Title	Differentiation of ankle sprain motion and common sporting motion by ankle inversion velocity		
Article type	Short communication		
Authors	Vikki Wing-Shan Chu[1,2], Daniel Tik-Pui FONG[1,2], Yue-Yan Chan[1,2,3], Patrick Shu-Hang YUNG[1,2,3] , Kwai-Yau Fung[3], Kai-Ming CHAN[1,2]		
Affiliations	Department of Orthopaedics and Traumatology, Prince of Wales Hospital, Faculty of Medicine, The Chinese University of Hong Kong, Hong Kong, China [1] The Hong Kong Jockey Club Sports Medicine and Health Sciences Centre, Faculty of Medicine, The Chinese University of Hong Kong, Hong Kong, China [2] Department of Orthopaedics and Traumatology, Alice Ho Miu Ling Nethersole Hospital, Hong Kong, China [3]		
Keywords	Ankle sprain, biomechanics, kinematics, supination		
Total words	1499	Words in abstract	233
Correspondence author			
Telephone	(852) 2632 3535	Facsimile	(852) 2646 3020
E-mail	dfong@ort.cuhk.edu.hk		

Abstract

This study investigated the ankle inversion and inversion velocity between various common motions in sports and simulated sprain motion, in order to provide a threshold for ankle sprain risk identification. The experiment was composed of two parts: Firstly, ten male subjects wore a pair of sport shoes and performed ten trials of running, cutting, jump-landing and stepping-down motions. Secondly, five subjects performed five trials of simulated sprain motion by a supination sprain simulator. The motions were analyzed by an eight-camera motion capture system at 120Hz. A force plate was employed to record the vertical ground reaction force and locate the foot strike time for common sporting motions. Ankle inversion and inversion velocity were calculated by a standard lower extremity biomechanics calculation procedure. Profiles of vertical ground reaction force, ankle inversion angle and ankle inversion velocity were obtained. Results suggested that the ankle was kept in an everted position during the stance. The maximum ankle inversion velocity ranged from 22.5 to 85.1 deg/s and 114.0 to 202.5 deg/s for the four tested motions and simulated sprain motion respectively. Together with the ankle inversion velocity reported in the injury case (623 deg/s), a threshold of ankle inversion velocity of 300 deg/s was suggested for the identification of ankle sprain. The information obtained in this study can serves as a basis for the development of an active protection apparatus for reducing ankle sprain injury.

Introduction

Ankle is the most popular injured body site in sport (Fong et al., 2007a). Among ankle injury, 80% were ligamentous sprain (Fong et al., 2009a). After acute ligament rupture, 20% of patients develop chronic ankle instability. It can be either mechanical with structural ligament lesion or functional with loss of the neuromuscular control (Krips et al., 2006). Over the years, different approaches have been employed to prevent ankle sprain injury. However, a recent epidemiological study has revealed that ankle sprain is still a prevalent sports related injury, as it has been shown to account for 14% of all attendances at an accident and emergency department (Fong et al., 2008) - this suggests that there is the potential for new ideas regarding ankle sprain prevention in sports.

Recently, there is an innovative attempt in designing an intelligent sprain free sport shoe for preventing ankle sprain injury (Chan, 2006). Before initiating an active correction mechanism in case of an ankle sprain, the shoe system measures and monitors ankle joint biomechanical changes in order to recognize if it is approaching the onset of an ankle sprain. In order to do so a system to identify sprain motion should be first developed. Ankle kinematics of common sporting motion and sprain motion can provide information to develop such a system. Therefore, this study focuses on the investigation of the kinematic, i.e. ankle inversion angle and velocity of common sporting motions and simulated sprain motion. Together with the kinematic data of an accidental ankle sprain injury event reported in a laboratory (Fong et al., 2009b), the findings provide information to determine a threshold to identify an ankle sprain injury from common sporting motions. With the suggested threshold, an in-shoe alarm system to monitor the ankle sprain injury risk could be devised with a recent advanced method to measure ankle inversion and inversion velocity with two tiny inertial and magnetic sensors (O'Donovan et al., 2007).

