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Neuromechanical adaptation induced by jumping on an elastic surface

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ABSTRACT

Jumping on an elastic surface produces a number of sensory and motor adjustments. This effect caused by jumping on the trampoline has been called "trampoline aftereffect". The objective of the present study was to investigate the neuromuscular response related with this effect. A group of 15 subjects took part in an experimental session, where simultaneous biomechanical and electromyographic (EMG) recordings were performed during the execution of maximal countermovement jumps (CMJs) before and after jumping on an elastic surface. We assessed motor performance (leg stiffness, jump height, peak force, vertical motion of center of mass and stored and returned energy) and EMG activation patterns of the leg muscles. The results showed a significant increase ($p \leqslant 0.05$) of the RMS EMG of knee extensors during the eccentric phase of the jump performed immediately after the exposure phase to the elastic surface (CMJ_1), and a significant increase ($p \leqslant 0.05$) in the levels of co-activation of the muscles crossing the ankle joint during the concentric phase of the same jump. Results related with motor performance of CMJ_1 showed a significant increase in the leg stiffness ($p \leqslant 0.01$) due to a lower vertical motion of center of mass (CoM) ($p \leqslant 0.005$), a significant decrease in jump height ($p \leqslant 0.01$), and a significantly smaller stored and returned energy ($p \leqslant 0.01$). The changes found during the execution of CMJ_1 may result from a mismatch between sensory feedback and the efferent copy.

1. Introduction

Adapting the stiffness of our musculoskeletal system to different surfaces is a daily process in our lives. For example, we adapt our musculoskeletal system during walking (MacLellan and Patla, 2006; Marigold and Patla, 2008), running (Ferris et al., 1998, 1999) and jumping (Ferris and Farley, 1997; Moritz and Farley, 2004, 2005). These adaptations can be explained by a simple biomechanical model, called "spring-mass model", so that when the surface stiffness decreases, the stiffness of the legs is increased, and vice versa (Ferris and Farley, 1997). Studies have shown that sudden and unexpected changes in the stiffness of the surface result in adjustments in the dynamics of the passive properties of body segments that can accommodate the stiffness of the legs immediately [52 ms] (Moritz and Farley, 2004; van der Krogt et al., 2009). These changes in stiffness appear to be associated with perceptual changes. For example, it was found that after a brief exposure of repeated jumps on an elastic surface, subjects show sensory-motor changes when they jump again on a rigid surface (Márquez et al., 2010). Repeated jumps on a trampoline cause an increase of the leg stiffness, a decrease of the height reached in the jump, an underestimation of the jump height and altered perceptual sensations, of the subsequent CMJ performed on the ground. The effects caused by jumping on the elastic surface have been called "trampoline aftereffect" (Márquez et al., 2010). Indeed, this phenomenon occurs even though the subjects are fully aware of the changes in the stiffness of the surface, suggesting the existence of a strong adaptive process.

The mechanism underlying the "trampoline aftereffect" remains unclear. Studies showing sensory and motor adaptations after the exposure to variations in the gravito–inertial force level (Lackner and Graybiel, 1980, 1981) have suggested that these effects are caused by a mismatch between the efferent copy and sensory feedback (Lackner and DiZio, 2000). This is an adaptive process that allows the generation of anticipatory motor commands to compensate for the changes occurring in the environment (Lackner and DiZio, 1994). Moreover, these adaptations have been linked to alterations in the discharge of the muscle spindles (Lackner and Graybiel, 1980, 1981), since they are essential for the limb position sense (Proske et al., 2000; Proske, 2005, 2006). Therefore, it is likely that the effect of repeated jumps on an elastic surface are associated with neuromuscular changes caused by the above mentioned factors.

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The aim of this study was to investigate the neuromuscular and mechanical adjustments during the CMJ performed after a brief exposure of repeated jumps on an elastic surface. Our hypothesis is that jumping on the elastic surface will produce changes in the EMG pattern and in the mechanical responses during the execution of the subsequent CMJ. This study may contribute to understanding of the neuro-mechanical adaptations induced by surfaces of different stiffness.

2. Methods

2.1. Subjects

We recruited fifteen healthy male subjects (Age: 22,2 ± 2,9 years; Weight: 73,6 ± 7,1 kg; Height: 178,3 ± 5,8 cm) from the Faculty of Sport Sciences of Toledo (Spain). Participants provided informed consent prior to participation. The experimental procedures conformed to the Declaration of Helsinki and were approved by the local ethics committee.

2.2. Material

2.2.1. Surface EMG and force platforms recordings

The test (CMJ) was performed on a 9281 CA Kistler platform (Kistler Instrument, AG, Winterthur, Switzerland) installed at ground level. Ground reaction forces (GRF) were recorded with a sampling frequency of 1000 Hz. All data were collected on a PC for further processing and analysis.

