolateral (ML), anteroposterior (AP) and vertical components of the ground reaction force (FX, FY and FZ, respectively) as well as the moments of force around the frontal and sagittal axes (MX and MY, respectively), with a sampling rate of 1000 Hz. COP displacements in ML and AP directions were calculated according to Winter, Prince, Frank, Powell, and Zabjek (1996). Data was resampled to 100 Hz and discarded the first and the last 2.5 seconds, then being low-pass filtered at 20 Hz with a fourth-order, zero-lag Butterworth filter.

Surface Electromyography (sEMG) signals were recorded with an 8-channel Trigno Wireless System (Delsys, USA), sampled at 2000 Hz and band-pass filtered at 20-450 Hz. Electrodes were placed over the right-side muscles of transversus abdominis (TrA), lumbar multifidus (LMF) and anterior deltoid according to Barbero, Merletti, and Rainoldi (2012). For muscle onset detection, a nonlinear Teager–Kaiser energy (TKE) method was applied to facilitate the visually inspection (Li & Aruin, 2007). The onset of anterior deltoid was set as T0, the beginning of the perturbation. APAs window was defined within the range of 100ms before T0 to 50ms after T0. The APAs EMG integrals (iEMG) were computed after 100Hz lowpass filter, rectification, and intra-/inter-subject normalizations (1, 2).

$$(1)\int APAs_{intra} = \int_{T0-100}^{T0+50} APAs \;-\int_{T0-600}^{T0-450} Baseline \qquad (2)\int APAs_{inter} = \frac{\int APAs_{intra}}{max\,(\int APAs_{intra})}$$

Statistical analyses were performed using IBM SPSS Statistics 25. RPE, HR, COP and APAs of the deep trunk muscles were compared between fatigue conditions and the groups using a repeated-measures analysis of variance (ANOVA) with one repeated measure (Fatigue, pre- versus post-) and one independent factors (Group, Trained and Untrained). Pairwise contrasts with Bonferroni corrections were used to explore significant effects. The level of significance was set at $p < 0.05$.

RESULTS: A significant interaction effect of RPE (F=27.434, P<0.001) revealed a higher RPE scores before fatigue (P=0.001) and lower RPE scores after fatigue (P=0.014) in trained group than untrained group. And the trained group kept a lower HR than untrained group throughout the tests (F=11.192, P= 0.002).

Table 1 showed that for both groups, the COP mean displacements, sway velocity, total displacements, and envelope area were significantly larger after fatigue (P<0.05). For AP sway velocity, except the main effect for Fatigue (F=42.457, P=0.001), there were significant main effect for Group (F=4.605, P=0.039) and a significant interaction effect between Fatigue and Group (F=5.217, P=0.029). Meanwhile, for total displacements, the results showed a significant interaction effect between Fatigue and Group (F=4.155, P=0.049). Post-hoc analysis revealed that AP sway velocity and total displacements were smaller in trained group than untrained group following fatigue.

Table 1: The variables of center of pressure in trained and untrained groups before and after fatigue protocol.

Variables	Mean±SD				Statistics					
Postural Stability	**Pre-fatigue**		**Post-fatigue**		**Group Factor**		**Fatigue Factor**		**Group-by-Fatigue Interaction**	
	Trained	**Untrained**	**Trained**	**Untrained**	**F**	**P**	**F**	**P**	**F**	**P**
Mediolateral direction										
COP mean displacements(m)	0.025±0.007	0.025±0.006	0.028±0.005	0.031±0.012	0.676	0.417	7.344	***0.01***	1.35	0.253
COP velocity(m/s)	0.01±0.003	0.009±0.002	0.011±0.003	0.012±0.005	0.105	0.748	11.127	***0.002***	2.08	0.158
Anteroposterior direction										
COP mean displacements(m)	0.02±0.007	0.022±0.009	0.026±0.007	0.027±0.01	0.663	0.421	9.33	***0.004***	0.068	0.795
COP velocity(m/s)	0.008±0.002	0.009±0.003	0.01±0.002	0.013±0.004	4.605	***0.039***	42.457	***0.001***	5.217	***0.029***
COP total displcements(m)	0.359±0.096	0.363±0.084	0.416±0.096	0.495±0.154	1.675	0.204	26.631	***0.001***	4.155	***0.049***
COP envelope area(mm^2)	339.4±151.3	391.5±208	475.1±201.2	577.7±334.9	1.526	0.225	12.003	***0.001***	0.296	0.59
Anticipatory Postural Adjustments	**Pre-fatigue**		**Post-fatigue**		**Group Factor**		**Fatigue Factor**		**Group-by-Fatigue Interaction**	
	Trained	**Untrained**	**Trained**	**Untrained**	**F**	**P**	**F**	**P**	**F**	**P**
Transversus Abdominis										
Onset(ms)	5.9±19.3	8.8±15.4	5.2±19.2	10±17.6	0.461	0.503	0.009	0.926	0.114	0.737
EMG integral	0.73±0.17	0.71±0.17	0.75±0.16	0.6±0.22	2.382	0.133	1.562	0.221	3.291	0.08
Lumbar Multifidus										
Onset(ms)	-24.09±18.45	-7.47±25.12	-24.15±15.87	-4.48±26.25	7.267	***0.011***	0.173	0.68	0.186	0.669
EMG integral	0.8±0.11	0.75±0.14	0.78±0.1	0.68±0.18	5.211	***0.029***	2.02	0.165	0.431	0.516

