Research article

THE INFLUENCE OF A FOOT ORTHOTIC ON LOWER EXTREMITY TRANSVERSE PLANE KINEMATICS IN COLLEGIATE FEMALE ATHLETES WITH PES PLANUS

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ABSTRACT

Non-contact anterior cruciate ligament (ACL) injuries in female athletes remain prevalent. Athletes with excessive foot pronation have been identified to be at greater risk for non-contact ACL injury. Excessive foot pronation has been linked to increased medial tibial rotation. Increased medial tibial rotation heightens ACL strain and has been observed at or near the time of ACL injury. Foot orthotics have been shown to decrease medial tibial rotation during walking and running tasks. The effect of a foot orthotic on activities that simulate a non-contact ACL injury mechanism (i.e. landing) however is unknown. Therefore, the objective of this study was to determine whether a foot orthotic was capable of altering transverse plane lower extremity kinematics in female athletes during landing. Twenty uninjured collegiate female athletes participating in the sports of basketball, soccer or volleyball with pes planus volunteered. Utilizing a repeated measures counterbalanced design, subjects completed two landing tasks with and without a foot orthotic using standardized footwear. The prefabricated orthotic had a rigid shell and a 6° extrinsic rear-foot varus post. Dependent measures included initial contact angle, peak angle, excursion and time to peak angle for both the tibia and femur. Statistical analysis suggested that the selected foot orthosis had little influence over lower extremity transverse plane kinematics. Several factors including: the limitation of a static measure to predict dynamic movement, inter-subject variability and the physical characteristics of the orthotic device likely account for the results. Future research should examine the influence of different types of foot orthotics not only on lower extremity kinematics but also tibiofemoral kinetics.

KEY WORDS: ACL, hyperpronation, intervention, navicular drop, pes planus.

INTRODUCTION

Despite intensive research efforts over the last decade, female athletes continue to experience non-contact anterior cruciate ligament (ACL) injuries at a greater frequency than their male counterparts in the comparable sports of basketball, soccer and volleyball (Agel et al., 2005). Perhaps one reason female ACL injuries have persisted is that the bulk of research over the last decade has primarily focused on identifying sex differences during functional activities (Boden et al., 2000; Ford et al., 2003; Lephart et al., 2002; Malnizak et al., 2001; Myer et al., 2005; Padua et al., 2005; Shultz et al., 2001; Uhorchak et al., 2003; Wojtys et al., 1998). Little work, however, has examined the

effectiveness of intervention programs (Hewett et al., 1999; Heidt et al, 2000; Mandelbaum et al., 2005; Myklebust et al., 2003; Petersen et al., 2005; Soderman et al., 2000).

Intervention programs that have been documented to reduce injury (Hewett et al., 1999; Mandelbaum et al., 2005; Myklebust et al., 2003; Petersen et al., 2005) have incorporated some level of: 1) instruction related to technique, 2) plyometric, 3) balance or 4) strength training exercise. While these programs have demonstrated an acute reduction in injury incidence, it remains unclear whether injury rates remain suppressed or return to pre-intervention levels over the long term. Arguably, after cessation of the intervention, without continued training and conditioning, key neuromuscular physiologic characteristics (i.e. strength, muscle response time), which ultimately may have been responsible for the findings, will return to or near baseline levels (Hakkinen et al., 2000). The ramifications of this 'detraining' could potentially negate the protective effect of the program. To effectively reduce injury rates over the long term, the effects of an intervention should not only be easily sustainable or permanent but also focused on modifiable risk factors.

A modifiable risk factor that has been identified, though received little attention, is that of excessive foot pronation (Hertel et al., 2004). Biomechanically, increased foot pronation has been associated with increased medial tibial rotation (Coplan, 1989). Given that medial rotation of the tibia on the femur increases ACL strain (Markolf et al., 1990), it is reasonable to assume that increased medial tibial rotation further increases ACL strain thereby heightening injury risk. Supporting this logic, several investigators have observed increased medial tibial rotation at or near the time of injury (McNair and Marshall, 1990; Olsen et al., 2004). Others have reported an increased incidence of non-contact ACL injury in athletes with pes planus (Beckett et al., 1992; Hertel et al., 2004; Loudon et al., 1996; Woodford-Rogers et al., 1994).

Reducing foot pronation and coupled medial tibial rotation would, therefore, seem to be desired. In fact, it is possible to reduce foot pronation and medial tibial rotation with a foot orthotic (McPoil and Cornwall, 2000; Mundermann et al., 2003). Recent work shows that a medially posted foot orthotic alters lower extremity kinematics during running (Mundermann et al., 2003) and walking (McPoil and Cornwall, 2000). Specifically, a medially posted foot orthotic demonstrated a decrease in both the rate and degree of medial tibial rotation during walking (McPoil and Cornwall, 2000). Furthermore, given that a foot orthotic

provides a mechanical barrier to pronation, the effect of a foot orthotic on lower extremity kinematic patterns should be permanent since the intervention effect is maintained. Whether a medially posted foot orthotic is capable of altering lower extremity kinematics during activities that are more representative of a mechanism that simulates non-contact ACL injury (i.e. landing) however is unknown. Therefore, the purpose of our study was to examine the effect of a medially posted foot orthotic on transverse plane lower extremity kinematics in female athletes with pes planus during landing. We hypothesized that the foot orthotic would decrease both the rate and excursion of tibial rotation during landing.