Electromyographic activity was recorded from the soleus (SOL), gastrocnemius medialis (GM), tibialis anterior (TA), vastus lateralis (VL), rectus femoris (RF) and biceps femoris (BF) of the right leg (Fig. 1), using pre-gelled bipolar surface Ag–AgCl electrodes (Blue Sensor, Ambu. Inc.). The electrodes were connected to a wireless data acquisition system of eight channels (Noraxon Telemyo 2400T USA). EMG activity was recorded at a 1000 Hz sampling rate. All signals were amplified and filtered with a bandwidth from 10–500 Hz, where each channel has an input impedance >100 MOhm, common mode rejection ratio >100 dB and a gain = 1000. All data were stored on a PC using the program Myoresearch XP (Noraxon Inc. USA) for off-line processing and analysis.

2.2.2. Properties of the elastic surface

The elastic surface consisted of a mini-trampoline (Gimnova), with a jump area of 0.60 m × 0.60 m connected to 32 springs along the outer edge, resulting in a linear stiffness of 14 kN/m. The stiffness of the surface was tested using a static load test (up to 2000 N, see Arampatzis et al., 2001). The linear regression between the surface displacement and the force was significant ($r^2 = 0.99$).

2.3. General procedures

2.3.1. Subject preparation

Electrodes were placed over the muscle belly along the longitudinal axis of muscle fibers, with ±2 cm inter-electrode distance, placing the reference electrode in the head of the fibula (Hortobagyi et al., 2009). Cables were secured with an adhesive tape and elastic mesh to prevent possible artifacts caused by movement. Electrodes were placed according to SENIAM guidelines.

2.3.2. Jump test (CMJ)

The subjects were instructed to start in an upright position, rapidly squat, and then jump into the air with maximal effort. The hands were akimbo throughout the test in order to eliminate the effect of arm swing during the performance of each jump. During the squat phase of the movement, the angular displacement of the knee was standardized so that the subjects were required to bend their knees to approximately 90°. A 90° knee bend was merely a reference value and not an excluding criterion. For a more detailed description about CMJ performance see Bosco et al. 1983.

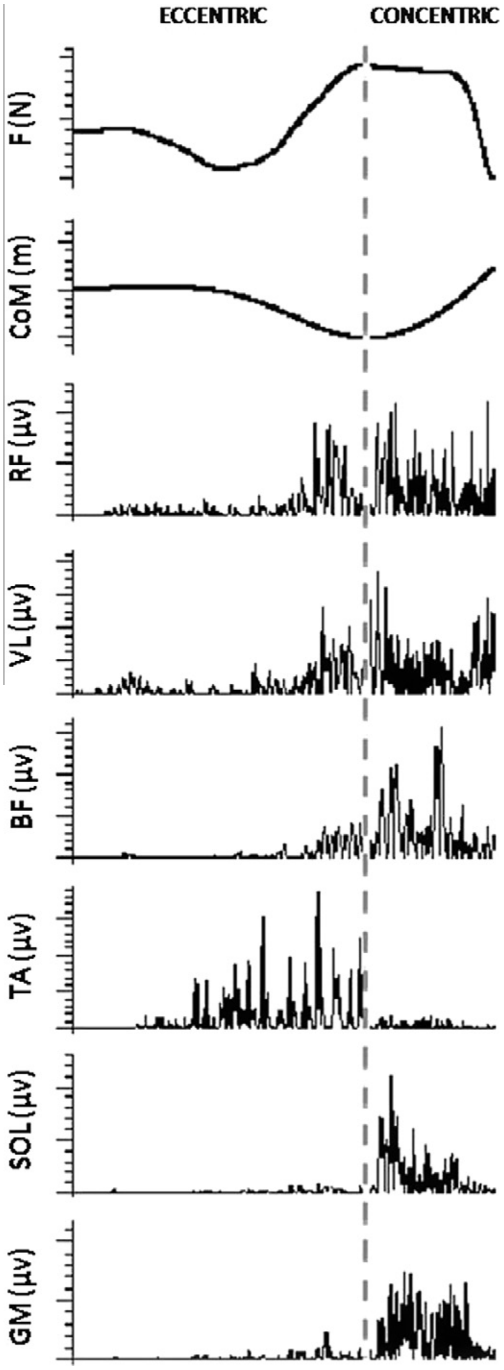

Fig. 1. Example of kinematics and EMG recordings during CMJ performance.

2.3.3. Repetitive jumps or exposure phase to the elastic surface

During the exposure phase on the elastic surface, the subjects were required to jump keeping their hands on their hips. In order to equate the number and rate of jumps, the subjects jumped in synchronization with a metronome at a rate of 1 Hz during 1 min. This was of importance since the jumping frequency has been shown to affect the leg stiffness (Farley et al., 1991; Hobara et al., 2010). This 1 Hz rate was chosen from pilot experiments that