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Unloading reactions in functional ankle instability

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Abstract

Past studies have suggested that unloading reactions may be a strategy to prevent ankle sprains. This study tested unloading reactions in individuals with functional ankle instability (FAI) in order to better understand this phenomenon. We provoked unloading reactions in 20 individuals with FAI and 18 healthy controls by delivering nociceptive electrical stimulation to the lateral aspect of the ankle during standing. Ground reaction forces, lower extremity kinematics, and EMG activity of five muscles of the lower limb were recorded. Individuals with FAI demonstrated increased and faster body weight unloading after stimulation. This hyper-reactivity may partially account for the sensation of the ankle ''giving way'' in those with a history of severe ankle sprain and subsequent functional instability.

Keywords: Ankle instability; Ankle sprain; Unloading; Reactions; Flexion reflexes; Electrical stimulation; Painful stimulation

1. Introduction

Lateral ankle sprains are common [1], and many individuals will develop functional ankle instability [2] following injury. FAI was described by Freeman [3] as a condition where individuals experience recurrent sprains or a feeling of the ankle ''giving way.'' Although this is argued to be caused by an impaired ''stabilization reflex of the foot,'' [3] the neuro-physiological mechanisms of FAI remain unclear.

Past studies have suggested that reflexive activation and pre-activation of the peroneal muscles may protect against sprain injuries [4,5]. A reduction in vertical loading may also reduce the severity of injury, since ankle sprains are frequently associated with downward loads applied to the supinated foot [5]. To reduce the vertical load during a potential injury event, individuals may use flexion reflexes (FR), also known as ''unloading reactions.'' These reactions are provoked by cutaneous stimulation of high and low threshold afferents identified as flexor reflex afferents (FRA) [6].

Santos and Liu [7] recently examined unloading reactions in a group of healthy individuals by applying electrical stimulation at the lateral aspect of the ankles in standing. When stretched (foot supinated), individuals showed greater unloading reactions than when in a neutral position. Unloading reactions were characterized by simultaneous movement of the body downwards and a shift of body weight towards the non-stimulated foot. This suggested that unloading reactions might help to reduce the risk of ankle sprain injuries.

Usually, individuals with FAI show chronic synovial inflammation at the ankle joint (sinus tarsi) [8]. This can sensitize the neurons involved in pain transmission [9]. Pain or fear of ankle injury may possibly lead to a residual hypersensitivity. In turn this could account for the symptom ''giving way'', a typical sign of FAI. Therefore, the purpose of the present study was to test the sensitivity of unloading reactions in individuals with FAI. Unloading reactions were induced by delivering nociceptive electrical stimulation on the lateral aspect of the affected ankle while standing with the stimulated ankle in a supinated position. Ground reaction forces, lower extremity kinematics, and EMG activity of five muscles of the lower limb were recorded and subsequently

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compared with a matched group of individuals with no ankle impairment. It was hypothesized that subjects with FAI would show increased magnitudes of unloading reactions (hyper-reactivity) compared with unimpaired individuals.

2. Methods

2.1. Subjects

Twenty individuals with unilateral FAI (14 women and 6 men; mean age ±30 years, range 20–51) and 18 individuals with no ankle pathology (14 women and 4 men; mean age ±30 years, range 22–54) were recruited from local college campuses. All participants provided informed consent (HSC-9878) and the study was approved by the Institutional Review Board of the University of Kansas Medical Center. Inclusion criteria for the FAI group were: (1) history of two or more ankle sprains in one of their ankle with at least one sprain in the last 6 months; (2) sensation of ankle instability presenting as "giving way;" (3) no acute inflammatory symptoms; (4) no history of fracture or surgery in either ankle; (5) no other serious orthopedic or neurological pathologies that could affect sensation or ankle control. Individuals in the healthy comparison group were free of any history of severe ankle, knee, and/or hip injuries, neurological disorder, or any other pathological conditions that could impair motor performance.

2.2. Instrumentation

Vertical forces were measured using two force plates (AMTI Measurements Group, Watertown, MA, USA) positioned at floor level. The signals from the force plates were sampled at a frequency of 200 Hz and filtered with a Butterworth filter (band-stop 20 Hz).

