THE EFFECT OF MYOELECTRIC STIMULATION ON PERONEAL MUSCLES TO RESIST SUDDEN SIMULATED ANKLE SPRAIN MOTIONS

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This study evaluated the effect of myoelectric stimulation on peroneal muscles to resist sudden simulated ankle sprain motions. Ten male subjects performed unanticipated inversion and supination spraining motions simulated by a mechanical sprain simulator. Myoelectric stimulations with different delay time were delivered to the peroneal muscles to initiate involuntary muscle contraction and ankle joint pronation torque to resist the spraining motion. The motion was captured and analyzed by a motion analysis system, and was quantified by the reduction of maximum heel tilting angle and angular velocity. Results showed significant effect in all conditions with the myoelectric stimulation of any delay time within 15ms. The maximum heel tilting angle and angular velocity dropped from 18 to 9-13 degrees and from 200-250 to 140-170 degree/s respectively. The present corrective mechanism could be implemented in our current research to develop an intelligent sprain-free sport shoe attempting to prevent ankle sprain injury in sports.

KEYWORDS: Sports medicine, inversion, supination, injury prevention.

INTRODUCTION: Ankle ligamentous sprain as caused by sudden excessive ankle inversion or supination is one of the most common sport-related injuries (Fong et al, 2007). The two most commonly suggested aetiologies are the incorrect foot positioning at landing which generates sudden and excessive ankle inversion or supination torque, and the delayed reaction time of the peroneal muscles at the lateral aspect of the ankle to accommodate by resistive eversion or pronation torque (Fong et al, 2009a). Our research team is developing an intelligent sprain-free sport shoe which firstly senses the ankle joint motion, then identifies if a hazardous ankle spraining motion is occurring, and finally actuates a corrective mechanism to prevent an ankle sprain injury (Chan, 2006).

One of the proposed corrective mechanisms for the aforementioned purpose is to deliver a myoelectric stimulation to the peroneal muscles to trigger quick contraction. The rationale is that it could generate peroneal muscle contraction and the subsequent ankle joint pronation torque within 21-25ms (Ginz et al, 2004). This could take over the role of the slower peroneal muscles which react within 60-90ms to resist the sudden ankle torque happening within 40-50ms after the start of ankle joint twisting (Fong et al, 2009b). This study evaluated its effect by quantifying the reduction of maximum heel tilting angle and angular velocity during sudden inversion and supination spraining motions simulated by a mechanical sprain simulator (Chan et al, 2008).

Figure 1. The simulated ankle sprain test.

METHOD: Ten male subjects (age = 22.6 ± 2.4 year, height = 1.72 ± 0.04 m, body mass = 68.1 ± 8.0 kg) with clinically examined healthy ankles were recruited from the university athletic team. The university ethics committee approved the study. Each subject performed five trials of simulated inversion test and supination test on a pair of mechanical sprain simulators (Figure 1) (Chan et al, 2008). For the simulated inversion test, the axis of the falling platform was aligned parallel to the perpendicular axis of the foot for pure ankle inversion motion. For the simulated supination test, the axis was tilted for 23 degrees medially from the perpendicular axis of the foot, which allows a natural ankle supination along the oblique axis of rotation of the subtalar joint (Hertel, 2002). In each trial, the subject was instructed to stand normally and relax with his weight evenly distributed on both platforms. Without prior notice to the subject, one of the two platforms fell freely and suddenly for 30 degrees. The fall was started by an electrical trigger operated by a research assistant when the subject was standing in a relax way as instructed. The falling sequence was randomized, and the procedure was repeated until five trials of with the right platform falling were performed.

