Journal of Physical Education and Sport Vol 27, no 2, June, 2010
e – ISSN: 2066-2483
p – ISSN: 1582-8131

JPES Journal of Physical Education and Sport

Online Publication Date: 20 June, 2010

ORIGINAL RESEARCH

THE EFFECTS OF A STRETCH-SHORTENING CYCLE FATIGUE PROTOCOL ON KNEE KINEMATICS DURING RUNNING IN UNTRAINED CHILDREN

Tsatalas T[2], Lazaridis S[1], Zaggelidis G., Kotzamanidis C[1].
1 Department of Physical Education and Sport Science, Aristotle University of Thessaloniki
2 Department of Physical Education, University of Thessaly

Corresponding Author: Savvas Lazaridis
16 Giannakopoulou 56121 Ampelokipi
Thessaloniki Hellas Tel: (+30) 2310 720843
E-mail: sav200m@gmail.com

ABSTRACT

The purpose of the current study was to examine the effects of an intensive stretch shortening-cycle **(SSC)** protocol (100 plyometric jumps) on knee kinematics during running on a treadmill in healthy children using 3D kinematics. Twelve healthy and untrained children volunteered. Their mean ± age, height and weight was 10,1±0,5 years, 142± 6,1 cm and 37 ±4,6kg, respectively. Muscle damage of lower extremities was caused by 100 maximal intensity plyometric jumps performed as 10 sets of 10 continuous jumps with a 30 second rest period between sets. Muscle damage indicators [delayed onset muscle soreness (DOMS), knee-joint flexion/extension angles during running on a treadmill (speed at 2.8 m/s)] were assessed pre-, 0h, 24h, 48h and 72h post exercise. Kinematic data were captured at 100 Hz using a six-camera 3D motion analysis system (VICON 612). Repeated measures one-way ANOVA with five levels were utilised for the parameters. All muscle damage indicators revealed significant changes post- compared to pre-exercise data *($p<0.05$)*. Kinematic analysis revealed that the 100 plyometric jumps decreased knee-joint angles at different phases of stance (impact, support, push-off phase). These changes were more evident just after (0h) the protocol and 48h after this, and remained till 72h post at a great extent *($p<0.05$)*. Lastly, children suffered from delayed muscle soreness on their thigh muscles which remained only 24 hours after this *($p<0.05$)*. Muscle damage causes alterations in treadmill running in knee kinematics of untrained children probable due to differentiation of their central nervous system running strategy.

Key words: kinematics, knee joint, muscle damage, running

INTRODUCTION

Muscular fatigue is defined as the reduction in the force-generating capacity of the neuromuscular system that occurs during sustained activity (Bigland-Ritchie et al. 1983) and is affected by many factors, such as the contraction type and intensity, the joint type, gender and age (Hakkinen, 1983; Clark et al., 2003; Halin et al., 2003; Hatzikotoulas et al. 2004). Although muscle fatigue has been extensively examined in adults and in common contractions (isokinetic, isometric steady on a cybex apparatus, only a few studies are available concerning children response to fatigue during intense fatiguing contractions arising from continuous jumping situation including the stretch-shortening cycle phenomenon. Stretch –shortening cycle (SSC) - type fatigue can lead to muscle damage and is associated with acute (post) and prolonged (1, 2 and 3 day) symptoms. Muscle damage induced by such type of exercise (SSC) in humans frequently occurs after unaccustomed exercise, particularly if the exercise involves a large amount of eccentric contractions (Byrne et al. 2004; Nosaka et al. 2002). Brown et al (1997) who examined six female and two male, who performed a bout of 50 maximum voluntary eccentric contractions of the knee extensors of a single leg, found indirect evidence of exercise induced muscle damage suggesting that myofibre disruption caused by the eccentric muscle contractions. Similarly, Mavrovouniotis et al. (2002), observed increased muscle tissue damage in adolescent volleyball players. The symptoms of SSC fatigue protocols have well been examined in functional demands such as jumping, lower extremities torque or even feel of muscle soreness and biochemistry alterations, but limited research is available regarding running. (Marginson et al. 2005; Paschalis et al. 2007; Clarkson 2002; 1992; Komi, 2000; Novachech, 1995).