METHODS

Subjects
An a-priori power analysis using results from a pilot study (Houglum and Carcia, 2004) conducted in our laboratory was performed. Results from this analysis suggested that inclusion of 20 subjects would yield a power of greater than 80%. To be included in the study, subjects had to be a university athlete participating in the sports of basketball, soccer or volleyball, have a navicular drop score of at least 8 millimeters (mm) and be able to perform simple landing tasks without pain. Subjects were excluded if they had a history of prior surgery on the dominant lower extremity or if they reported acute injury to the dominant lower extremity within the last six months. An acute injury was defined as one that necessitated the use of an assistive device for greater than a day. Twenty females (height = 1.69 ± 0.10 m; weight = 69.7 ± 9.7 kg; age = 20.1 ± 1.0 yrs) volunteered to participate. Before participation, all subjects read and signed an informed consent form which was approved by the University's Institutional Review Board.

Procedures
All procedures were completed in the Kristen McMaster Motion Analysis Laboratory in a single forty-five minute session. After recording height and weight, lower extremity dominance was identified using a self-selection procedure. Each subject was asked to perform a single leg landing from a 20cm high wooden box. The lower extremity the subject chose to land on for two out of three trials was defined as the dominant lower extremity. All subsequent testing was performed using this extremity. Navicular drop was then measured using a modified Brody technique (Brody, 1982). Specifically, the subject stood in single leg stance adjacent to an examination table. She placed a hand

lightly on the table top to facilitate a steady, static posture. Next, the examiner marked the skin over the most prominent aspect of the navicular with a pen. Once instructed, the subject supinated and pronated their foot while the examiner palpated the medial and lateral aspects of the talar head between his thumb and index finger. When the medial and lateral aspects of the talar head were congruent, the subject was asked to actively hold this position. The distance from the navicular mark to the floor was then measured in millimeters with a clear plastic ruler. The subject was then instructed to relax their foot and the distance between the pen mark and the floor was once again measured. Navicular drop was defined as the difference between the two measures. This process was repeated three times and an average of the scores was used for data analysis. All navicular drop measures were performed by the primary investigator (CRC) who had established a day to day intra-rater reliability ($ICC_{2,1}$) of 0.90 ± 0.5 mm before the study's commencement.
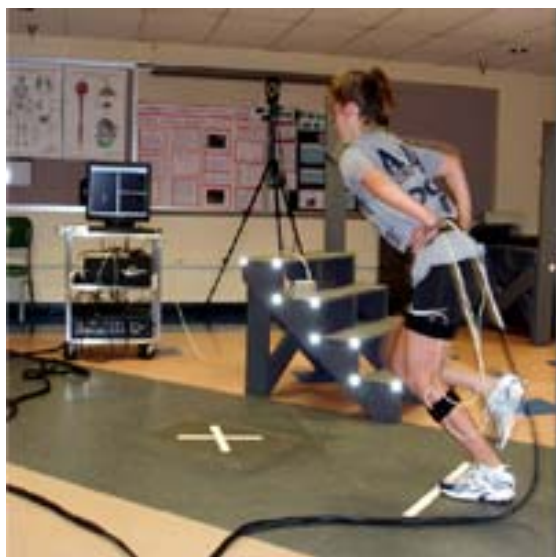

Figure 1. Hop task.

Subjects then performed two to three practice trials of the selected tasks. A single-leg forward hop was performed from a distance equal to 45% of the subject's height onto the center of a force plate (Bertec; Columbus, OH) (Figure 1). For the second task, subjects performed a drop landing onto the center of the force plate from a 20cm-high wooden box positioned 11cm from the edge of the force plate. The hop and land activities were chosen as they are reasonable laboratory simulations of non-contact ACL injury mechanisms. Additionally, similar methodology has been used by other investigators (Lephart et al., 2002) thereby facilitating the comparison of our findings to published work. To minimize the influence of upper extremity position on lower extremity kinematics,

the subject's hands were placed on their iliac crests for all trials. Neither the position of the subject's head nor direction in which the subject was looking during the tasks was standardized. Once the subject and principal investigator were comfortable with the subject's performance during the practice trials, the subject was prepared for kinematic motion analysis. Three electromagnetic sensors (Ascension Technology; Burlington, VT) coupled with The Motion Monitor Software (Innovative Sports Training; Chicago, IL) measured three-dimensional lower extremity kinematics while the force plate identified ground contact. Prior work has established the reliability of the motion analysis system (Bull et al., 1998; McQuade et al., 2002; Milne et al., 1996). The motion analysis system and force plate were synchronized and collected data at 100 and 1000 Hertz respectively. Sensors were placed over the L5-S1 junction, mid-lateral thigh and laterally just distal to the fibular head using prefabricated neoprene cuffs. To prevent undesired movement of the sensors, each neoprene cuff was further secured by circumferentially wrapping three-inch pre-wrap (Mueller®; Praire Du Sac, WI) followed by 1½ inch athletic tape (Johnson & Johnson; New Brunswick, NJ) over each cuff. The proximal and distal aspects of the segments were then digitized using standard procedures with the subject standing in the anatomical position.

