AN IN-SHOE ANKLE SUPINATION TORQUE MEASURING METHOD IN RUNNING

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This study presented an in-shoe ankle supination torque measuring method in running. One subject performed 56 valid steps during heel-toe walking and running in canvas shoe at different speeds (0.85-4.00m/s). Motion data, ground reaction force data and plantar pressure data were simultaneously recorded. Ankle joint torques in dorsiflexion / plantarflexion and inversion / eversion directions were obtained, and were trimmed from touchdown to takeoff. Pressure values at each of the 99 sensors were used to predict these two parameters by linear stepwise regression. Prediction models with 80%, 85%, 90% and 95% explained variance were constructed. A 9-sensor system is suggested for further development of an in-shoe ankle supination torque measuring device.

KEY WORDS: kinetics, joint moment.

INTRODUCTION: Epidemiology studies on sports injury generally showed that ankle is one of the most traumatized body sites, which accounts for 10-30% of all sports injuries. Most ankle injuries were sustained during running and jogging, racquet sports and ball games. About 80% of the ankle injuries are lateral ankle sprains which involve injury to the lateral ligament complex at ankle. It is often caused by sudden supination torque at ankle joint, which supinates the ankle excessively in a short time, overloads and damages the lateral ligaments at ankle before the peroneal muscles can react to produce compensating pronation torque. We aim to design an intelligent sprain-free sports shoe which can first detect the external force and foot motion, then estimate the supination torque and identify the spraining risk, and finally initiate protective action to stop further supination immediately to prevent spraining.
The first task is to measure the ankle supination torque during motion. Joint kinetics information is often obtained by employing inverse dynamics calculation with anthropometry, kinematics and kinetics data collected in laboratory. However in the proposed sprain-free sports shoe, the measuring device must be implanted in the shoe body. Recently, we established a method to estimate complete ground reaction forces and ankle joint torques from pressure insole data in walking and running (Fong et al, 2006). In this study, we further construct another model to better estimate the supination torque for the sensing system development in the proposed sprain-free sports shoe. As most ankle injuries were sustained in running, we aim to first establish the method to measure ankle supination torque in running.

METHODS: One male subject (age = 27 yr, height = 1.74m, mass = 68kg) performed a total of 58 trials with 56 valid steps (left: 28; right: 28) during heel-toe walking and running with canvas shoes at different speeds. A step was determined invalid if there were missing markers (1 trial), errors in pressure recording from insoles (1 trial), or with part of the foot landing out of the force plate (24 trials). The speeds were controlled by instructing the subject to walk and run with given rhythms (80, 120 and 160 bpm for walking; 120, 160 and 192 bpm for running) to achieve speeds of 0.85, 1.30 and 1.66m/s in walking and 2.25, 2.60 and 4.00m/s in running. Motion and ground reaction force data were recorded with an eight-camera VICON motion capture system and four AMTI force plates at 600Hz. Reflective markers were attached at anterior and posterior superior iliac spines, lateral femoral

condyles, lateral malleoli, 2nd metatarsal heads and calcaneus at both left and right sides. Four more stick-mounted markers with base plates were attached at left and right thighs and shanks. Plantar pressure data were simultaneously recorded at 100Hz with Novel Pedar pressure insoles (model W) inserted in subject's shoes.
Motion data were imported to Visual 3D software (C-Motion, USA) for calculating ankle joint torques. As supination is a combination of plantarflexion and inversion, the joint torques in dorsiflexion / plantarflexion and inversion / eversion directions were extracted. These two parameters were time-normalized in order to have data point in every 0.01s to match the sampling frequency of pressure data. The signs of these parameters were adjusted to make positive values mean torques in dorsiflexion and inversion directions. Every valid step was trimmed from touchdown to takeoff. Corresponding pressure values were exported and were used to predict the ankle joint torques separately by linear stepwise regression. Regression models with 80%, 85%, 90% and 95% explained variance (R2) were constructed for each of the two parameters. With the prediction models, the estimated ankle joint torques were calculated. Mean standard error of estimate (SEE) of each of the 26 running steps were reported to indicate the prediction accuracy of each model. T-test was conducted to examine any significant difference in SEE between established models.

RESULTS AND DISCUSSION: In estimating torque in dorsiflexion / plantarflexion direction, model with 80% and 85% explained variance were not applicable as the first model already reached a 90.3% explained variance. Therefore, a total of six prediction models were constructed (Table 1).

Table 1 – Prediction models for the two torque directions.

	Prediction model	**R2**	**SEE**
Torque	Tx90(n) = -4.472 - 0.439(P71)	.903	7.35 (4.23)
(DF/PF)	Tx95(n) = 1.193 + 6.221E-2(P71) - 0.231(P98) - 0.267(P74) - 0.354(P70)	.953	6.52 (3.31)
Torque	Ty80(n) = -1.845 - 0.315(P69) - 0.293(p31)	.822	5.29 (3.29)
(IN/EV)	Ty85(n) = -1.198 - 0.264(P69) - 0.333(p31) - 0.276(p89)	.869	5.61 (3.37)
	Ty90(n) = -3.741 - 0.640(P69) - 0.226(p31) - 0.254(p89) - 5.375E-2(p53) + 0.370(p70) - 0.118(p66)	.905	4.74 (2.83)
	Ty95(n) = -0.171 - 0.247(P69) - 6.408E-2(p89) - 0.165(p53) + 0.283(p70) - 2.828E-2(p66) - 0.289(p90) - 0.308(p91) - 0.126(p83) - 0.242(p92) + 0.154(p61) - 0.167(p14) + 0.247(p13) - 0.157(p99) + 0.160(p96) - 0.180(p65) - 0.181(p78) - 0.220(p55) + 0.763(p41) - 0.378(p20) + 0.164(p85)	.951	3.96 (2.56)

(* Unit: torque in Nm. PX is the value of pressure in kPa of the pressure sensor number X.)