Ankle and knee joint angles were quantified using an Optotrack motion analysis system. Light emitting diode (LED) markers were fixed on the lateral head of the fifth metatarsus, the lateral malleolus, the lateral aspect of the knee joint (articular line), and the greater trochanter of the femur. Three-dimensional coordinates of these LEDs were recorded at 100 frames/s using an Optotrak (model 3020, Northern Digital, Ontario, Canada). Three vectors were defined as follows: (1) vector one, from the lateral head of the fifth metatarsus to the lateral malleolus; (2) vector two, from the lateral malleolus to the midline of the knee joint; (3) vector three, from the midline of the knee joint to greater trochanter. The ankle and knee angles were measured between vectors one and two, and two and three, respectively.

Bipolar surface electrodes (8 mm diameter stainless-steel electrodes with a 21 mm inter-electrode distance) were placed at the lateral aspect of the ankles, below and anterior to the lateral malleolus, to deliver electrical stimuli. An electrical stimulation device (S48K square pulse stimulator, Astro-med, Inc./Grass Telefactor, West Warwick, RI, USA) generated 25 ms of continuous rectangular pulses of 1 ms duration that were delivered to the skin at a frequency of 200 Hz (5–6 pulses). To ensure isolation, stimuli were delivered to individuals through an isolation unit (model SIU5, Grass Telefactor, West Warwick, RI, USA).

EMG activity was recorded using a Noraxon Myosystem 2000 (Noraxon USA, Inc., Scottsdale, AZ, USA) for tibialis anterior (TA), soleus (SOL), vastus medialis (VM), biceps femoris (BF) and peroneus longus (PER). After skin preparation with alcohol, two gel-adhesive silver-chloride (Ag/AgCl) electrodes with 30 mm × 22 mm skin contact area (Blue sensor N, Ambu A/S, Ballerup, Denmark) were attached to the muscle belly along the direction of the muscle fibers [10] at an inter-electrode distance of approximately 10 mm (skin contact area). After similar skin preparation, a reference electrode was attached on the anterior aspect of the leg over the tibia. The EMG signals were amplified 1000 times (common mode rejection ratio, 100 dB at 60 Hz) and the final recorded EMG signal was given in V. All EMG data were digitized at 1024 Hz by an A/D board (ODAU system, Northern Digital, Waterloo, Canada) enabling 16-bit synchronized collection of analog and digital data with the Optotrak system. These EMG data were filtered (Butterworth filter, band-pass 20–500 Hz), fully rectified, and smoothed (RMS) using a 100 ms moving average window using a custom-written Matlab program (Matlab 6.5, The MathWorks Inc., Boston, MA, USA).

2.3. Experimental procedure

Participants stood without shoes on two force platforms with the stimulated foot in a supinated position and the other foot on a level surface. To attain this position, one foot was placed with the ankle at approximately 15° of plantar flexion and 30° of inversion on a wooden wedge on the top of one force platform. The other foot was placed on a level surface of a wooden box on top of the other force platform. The boxes had the same weight and height [7].

Electrical stimulation was applied on the lateral aspect of the ankle joint with an intensity of 20% above the individual's pain threshold. The pain threshold was determined by gradually increasing the intensity of stimulation until the person reported a pinching or burning sensation [7,11].

For the FAI group, the unstable ankle was placed in a supinated position (stimulated side) and the other ankle was positioned on a level surface. For the control group, the right side was designated as both the supinated and stimulated side. Three electrical stimuli were delivered to the ankle at an interval from 30 to 60 s. Prior to delivery of each stimulus, the weight distribution was monitored on a computer screen and the participant was given feedback to maintain a posture with equal weight distribution on both feet.

2.4. Data processing and analysis

The data recorded from force platforms, the motion measurement system, EMG, and the electrical stimuli generator were processed and synchronized in the method described previously [7]. The peaks of vertical forces (positive or negative) from both platforms after the stimulation were identified visually (Fig. 1). Usually a small symmetrical change of vertical forces was observed preceding a large peak, i.e., an increase (positive) in the stimulated side and a decrease (negative) in the opposite side. These small symmetrical changes in vertical forces, normally less than 50% of the large peak, are consistent with those described previously as anticipatory postural adjustments (APA) [12,13]. A larger peak on the stimulated side following the APA was considered to represent the principle response to the stimulation. The difference between the principle response and the mean of vertical forces 100 ms before the stimulation was calculated and averaged over three trials as a vertical force variation (VFV). The VFV was allocated a value of zero if it was less than 2 N [14].

The peak values of the ankle and knee joint angles within 1 s immediately after the stimulation were subtracted from the mean joint angle during 100 ms window preceding stimulation. The