Using a repeated measures counterbalanced design, subjects completed three trials of the hopping and landing task with and without an orthotic device (Interpod®; St Kilda, Australia) wearing standardized footwear (New Balance; Boston, MA). Approximately 15 seconds elapsed between trials. A repeated measures design has been recommended by prior investigators to account for the between subject variability associated with transverse tibial rotation (McPoil and Cornwall, 2000). Additionally, the day to day reliability of tibial rotation excursion (ICC = 0.82) and time to peak angle (ICC = 0.97) during a landing activity have been reported (Stevens and Schmitz, 2003) using identical hardware and software. The prefabricated foot orthotic was rigid and manufactured with an extrinsic 6° rear-foot medial (varus) post (Figure 2). Prefabricated orthoses are less expensive than custom orthoses, are readily available over the counter and have been shown to be just as effective as other types of orthoses for controlling tibial rotation during functional tasks (Brown et al., 1995; McPoil and Cornwall, 2000). Furthermore, a rear-foot varus post of 6° is not only a common clinical prescription, but with pilot testing (Houglum and Carcia, 2004) it was capable of limiting medial tibial rotation during forward

Table 1. Navicular Drop descriptive statistics by sport. Data are means (±SD) [range].

	Basketball (n = 3)	Soccer (n = 11)	Volleyball (n = 6)	Mean
Navicular Drop (mm)	10.4 (1.3) [9.6 – 12.0]	9.8 (3.3) [8.0 – 19.3]	8.9 (.7) [8.0 – 10.0]	9.6 (2.5)

hopping in a convenience sample of female subjects. The selected sneaker was a cross-trainer that had neither a supination nor pronation bias.

Figure 2. Prefabricated orthotic (Interpod®; St Kilda, AU).

Dependent variables included initial contact angle, peak angle, excursion and time-to-peak angle for both the tibia and femur. Excursion was defined as the difference between peak and initial contact joint angles for each segment. Time-to-peak angle was the time in milliseconds it took for the respective segment to rotate from initial contact to peak angle. Initial contact was defined as the time at which the vertical ground reaction force exceeded 50 Newtons.

Statistical analysis
A mean of three trials for both tasks (hop and land) and each condition (with and without orthotic) was used for data analysis. A separate paired t-test was used to determine the effect of the orthotic on the dependent variables for the hop and land tasks. Alpha levels for all analyses were set a-priori at $p < 0.05$.

RESULTS

Descriptive statistics by sport for navicular drop are provided in Table 1. Means and standard deviations for kinematic data for each task with and without the orthotic device are detailed in Tables 2 and 3. Composite tracings of each task and condition are represented in Figures 3, 4, 5 and 6.

DISCUSSION

The primary finding of our study was that the prefabricated foot orthotic did not alter lower extremity transverse plane kinematics in female athletes with large navicular drop scores during either the hop or the land task. Several reasons, including the limitation of a static measure to predict dynamic movement, large inter-subject variability, as well as the characteristics of the orthotic likely account for the findings.

Static measure
Creating a link between static, clinical anatomical measures and an increased injury incidence has been the thrust of several studies (Beckett et al., 1992; Hertel et al., 2004; Loudon et al., 1996; Woodford-Rogers et al., 1994). A link between certain static measures (single or multiple), which are different from established norms, and increased injury risk is an appealing model to both investigators and clinicians. A model of this nature provides a means for clinicians to assess an athlete's injury risk via pre-participation screening. Once an athlete is identified as having a greater injury risk, specific intervention programs may then be prescribed and implemented. Ultimately, it is the intent of this process to reduce injury frequency. Creating a link between static anatomical measures and injury incidence, however, neglects the influence of the

Table 2. Hop task statistics. A negative sign (-) indicates the excursion was in a medial direction. Data are means (±SD).

	Tibia			Femur		
	No Orthotic	Orthotic	*P*	No Orthotic	Orthotic	*P*
Initial Contact	2.24 (4.70)	3.15 (5.00)	.03	.84 (4.80)	1.11 (4.50)	.33
Peak Angle	2.75 (4.90)	3.08 (4.60)	.39	3.14 (5.30)	2.76 (5.50)	.31
Excursion (°)	.51 (4.10)	-.07 (4.50)	.16	2.29 (1.80)	1.66 (2.50)	.18
Time to Peak (ms)	133.5 (62.6)	134.0 (58.4)	.97	82.3 (48.7)	81.3 (50.50)	.93

Table 3. Land task statistics. A negative sign (-) indicates the excursion was in a medial direction. Data are means (±SD).