Materials and Methods

1) Common sporting motion

Ten recreational male athletes were recruited (age = 23.4 ± 3.0 yr, height = 1.73 ± 0.03 m, body mass = 65.1 ± 9.7 kg, foot length = 255-260 mm). Each subject wore a pair of cloth sport shoes (Fong et al., 2007b) and performed ten trials of running, 45-degree cutting, vertical jump-landing and stepping-down (from a block) motions in a random sequence in a motion biomechanics laboratory. Subjects were asked to perform the motions with their full effort and own landing strategy. These motions were chosen because they are common in various kinds of sports. In each trial, the subject performed the motion and stepped on a force plate (Advanced Mechanical Technology Inc., USA) with their right foot. Foot strike time was defined as the moment when vertical ground reaction force exceeded 20N (Fong et al., 2007b).

2) Simulated sprain motion

Five recreational male athletes (age = 23.8 ± 2.8 yr, height = 1.72 ± 0.05 m, body mass = 63.7 ± 9.7 kg) participated in the test. Each subject wore a pair of cloth sport shoes performed simulated supination sprain motions in different degree of supination on the supination sprain simulator (Chan et al., 2008). When the fall platform is set at 0^oor 90^o, rather pure inversion or planter flexion motion is provided respectively. Five angles (0^o, 23^o, 45^o, 67^o and 90^o) were used in the test. In each angles, five trials were performed.

The university ethics committee approved the study. Five reflective skin markers were attached at the position of fifth metatarsal head, heel, lateral malleolus, tibial tubercle, and lateral femoral epicondyle, either directly on the skin or on the shoe surface. An eight-camera motion capture system (VICON, UK) was used to record the coordinates of the markers at 120Hz. Before the test, each subject was instructed to stand still to record the offset position of the ankle joint. The ankle inversion and inversion velocity was calculated by a standard lower extremity biomechanics calculation procedure (Vaughan et al., 1992). The average value of vertical ground reaction force, ankle inversion angle and ankle inversion velocity of the subjects were obtained. The average profiles of the subjects and the peak values of ankle inversion and inversion velocity from these profiles were determined.

Results

1) Common sporting motion

The profiles of vertical ground reaction force, ankle inversion angle and ankle inversion velocity during the four common sporting motions are shown in Figure 1. Degree 0 represented the ankle joint position during the steady upright anatomical standing posture. In all motions, there was a sharp ankle eversion (a drop of ankle inversion angle) at the first 0.1s after the foot strike. This is also indicated by the sharp peak of ankle eversion velocity (a negative ankle inversion velocity). The ankle was kept in an everted position in correspondence to the offset position during the trimmed stance period for all motions.

The peak values and the time of peak value of the ground reaction force, the ankle inversion angle and the ankle inversion velocity during the four motions are shown in Table 1. For jump-landing and stepping-down, the time of maximum ankle inversion was before the foot strike – this suggests that the ankle everted after foot strike and did not return back to the orientation just before foot strike. The maximum ankle inversion velocity was higher in running (85.1 deg/s), and was achieved at a time during late stance. This was to initiate ankle inversion in order to push off the ground to propagate.

2) Simulated sprain motion

The profiles of ankle inversion angle and ankle inversion velocity during the platform fall at different angles are shown in Figure 2. For inversion angle, there were two local peaks during each supination, ranging from 9.9^{o} to 17.7^{o} at 0.12-0.16s. The maximum inversion velocity ranges from 114.0 to 202.5 deg/s (Table 2). Both inversion angle and velocity were decreasing as the angle of the fall platform increased.

Discussion

The results suggested that the maximum ankle inversion velocity was below 90 deg/s in all common sporting motions. Moreover, the profiles of the ankle inversion velocity (Fig. 1) suggested that the maximum ankle inversion velocity happened at the end of the stance, for the ankle to invert and push off the ground for the next step. This finding, together with the ankle orientation profile, further suggested that ankle inversion does not happen in normal non-injury sport motions. This is in agreement with previous study to show that ankle eversion takes place during the stance time in running (Stacoff et al., 2000). One should note that for the subject with ankle instability, this may not be true since their gait kinematic was altered (Monaghan et al., 2006; Delahunt et al., 2006 & 2007).

For the data of simulated sprain motion, there was a general tendency for a decrease of inversion angle with the increase of platform angle. This is because when the platform angle increased, the rotating axis of the sprain simulator moved away from the inversion/eversion axis and approached the plantar flexion/dorsiflexion axis of the ankle of the tested subject. There is no much different between the inversion angle of the common sporting motion and simulated sprain motion. However, the inversion velocity of simulated sprain motion is much greater than the common sporting motion. Therefore, inversion velocity can be used to differentiate common sporting motion and sprain motion.

