THE EFFECT OF MAXIMAL FATIGUE ON THE MECHANCIAL PROPERTIES OF SKELETAL MUSCLE IN STRENGTH & ENDURANCE ATHLETES.

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The purpose of this study was to compare the effects of maximal fatigue on the mechanical performance of strength and endurance athletes. Ten strength trained athletes and nine endurance athletes performed a maximum fatigue protocol on a sledge and force plate apparatus followed by drop and rebound jumps at 15, 45, 120, 300 and 600 seconds post fatigue. Measurements of peak force, ground contact time, leg spring stiffness and height jumped were calculated prior to the fatigue protocol to establish baseline values, and also for each jump following the fatigue protocol. The fatigue protocol resulted in a significant reduction in peak force ($p<0.01$) and height jumped ($p<0.01$) in both groups while leg spring stiffness was also reduced in the strength athletes ($p<0.01$). In addition the endurance athletes indicated a potentiation effect with a significant increase in peak force ($p<0.01$) and leg spring stiffness ($p<0.05$) during the post fatigue jumps.

KEY WORDS: fatigue, potentiation, SSC, strength athletes, endurance athletes

INTRODUCTION: Fatigue is a complex, multidimensional phenomenon and is a reflection of the type of work that has been done. It has been described as “the transient decrease in performance capacity of muscles when they have been active for a certain time, usually evidenced by a failure to maintain or develop a certain force or power” (Asmussen, 1979). The nature and cause of fatigue depends on the type of exercise being performed. Differences in fatigue between strength and endurance athletes have been documented (Skurvydas et al, 2002; Edwards et al, 1977; Sahlin et al 1998) but are usually attributed to muscle metabolism. A number of studies, however, have reported that muscle fatigue is not always associated with metabolic changes (Edwards et al, 1977; Sahlin et al 1998). Decreases in muscle performance following exercise may be somewhat the result of the impaired utilization of muscle stiffness-mediated elastic energy (Avela & Komi, 1998). Komi et al (1986) reported similar findings when they concluded that repetitive impact loads may decrease the ability of the leg extensor muscles to maintain the necessary load and subsequently the muscle may lose its recoil ability. When active muscle is stretched, or when passively stretched muscle is suddenly activated, the muscle increases its tension and stores potential elastic energy in its series elastic component, which can then reappear during a subsequent shortening of the muscle. This phenomenon involving eccentric and concentric contractions is known as the stretch shortening cycle (SSC).
In coexistence with fatigue is the concept of potentiation. Post-activation potentiation (PAP) is an acute transient improvement in performance as a result of prior muscle activation. PAP initially exhibits a depression, most likely the result of acute fatigue, followed by a rapid rise in muscle function. Few studies have examined the effect of maximal SSC fatigue on the performance of subsequent SSC activities. Consequently the aim of this study was to investigate and compare the affect of maximum SSC fatigue on endurance and strength trained athletes and to also investigate the path of recovery with any subsequent PAP.

METHODS: Ten strength trained athletes (STA) (rugby players) and nine endurance trained athletes (ETA) (rowers) participated in this study. All 10 STA and 6 of the ETA were high level national athletes while 3 ETA were international athletes.

Table 1: Physical Characteristics of the Subjects.

	Age (years)	Height (cm)	Mass (kg)
ETA	25.9 ±6.3	187.7 ±9.1	82.2 ±11.4
STA	20.0 ±0.8	180.9 ±4.9	89.8 ±12.8

