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INFLUENCE OF ATHLETIC TRAINING ON VERTICAL STIFFNESS ATTENUATION

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The purpose of this study was to assess the stiffness differences between dancers, middle distance runners and recreational athletic populations under unfatigued and maximal effort tasks. A second aims was to evaluate the impact of athletic training in modulating stiffness under fatigued during maximal and sub-maximal tasks. A total of 18 participants between 18 and 30 years old were recruited for this study. All participants undertook pre- and post-fatigue vertical stiffness assessments through a discrete maximal and repetitive sub maximal counter movement jumps. Statistical tests revealed trends towards pre-existing unilateral vertical stiffness difference between maximal and sub-maximal populations. It is suggested that sub-maximal and maximal populations are able to attenuate stiffness under fatigued conditions due to training adaptations.

KEY WORDS: fatigue, maximal, sub-maximal, female, unilateral, athletic populations.

INTRODUCTION: Stiffness of the lower extremities, understood as the relationship between the amount of joint flexion and the load to which limbs are subjected to (Butler, Crowell, & Davis, 2003), has been suggested to increase the muscle's ability to store and return elastic energy(Kuitunen, et al., 2007). Fatigue, the temporary loss of muscle's force generation ability resulting from recent sustained muscle contraction, has been shown to reduce the capacity of an individual to produce and maintain optimal levels of vertical lower extremity stiffness (Keeton & Binder-Macleod, 2006; Nicol, Avela, & Komi, 2006).Significant declines in vertical stiffness generation under fatigued conditions during tasks where maximal force outputs are required, such as maximal vertical jumps, have been reported, predominately in recreational populations (Kuitunen, et al., 2007; Morin, et al., 2006; Padua, et al., 2006). Less however has been reported on the effects of fatigue on stiffness generation during tasks where sub-maximal force outputs are required or when these tasks are specific to the investigated populations.

Individuals accustomed to performing high intensity tasks (maximal athletic populations) i.e. sprinters and dancers; display different kinetic and kinematic strategies when compared to individuals who customarily perform repetitive movement patterns at approximately 70% of maximal intensity (sub-maximal athletic populations) i.e. endurance and middle distance runners (Bushnell & Hunter, 2007). In running for instance it was found that sprinters alter their segment kinematics through greater ranges of motion at the hip joint during flexion to reach maximal running speeds with little consideration for economy, while endurance runners aimed to preserve running economy through minimal vertical oscillation (Bushnell & Hunter, 2007).

Questions have been raised (Komi, 2000; Nicol, et al., 2006) on the impact of athletic training on stiffness attenuation strategies. Particularly under fatigued and task specific settings. It has been suggested for instance that athletes who are accustomed to performing under fatigue conditions may be able to effectively attenuate stiffness under these conditions (Nicol, et al., 2006).

The purposes of this study was to i) assess the stiffness differences between maximal, sub-maximal and recreational athletic populations under unfatigued and maximal effort tasks, ii) evaluate the impact of athletic training in modulating stiffness under fatigued conditions and maximal effort tasks, and ii) understand the modulation of stiffness in sub-maximal effort tasks under fatigued conditions.

METHOD: Ethical clearance was obtained from the Australian Catholic University Human Research Committee for this study. Eighteen female participants were recruited for the study and were split into three matched sub-populations (n=6); advanced contemporary dancers; age 20.5 ± 2.07 years; height 1.62 ± 0.06 m; weight 63.79 ± 9.98 kg; training years 13.83 ± 3.43 years (maximal population); state-national middle distance runners, age 21.17 ± 5.38 years; height 1.68 ± 0.05 m; weight 60.79 ± 12.42 kg; training years 13.67 ± 7.50 (sub-maximal population) and a group of control individuals; age 20.83 ± 0.41 years; height 1.62 ± 0.09m; weight 59.84 ± 4.86 kg(recreational population). The study focused on the unilateral vertical stiffness of the leg in participant's dominant leg, generated during the eccentric component of the braking phase of movement. The study was a cross-sectional stratified study design.

