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Original Research

Neuromechanical response to passive cyclic loading of the ACL in non-professional soccer players: A pilot study

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ABSTRACT

Objective: To investigate the effects of passive cyclic loading (CYC) on anterior tibial translation (ATT), knee extensor and flexor muscle strength and activation in soccer players.
Design: Cross-sectional study.
Setting: Functional Assessment Laboratory; Participants: Eight healthy competitive soccer players.
Interventions: The knee of the dominant limb was subjected to 10 min of CYC at 200 N force.
Main outcomes measures: ATT was measured before and after CYC. Percentage of variation was used to estimate ACL creep. Knee extension and flexion maximal voluntary contractions (MVCs) were assessed both before and after CYC. EMG amplitudes of both Biceps Femoris (BF) and Vastus Lateralis (VL) were recorded during both MVCs and CYC.
Results: There was a 20.7% increase in ATT after CYC application ($p<0.001$). Post-CYC agonist and antagonist BF activations were 37.7% and 18.4% lower than pre-CYC ones during MVCs ($p<0.05$). BF EMG activity in the last 30s of CYC was 19.9% higher than in the first 30s ($p<0.05$).
Conclusion: The increased ATT and the variations in neuromuscular activation of the BF in response to loading may expose the knee at higher injury risk by increasing joint instability. Further studies are required to thoroughly investigate these aspects in both laboratory and real-field settings.

1. Introduction

Non-contact ACL injuries are common in multidirectional team sports and the increasing incidence in soccer is particularly alarming (Griffin et al., 2000; Hootman, Dick, & Agel, 2007; Waldén et al., 2011). Although no unanimous agreement among researchers has been reached, several prospective and retrospective investigations have consistently recognized anterior knee-joint laxity (AKL) as a risk factor for ACL injury (Griffin et al., 2006; Myer et al., 2008; Uhorchak et al., 2003; Woodford-Rogers, Cyphert, & Denegar, 1994). Studies conducted over the last decades showed that engaging in vigorous and prolonged sports activities leads to an acute 20–30% increase in AKL.[8–11]Although it can be considered a physiological response, this phenomenon may expose individuals to higher risk of injury by affecting the biomechanics of sports-related movements (Shultz et al., 2015). Such acute increase in AKL was mainly ascribed to ligamentous creep (Shultz et al., 2015; Solomonow, 2004) defined by Solomonow (2004) as the transitory "stretch" or "deformation" of a viscoelastic tissue when subjected to a static loading over a prolonged period (Chu et al., 2003; Solomonow, 2004).

Studies *in-vivo* showed that both static and cyclic loads applied on healthy knee joints result in the development of ACL creep and associated neuromuscular changes (Chu et al., 2003; Sbriccoli et al., 2005) which, together, may transitorily affect the dynamic stability of the knee joint (Shultz, Carcia, & Perrin, 2004; Solomonow, 2004). Specifically, a significant increase in quadriceps and hamstrings agonist EMG activity as well as a tendency towards higher peak extension and flexion forces, were found in response to 10-min static load application, as a result of the increased AKL and related creep development (Chu et al., 2003). Interestingly, however, such changes were not followed by the concomitant antagonist co-activation, so exposing the knee to increased risk of instability (Chu et al., 2003). In contrast, Sbriccoli and colleagues

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(2005) showed that cyclic loading applied on healthy knees, elicits different neuromuscular alterations consisting in substantial lower peak extension force and decreased EMG amplitude of both agonist and antagonist muscles, as a consequence of creep development (Sbriccoli et al., 2005). The appearance of random spasms, defined by Pederson, Blunk, and Gardner (1956) as non-volitional and unpredictable muscular activity elicited by micro-damages in the collagen fibers (Pederson et al., 1956), was also observed in response to both static and cyclic loading, mostly in the hamstrings and mainly during the intervention at a knee angle of 35°, likely emphasising the attempt of the knee flexors to preserve the ACL from further stress and damages (Chu et al., 2003; Sbriccoli et al., 2005).

The mechanisms underpinning such transitory neuromuscular changes seem to be related to the reduced sensitivity of the mechanoreceptors in response to creep. Specifically, the resultant decrease of afferent drive may alter the activity of the fusimotor system which, by modulating the neural pathways related to the control of muscle stiffness and coordination, may adversely impact on functional stability of the knee joint (Needle et al., 2014; Sjölander, Johansson, & Djupsjöbacka, 2002).

The ACL of soccer players is repeatedly subjected to high-level external loads for rather long periods (Griffin et al., 2006; Solomonow, 2006). Considering the close relationships existing between exercise, AKL development and altered neuromuscular response affecting functional stability of the knee joint (Baumgart et al., 2015; Kirkley, Mohtadi, & Ogilvie, 2001; Nawata et al., 1999; Sbriccoli et al., 2005; Shultz et al., 2015), a thorough understanding of the underlying mechanisms increasing the susceptibility of ACL injury in soccer players, is imperative from a preventive point of view. To date there is a paucity in the literature on the neuromechanical response of the knee joint to loading in high-risk population as soccer players.