The effects of a SSC protocol and subsequent muscle damage on running could be reflected in lower extremities kinematics and be responsible for a different running strategy. A different running strategy could lead to perturbations and increase the risk of musculoskeletal injury. Only a recent study examined the effects of muscle damage on running biomechanics but an isokinetic eccentric exercise and not a SSC protocol was employed (Paschalis et al. 2007) and this focused only on adult population. Therefore, the purpose of this study was to investigate the effects of an intensive exercise protocol including 100 intermittent plyometric jumps on particular kinematic parameters in treadmill running, both at acute and prolonged level, in untrained children.

MATERIAL AND METHODS

Subjects and experimental procedure

Experiments were performed on 12 healthy children 9-12years of age without any history of neurological or orthopaedic disease. All of them were male students, occasionally participating in various recreational activities. The characteristics of participants are presented in table 1.

All subjects wore gym shoes in all the experimental visits. Participants visited the laboratory venue on four different timing periods. The first was reserved for familiarisation with the assessment instruments as well as for the baseline and post-protocol measurements (running treadmill) and the experiment procedures (execution of 100 plyometric jumps). At the following three days (24, 48 and 72 hours post protocol) the same data were collected.

Muscle damage of lower extremities was caused by 100 maximal intensity plyometric jumps performed as 10 sets of 10 continuous jumps. Participants stood with feet shoulder apart and hands on hips. Assuming this posture, they were asked to jump as high as possible on each jump after a preparatory downward eccentric movement, to a knee bend of 90˚, which was performed as fast as possible (Lazaridis et al., 2010; 2006). Each set of 10 jumps was separated by a 30 seconds rest period. All jumps of the protocol were performed on a 0.6x0.6 Bertec force plate (Type 4060, Bertec Corporation, Columbus, OH) collecting at 1000 Hz, which served as a landing area.

Assessments-Data collection

Muscle indicator

For the evaluations of delayed onset muscle soreness (DOMS), each participant palpated his muscle belly and the distal region of the vastus medialis, vastus lateralis and rectus femoris in a seated position with the muscles relaxed. Perceived soreness was then rated on a scale ranging from 1 (normal) to 10 (very sore). This method and scale has been previously documented by other investigators (Clarkson et al., 1992; 2002; Zaggelidou et al., 2009)

Running kinematics

Running was performed on a treadmill set at 2.8 m/s, graded at 0%. Kinematic data were obtained using a six-camera optoelectronic system (VICON 612 M3, Oxford Metrics, UK), sampling at 100 Hz. Sixteen reflective markers (14 mm spheres) were placed at anatomical bony landmarks of each lower extremity (posterior superior iliac spine, anterior superior iliac spine, lateral thigh, femoral epicondyle, lateral tibia, lateral malleolus, calcaneus, 5th metatarsal head, and the dorsum of the foot). The static and dynamic calibration for the motion analysis system was assessed by the same investigator according to the manufacturer recommendations before each data collection session. Trajectories were filtered with the generalized cross validated splines (Woltring et al. 1986). All trajectories were filtered using the generalized cross-validated splines technique as reported by Woltring. Prior to the kinematic evaluation, each participant was recorded in the standing position, which was used as reference for joint movement. 10 continuous steps (after a 20sec. period for start) were analysed and averaged for every participant of its right side. The study of biomechanical variables focused on the knee extension/ flexion across all the four parts of a running cycle (impact, support, pushing, swing phases).

All the parameters mentioned were measured before exercise protocol and immediately after, 24 h, 48 h and 72 h after this.

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Table 1. Characteristics of adult participants

	Children
Characteristics	
Subjects	12
Sex	Male
Age (years)	10,1± 0,5
Body weight (kg)	37 ± 4,6
Height (cm)	142 ± 6,1
% of Body Fat	17,3 ± 3.5

Statistical analysis

The results are presented as mean and standard deviation (mean± SD). Repeated measures one-way ANOVA with five levels (pre-exercise, immediately post exercise, 24, 48 and 72 hours post exercise) were utilised for indirect muscle indicators. The significance level was set at $P < 0.05$. The Statistical Package for Social Sciences (SPSS 16 Inc., Chicago, IL) was used for the analysis.

RESULTS

In the case of DOMS, values found to elevate just after the protocol and present their peak value at 24 hours post exercise [$P < 0.01$ (Figure 1)]. These values remained higher compared to baseline even 48 hours post exercise.