A recent case report of an accidental supination ankle sprain injury event reported the ankle biomechanics determined by a multi-view high speed video sequence analysis (Fong et al., 2009b). It suggested that there were two phases, risk-developing phase and injury phase, during sprain injury. During the risk-developing phase, the maximum inversion velocity was 632 deg/s and the sprain injury has not been induced in this phase. Therefore, it is safe to set the threshold at 300 deg/s. Also, this threshold would not restrict the motion of the ankle since the inversion velocity of the common sporting motion is below 100 deg/s (Fig. 3). One should note that the threshold suggested here is only based on the preliminary data of single sex and small sample size. In order to extrapolate the results to a wider audience, a further study with larger sample size is needed. Using two tiny inertial and magnetic sensors for ankle kinematics measurement, an in-shoe sensor system could be devised for the identification of significant ankle sprain injury risk.

Conclusion

This study investigated the ankle inversion and inversion velocity during various common motions in sports and simulated sprain motion. Together with the information reported in the case report of an accidental ankle sprain injury, a threshold ankle inversion velocity of 300 deg/s was suggested.

Conflict of interest

The authors declare no financial and personal relationships with other people or organizations that could inappropriately influence this submitted work.

Acknowledgments

This research project was made possible by resources donated by The Hong Kong Jockey Club Charities Trust. The Innovation Technology Fund from the Innovation and Technology Commission, Hong Kong Special Administrative Region Government also financially supported the project. (Project Number: ITS/013/07).

References

1. Chan KM, 2006. Ankle injuries in sports - What's new on the horizon? Journal of Medical Biomechanics 21(Supp),6-7.
2. Chan YY, Fong DTP, Yung PSH, Fung KY, Chan KM, 2008. A mechanical supination sprain simulator for studying ankle supination sprain kinematics. Journal of Biomechanics 41,2571-2574.
3. Delahunt E and Monaghan K, 2006. Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. The American Journal of Sports Medicine 34,1970-1976.
4. Delahunt E, Monaghan K, Caulfied B, 2007. Ankle function during hopping in subjects with functional instability of the ankle joint. Scandinavian Journal of Medicine and Science in Sports 17,641-648.

5. Fong DTP, Chan YY, Mok KM,Yung PSH, Chan KM, 2009a. Understanding acute ankle ligamentous sprain injury in sports. Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology 1:14.
6. Fong DTP, Hong Y, Chan LK, Yung PSH, Chan KM, 2007a. A systematic review on ankle injury and ankle sprain in sports. Sports Medicine 37,73-94.
7. Fong DTP, Hong Y, Li JX, 2007b. Cushioning and lateral stability functions of cloth sport shoes. Sports Biomechanics 6,407-417.
8. Fong DTP, Hong Y, Shima Y, Krosshaug T, Yung PSH, Chan KM, 2009b. Biomechanics of supination ankle sprain - a case report of an accidental injury event in laboratory. The American Journal of Sports Medicine 37,822-827.
9. Fong DTP, Man CY, Yung PSH, Cheung SY, Chan KM, 2008. Sport-related ankle injuries attending an accident and emergency department. Injury 39,1222-1227.
10. Krips R, de Vries J, van Dijk CN, 2006. Ankle instability. Foot and Ankle Clinics of North America 11,311-329.
11. Monaghan K, Delahunt E, Caulfield B, 2006. Ankle function during gait in patients with chronic ankle instability compared to controls. Clinical Biomechanics 21,168-174.
12. O'Donovan KJ, Kamnik R, O'Keeffe DT, Lyons GM, 2007. An inertial and magnetic sensor based technique for joint angle measurement. Journal of Biomechanics 40,2604-2611.
13. Stacoff A, Nigg BM, Reinschmidt C,van den Bogert AJ, Lundberg A, 2000. Tibiocalcaneal kinematics of barefoot versus shod running. Journal of Biomechanics 33,1387-1395.
14. Vaughan CL, Davis BL, O'Conner JC, 1992. Dynamics of Human Gait: Human

Kinetics. Publishers Champaign.

Figure legends

Figure 1 – The profiles of (a) vertical ground reaction force, (b) ankle inversion angle and (c) ankle inversion velocity during the four common sporting motions performed in this study. A negative ankle inversion angle means that the ankle is everted in correspondence to the offset position. A negative inversion velocity means that the ankle is performing eversion. Dotted lines indicate one standard deviation from the mean.

Figure 2 – The profiles of (a) ankle inversion angle and (b) ankle inversion velocity during the simulated sprain motions performed in this study. A negative ankle inversion angle means that the ankle is everted in correspondence to the offset position. A negative inversion velocity means that the ankle is performing eversion.