The nature of the study was explained to each participant and written informed consent was obtained. The protocol was approved by the University of Limerick research ethics committee. All participants attended the laboratory for one session to complete the testing. On arrival at the laboratory the drop jump (DJ) and rebound jump (RBJ) technique was explained and demonstrated to the participants and following a general warm up of jogging and stretching the participants performed practice jumps. The jumps were performed on a sledge and force plate apparatus with the sledge inclined at 30º and the AMTI OR5-6 force platform mounted at right angles to the sledge apparatus. For all jumps the participants were secured to the chair with a harness and waist belt. Instruction was given to the participants to keep both arms folded across the shoulders in order to minimise upper body movement during the jumps. The participants were also instructed to perform each jump maximally while attempting to minimise ground contact time (CT) and maximise jump height (JH). Prior to the fatigue workout sets of jumps comprised of one DJ followed immediately by a RBJ were performed to establish the participant's baseline values for each of the dependent variables: peak ground reaction force (pGRF), CT, JH and leg spring stiffness (k_{vert}). Testing commenced with four sets of DJ and RBJ with the participants being dropped from a predetermined height of 30 cm. Each set of jumps was immediately analysed using AMTI Bioanalysis software. Through use of the AMTI force plate instants of initial foot contact, take off and subsequent landing were obtained. From these ground reaction force traces, each of the dependent variables were calculated. Peak GRF was identified as the maximum force reading recorded from the ground reaction force traces from the force plate which was sampling at 1000Hz. CT was calculated as the difference between the time of initial foot contact and the time of take off. JH was calculated from the flight time (time difference between the take off and landing for jumps) and the use of the equation for linear motion $s=ut+0.5at^2$. The calculation of k_{vert} involved the use of SVHS video recordings which were digitised using Peak Motus (Peak Performance Technologies, Colorado, USA) to identify the displacement from landing to full crouch. The pGRF was then divided by this displacement to calculate k_{vert} which is defined as the ratio of GRF to the displacement of a spring.
Following the analysis of each set of baseline jumps, the jump with the highest recorded JH was selected for further analysis. 90% of this maximum jump was calculated and this value was marked on sledge rails from a position where the participant was seated in the chair with the dominant leg fully extended. The fatigue workout then began with the participant being dropped from a height of 30cm for 1 DJ followed by repeated RBJ until the 90% mark was not reached on three consecutive jumps. 15, 45, 120, 300 and 600 seconds following the termination of the fatigue workout the participants were dropped from 30cm to perform one set of DJ and RBJ. From these recovery intervals each subject's minimum and maximum score for each dependent variable, irrespective of time, was identified. This allowed for identification of fatigue and any possible PAP without the interference of individual variation across recovery times.

Statistical Analysis: The software package SPSS (Version 16) was used to conduct all statistical analysis. A mixed effect split plot analysis of variance (SPANOVA) with repeated measures was used to evaluate differences between the average of the baseline scores and the minimum and maximum scores achieved during each recovery interval. The SPANOVA had 1 within-subjects factor namely Condition with 3 levels (baseline, minimum and maximum) and one between-subjects factor namely Group with 2 levels (ETA and STA)

RESULTS: Table 2 shows the mean ±SD of the number of jumps performed during the fatigue workout and the duration of the workout.

Table 2: Results of fatigue workout

	No of jumps	Duration of workout (s)
ETA	65.3 ±29.3	84.6 ±32.8
STA	55 ±24.9	69.3 ±21.2

The mean dependent variable scores for the baseline jumps were subtracted from the maximum and minimum scores for the jumps done after the fatigue workout and the results can be seen in figure 1. In this figure the baseline value is represented by the x-axis. The statistical results (GLM ANOVA) revealed a significant reduction in pGRF ($p<0.01$) and JH ($p<0.01$) in both groups of athletes following the fatigue workout and is illustrated by the "error" bars in the figure below. The STA also showed a significant reduction in k_{vert} ($p<0.01$), and while the ETA had a reduction of 6.38% in k_{vert} it was not a significant change. The difference between the baseline jumps and the maximum scores achieved during the 600 second recovery showed a significant increase in pGRF ($p = 0.001$), an increase of 8.44% and k_{vert} ($p = 0.049$), an increase of 23.75% for the ETA. The STA also showed increases in these dependent variables, a change in GRF of 7.34% and a change in k_{vert} of 11.62%, but neither was statistically significant.