	Tibia			Femur		
	No Orthotic	**Orthotic**	***P***	**No Orthotic**	**Orthotic**	***P***
Initial Contact	-.40 (4.50)	.39 (5.10)	.06	-4.53 (4.20)	-4.37 (4.4)	.64
Peak Angle	3.11 (4.30)	4.03 (5.80)	.05	.59 (5.90)	.64 (5.4)	.91
Excursion (°)	3.52 (4.70)	3.64 (4.80)	.78	5.13 (3.50)	5.01 (3.20)	.74
Time to Peak (ms)	138.5 (67.3)	144.1 (59.30)	.71	137.5 (54.4)	127.1 (52.3)	.27

neuromuscular system. As clinicians, we are well aware that a positive static test which suggests mechanical instability does not necessarily correlate with functional instability. Exemplifying this, Eastlack et al demonstrated that a sub-group of ACL deficient subjects with increased anterior tibial translation was not related to functional knee instability (Eastlack et al., 1999). The authors note that with sufficient neuromuscular control despite a deficiency in the static stabilizers, it is possible to keep the joint stable during functional activity. Similarly, it is plausible that subjects with large navicular drop scores and adequate neuromuscular control do not exhibit increased foot pronation and tibial rotation. Without excessive motion, a foot orthotic which is designed to block excessive pronation and subsequent segment rotation is not warranted and therefore unlikely to produce an effect. As we did not measure dynamic foot pronation or any aspect of neuromuscular control, the validity of this hypothesis is unknown. Our pilot work (Houglum and Carcia, 2004), however,

indirectly lends credence to this hypothesis. Tibial rotation excursion during an identical hopping task was 3.5° greater in the female subjects of our pilot study when compared to the athletes in this study. Given that the activity level of the females in the pilot study was less than that of the athletes in this study, it is likely they did not possess the level of neuromuscular control compared to the present competitive, athletic population. These findings suggest that there may be an interaction between neuromuscular control and lower extremity kinematic patterns. Further study is necessary to clarify the influence of neuromuscular control on foot pronation and lower extremity rotation in subjects with large navicular drop scores.

Inter-subject variability
As demonstrated by the large standard deviations, there was substantial variability observed among the participants for all dependent measures during both tasks.
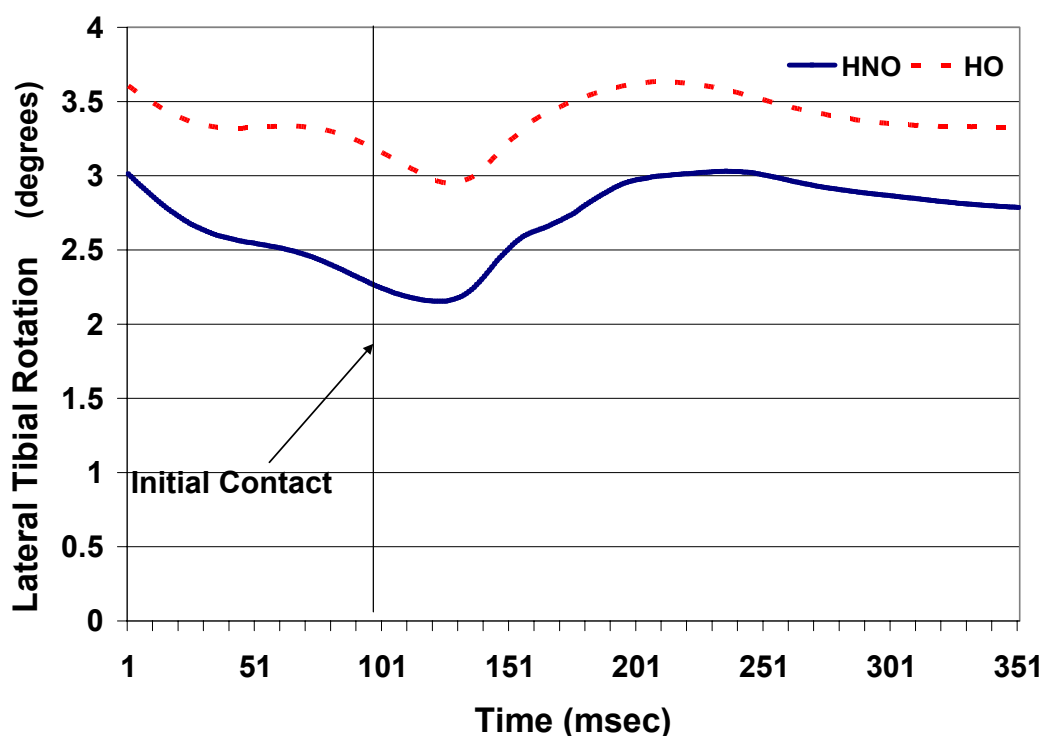