The locations of the sensors required in each model were shown in Figure 1. Two combined models which added up the Tx95(n) model with either Ty95(n) and Ty90(n) model were established, having 23 and 9 sensors respectively. From the Tx90(n), Tx95(n), Ty90(n) and y95(n) models, the real data and the predicted data of one slow, one moderate and one fast running trial were shown in Figure 2. In general, both model at each speed and parameter showed good estimation. T-test showed that models with 95% explained variance showed better estimation as indicated by a significant smaller SEE.
Therefore we suggested the model Tx95(n)+Ty90(n) to be employed in further developing the in-shoe supination torque measuring system for running.

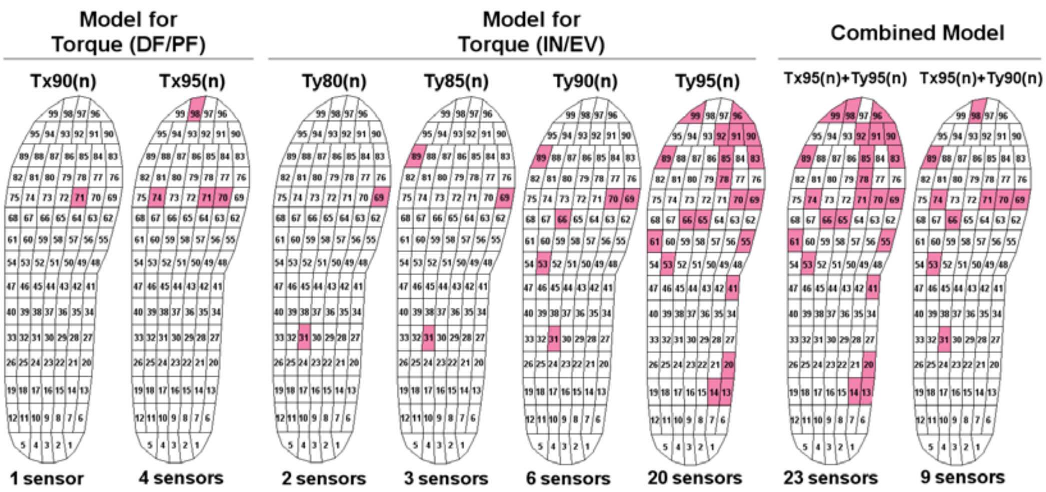

Figure 1 – Locations of the sensors in the prediction models (left insole).

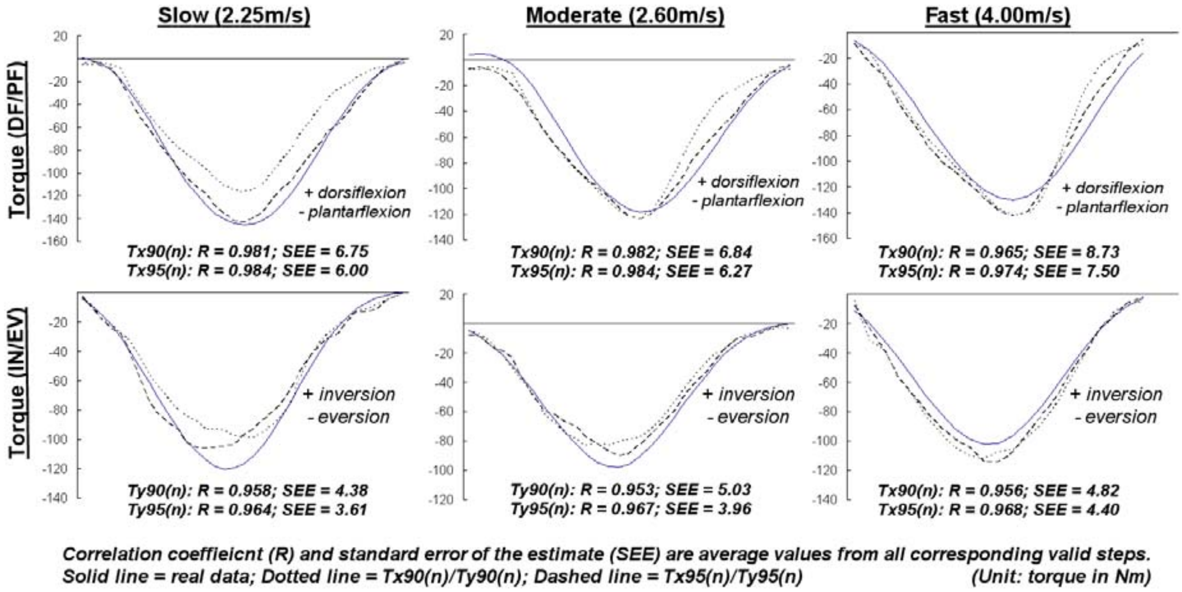

Figure 2 – Real and predicted data in slow, moderate and fast running.

This is the first of a series of studies. In a lateral ankle sprain, there is very often a large medio-lateral shear force and only lateral edge contact between the shoe and the ground. Therefore the prediction method in this study is only applicable in safe running but not in a situation nearly to have a sprain. Future studies will extend the current study to other motion, such as cutting, pivoting, landing, and the most important, a simulated spraining motion. Moreover, more subjects will be investigated to report the generalizability of the method if any.

CONCLUSION: This study presented a method using pressure sensor data to estimate ankle supination torque during running. A 9-sensor system is suggested for developing the in-shoe supination torque measuring device for safe heel-toe walking and running.

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