Figure 3 – Mean and standard deviation of peak value of inversion velocity. Dotted line is the threshold suggested.

Table 1 – The peak values and the time of peak value of the ground reaction force, the ankle inversion angle and the ankle inversion velocity during the four common sporting motions.

	Running	Cutting	Jump-landing	Stepping-down
Peak VGRF (N)	1648.8	1151.0	1882.8	1832.2
Peak VGRF (Body weight)	2.39	1.66	2.72	2.66
Time of peak VGRF (s)	0.08	0.02	0.05	0.05
* Max ankle inversion (deg)	-16.4	-2.9	-8.0	-25.2
** Time of max ankle inversion (s)	0.06	0.15	0.19	0.19
Max ankle inversion velocity (deg/s)	85.1	37.2	22.5	70.1

** Time of max ankle inversion velocity (s)	0.16	-0.04	0.13	0.56

* Negative value in maximum ankle inversion means that the ankle was in an everted position relative to the offset position.

** Negative time means that the time was before the moment of foot strike.

Table 2 – The peak values and the time of peak value of the ankle inversion angle and the ankle inversion velocity during the five simulated sprain motions.

Platform angle (deg)	0	23	45	67	90
Max ankle inversion (deg)	17.7	15.4	13.5	11.8	9.9
Time of max ankle inversion (s)	1.0	0.12	0.15	0.30	0.13
Max ankle inversion velocity (deg/s)	202.5	158.7	149.5	118.6	114.0
Time of max ankle inversion velocity (s)	0.07	0.07	0.08	0.09	0.05