Figure 3. Hop task – Tibia. HNO = Hop no orthotic; HO = Hop Orthotic. Standard deviations are not illustrated for clarity.
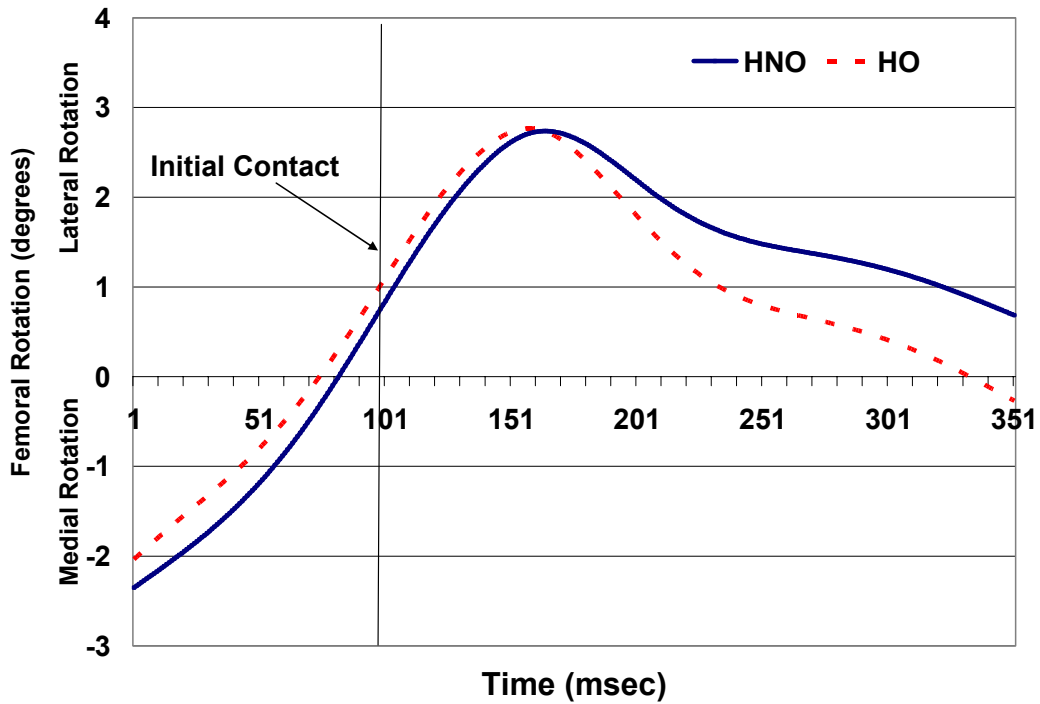
Figure 4. Hop task – Femur. HNO = Hop no orthotic; HO = Hop Orthotic. Standard deviations are not illustrated for clarity.

This variability is similar in magnitude when compared to the transverse plane values (both excursion and time to peak) reported by Lephart et al. (2002) using similar procedures in a comparable population. Likewise, the standard deviations were within a degree of the tibial transverse plane values reported by McPoil and Cornwall (2000) during gait.

The variability may be partially explained by the fact that human movement is diverse. Exemplifying this, during the hop task after ground contact, nine subjects demonstrated a medial rotation kinematic pattern of the tibia while the remaining 11 subjects demonstrated a lateral rotation kinematic pattern. Unlike tibial kinematics and despite large standard
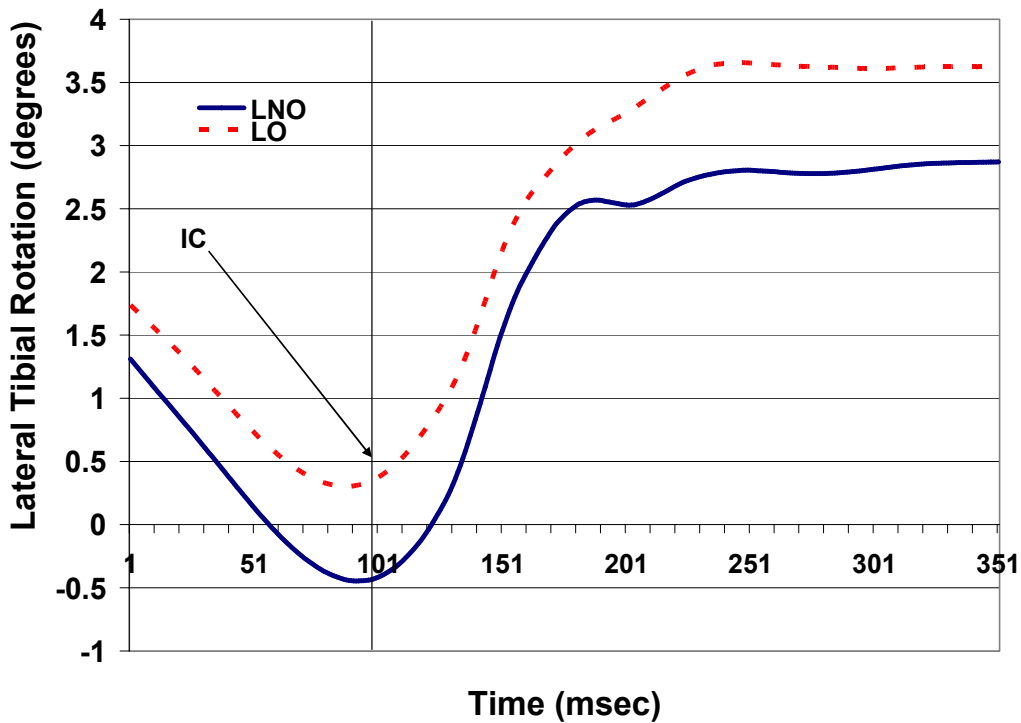