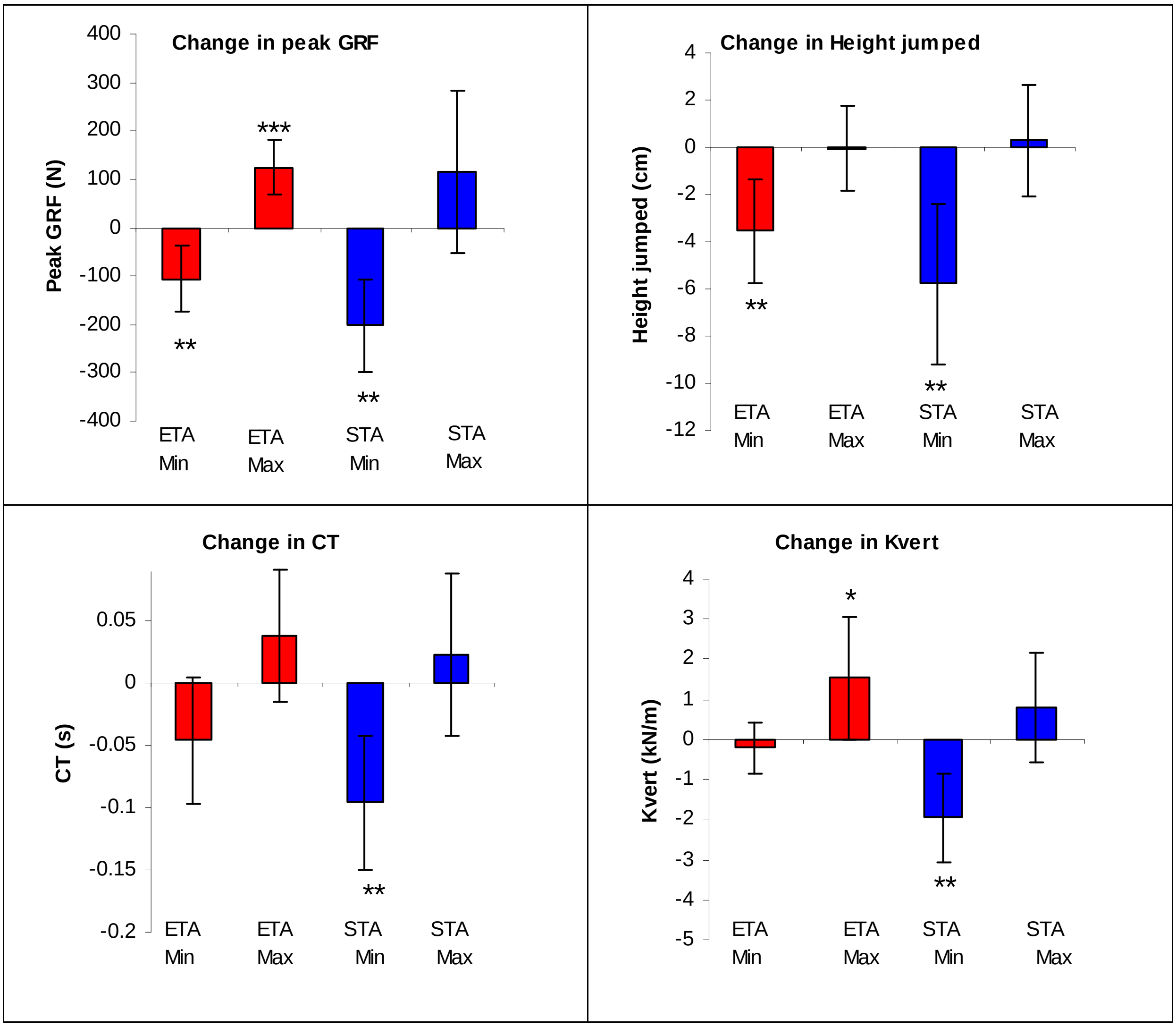

Figure 1: Mean ± 95% confidence interval pGRF, JH, CT and k_{vert} difference between the baseline jumps and the minimum and maximum values achieved following the fatigue workout. (*$p<0.001$; **$p<0.01$; *$p<0.05$))**

DISCUSSION: The maximal fatigue workout resulted in significant reductions in pGRF and JH for both ETA and STA. STA also showed a significant reduction in k_{vert}. These findings are similar to studies which utilised submaximal SSC fatigue workouts (Avela & Komi,1998; Gollhofer et al. 1987 a,b; Nicol et al. 1991) and to a study which utilised maximal SSC fatigue workouts (Comyns, 2006). Comyns (2006) found a loss of efficacy in the SSC in a group of strength trained rugby players through a significant reduction in flight time and pGRF and an increase in ground contact time. Comyns (2006) also identified a reduction in k_{vert}, however it was not statistically significant.

