THE USE OF UNI-AXIAL GYROSCOPE FOR MONITORING HEEL TILTING VELOCITY DURING SIMULATED ANKLE SUPINATION SPRAIN MOTIONS

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This study investigated the feasibility of using a uni-axial gyroscope to monitor the motion of foot segment. Five male subjects performed supination spraining motion simulated by a mechanical sprain simulator. A uni-axial gyroscope was attached on the shoe surface at the heel position of the right shoe to collect the heel tilting velocity. Optical motion analysis was also used to obtain heel tilting velocity as a standard. The intra class correlation and root mean square error of tilting velocity measured by the two methods are 0.70 – 0.99 and 8.21 – 37.11 deg/s, respectively. The result shows that it is possible to use only one uni-axial gyroscope for monitoring foot segment motion. This monitoring method can be contributed to the currently developing active protection “sprain-free shoe”.

KEYWORDS: motion sensor, ankle kinematic, ankle sprain

INTRODUCTION: Recently, our research group have been working on the development of innovative intelligent sprain free sport shoe for the prevention of ankle sprain injury (Chan, 2006). Before initiating active correction mechanism in case of an ankle sprain, the shoe system measures and monitors the ankle kinematic changes in order to recognize if it is approaching to a sprain injury. Accelerometer, gyroscopes and magnetic sensors can be used to monitor the ankle motion in a real time manner. Despite the small size, lightweight and generally low power of the sensors, it is still a very challenging task to assembly all these on the foot, lower leg and thighs of both limbs for daily use. Therefore, the number of sensors should be minimized and housed into the shoe such that it is suitable for the consumer product. Here we propose an idea of using one uni-axial gyroscope to measure heel titling velocity. Heel tilting is defined as the motion of the foot segment relative to the ground. It is difference from inversion motion, which relatives to the shank. Hence, at least two motion sensors are needed for the measurement of inversion motion. This study is to examine the validity of the gyroscope relative to the optical motion analysis system when using one gyroscope at heel cup to monitor the tilting angle of the foot segment. This can serves as a platform for the real time monitoring of ankle sprain injury risk of the “sprain-free shoe”.

METHOD: Five male subjects (age = 21.8 $\pm$ 1.48 year, height = 1.7 $\pm$ 0.03 m, body mass = 66.2 $\pm$ 7.19 kg) with healthy ankles were recruited from the athletic team of The Chinese University of Hong Kong. The study was approved by the university ethics committee. For each subject, 3 trials on 5 different simulated supination sprain motions were performed on the supination sprain simulator (Chan et al., 2008). By rotating the fall platform of the supination sprain simulator, different degrees of supination from inversion to plantarflexion can be simulated. (when the fall platform set at 0^o was puer inversion, at 23^o, 45^o and 67^o were supination and 90^o was pure plantarflexion). The different type of supination sprain motions allowed a wide range of data to be collected. A uni-axial gyroscope (Sengital Ltd., Hong Kong, China) which measured heel tilting velocity was attached on the shoe surface at the heel position of the right shoe to collect the heel tilting velocity at a sampling rate of 500Hz. The axis of the gyroscope was aligned to measure the foot segment inversion and eversion velocity. For the consistency of this alignment axis, all subjects wore the same shoe with the sensor attached throughout the study.

The heel tilting velocity was also obtained by an optical motion analysis system as a standard to validate the data obtained by gyroscope. Twelve reflective markers (5 mm in diameter) were attached to lateral fibula epicondyle, 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, either on the skin or shoe surface. Marker coordinates were recorded by an optical motion analysis system with 16 cameras (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 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). Foot tilting angle was defined as the angle between the LCS vertical axis and the normal of the foot transverse plane, and the foot tilting velocity is its change with respect to time. The data analysis was processed by a customized Matlab program.