Figure 5. Land task – Tibia. LNO = Land no orthotic; LO = Land Orthotic. Standard deviations are not illustrated for clarity.
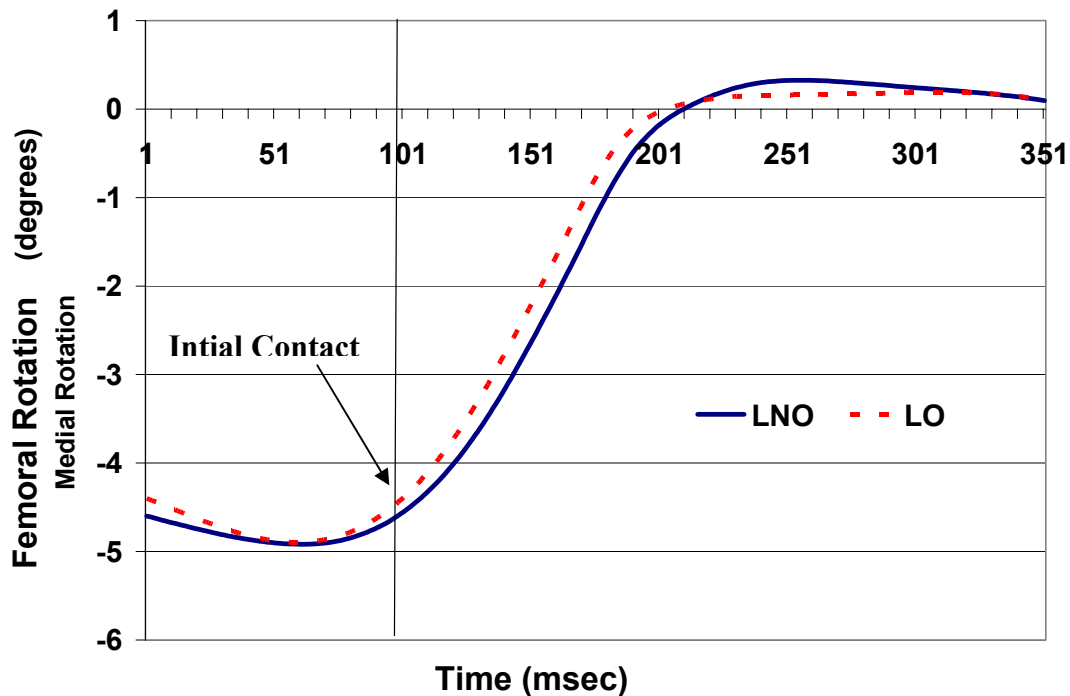
Figure 6. Land task – Femur. LNO = Land no orthotic; LO = Land Orthotic. Standard deviations are not illustrated for clarity.

deviations, femoral movement occurred in a similar fashion among all subjects. In summary, our work reinforces substantial variability is present in transverse plane lower extremity kinematics during functional activities. This variability makes differences between test conditions challenging to identify.

Foot orthosis
While the variability in the data contributed to an inability to identify significant differences between test conditions, mean differences, regardless of the standard deviations, were small (<1° for excursion and <1 ms for time to peak). While no studies were identified that compared lower extremity kinematics between no orthotic and orthotic conditions during landing tasks, evidence regarding the ability of an orthotic device to influence lower extremity kinematics has been reported during walking (Nester et al., 2001; McPoil & Cornwall, 2000) and running (Mundermann et al., 2003). The lack of differences between conditions in this study may have been influenced by the physical characteristics of the foot orthotic. Baitch et al. (1991) reported for every 5° of rear-foot posting only a 1° change in static calcaneal position is evident. These findings imply that it is likely that even a greater amount of posting would have been necessary to alter the kinematics of the more proximal segments. Our pilot work (Houglum and Carcia, 2004), however, indicated the chosen orthotic did have the capability of limiting tibial

rotation during the hopping task. As previously mentioned, the root of this phenomenon may be related to neuromuscular control. Interestingly, without solicitation, most athletes reported that they felt more comfortable and 'controlled' when using the orthotic during the tasks. It is possible that the orthotic device altered some other variable (i.e. tibiofemoral moments, time to stabilization) not quantified in this study. Beyond the size of the extrinsic posts, research suggests that molding methods are more dominant on altering lower extremity kinematics and kinetics when compared to traditional posting methods alone (Mundermann et al., 2003). Clearly, additional research is warranted to explore the effect of different types of orthotic devices on lower extremity kinematics during landing tasks.