Potentiation is known to co-exist with fatigue, whereby after an initial decline in performance following fatigue, there is a rapid rise in performance. While both ETA and STA in this study demonstrated an increase in performance following their initial decline, only the ETA demonstrated a significant improvement. The ETA showed a significant improvement in both pGRF (8.44% improvement) and k_{vert} (23.75% improvement). While ETA have been reported to withstand fatigue better and recovery quicker than strength athletes, (Hakkinen & Myllyla, 1990), there is a dearth of information surrounding the potential for ETA to benefit from the phenomenon of potentiation and several studies have suggested that ETA are indeed not capable of receiving potential benefits of potentiation. Comyns et al. (2005) reported a similar potentiation effect, to that found in this study, on the biomechanics of performance of a fast SSC exercise due to a prior contractile activity, except with strength trained athletes. The results of the present study, however, indicate that ETA have the ability to alter the biomechanics of rebound jumps and perform the jump with a stiffer leg action.

CONCLUSION: The results of the study indicate that ETA and STA fatigue significantly in pGRF generation and JH following a maximal fatigue workout. STA also show a significant reduction in k_{vert}, while ETA, despite showing a significant reduction in all other areas, appear to resist a significant reduction in k_{vert}. The results also indicate that during the recovery after a maximal fatigue workout, ETA have an ability to potentiate. This was evident from a significant increase in pGRF and k_{vert} above baseline values. These changes indicate that there is an enhancement in RBJ performance shortly after maximal fatigue as the RBJ is performed with a stiffer and more elastic leg spring action.

REFERENCES:

Asmussen. A. (179). Muscle Fatigue. *Medicine and Science in Sports*. **11(4),** 313-312

Avela, J., and Komi, P.V. (1998). Interaction between muscle stiffness and stretch-reflex sensitivity after long-term stretch-shortening cycle exercise. *Muscle & Nerve*. **21**, 1224-1227.

Comyns, T.M., Harrison A.J., & L.K. Hennessy (2006). The effect of a maximal stretch-shortening cycle fatigue workout on fast stretch-shortening cycle performance. *Proceedings of the XXIV International Symposium of Biomechanics*

Edwards, R., Hill, D., Jones, D. & Merton, P. (1977). Fatigue of long duration in human skeletal muscle after exercise. *J Physiol*. **272**, 769-778

Gollhofer, A., Komi P.V., Fujitsuka, N. and M. Miyashita. (1987a). Fatigue during stretch-shortening cycle exercises. II. Changes in neuromuscular activation patterns of human skeletal muscle. *International Journal of Sports Medicine*. **8** (Suppl.), 38-47.

Gollhofer, A., Komi P.V., Miyashita, M. and Aura, O. (1987b). Fatigue during stretch-shortening cycle exercises. I. Changes in mechanical performance of human skeletal muscle. *International Journal of Sports Medicine*. **8** (Suppl.), 71-78.

Hakkinen, K. & Myllyla, E. (1990). Acute effects of muscle fatigue and recovery on force production and relaxation in endurance, power and strength athletes. *J Sports Med Phys Fitn*. **30**, 5-12

Komi, P. (1986) Training of muscle strength and power: interaction of neuromotoric, hypertonic, and mechanical factors. *Inter J Sports Med*. **7**(suppl.) 10

Nicol, C. and Komi, P.V. (1991). Fatigue effects of marathon running on neuromuscular performance. I. Changes in muscle force and stiffness characteristics. *Scandinavian Journal of Medicine and Science in Sports*. **1**, 10-17.

Sahlin, K., Tonkonogi M. & Soderlund, K. (1998). Energy supply and muscle fatigue in humans. *Acta Physiol Scand*. **162**, 261-266

Skurvydas, A., Dudoniene, V., Kalvenas, A. & Zuoza, A. (2002). Skeletal muscle fatigue in long-distance runners, sprinters and untrained men after repeated drop jumps performed at maximal intensity. *Scand J Med Sci Sports*. **12**, 34-39

Acknowledgement

The researchers would like to thank IRCSET for providing funding for this research.