Participants underwent i) pre-fatigue stiffness assessment ii) fatigue protocol iii) post fatigue stiffness assessment. Pre and post fatigue assessments of vertical stiffness consisted of three trials of i) maximal effort task; maximal vertical counter movement jump (CMJ) and ii) sub-maximal effort task; ten continuous repetitions of sub-maximal vertical CMJ (at 70% of maximal jump height). Targets were set to ensure participants reached the determined jump heights. Following Padua's et al. (2006) protocol participants were asked to squat with a load equal to one third of their body weight at 50 repetitions per minute until fatigued. Fatigue was determined when less than 46 repetitions per minute for two consecutive sets could not be performed. Data were collected 30 seconds post termination of the fatigue protocol.

A high speed camera (Phrotron Inc., SanDiego, U.S.A.) sampling at 500 Hz was used to capture the two dimensional sagittal view of jumping tasks. Data were subsequently digitized using Peak Motus™ 9.1. Standard marker set of shoulder, greater trochanter, lateral epicondyle of the femur, lateral malleoulus and distal head of the fifth metatarsal bone was used. Ground reaction force data was concurrently obtained using a ground mounted AMTI force plate (Advanced Mechanical Technology Inc., Watertown, U.S.A.) at a sample frequency of 1000 Hz. Kinematic data were used to locate the centre of mass using the segmentation method (Winter, 2009). These data along with the peak ground reaction force (GRF) were used as inputs to calculate vertical stiffness of the leg using the McMahon and Cheng (1990) formula $k_{vert} = \frac{Fmax}{\Delta y}$; where F_{max}= peak vertical ground reaction force and Δy= maximum centre of mass displacement during the eccentric displacement (landing) of the center of mass.

Tests for normality and outliers screening were performed prior statistical analysis.. Pre-existing differences in vertical stiffness levels between populations during maximal effort tasks were assessed using analysis of variance with a post-hoc Fisher's least significant difference (LSD). Dependent paired t-tests were used to evaluate descriptive data (height weight, age and training years) as well as to assess the effects of fatigue on vertical stiffness within individual populations. All statistical analyses were undertaken using SPSS 18.0 statistical software (SPSS, Inc., Chicago, IL, USA). Significance was set at α=0.05 for all analysis. The best trial (maximum jumping height) was selected for analysis for maximal effort task, while all sub-maximal effort tasks were included for data analysis.

RESULTS AND DISCUSSION: Unfatigued vertical stiffness data from maximal effort tasks for each population are presented as mean and standard deviations in Table 1. Mean vertical stiffness was higher in the sub-maximal population and lowest in maximal population. Post hoc Fisher's LSD analysis revealed no significant differences between recreational and sub maximal populations $F(2,15)=1.69$, p=0.392, recreational and maximal populations $F(2,15)=1.69$, p=0.261. Differences between sub-maximal and maximal populations were shown to reveal a trend towards significant differences $F(2,15)=1.69$, p=0.058. While recreational athletes had stiffness scores situated between these populations. It is speculated statistical significant differences were not reached due to small sub-population sample size and small effect size (η^2=0.220) determined using partial eta squared. It can be inferred that habitual training and the subsequent muscle adaptations account for these differences.

Table 1
Vertical CMJ stiffness data at baseline

Dependent Variable	Maximal (n=6)	Sub-maximal (n=6)	Recreational (n=6)
Vertical stiffness (maximal CMJ) kN/m	27.90 ± 4.96	38.28 ± 11.43	33.81 ± 8.70

Mean (±SD) pre and post fatigue stiffness data for maximal vertical CMJ are presented in Table 2. No significant differences between pre and post fatigued conditions were found in the maximal $t(5)=-0.65$, p=0.544 and sub-maximal $t(5)=-1.54$, p=0.184 populations. Significant declines in vertical stiffness under fatigued conditions were however found in the recreational population $t(5)=4.53$, p=0.006. The inability to maintain stiffness under fatigue and maximal effort tasks shown by individuals from the recreational population can be attributed to lack of neural adaptations to fatigue, which is developed through athletic training and conditioning (Binder-Macleod, Lee, Fritz, & Kucharski, 1998; Nicol, et al., 2006). This was found to be in agreement with previous studies (Kuitunen, et al., 2007; Morin, et al., 2006; Padua, et al., 2006). Data from this section indicate that systematic athletic training allows individuals from maximal and sub-maximal populations to successfully regulate stiffness under fatiguing conditions when discrete maximal effort tasks are performed. A similar suggestion that stiffness attenuation is training specific was found reported in the literature (Komi, 2000; Nicol, et al., 2006).