Therefore, the main aim of this pilot study was to study the effect of passive cyclic loading applied to the knee joint, on both neuromuscular and mechanical parameters related to knee stability in a group of healthy non-professional male soccer players.

2. Methods

2.1. Participants

The study was approved by local ethics committee. A written informed consent was obtained from eight healthy non-professional male soccer players (age: 23 ± 3 years; body mass: 70.6 ± 4.6 kg; stature: 1.77 ± 0.05 m) who volunteered to take part to this investigation. The following inclusion criteria were adopted: a sporting career of at least 5 years; no previous, current or ongoing neuromuscular diseases or musculo-skeletal injuries affecting the knee-joint; current participation in competitive soccer championship. The dominant limb was chosen for this test by asking participants which was their preferred kicking leg (Labanca et al., 2015; Macaluso & De Vito, 2003). Participants were instructed to refrain from any kind of physical training in the 24 h preceding the experiment and data collection, to ensure their ability to perform the trial in their best possible physical conditions. The tests were carried out at X.

2.2. Experimental setup and protocol

Participants were tested on a single experimental session involving three sequential steps:

- Pre-loading MVC assessment of both knee extensor and flexor muscles;
- Passive cyclic loading application (CYC);
- Post-loading MVC assessment of both knee extensor and flexor muscles.

2.2.1. MVC Assessment

Participants were seated comfortably on a dynamometer and positioned with their trunk erect. MVC during knee extension was exerted by the participants at a knee angle of 90° and measured on a leg-extension machine (Technogym, Forli-Cesena, Italy) with a load cell connected to a computerized system unit (Muscle Lab, Bosco System Technology, Rieti, Italy). Similarly, MVC during knee flexion was measured on a leg-curl device at a knee angle fixed at 35° (Technogym, Forli-Cesena, Italy).

Prior to the force measurements, each participant warmed up on an exercise bicycle for five minutes at a low resistance; in addition, they were asked to carry out eight brief serial extension and flexion MVCs to familiarize with the task.

Subsequently, volunteers were carefully instructed and required to carry out their MVCs by exerting force as hard as possible. Participants were able to follow their performance on a computer screen in order to receive a visual-feedback as a real-time display of the dynamometer force output. Furthermore, they were verbally encouraged to give maximal effort and to maintain it for at least 3 s before relaxing. While keeping the arms folded on the chest, participants performed 3 trials per task (extension and flexion respectively) lasting 3–5 s, separated by an inter-trial rest of 3 min, which was imposed to prevent the onset of muscle fatigue. The peak extension and flexion MVC values were used for subsequent normalization as described in the data analysis section.

2.2.2. Passive cyclic loading (CYC)

The passive cyclic loading setup is represented in Fig. 1. Volunteers were asked to comfortably lay in a supine position for allowing the preparation of the arthrometer GNRB (GeNouRoB, Laval, France) by which a cyclic load up to 200 N was applied for 10 min, at a frequency of 0.1 Hz, for a total of 60 cycles. The GNRB was shown to be a valid tool for measuring anterior knee laxity (Jenny et al., 2017) and a reliable device that ensure good measurements reproducibility, independently of the operator's experience and the tested side. (Collette, Courville, Forton, & Gagnière, 2012), (Robert et al., 2009), Mouton, Seil, and Meyer. (2015) demonstrated a minimum detectable change (MDC) of 1.2 mm at 200 N (Mouton et al., 2015).

The constant push load translating anteriorly the tibia was cyclically applied on the upper surface of the calf by means of an electric actuator (Linak, Nordborg, Denmark). To fasten the femur and ensure the unique ATT (Anterior Tibial Translation), a symmetric pressure was applied upon the patella. The knee was in neutral rotation and its flexion angle was determined by the device's characteristics and set at 20°. ATT was measured by means of a displacement sensor (0.1 mm accuracy; FGP sensor, Global Headquarters, Hampton, VA, US), placed upon the tibial tuberosity (Collette et al., 2012). The frequency of the cyclic load was marked and visually checked by means of a metronome.

2.3. EMG recordings

The EMG signal was recorded from the Vastus Lateralis (VL) and Biceps Femoris (BF) muscles during extension and flexion MVC assessment (pre-post CYC) and during the 10-min CYC.

The skin overlying VL and BF was cleaned with rubbing alcohol prep pads and 2 pairs of 1-cm-diameter silver/silver chloride, pregelled, self-adhesive disc electrodes (20 mm inter-electrode distance) were applied parallel to the muscle fibres, between the