Figure 1
Click here to download high resolution image

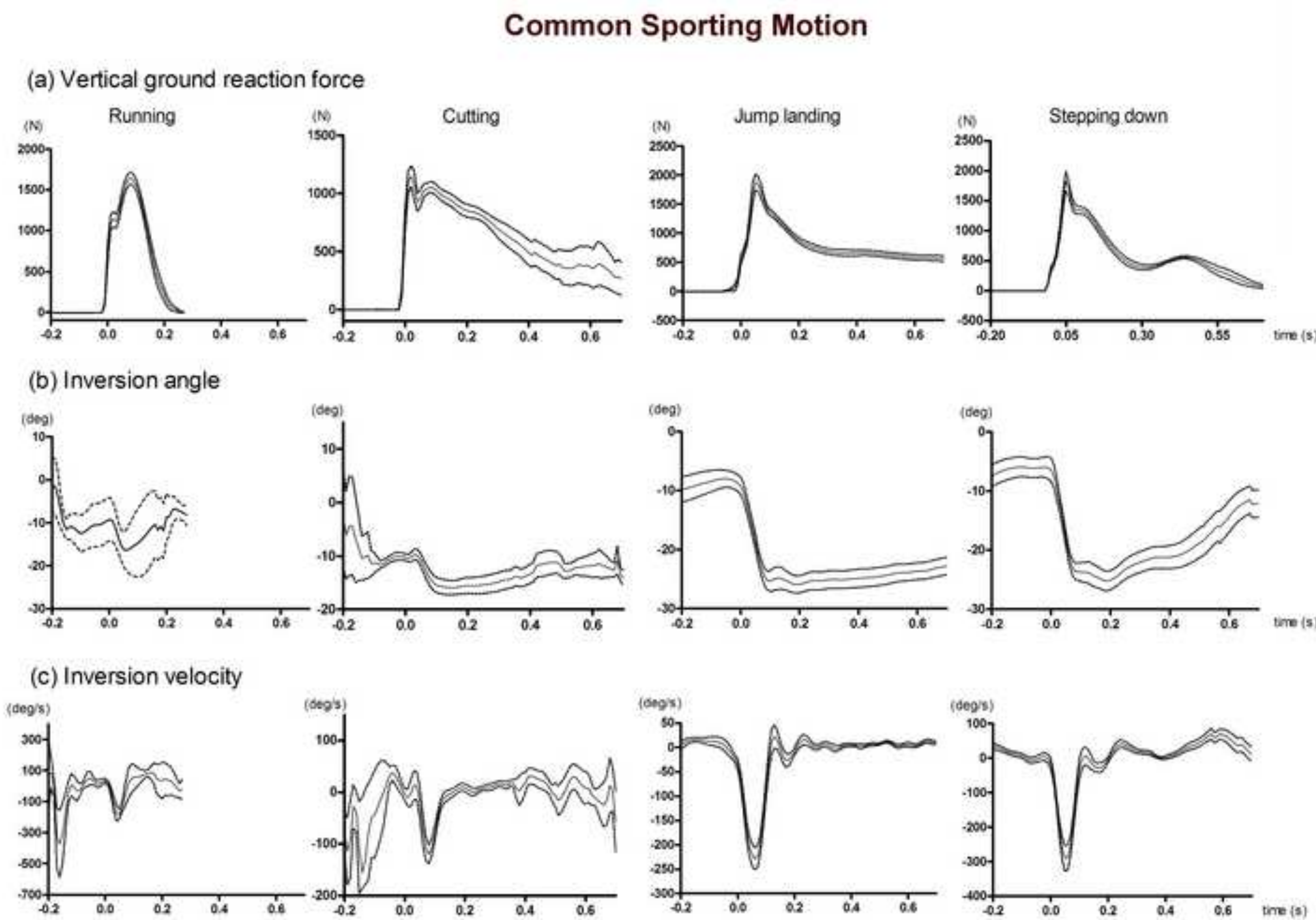


Figure 2
Click here to download high resolution image

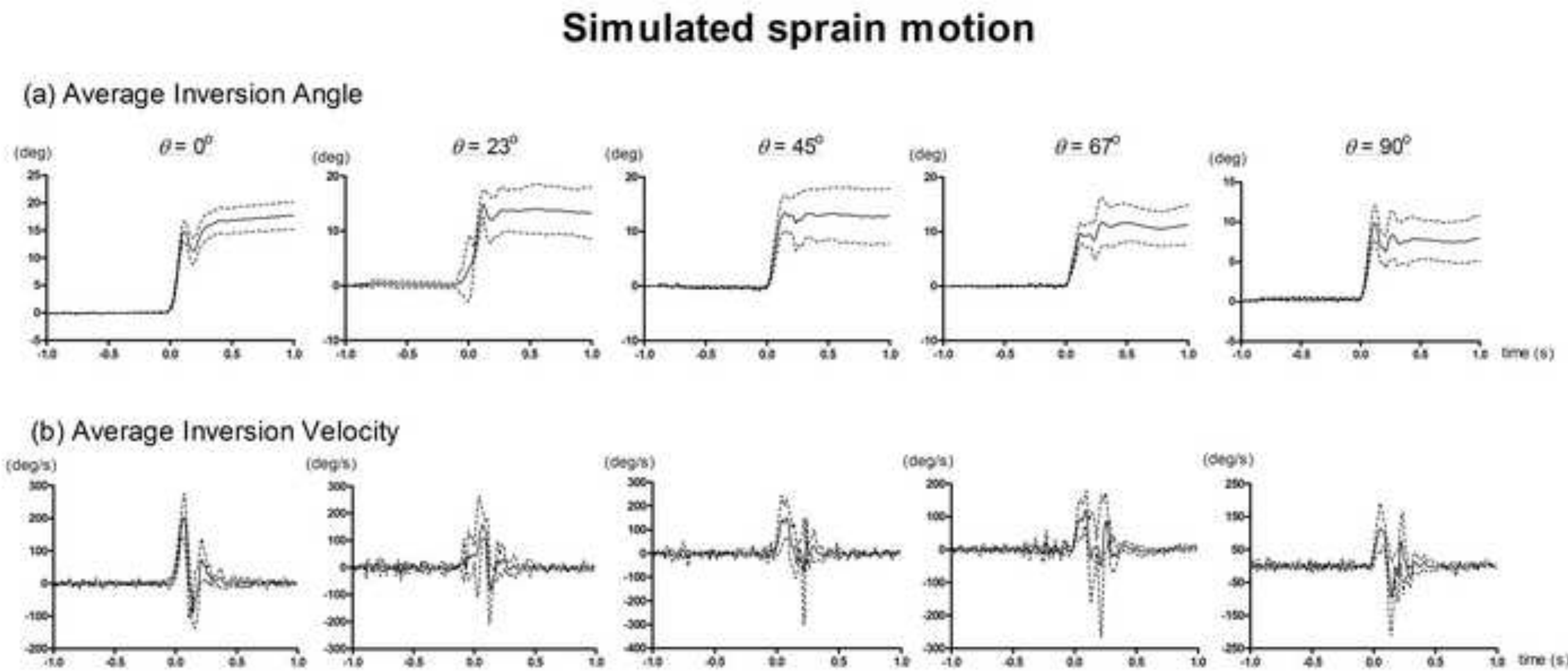
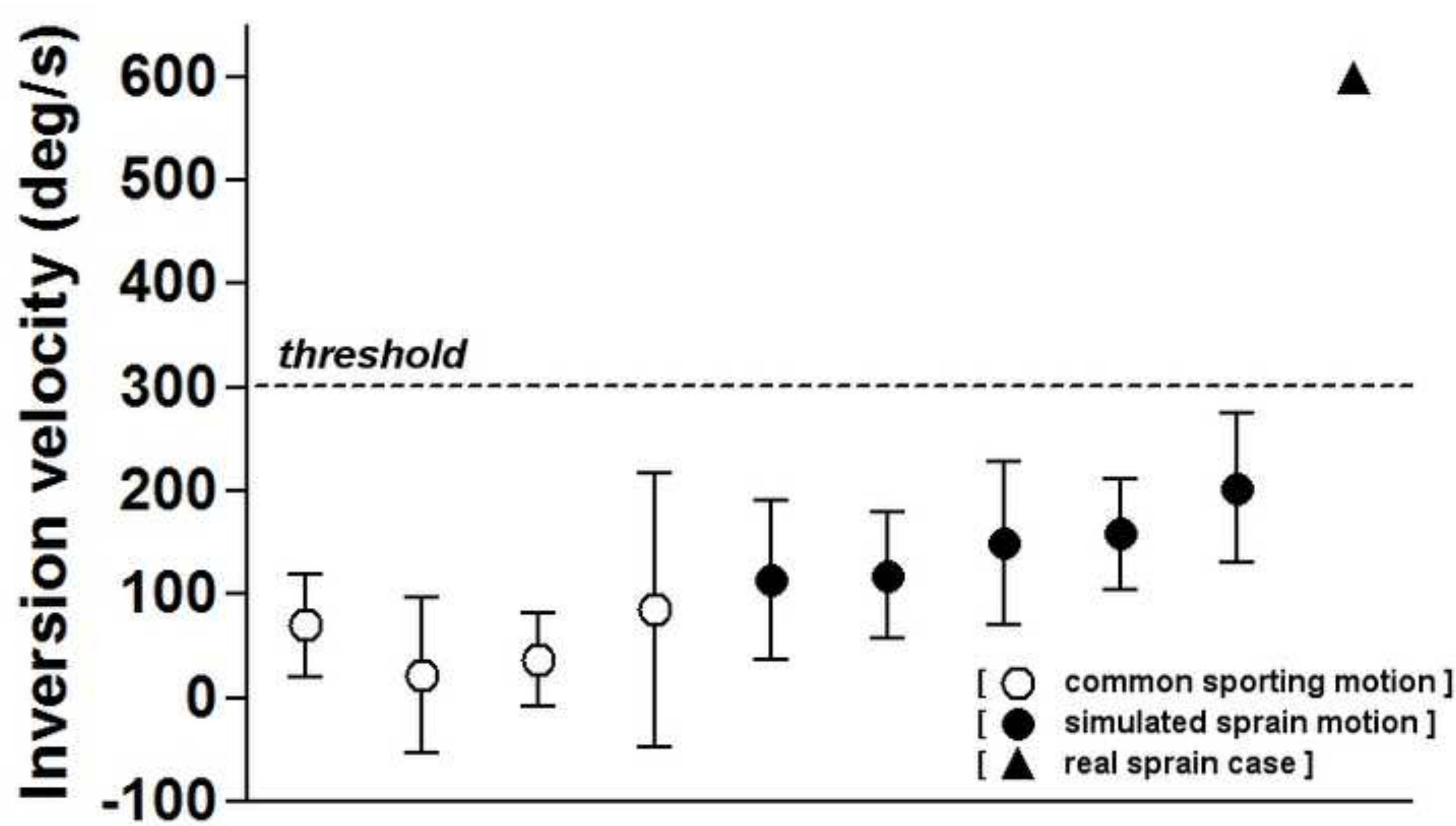


Figure 3
Click here to download high resolution image



*Conflict of Interest Statement

Conflict of interest

Dear Editor of Journal of Biomechanics,

REF: Submission of manuscript titled “Differentiation of ankle sprain motion and common sporting motion by ankle inversion velocity”.

The authors declare no financial and personal relationships with other people or organizations that could inappropriately influence this submitted work.

____

Daniel Tik-Pui FONG
Mar 11th, 2010.