RESULTS: Table 1 shows good agreement between the tilting velocity measured by gyroscope (gyro data) and optical motion analysis system (standard data). The average of intra class correlation was higher than 0.9, except in the case of pure plantarflexion (90^o). Root mean square error (RMSE) difference between the two methods was between 8.21 – 37.11 deg/s. Table 2 shows the peak magnitudes obtained by gyroscope and optical motion analysis system. The peak magnitudes of the gyro data were about 88 – 135% of that of the standard data except that in the case of plantarflexion. For the case of plantarflexion, the maximum difference was up to 200%. Figure 1 shows the pattern and the absolute error of the tilting velocity obtained by two methods of one selected trial in each supination angle. In general, the gyroscope data followed the pattern of the standard data well.

Table 1. Accuracy of the peak tilting velocity as represented by the intra class correlations (ICC) and the root mean square error (RMSE) in the unit of deg/s

Supination	0^o		23^o		45^o		67^o		90^o	
Angle	ICC	RMSE	ICC	RMSE	ICC	RMSE	ICC	RMSE	ICC	RMSE
Subject 1	0.81	24.59	0.99	9.29	0.96	11.76	0.94	14.60	0.89	13.03
Subject 2	0.97	37.11	0.93	9.63	0.97	10.66	0.83	11.27	0.74	11.32
Subject 3	0.88	18.75	0.95	16.37	0.99	10.59	0.94	12.17	0.79	13.37
Subject 4	0.97	18.30	0.94	13.40	0.98	10.47	0.97	8.21	0.70	21.13
Subject 5	0.95	13.51	0.99	24.55	0.96	11.04	0.87	20.36	0.81	28.46
Average	0.92	22.45	0.96	14.65	0.97	10.90	0.91	13.32	0.79	17.46
S.D.	0.07	9.09	0.03	6.25	0.01	0.52	0.06	4.55	0.07	7.22

Table 2. Peak magnitudes of tilting velocity obtained by gyroscope (gyro data) and optical motion analysis system (standard data) in the unit of deg/s

Supination Angle	0^o		23^o		45^o		67^o		90^o	
	Standard data	Gyro data	Standard data	Gyro data	Standard data	Gyro data	Standard data	Gyro data	Standard data	Gyro data
Subject 1	448.3	405.3	283.5	271.2	203.7	225.5	113.6	127.4	102.9	106.0
Subject 2	387.1	383.5	238.5	238.2	191.6	221.7	158.8	146.2	73.6	68.9
Subject 3	244.8	222.2	299.4	283.7	204.3	211.1	120.3	161.9	172.3	240.5
Subject 4	431.7	379.8	208.3	204.9	195.3	190.7	121.0	130.1	123.3	240.2
Subject 5	290.0	291.1	396.2	363.0	194.2	196.1	142.4	146.9	90.4	269.2

Average	306.4	336.4	285.2	272.2	197.8	209.0	131.2	142.5	112.5	185.0
S.D.	89.2	77.4	71.8	59.3	5.8	15.3	18.8	14.1	38.0	90.7