A battery-powered myoelectric stimulation device (Figure 2a) was fabricated by the university electronics services unit by modifying a previous design (Thorsen and Ferrarin, 2009), in order to generate an adjustable electric stimulus by varying the magnitude, the duration, and the time delay of the stimulus from the start of the electrical trigger. For each subject, a pair of electrodes (Panasonic EW4312P, Japan) was attached to the muscle belly of the peroneal muscles at the lateral shank. The muscle belly was identified when the subject was instructed to perform voluntary ankle joint pronation. The skin surface was shaved and cleaned before the attachment of the electrodes. The subject was then requested to sit down and relax with both feet on the floor. A myoelectric signal of 130V was then delivered to the peroneal muscles of the subject to check if the system was well equipped to the subject, as indicated by an involuntary ankle pronation motion right after the delivery of myoelectric signal (Figure 2b). The procedure was successful for all subjects in this study. The delay time was set at 0, 5, 10 and 15ms in order to determine the maximum delay between the moment an ankle sprain starts to occur until the latest time which the device could still prevent an ankle sprain injury. Since the electromechanical delay was reported to be 21-25ms, a delay time greater than 15ms was not investigated as it could hardly catch up with a vigorous ankle sprain motion happening within 40-50ms. The activation time was set to 500ms, which is enough to cover the duration of an ankle sprain motion.

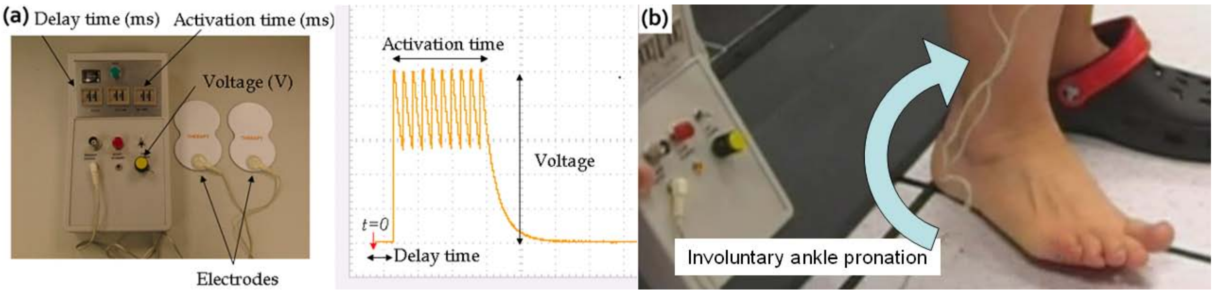

Figure 2. The myoelectric stimulation device to deliver myoelectric stimulus to peroneal muscles.

Twelve reflective markers (5mm diameter) were attached to lateral fibula head, tibial tuberosity, lateral proximal shank, medial proximal shank, anterior distal shank, lateral distal shank, medial distal shank, posterior heel, lateral heel, medial heel, medial foot and dorsal foot. Marker coordinates were recorded by an optical motion analysis system (VICON, UK) at 500Hz. The marker coordinates were filtered by Generalized Cross-Validation package of Woltring with 15Hz cut-off frequency (Woltring, 1986). A static calibration trial with the subject standing on the platforms in the anatomical position served as the offset position to determine the segment embedded axes of the shank and foot segment. The foot and shank segment were embedded with the Laboratory Coordinate System (LCS). A singular value decomposition method was employed to calculate the transformation from triad reference frame to anatomical shank and foot reference frame (Soderkvist, 1993). Joint kinematics was deduced by the Joint Coordinate System (JCS) method (Grood, 1983). Heel tilting angle was defined as the angle between the LCS vertical axis and foot sagittal plane directional axis,

and the heel tilting velocity was its change with respect to time. The maximum measurements of these two parameters were investigated. The data analysis was processed by a customized Matlab program.
Shapiro-Wilk test was conducted to check the normality of each parameter in each condition. If normality was achieved, multivariate analysis of variance (MANOVA) with repeated measures and post-hoc Tukey t-test was conducted to investigate the measured parameter in a condition statistically differ from that of control, with no myoelectric stimulation being delivered during the simulated spraining test. If normality was not achieved, Kruskal-Wallis analysis of variance and post-hoc Mann-Whitney U test was conducted instead. Statistical significance was set at $p<0.05$.