Limitations
Our study, like all research studies, had several limitations that should be acknowledged. Subjects were tested within minutes after the orthotic device was placed inside the sneaker. Whether a greater period of time between introducing the orthotic device into the sneaker and testing would have altered the manner in which the subject executed the tasks is unknown. Further, we did not formally track the number of subjects who wore foot orthoses on a regular basis for daily or sport activities. Information in this regard would have provided insight as to whether subjects had experienced symptoms at some juncture secondary to their foot posture and

function. While the mean navicular drop of our healthy subjects (9.6mm) was greater than the navicular drop scores of the ACL injured subjects reported by Hertel et al (2004) (8.4mm) and Woodford-Rogers et al (1994) (5.0mm) it was less than the values reported by Beckett et al. (1992) (12.7mm). Additionally, our navicular drop scores were less than the 'abnormal threshold' suggested by Mueller et al. (1993) (10mm) and Brody (1982) (15mm). If anything, we suspect methodological differences may have underestimated the navicular drop scores of our subjects. Specifically, the first measure of navicular height using the technique suggested by Brody (1982) is quantified with the subject seated. Our first (and second) measure of navicular height was taken in a weight bearing posture. It is likely that body weight alone reduced the height of the navicular thereby making the difference score smaller than what we would have ascertained had the first measure been taken in sitting. Research is on-going to address this issue. Lastly and as previously mentioned, we did not measure dynamic foot pronation and, therefore, are uncertain as to whether our subjects actually did display excessive pronation during the land and hop tasks. Future studies should investigate the relationship between dynamic foot pronation and lower extremity transverse plane rotation with and without an orthotic device during landing tasks in female athletes.

CONCLUSION

A prefabricated , rigid foot orthosis with a six-degree extrinsic varus post does not alter the quantity or rate of transverse plane lower extremity kinematics in female athletes with navicular drop scores greater than or equal to eight millimeters when performing a forward hop or landing task in the laboratory. The findings suggest that other factors (i.e. neuromuscular control) may be responsible for controlling tibial rotation in female athletes with large navicular drop scores during landing activities. Future study should assess various aspects of this hypothesis to determine its validity. Additionally, before firm conclusions regarding the effectiveness of orthotic intervention on transverse plane kinematics in this population can be drawn, this line of study should continue to be pursued. An orthotic device which has the capability of favorably altering lower extremity movement and or neuromuscular recruitment patterns has great promise for reducing the incidence of non-contact ACL injury in female athletes. This type of intervention would be cost-effective and the impact should be immediate. Future work should examine the effectiveness of different types of orthoses (i.e inverted), as well as consider other dependent measures such as tibiofemoral kinetics and neuromuscular activity.

REFERENCES

Agel, J., Arendt, E.A. and Bershadsky, B. (2005) Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *American Journal of Sports Medicine* **33**, 524-530.

Baitch, S.P., Blake, R.L., Finegan, P.L. and Senatore J. (1991) Biomechanical analysis of running with a 25° inverted orthotic devices. *Journal of the American Podiatric Medical Association* **81**, 647-652.

Beckett, M.E., Massie, D.L., Bowers, K.D. and Stoll D.A. (1992) Incidence of hyperpronation in the ACL injured knee: a clinical perspective. *Journal of Athletic Training* **27**, 58-62.

Boden, B.P., Dean, G.S., Feagin, J.A. and Garrett, W.E., Jr. (2000) Mechanisms of anterior cruciate ligament injury. *Orthopedics* **23**, 573-578.

Brody, D.M. (1982) Techniques in the evaluation and treatment of the injured runner. *Orthopaedic Clinics of North America* **13**, 541-558.

Brown, G.P., Donatelli, R., Catlin, P.A. and Wooden, M.J. (1995) The effect of two types of foot orthoses on rearfoot mechanics. *Journal of Orthopaedic & Sports Physical Therapy* **21**, 258-267.

Bull, A.M.J., Berkshire, F.H. and Amis, A.A. (1998) Accuracy of an electromagnetic measurement device and application to the measurement and description of knee joint motion. *Proceedings Institution of Mechanical Engineers* **212**, 347-355.

Coplan, J.A. (1989) Rotational motion of the knee: a comparison of normal and pronating subjects. *Journal of Orthopaedic & Sports Physical Therapy* **10**, 366-369.

Eastlack, M.E., Axe, M.J. and Snyder-Mackler L. (1999) Laxity, instability and functional outcome after ACL injury: copers versus noncopers. *Medicine & Science in Sports & Exercise* **31**, 210–215.

Ford K.R., Myer, G.D. and Hewett, T.E. (2003) Valgus knee motion during landing in high school female and male basketball players. *Medicine & Science in Sports & Exercise* **35**, 1745–1750.

Hakkinen, K., Alen, M., Kallinen, M., Newton, R.U. and Kraemer W.J. (2000) Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *European Journal of Applied Physiology* **83**, 51-62.

Heidt, R.S., Jr., Sweeterman, L.M., Carlonas, R.L., Traub, J.A. and Tekulve, F.X. (2000) Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine* **28**, 659–662.

Hertel, J.N., Dorfman J.H. and Braham, R.A.(2004) Lower extremity malalignments and anterior

cruciate ligament injury history. *Journal of Sports Science and Medicine* **3**, 220-225.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. and Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes – a prospective study. *American Journal of Sports Medicine* **27**,699-706.

Houglum, P.A. and Carcia, C.R. (2004) Prefabricated foot orthotics decrease internal tibial rotation during hopping in females. *Journal of Athletic Training* **39**, S-29.

Lephart, S.M., Ferris, C.M., Riemann, B.L., Myers, J.B. and Fu, F.H. (2002) Gender differences in strength and lower extremity kinematics during landing. *Clinical Orthopaedics and Related Research* **401,** 162–169.