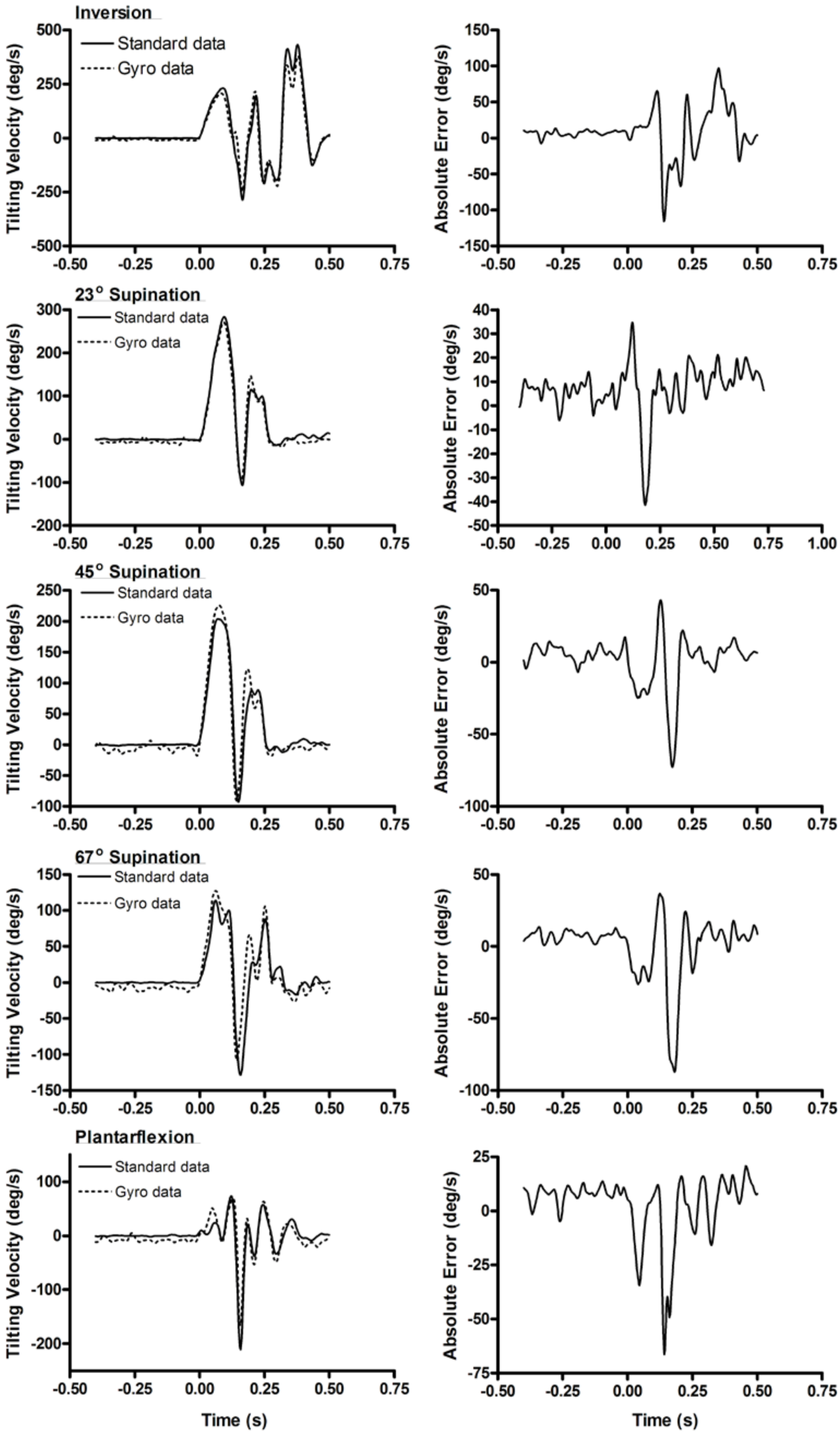

Figure 1. The pattern and the absolute error of the filtered tilting velocity obtained by gyroscope and optical motion analysis system of one selected trial in each supination angle.

DISCUSSION: In this study, the measurement of tilting velocity by a gyroscope was validated by an optical motion analysis system. The result shown that it have acceptable accuracy (ICC>0.9), except for the peak magnitudes of the tilting velocity in the case of plantarflexion (90^o), which with a relatively large variation. It should be noted that the value of the peak tilting velocity was not consistence between optical motion analysis and gyroscope. In some cases, the peak tilting velocity were higher with the gyroscope, in others they were lower. Such deviation may due to the variations in the distances between markers and also could be a result of camera noise, limited sight of markers, or vibrations of the marker (Ehara, 1997). Sensitivity and noise of the gyroscope is also sources of error. The limitations of this experiment include placing markers on shoe surface but not the foot and the use of sprain simulator but not the real motion. Simulated sprain motion was chosen in this study since we are developing a "sprain-free sport shoe" (Chan, 2006). We are seeking an inexpensive and simple way for real-time ankle sprain motion monitoring and detection. The present method only needs one gyroscope, thus is inexpensive and readily available to be implanted in a sport shoe. In the future, we will compare the foot tilting velocity data to the data collected from other common sporting motion, in order to establish a database to define the criteria for the identification of a hazardous ankle spraining motion.

CONCLUSION: This study showed the feasibility of using a gyroscope to monitor the foot segment tilting velocity. The device serves as a platform for a recently developed "sprain-free sport shoe" for real-time monitoring and detection of hazardous ankle spraining motion. Its advantage is being inexpensive and tiny, and could be implanted into sport shoe easily.

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