Table 2
Pre and post fatigue maximal vertical CMJ stiffness data

Population	Pre Vertical Stiffness (kN/m)	Post Vertical Stiffness (kN/m)	p value
Maximal (n=6)	27.90 ± 4.96	28.73 ± 7.03	0.544
Sub-maximal (n=6)	38.28 ± 11.43	44.73 ± 16.95	0.184
Recreational (n=6)	33.82 ± 8.70	25.53 ± 7.27	0.006*

*- significant difference

Table 3 reveals that no significant differences in vertical stiffness scores were found between pre and post fatigued conditions in the sub-maximal population when performing sub-maximal continuous CMJ $t(117)=-1.23$, p=0.222. Differences however were significant in recreational population $t(157)=2.21$, p=0.028. In contrast to their performance under fatigued discrete maximal effort conditions maximal population were unable to sustain levels of vertical stiffness when performing continuous fatigued sub-maximal effort tasks $t(154)=3.27$, p=0.001. The evidence found in this study, from all the investigated groups, suggests that training adaptations account, among other factors, for the different responses in stiffness to fatigue and specificity of the performed task. This indicates by implication that stiffness responses are trainable and task specific.

Table 3
Pre and post fatigue vertical sub-maximal CMJ stiffness data

Population	Pre Vertical Stiffness (kN/m)	Post Vertical Stiffness (kN/m)	p value
Maximal (n=6)	38.77 ± 9.88	36.33 ± 10.37	0.001*
Sub-maximal (n=5)	44.69 ± 7.85	46.69 ± 14.02	0.222
Recreational (n=6)	43.72 ± 10.90	41.78 ± 9.90	0.028*

*- significant difference

Fatigue reduces an individual's neural drive, force output and subsequent capacity to produce and maintain optimal levels of stiffness and storage and return of elastic energy (Keeton & Binder-Macleod, 2006). However evidence from this study suggests that stiffness attenuation under fatigued conditions is training specific, especially during sub-maximal

tasks. Whereby sub-maximal population were able to effectively attenuate stiffness during all tasks as this population is accustomed to performing under fatigued condition. While maximal population were only able to attenuate stiffness during maximal tasks as they are accustomed to performing maximal discrete tasks. However the recreational population do not have the necessary muscular adaptations developed through training to attenuate stiffness under fatigued conditions.
Given that stiffness is calculated from peak GRF data and maximal displacement of the centre of mass, a reduction in the centre of mass displacement results in increased stiffness (McMahon & Cheng, 1990). Thus, limiting joint ranges of motion and hence muscle length changes and shortening velocity, would therefore result in increased stiffness and muscle force output at landing. It is plausible that the levels of post fatigue stiffness during sub-maximal tasks displayed by the sub-maximal population respond to the need of maintaining muscle tissues on favourable regions of the force-length and force-velocity curves, and that intrinsic muscle properties can be utilised to increase efficiency when performing repetitive sub-maximal tasks. This contention needs however further investigation.

CONCLUSION: Although findings from this study are in agreement with research by (Kuitunen, et al., 2007; Morin, et al., 2006; Padua, et al., 2006) concerning recreational populations under fatigued conditions; this study is one of few in which differences in stiffness levels amongst athletic demographics of maximal, sub-maximal and recreational populations that result from habitual training were investigated. It is suggested that pre-existing differences in training status and the corresponding muscular, neural and physiological adaptations influence a population’s ability to attenuate stiffness properties during fatigued conditions. It is important to account for the habitual training and associated physiological adaptations to specific tasks and conditions when assessing stiffness production, as stiffness production has been found to be training specific. This highlights the importance of developing training methods aimed to boost performance benefits and injury preventative measures associated with stiffness production of the lower extremities, through increased stability of the joint and greater potential to store and return elastic energy.

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