Regarding knee kinematics during running, there was a significant knee joint angle decrement almost in the entire stride during running and mainly at the swing phase of it [*P<0.05* (Table 2)]. These alterations presented their statistical significance compared to baseline data at 24h post exercise and to a lesser extend at 48 and 72h after that.

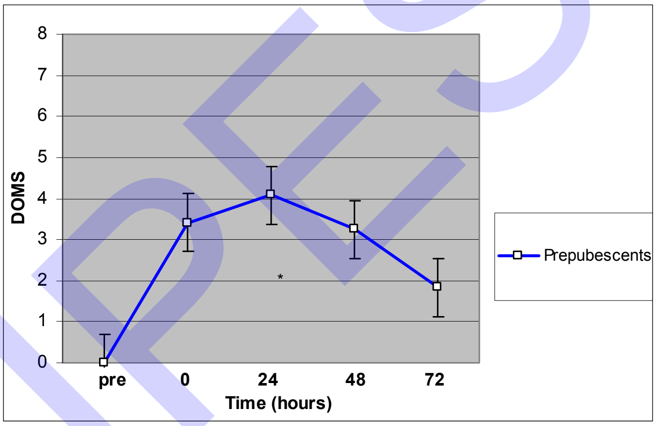

Figure 1. Delayed onset muscle soreness in children

Table 2. Knee joint angles (deg) during running in children.
Data are means ±SD.

Running (n=12)					
	Baseline	**Acute (0h)**	**24h**	**48h**	**72h**
Knee (impact)	10± 3	9± 2*	8± 4*	11± 3	11± 2
Knee (support)	41± 5	36± 4**	39± 5*	40± 5	40± 6
Knee (pushing)	18± 2	17±3	14± 5*	13± 5**	18± 4
Knee (swing)	76± 8	76 ± 7	72± 8*	74± 6*	76± 8

DISCUSSION

The purpose of this study was to investigate the effects of an intensive SSC protocol including plyometric jumps on knee kinematics during running in untrained children. The main finding was that muscle damage significantly altered the knee joint angle during the stance and swing phases of treadmill running. In fact, our participants failed to flex adequate their knee-joint mostly in the swing phase of running at a steady speed (2,8 m/s) and that occurred more evidently 24 h after the protocol. The sense of muscle pain may be responsible for this alteration (Paschalis et al. 2005;Child et al. 1998). In addition to this, this strategy or inability of knee flexion may be an attempt to increase knee stability following fatigue as a neuromuscular protective mechanism and to prevent from further damage. The above finding comes in accordance with that of a recent similar study (Paschalis et al. 2007) but to mention that focused on adult participants. In their attempt to fulfil the exercise protocol following fatigue, probably presented a self-protection strategy in order to run onto the treadmill on a relatively high speed (2.8m/s), which was for most of them an unaccustomed exercise and especially after unaccustomed fatigue caused by the 100 jumps. Lastly, participants suffered from delayed muscle soreness on their thigh muscles but this peaked 24h after that and 48 and 72hours after the protocol the values presented decrement. Concerning this aspect, the low values of muscle soreness presented in children are attributed to either muscular and/or neural mechanisms (Ratel et al. 2003; Jansson, 1996; Bar, 1995; Gaitanos et al. 1993). Children, in fact, seemed to be fatigue resistant and this is obvious by their quick and acute recovery from the protocol and across the following re-assessments (48 and 72 after protocol). Further investigation is required on running kinematics probably with the use of electromyography around the knee joint in order to shed light on the total behaviour of the knee musculature after exercises which cause neuromuscular fatigue and muscle damage.

CONCLUSION

Muscle damage causes alterations in treadmill running in knee kinematics of untrained children probable due to differentiation of their central nervous system running strategy. These alterations remained till 24h after protocol. Children suffered from delayed muscle soreness on their thigh muscles which remained only 24 hours after this and then returned to baseline data. Future research should investigate mechanisms for the reduced severity of symptoms of exercise-induced muscle damage in boys compared with adults. This study gives evidence that children are fatigue resistant to an intensive protocol of plyometric jumps. This should not be omitted when there are designed training protocols for children. The speed of recovery from the 100 plyometric jumps exhiibited by the boys supports the use of plyometric training methods in boys.

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