RESULTS: Figure 3 shows the maximum heel tilting angle and angular velocity in the simulated inversion and supination test, with the myoelectric stimulus delivered after different delay time. In the control conditions, no myoelectric stimulus was delivered. In both simulated inversion and supination tests, the maximum heel tilting angle dropped from around 18 degrees to 9-13 degrees, and the maximum heel tilting angular velocity dropped from 200-250 degree/s to 140-170 degree/s. Shapiro-Wilk test showed normality of all parameters, and the subsequent MANOVA with repeated measures and post-hoc Tukey t-test showed that the drop of the two parameters were statistically significant in all conditions with myoelectric stimulus with any delay time within 15ms.

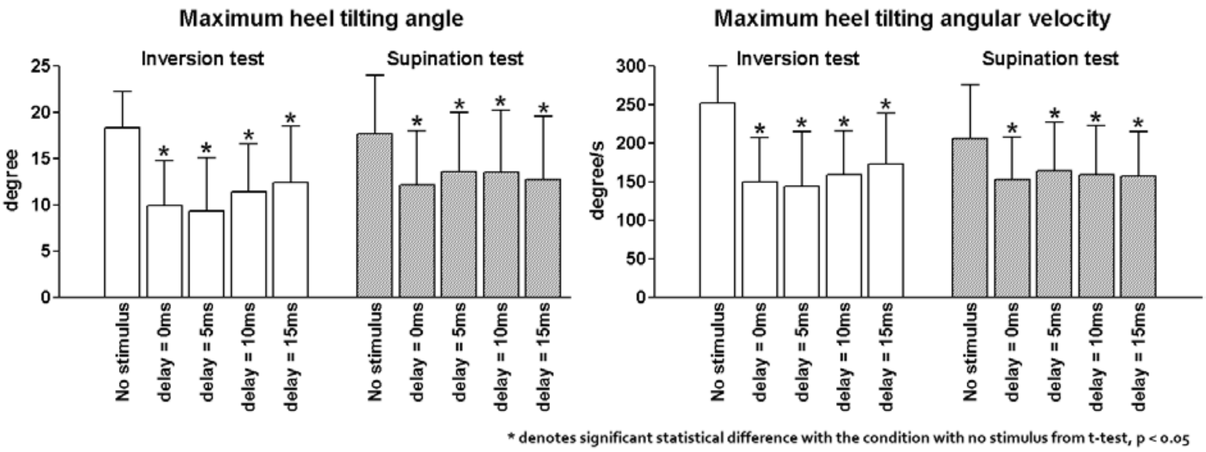

Figure 3. Maximum heel tilting angle and angular velocity in inversion test and supination test.

DISCUSSION: In this study, the myoelectric stimulation on peroneal muscles was found to be effective in reducing the maximum heel tilting angle and angular velocity in the simulated ankle sprain tests. The study was delimited to simulated but not real ankle sprain injuries, since it would be unethical and not reproducible to conduct injury trials in a laboratory. We postulated that such a sub-injury motion, which is a motion leading up to an irreversible ankle inversion or supination sprain injury, is undesirable. Therefore, it is reasonable to start the protection when such a sub-injury motion has occurred, or else an ankle sprain injury would be inevitable.
The condition with the myoelectric signal delivered after the maximum delay, which was 15ms after the start of the simulated spraining motion, was still found to be effective. As our research team is currently developing an ankle sprain identification method utilizing motion sensors to detect any hazardous ankle spraining motion (Chan et al, in press; Chu et al, in press), the results in this study suggested that we may have a maximum time period of 15ms for the sensors to successfully detect a sprain motion, and to actuate the corrective system presented in this study. Future studies should investigate the effect of the real-time sensing and identification method to serve as the trigger to activate the ankle sprain corrective mechanism, and its effect to resist the sudden ankle inversion in time.

CONCLUSION: This study showed a good feasibility of delivering myoelectric stimulation on peroneal muscles with 15ms to resist sudden simulated ankle sprain motions. This corrective mechanism could be implemented in the intelligent sprain-free sport shoe to prevent ankle sprain injury in sports.

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