Loudon, J.K., Jenkins, W. and Loudon, K.L. (1996) The relationship between static posture and ACL injury in female athletes. *Journal of Orthopaedic & Sports Physical Therapy* **24**, 91-97.

Malnizak, R.A., Colby, S.M., Kirkendall, D.T., Yu, B. and Garrett, W.E. (2001) A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics* **16**, 438–445.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. and Garrett W, Jr. (2005) Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: two-year follow up. *American Journal of Sports Medicine* **33**,1003 – 1010.

Markolf, K.L., Gorek, J.F., Kabo, M. and Shapiro, S. (1990) Direct measurement of resultant forces in the anterior cruciate ligament. *Journal of Bone and Joint Surgery* **72A**, 557–567.

McNair, P.J. and Marshall, R.N. (1990) Important features associated with acute anterior cruciate ligament injury. *New Zealand Medical Journal* **103**, 537-539.

McPoil, T.G. and Cornwall, M.W. (2000) The effect of foot orthoses on transverse tibial rotation during walking. *Journal of the American Podiatric Medical Association* **90**, 2-11.

McQuade, K.J., Finley, M.A., Harris-Love, M. and McCombe-Walker, S. (2002). Dynamic error analysis of ascension's flock of birds electromagnetic tracking device using a pendulum model. *Journal of Applied Biomechanics* **18**, 171-179.

Milne A.D., Chess, D.G., Johnson, J.A. and King, G.J.W. (1996) Accuracy of an electromagnetic tracking device: a study of the optimal operating range and metal interference. *Journal of Biomechanics* **29**, 791-793.

Mueller, M.J., Host, J.V. and Norton B.J. (1993) Navicular drop as a composite measure of excessive pronation. *Journal of the American Podiatric Medical Association* **83**, 198-202.

Mundermann, A., Nigg, B.M., Humble, R.N. and Stefanyshyn, D.J. (2003) Foot orthotics affect lower extremity kinematics and kinetics during running. *Clinical Biomechanics* **18**, 254-262.

Myer, G.D., Ford, K.R. and Hewett, T.E. (2005) The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *Journal of Electromyography and Kinesiology* **15**, 181–189.

Myklebust, G., Engebretsen, L., Braekken, I.H., Skolberg, A., Olsen, O.E. and Bahr, R. (2003) Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clinical Journal of Sport Medicine* **13**, 71–78.

Nester, C. J., Hutchins, S. and Bowker, P. (2001) Effect of foot orthoses on rearfoot complex kinematics during walking gait. *Foot & Ankle International* **22**, 133-9.

Olsen, O-E, Myklebust, G., Engebretsen, L. and Bahr R. (2004) Injury mechanisms for anterior cruciate ligament injuries in team handball – a systematic video analysis. *American Journal of Sports Medicine* **32,** 1002–1012.

Padua, D.A., Carcia, C.R., Arnold, B.L. and Granata, K.P. (2005) Gender differences in leg stiffness and stiffness recruitment strategy during two-legged hopping. *Journal of Motor Behavior* **37**, 111-125.

Petersen, W., Braun, C., Bock, W., Schmidt, K., Weimann, A., Drescher W., Eiling E., Stange, R., Fuchs, T., Hedderich, J. and Zantop, T. (2005) A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Archives of Orthopaedic & Trauma Surgery* **125**, 614-21.

Shultz, S.J., Perrin, D.H., Adams, M., Arnold, B.L., Gansneder B.M.and Granata, K.P. (2001) Neuromuscular response characteristics in men and women after knee perturbation in single-leg, weight-bearing stance. *Journal of Athletic Training* **36,** 37-43.

Soderman, K., Werner, S., Pietila, T., Engstrom, B. and Alfredson, H. (2000) Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surgery, Sports Traumatology, Arthroscopy* **8**,356–363.

Stevens S.W. and Schmitz, R.J. (2003). Kinematic and kinetic reliability during landings from a rotating jump. *Journal of Athletic Training* **38**, S-23.

Uhorchak, J.M., Scoville, C.R., Williams, G.N., Arciero, R.A., St Pierre, P. and Taylor DC. (2003) Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *American Journal of Sports Medicine* **31,** 831-842.

Wojtys,E.M., Huston, L.J., Lindenfeld, T.N., Hewett, T.E. and Greenfield, M.L. (1998) Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. *American Journal of Sports Medicine* **26,** 614-619.

Woodford-Rogers, B., Cyphert, L. and Denegar, C.R. (1994) Risk factors for anterior cruciate ligament

injury in high school and college athletes. *Journal of Athletic Training* **29**, 343-346.

KEY POINTS

- Lower extremity transverse plane kinematics in female athletes during a landing task exhibit substantial variability.
- A rigid prefabricated foot orthotic does not significantly alter transverse plane lower extremity kinematics in female athletes with a navicular drop of at least 8mm.
- Additional study is necessary before firm conclusions regarding the influence of an orthotic device on lower extremity kinematics, kinetics, neuromuscular control and ultimately injury rates can be made.

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