Comparing to untrained group, LMF in trained group activated significantly earlier (F=7.267, P=0.011) and larger (F=5.211, P=0.029) regardless of fatigue conditions (Table 1, Figure 1). No significant change was found for the onset and APAs iEMG of TrA between Groups and Fatigue conditions.

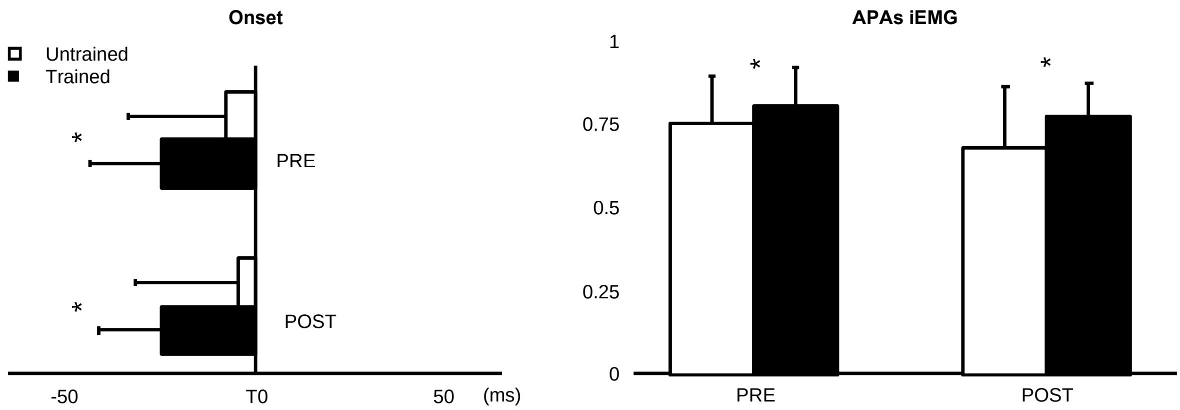

Figure 1: The onset and integral of Lumber Multifidus in trained and untrained groups pre- and post-fatigue protocol. *Indicates a significant effect between groups, P< 0.05.

DISCUSSION: Similar Impulse Hypothesis (Vuillerme, Nougier, & Teasdale, 2002) and the Critical Force Hypothesis (Tsao & Hodges, 2007) proposed by previous studies suggested adaptive APAs strategies that specific postural muscles activated earlier so as to maintain the similar muscle force or impulse required in non-fatigue state. It was based on the premise that muscle force production capability was deteriorated following fatigue. However, Panjabi (1992) considered the trunk muscles had sufficient strength to satisfy the demands of balance control. As we all known that human bipedal balance control was a remarkable complex sensorimotor mechanism, which has been admitted as a function of sensory inputs to the central nervous system and neuromuscular control (Springer & Pincivero, 2009). Consistent APAs strategies of the deep trunk muscles accompanied with impaired postural stability performances after fatigue found in this study hinted the rowing ergometer fatigue led to deteriorations of sensory inputs, but no further effect on the feedforward postural control mechanism.
The limitations of previous studies on training effect lied in the focus on acute output of APAs strategies from single-session functional training (Kanekar & Aruin, 2015), or the short-term muscle-specific training (Tsao & Hodges, 2007) intervention. This study, however, recruited subjects with long-term athletic training experience and found LMF in trained group exhibited unneglectable earlier onset and larger APAs iEMG than untrained group regardless of fatigue conditions. It was consistent with the previous study conducted by Shin (2019), who found earlier activations of back muscles during fast arm raising test in healthy young adults following an 8-week boxing training. The unique part of this study was that the subjects in the trained group had at least 2-year consecutive athletic training experience before entering college. It suggested a possible effect of long-term athletic training experience on altering the efficacy of the central nervous system and pointed out the importance of LMF in counter-perturbation feedforward control.

CONCLUSION: This study suggests that trained group activated APAs of LMF earlier and larger regardless of fatigue conditions, and were accompanied with slower AP sway velocity and less total displacements after fatigue when compared to untrained group. However, APAs of TrA showed no significant difference between groups and fatigue conditions. These findings indicate no effect of rowing ergometer fatigue on APAs strategy, but suggest a beneficial effect of long-term training experience on counter-perturbation feedforward control and highlight the distinguishing role of LMF in evaluation and rehabilitation of motor dysfunction.

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